Working Document
No. 116

Cassava Program 1987-1991

October 1992

CIAT
Centro Internacional de Agricultura Tropical

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CASSAVA PROGRAM REPORT 1987-1991

EXECUTIVE SUMMARY

This report presents the work and achievements of CIAT's Cassava Program over the period 1987-1991. The period corresponds to one in which total world cassava production rose from 137 million t in 1986 to 150 million t in 1990, a growth rate of 2.3% per annum.

The Cassava Program at CIAT forms part of a global cassava research and development system. Together with its sister program at the International Institute of Tropical Agriculture (IITA), the Program generates basic knowledge on the crop and develops improved component technologies, trains national cassava researchers and extension leaders and provides an important link between institutions in the developing and developed world.

At headquarters the Cassava Program undertakes strategic and applied research of global significance. The Program ensures the integration of its activities with those national cassava R&D systems in the Americas, Asia and with IITA in Africa through regional collaborative programs and projects.

During the period 1987-1991, the number of senior staff positions within the Program increased from 9 to 11. These human resources were complemented by scientific personnel contracted through a number of special projects.

HEADQUARTERS-BASED RESEARCH

Cassava Germplasm

Collection, characterization and conservation. The receipt of cassava germplasm accessions, from IITA and from Asian national programs, constitutes the basis for cooperation in Africa and Asia. Recent germplasm introductions from Brazil will give proper representation to one of the richest countries in terms of genetic diversity. A complete morphological and biochemical characterization of accessions in the germplasm collection is allowing the detection and elimination of duplicates. A core collection representing the overall genetic diversity has been defined and will be available in 1992 for duplication in another institution. An *in vitro* and field collection of wild *Manihot* relatives has been initiated. Some of the species are already included in crossability studies, biochemical and molecular characterization.

Breeding. The ecosystem approach to cassava breeding has been expanded to include semiarid areas, where cassava can contribute to the alleviation of food shortages. As a result of a cyclic process of selection and recombination over more than ten years, a large number of elite clones for humid and subhumid lowland tropics and highland tropics have been identified. Over the last five years 15 varieties derived from CIAT's gene pools have been released in 9 countries in Latin America and Asia. A wide range of genetic diversity has been introduced to Africa from CIAT, increasing the potential impact of IITA's cassava breeding program on that continent. A promising collaborative effort with Brazilian institutions to develop cassava germplasm for semiarid and subtropical regions of the world has been initiated. A participatory research model has been developed, in cooperation with national institutions in Colombia, which takes into consideration farmers' criteria for selecting and adopting new cassava varieties; this has contributed to the refinement of breeder's selection criteria. Preliminary experiments on seed treatment and germination have been undertaken as part of a multidisciplinary project to explore the development of true cassava seed as a production alternative.

Physiology

Water Stress. Research on cassava tolerance to prolonged mid-season water stress have revealed that certain physiological and morphological characteristics are associated with tolerance to water stress and with yield stability. Most notably, the ability to rapidly form and maintain leaf area is of paramount importance. Second, genotypic characteristics related to better partitioning of biomass between leaf and stem such as high specific leaf area and high leaf area ratio may lead to higher leaf area index without adverse effect on root yield. Cassava appears to tolerate prolonged drought by restricting leaf canopy and top growth and by partially closing its stomata while maintaining reasonable CO_2 uptake rates, hence reducing water loss and continuing to accumulate dry matter into storage roots. Moreover, cassava is capable of extracting deep soil water slowly when available. These characteristics are advantageous in drought-prone areas such as Sub-Saharan Africa, Northeast Thailand and Northeast Brazil. Under dry conditions, cassava can produce reasonable yields while most other food crops would fail. The ability of cassava to survive and produce under prolonged drought of several months is based on its high water use efficiency as compared to other food crops. Screening for low HCN content under water stress has revealed that genotypic differences exist with some clones maintaining low HCN levels under both wet and stress conditions. Maintaining low HCN under stress is of a paramount importance when fresh cassava is used for human consumption.

Photosynthesis. Research on cassava photosynthesis in relation to crop productivity has revealed that cassava's high photosynthetic potential underlies its high productivity under favorable conditions as well as its tolerance to stressful environments. Cassava requires high ambient temperature and high solar radiation for optimal leaf development and for the expression of its photosynthetic potential. The high sensitivity of photosynthesis to temperature suggests the need for genotypes more tolerant to low temperatures, which could be used in the highland tropics and in the subtropics. Moreover, the positive association of photosynthesis with productivity suggests that selection for high photosynthesis in parental materials may lead to higher yield when combined with other yield determinants. In addition to high harvest index, leaf area duration and number of storage roots are among the most important yield determinants. Wide ranges of variability in these characteristics exist among cassava clones which could be exploited in cassava breeding programs.

Quality

Cyanide. The use of the improved enzymatic method of cyanide analysis has resulted in a cheaper and more flexible assay for this important chemical constituent. No significant correlation was found to exist between the enzymatic and picric acid methods of cyanide determination. A priority has thus been placed on the development of a new method for rapid cyanide estimation for germplasm screening purposes. Analysis of some wild *Manihot* species showed high levels of cyanide in both root and leaf samples.

Starch quality. In addition to starch and sugar content analyses, the methodologies for amylose contents, microscopic evaluation of starch grains, x-ray analysis, differential scanning calorimetry, Brabender viscoamylograms and starch solubility and swelling power have all been developed, either at CIAT or in collaborating Colombian institutions. Varietal differences in amylose content (range 16-25%) and functional properties have become apparent. M Col 1522, which produces high quality sour starch has different structural, physical and functional properties from the other varieties so far evaluated.

Eating quality. An expert taste panel for eating quality evaluation identified the characteristics of high quality cassava. Cassava taste and hardness (texture) of fresh, boiled cassava were the two most related to preference, while no relationship was found between starch properties and eating quality. The panel identified significant changes in eating quality due to the pre-harvest environment.

Effect of pre-harvest environment on quality. Soil fertility significantly affected root quality. The application of potassium reduced cyanide and increased dry matter content, while phosphorus tended to have the opposite effect. Drought stress affected root dry matter and cyanide contents, with large varietal differences in response.

Biotechnology

Molecular fingerprinting. Electrophoretic analysis of Esterase (EST) isozymes were developed to identify cassava genotypes. Recently more powerful, DNA-based, techniques for the analysis of *Manihot* genetic diversity have been developed. Several random amplified polymorphic DNA markers (RAPD) and hte phage M13 probe have been effective in differentiating cassava genotypes. EST fingerprinting of cassava is now routine activity in the GRU. Both EST and DNA fingerprinting will be useful for genotype identification, to assess germplasm relatedness and gene pool origin.

In vitro Active Gene Bank (IVAG) and Cryopreservation. The conservation of cassava germplasm under reduced growth conditions has been developed in the BRU and recently transferred to the GRU. The cassava IVAG at CIAT is probably the largest and most complete for any crop in the world; over 4500 accessions are currently maintained. This year, consistent recovery of plants from cassava shoot tips, cryopreserved in liquid nitrogen (-196°C), has been achieved. This break through opens the way to a long-term, gene bank storage of cassava.

Genetic transformation. Plant regeneration is necessary for a transformation system in cassava. Plant regeneration through somatic embryogenesis on immature leaves and meristem tips has been developed. Using a plasmid construct with two selectable markers (bar gene and NPT II gene) and one reporter maker (gus A gene), the transient expression of GUS activity in somatic embryos after bombardment of metallic particles coated with the plasmid on early stage embryogenic callus has been obtained. This is an important first step towards a transformation system in cassava.

Molecular mapping. A special research project to construct saturated molecular and physical maps of cassava has been initiated. Such maps will be useful to tag, and eventually isolate and clone, cassava genes. Pst I and Hind III genomic libraries provided probes with the highest polymorphisms. Polymorphism between a cassava cv. and a wild *Manihot sp.* was dramatically higher than within varieties.

The Cassava Biotechnology Network (CBN). The CBN was founded in a workshop at CIAT in September 1988. The general goal of the network is to contribute to the solution of priority constraints in cassava production and utilization which have proved recalcitrant to the application of traditional methodologies. The CBN has received wide acceptance. This is shown by the number of projects underway on research constraints and technological bottlenecks, from 5 in 1988 to 22 in 1991. A proposal for funding critical network activities has been presented to the DGIS, the Netherlands. The project includes funding for a coordinator, scientific and steering committee meetings, training for developing country scientists and bridging funds for critical research.

Pathology

Etiological studies. The following unreported pathogens of cassava were characterized: *Scytalidium* sp. and *Verticillium dahliae*. *Fusarium solani* and *F. oxysporum* were also reported for the first time as cassava root pathogens.

Epidemiological studies. The relationships between mycorrhiza-*Phytophthora* and flooding-*Phytophthora* incidence were investigated.

Control of important cassava diseases. Production recommendations have been formulated for the control of cassava bacterial blight (CBB), the *Phytophthora/Fusarium* root rot complex, *Diplodia* root rot, and the witches' broom mycoplasma disease which cause severe epidemics in 4 important cassava growing areas. These recommendations integrate several control approaches to reduce bacterial or fungal infections of planting material and soil, and pathogen dissemination. The release of two resistant clones in Brazil with production recommendations has been an outstanding success.

Biological control. Research on novel biological control strategies is leading to the development of practical applications based on the use of microorganisms for the control of foliar pathogens (CBB and the superelongation disease) and preharvest or postharvest root rots, as well as microorganisms capable of producing growth regulators that can promote yield production. Advances have been made in development of the cultural practices which promote beneficial microbial residents in different ecological zones.

Endophytes. The existence of unreported, potentially deleterius endophytes in improved clones was demonstrated for the first time. This finding partially explains yield instability in most cassava, and opens up a new potential for development of control measures. Similarly, the identification of beneficial endophytes could lead to their use as biological control agents, plant growth stimulants, and inducers of drought resistance.

Stake storage. A system for the effective storage of cassava stakes was designed for solving problems of establishment and production in areas where this agronomic practice is necessary.

Method for interchanging indexed vegetative planting material. A new method for the interchange of virus-indexed vegetative planting material of cassava was developed to assure establishment of introduced genotypes.

Geographic distribution of cassava diseases. The geographic distribution and areas of potential risks have been determined for *Phytophthora* root rot, *Fusarium* stem and root rot; the witches' broom mycoplasma, superelongation disease, *Diplodia* root rot, and cassava bacterial blight, the most important diseases of cassava in Latin America. These were obtained by extrapolating epidemiology studies, surveys and agroecological data bases. This information will assist scientists in planning research projects, strategies for disease control and quarantine regulations.

Virology

Frogskin (FSD) and Caribbean mosaic disease (CMD). Progress has been made on the identification of phytoreovirus-like agents associated with FSD and CMD. Virus-like particles and viroplasm-like bodies have been found in affected plants. Nine ds-RNA segments are consistently found in affected plants. Hybridization studies provide evidence that the ds-RNAs associated with FSD and CMD are either identical or closely related. The whitefly *Bemisia tuberculata* appears to be the vector of these phytoreovirus-like agents. A cDNA probe has been developed to identify rapidly the ds-RNAs associated with this disease complex. Research on FSD and CMD continues and is centered on confirming the association of the phytoreovirus-like agents and the complex of disease symptoms.

Cassava vein mosaic virus (CCMV). The sequencing of CCMV is nearly complete. The virus is 6400 bases in length and it is most closely related to potato virus X (PVX). Most of the sequencing of CCMV was done at the VRU in CIAT and this is perhaps the first plant virus to be sequenced in Latin America.

Cassava vein mosaic virus is most prevalent in the northeastern states of Brazil, especially in the hot semiarid zones where it is not unusual to find more than 50% of the plants infected with CVMV. Since the virus is not present in Colombia, all work on this virus had to be done in Brazil. A cDNA clone to CVMV has been obtained, and this will facilitate efforts at molecular characterization and the development of rapid diagnostic tests.

African Cassava mosaic virus (ACMV). African cassava mosaic virus is the most destructive cassava virus in the world. Efforts are being made to find new sources of resistance through the CIAT-IITA cooperative germplasm exchange project. The identification of ACMV resistant germplasm adapted to the Americas will be a safeguard against the possible establishment of ACMV in this hemisphere.

Other viruses. Beside the major diseases, there are seven other known viruses that infect cassava most of which are symptomless viruses that are not known to cause disease. Diagnostic methods are available at CIAT to the four viruses that cause disease and to the three symptomless viruses found in Latin America. These diagnostic methods help assure the safe movement of cassava germplasm, and research will continue to develop more sensitive detection methods.

The control of viral diseases requires either the identification of resistant germplasm or the implementation of cultural practices that mitigate losses. Most viral diseases are controllable with current technology, and continued development of rapid diagnostic techniques together with the deployment of resistant germplasm should further reduce the losses caused by viruses.

Entomology and Acarology

Host plant resistance. Sources of host plant resistance to mites, mealybugs, whiteflies, thrips and lacebugs have been identified, and partially characterized for mites and thrips. Cassava hybrids with resistance to mites, mealybugs, whiteflies and thrips have been developed and several have been released by national programs.

Cassava mealybugs. The geographical distribution of the most important species of cassava mealybugs has been determined. Their key natural enemies have been identified. Several species of parasites and predators have been evaluated in the laboratory and field for their potential as biological control agents, leading to the introduction and release in Colombia of the parasite, *Aenasius near vexans*, discovered in Venezuela. Several species of natural enemies have been sent to IITA in Africa for evaluation and release against the introduced pest, *Phenacoccus manihoti*.

Cassava hornworm. Effective biological control of the cassava hornworm, a migratory lepidopteran which causes severe defoliation, is based on a hornworm-specific baculovirus. The timing, application frequency and optimal concentration of virus prepared from field-collected, diseased hornworms have been determined, and methods for storage of the virus have been developed. Application of the virus during the initial stages of a hornworm attack, when hornworm larvae are most susceptible results in better than 95% control.

Cassava whiteflies. Because of recent increases in direct crop damage due to cassava white flies and in their potential importance and impact as vectors of virus diseases, higher priority has been given to research on whiteflies. High levels of resistance have been identified and incorporated into high yielding hybrids. Several species of natural enemies have been identified and are being studied.

Burrowing bugs. Chemical control of burrowing bugs which attack cassava roots is feasible, but requires the use of highly toxic pesticides. Ecologically sound alternatives based on cultural practices are being sought. Intercropping of cassava with crotalaria reduces pest damage through allelopathy, but has not been adopted by farmers. Commercially acceptable cultural control systems based on allelopathy are being sought. The potential of entomophagous nematodes for biological control of the burrowing bugs is under study, and preliminary results have been positive.

True cassava seed and dried cassava. Research efforts on potential arthropod pests of true cassava seed, wild *Manihoti* species and of dried, stored cassava have been initiated.

Cassava green mite. CIATs contribution to biological control of the Cassava Green Mite (CGM) in the Americas and Africa includes 1) extensive surveys for natural enemies in Colombia, Venezuela and Ecuador and smaller-scale surveys in Northeast Brazil, Trinidad & Tobago, Guyana, Peru, Paraguay, Mexico, Cuba, Panama and Nicaragua; 2) development of culture, packing and shipping methods for natural enemies; 3) ecological and biological characterization of predatory mites, coleopteran predators, and the fungal pathogen, *Neozygites sp.*; and 4) estimation of field impact of natural enemies. As a consequence of the research conducted on behalf of IITA, CIAT characterized the biological and ecological nature of the CGM problem identified by EMBRAPA in Northeast Brazil, and developed a strategy for CGM management as part of an integrated crop protection effort.

Cropping Systems

Cassava-maize intercropping. The evaluation of newly released maize varieties for performance in association with cassava indicates that environmental conditions during maize development and the agronomic management of the maize are key factors determining the yield of cassava in the North Coast of Colombia. Land use is more efficient when maize and cassava are planted together than when either is planted alone. Cassava yields significantly more in association with improved than traditional maize varieties, thereby increasing land use efficiency further. In less favorable environments, yields of cassava in association with maize were significantly lower than in monoculture.

Improved maize varieties allocate more dry matter to the grain than traditional varieties. Total nutrient removal in improved maize is greater than in traditional varieties. As new varieties replace traditional maize, nutrient balance within the farm will be different, since more nutrients will be exported from the system. Unless soil fertility is maintained by lengthening fallow periods or by other means, yields will decline. Maize type did not influence uptake of nutrients by cassava.

Since the restoration of nutrients to the farm is vital for the sustainability of the cassava/maize association, chemical fertilization is a possible short term solution in some regions. In trials with low levels of fertilization improved maize yielded significantly more than traditional maize. Cassava yields were not affected by the level of fertilization applied to maize. the highest marginal return in intercropped cassava/maize was obtained with low levels of fertilization.

Cassava-cowpea intercropping. The cassava/cowpea association is important in areas with prolonged dry seasons. Yields of intercropped cowpea are often similar to yields obtained in monoculture, however cassava yields are negatively affected by cowpea competition, particularly if environmental conditions favor the early development of cowpea. More vigorous cassava clones are less affected by cowpea competition.

Pre-production trials. Farming involves a yearly sequence of events beginning before the onset of planting and ending with post harvest activities. Testing of new production practices should be done in this context, particularly since the adoption of any technology component depends strongly on the interaction between new and existing technology and labor requirements, particularly during peak demand periods. Improved technology for the cassava/maize association was tested by farmers over two years on a total of 76 plots. Maize yields with improved technology were superior and cassava yields were equal or superior to those obtained with traditional technology. Hand labor requirements of the improved and traditional technology were similar. Total production costs of the improved technology were 8% above those of the traditional technology.

Plant nutrition and soil fertility

Management of low fertility soils. Research on plant nutrition and soil fertility management in relation to cassava productivity have revealed that cassava is tolerant to low fertility soil provided that soil organic matter is high. Continuous cultivation of cassava for several years in acid soils high in organic matter did not result in large declines in yield in absence of phosphorus and nitrogen fertilizer. On the other hand, large yield responses to potassium fertilizer were notable in these soils. The removal of large amounts of potassium in the harvestable roots leads to gradual depletion of this element. To sustain productivity, moderate amount of potassium fertilizer should be used. Where cassava is produced in sandy soils low in organic matter and in the absence of a fallow system, moderate levels of NPK fertilizer are required to sustain productivity. Yield response to NPK fertilizer was notable in these soils. Alternatively, cassava productivity could be increased by application of surface plant mulch in poor sandy soils. Mulch application appears to be beneficial in improving the chemical and physical properties of the soil. Moreover, mulch can alleviate water stress by reducing water evaporation from the surface soil exposed to high temperature. Reducing evaporation is important, since these sandy soils are characterized by a low water retention capacity. Another advantage of mulching is the large reduction in HCN content of cassava roots in the absence of fertilizer application.

Adaptation to low-phosphorus soil. Screening cassava germplasm for adaptation to low-phosphorus soils indicated a wide range of adaptation among the tested materials. Several varieties well-adapted to low-P soils were identified, including land races as well as advanced breeding lines. Most notably, the two CIAT clones CM 523-7 and CG 2177-2 recently released as commercial varieties for los Llanos Orientales of Colombia were among the highly adapted lines to low-P soils. Research on mechanisms underlying varietal response to P suggested that varietal differences were not closely related to P-uptake. On the other hand, internal use of absorbed phosphorus, growth habit and patterns of biomass allocation to tops and roots are more important. Varieties that partitioned more dry matter to roots, as compared to top growth, had higher P use efficiency in terms of yield gains. It appears that adaptation to low-P soils could be enhanced by selection for both high fibrous root length density and high storage roots sink capacity.

Soil conservation

Control of soil erosion. Research on soil conservation in cassava-based cropping systems on hillsides indicated a high level of soil erosion. Annual soil losses from bare soils exceeded 100 t of dry soil/ha. Since cassava planting usually coincides with periods of intense rainfall, soil loss from steep lands might exceed the tolerable levels unless the soils were appropriately managed. Several cropping systems and cultural practices were tested in relation to soil erosion and crop productivity. Growing cassava in contour ridges or in combination with live grass barriers greatly reduced soil erosion while maintaining cassava productivity as compared to traditional practice. On the other hand, growing cassava in down-slope ridges resulted in high levels of soil losses and more runoff than any other practices. Growing cassava in association with forage legumes was effective in reducing soil loss but cassava productivity varied with the degree of legume competition. Reduction in cassava yield ranged from 10 to 40% depending on the legume used and on the intensity of the legume cover. The potential of cassava/forage legume systems in controlling soil erosion and in maintaining productivity requires further investigation taking into account both the short- and long-term consequences.

Process and product development

Methodology. A 4-stage methodology for cassava process and product development, comprising identification of opportunities, lab and prototype research, pilot scale testing and commercial expansion has been developed in collaboration with national institutions.

Dried cassava for animal feed. The commercial expansion of dry cassava chip production, introduced by CIAT in collaboration with the Integrated Rural Development Fund on Colombia's Atlantic Coast, is now self reliant and autonomous. Feedback from this project has resulted in research on improvements in drying efficiency and product quality. The production of cassava-based chicken feed rations was found to be a viable option at the level of small farmer cooperatives.

Fresh cassava conservation. Pilot scale testing in the city of Barranquilla, Colombia has demonstrated the technical and economic feasibility of the fresh cassava storage technology developed by CIAT and NRI. Problems with urban distribution have frustrated large scale adoption of the storage technology. However, private entrepreneurs are now actively taking on distribution functions, and supplying supermarkets, restaurants and small shops. The storage technology is being successfully used commercially by a cooperative in Santander department Colombia and pilot testing has been successful in Paraguay.

Cassava flour. The pilot stage of a project to develop high quality flour for human consumption is currently being executed. Market studies, including industrial trials of the flour, have demonstrated that cassava flour will have both price and quality advantages over wheat flour in some market segments (e.g. cookies and processed meats). A potential market of over 20,000 t/yr in Colombia was estimated. The pilot processing plant currently under evaluation is operated by a small farmer cooperative and employs artificial drying of chips produced from washed roots. The high quality chips are milled at a wheat flour mill with conversion rates of chips to flour of 90%. Current information suggests that the project is economically feasible in Colombia, and that the rate of return is improved if in-plant milling is adopted. A small scale prototype mill has been designed which will permit in-plant production of flour.

Cassava starch. A CIRAD/CEEMAT-CIAT research program on cassava starch started in 1989 focusing primarily on sour or fermented starch. Evaluation of existing traditional small scale production units in Colombia identified areas for process improvement to increase efficiency and improve product quality. Two pilot plants incorporating process improvements are now under evaluation. The characteristic "expansion power" of sour starch as measured by specific volume correlated significantly with organic acid contents and certain viscoamylogram characteristics. The natural fermentation process has been found to be predominantly lactic, with CO_2 and lactic acid production and amylolytic enzyme action pitting starch grains. Maximum viscosity of sour starch is lower than that of raw starch and gelling ability is reduced.

REGIONAL COLLABORATION

Latin America[1]

Many countries in the Americas have become aware of the important role that cassava can play in providing a vehicle for income and employment generation in the rural sector, consequently the last five years has seen a resurgence of interest in cassava activities. In addition to direct collaboration with national research programs, participation in multi-institutional integrated cassava research and development projects in several countries has formed the basis of the Cassava Program's activities in the region, with priority placed on Colombia, Brazil, Ecuador and Paraguay. These projects aim to link cassava farmers with expanding markets through the introduction of novel or improved cassava processing alternatives, thus providing incentives for farmers to increase production.

Emphasis in training during the period has been on the support of in-country courses, with fewer CIAT-based production and utilization courses. Training at CIAT has increasingly focused on disciplinary in-service specialization. Networks, both specialized and sub-regional in nature, have been consolidated or established; these include the Panamerican Cassava Breeders' Network, an Integrated Cassava Projects Network, a Cassava Utilization Research Network and a network for Cassava Development in the Southern Cone countries. These networks plays a key role in definition of regional research priorities and identification of opportunities for horizontal collaboration.

Colombia

As CIAT's host country, Colombia plays an important role in providing situations for the testing and adaptation of component technologies and participatory research and

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[1] For the purpose of this report the term Latin America includes Mexico, Central America, the Caribbean and South America.

technology transfer methodologies. As such it provided the site for the first integrated cassava project initiated in 1981 on the Atlantic Coast. Rapid and dynamic growth of both farmer cooperative and private cassava drying plants has occurred over the last two years. There are now over one hundred plants located on the Atlantic Coast and expansion of the cassava drying technology to other areas of the country has been achieved through a joint National Rehabilitation Plan/CIAT project. The national production of dry cassava is now estimated at 25000 t with benefits accruing to over 5000 families. The increased market for cassava has stimulated demand from farmers for improved cassava production technologies.

A study on the adoption of cassava production technology components in the Atlantic Coast of Colombia was undertaken in 1991. Preliminary results of a sub-sample of the data shows that:

- Cassava varieties "Venezolana" (M Col 2215) and "Verdecita" (M Col 1505) have been adopted by 91% and 5% of cassava farmers, respectively. Together they cover 44,000 ha in the three principal cassava producing departments of Colombia.

- Stake treatment and storage technologies have been adopted by 10% and 71% respectively. Planting density and weed control technologies have been adopted by 60% and 53%, respectively.

- Technology adoption has been the principal factor for cassava yield increases. Since 1982 cassava yields (cassava/maize intercrop) increased by 52%, 56%, and 76% in the departments of Bolivar, Sucre and Cordoba, respectively.

- Cassava area has increased significantly as a reaction to improved prices and demand. Cassava farmers have increased area planted to cassava decreased fallow area and period, and 95% of farmers are harvesting the same area as planted rather than leaving cassava in the ground until markets improve.

- As a reaction to improved cassava prices and overall demand, cassava farmers have decreased on farm cassava consumption (as share of total production) by some 50% since 1982. Sales to drying plants currently constitute 22% of total cassava production.

- Overall, 71% of cassava farmers have adopted at least one production technology component, and 80% responded that they have increased their incomes as a result of improved technology and the increased demand and improved market.

The data clearly show that cassava drying plants have served as an effective vehicle for cassava technology diffusion.

Ecuador

The Ecuador integrated cassava project operates primarily in two coastal provinces, Manabí and Esmeraldas. The goal of the project is to unite and integrate the efforts of local, national and international agricultural development institutions engaged in research, extension and education in order to identify cassava production, processing and utilization technologies appropriate for low-resource cassava farmers.

Current project beneficiaries are 18 farmer associations (APPYs) with 350 members in Manabí and 5 with 60 members in Esmeraldas. Among the APPYs, four have all women members, eight have only men and eleven have mixed membership. The women's APPYs produce cassava starch exclusively while the men's and mixed associations produce cassava chips which are milled into various flour products. The APPYs in each province are organized into unions (UAPPYs) which are responsible for providing the associations with credit, training and technical assistance, and handle the marketing of processed cassava products.

Total output from the UAPPY-Manabí increased markedly from 50 t of cassava flour during the initial year of the project (85-86) to 1,346 t of flour and 104 t of starch during the 90-91 processing year.

Research conducted within the project until 1989 was primarily focused on adapting cassava processing technology from the Atlantic Coast of Colombia to the agroecological and social conditions of Manabí and Esmeraldas. In 1989, an unexpected downturn in the demand for cassava flour as the agglutinant for making shrimp feed pellets caused a dramatic shift in the cassava program. Farmer processors demanded assistance in identifying new markets for their existing products, technology for producing new products and methods to improve processing quality. An intensive market diversification effort was therefore initiated. Today the primary markets for the UAPPYs products include cardboard box factories, plywood mills and food industries as well as the shrimp feed industry.

Farmers, now aware of the need for better fresh cassava quality, are demanding new varieties with higher dry matter, improved drought tolerance and earliness. The first new variety meeting these requirements, M Col 2215, introduced through CIAT in 1987, will be released by INIAP this year.

Countries like Ecuador, where farmers are demanding improved production and processing technology and there is no single institution with post-harvest research capability, require new mechanisms for conducting research. The formation of multi-institution and interdisciplinary teams with the active participation of trained UAPPY para-technicians is proving to be an efficient alternative approach which ensures the continuous involvement of farmer users in the research process.

Brazil

Following intensive contacts with Brazilian research and extension agencies through training events and study tours in Colombia and Ecuador, an integrated cassava development project was initiated in the State of Ceará in 1989. The project which is executed by the Ceará State Cassava Committee (CCC) is partially financed by the W.K. Kellogg Foundation.

One of the principal activities of the project has been the organization of farmers' groups for the construction, operation and administration of cassava processing facilities. When the project initiated activities in May 1989 12 drying plants already existed. By the end of August 1991, the total number of small-scale processing plants had risen to 59 and 1380 farmers were benefitting directly from the project.

The building up of local institutional capacity and support for the project has progressed steadily and the role of the CCC as the coordinating body for all activities related to cassava development has gained general recognition. In addition, five Regional Cassava Committees (RCC) have been established and are contributing to the rapid and efficient decentralization of project activities.

The identification of local financial resources for expansion of the project into new areas has been actively sought. The total value of resources obtained and allocated to farmers' groups to finance the construction of their cassava processing facilities now amounts to US$347,048. Marketing channels for dry cassava chips have started to consolidate. The main consumers of the dry cassava chips have been dairy farmers located in the vicinity of the drying plants. In 1990, the total number of purchasers was 410, with 19 (5%) of these buying 62% of the total production.

The first results from the 15 pre-production plots planted in 1990 have shown that, at 15 months, average yields of cassava were 60% higher than those obtained by farmers employing traditional production practices.

Paraguay

Paraguay is the largest per capita producer of cassava roots in the world and the crop is considered strategic in terms of the country's food security. CIAT's Cassava Program has been instrumental in orienting and supporting a young, unexperienced but dedicated group of researchers and extension leaders in defining priorities, formulating objectives and strategies and executing projects with the objective of maintaining cassava's position as a principal source of carbohydrates for both human consumption and animal feed.

The focus of cassava related activities in Paraguay has been centered on (a) sustaining and improving production, with particular emphasis on soil fertility and erosion control and

(b) making better use of the crop through improvements in post harvest handling, processing and marketing.

Since 1985, a project partially financed by the International Development Research Centre, IDRC, has concentrated on two important cassava growing areas: Paraguarí, a Department close to the capital Asunción, where soil degradation has significantly reduced the quantity and quality of the cassava produced with the result that the area is a net importer of roots; and Caaguazú, a Department where the native forest has been opened for agriculture within the last twenty years and is the principal supplier of cassava for the Asunción market.

The development of technological components to improve cassava production in Paraguarí and Caaguazú have led to the formulation of two complete technical recommendations for farmers. The fresh cassava storage technology developed by CIAT/NRI is being tested and adapted to conditions in Paraguay. Starch is used mainly to make a traditional bread known as "chipa"; work is underway to improve extraction efficiency and product quality and to introduce simple effluent treatment.

Seed systems

The opportunities for increased cassava root utilization described above and the demand from farmers for improved production components that will increase productivity and reduce costs, has highlighted the need to undertake activities oriented toward the development of organized cassava seed supply systems that will ensure the availability of high quality planting material of either local origin or from improved genotypes. This area is seen as a major constraint in the evolution of the integrated cassava projects towards increased and more stable cassava production at lower costs. In collaboration with the Colombian Agricultural Institute, ICA, the Seed Unit has been developing pilot models for the organization of seed production in different regions of the country which differ according to the user groups and end uses of cassava. The experience gained will provide the basis for implanting similar models in other countries.

<u>Asia</u>

In Asia, cassava faces fewer market constraints as compared with tropical America, the crop having made the transition from being purely a starchy staple to a multipurpose carbohydrate source in many countries. In addition, cassava research programs are relatively stronger with a low turnover in personnel. Priorities for research at the regional level have been focused on germplasm improvement and soil fertility maintenance as key elements in ensuring highly productive cassava-based cropping systems. The promotion of horizontal exchange of information on post harvest processing and marketing has also received attention. Training of personnel, the execution of joint projects through research contracts, and the formation of a regional cassava research network that meets every three years have been the principal mechanisms for improving national programs' research capacity.

As a result of CIAT's collaboration, the research capacity of cassava programs in Thailand, Indonesia, China, the Philippines, and Malaysia has been greatly strengthended and new cassava research programs established in Vietnam and Myanmar. Through CIAT involvement, interinstitutional cooperation at a national level has improved in Vietnam, China and Indonesia. Thailand is contributing its best breeding materials to other Asian countries through CIAT.

Cassava varietal improvement in Asia

Generation of breeding materials. Cassava breeding programs in Asia have benefitted significantly from the availability of selected and upgraded genetic materials from CIAT/Colombia, which are characterized by improved harvest index (HI) and tolerance to biotic and abiotic constraints. Since 1975, 274,196 hybrid seeds from CIAT/Colombia have been distributed to 9 countries. The establishment of a joint Thai-CIAT cassava breeding program has brought about further yield improvement through higher bio-mass and root dry matter content as well as adaptation to semiarid lowland tropics and improvement plant type. From this program 47,224 hybrid seeds have been distributed to 9 countries since 1985 and 215 clones have been shipped to 11 countries since 1988.

Varietal selection. Steady progress in varietal selection has been made by the cassava breeding programs in Thailand, China, Vietnam, Malaysia and the Philippines with promising materials being selected from CIAT/Colombia and Thai-CIAT introductions and local-CIAT crosses. In Thailand 7 clones with different adaptive niches have been or are in the process of being released over the period 1984-93.

Varietal release. A total of 12 varieties in five countries have been released. The number is expected to increase steadily in the future with selections from Thai-CIAT crosses and Thai-CIAT clonal introductions gaining in importance.

Adoption. Rayong 3 in Thailand and Adira 4 in Indonesia are planted on more than 50,000 ha. The extent and factors affecting adoption of both these varieties are currently being studied in close collaboration with the respective national research and extension programs. VC 2 and M Col 1684 (not officially released yet) in the Philippines and Nanzi 188 in China are planted on smaller hectareages.

Soil conservation and fertility maintenance research in Asia

Priority setting and improving research capacity. After the establishment of the Cassava Agronomy Program in Asia in late 1986, a network of cassava agronomists and soil scientists working in national programs in Asia was developed by conducting collaborative research on high priority topics. Through frequent visits to the national programs to see the trials and to discuss the results, the organization of workshops and training courses and distribution of cassava literature, the capacity and efficiency of the research was improved. Since 1986 two Regional Cassava Workshops and a Symposium of the International Society for Tropical Root Crops were organized in Asia, while a production training course for Asian cassava workers was held at CIAT headquarters in Colombia.

Agronomy research results. Collaborative cassava agronomy research on cultural practices, on erosion control and soil fertility managements has been conducted in nine countries. The most promising economically viable erosion control practices were minimum tillage, fertilizer application, contour ridging, close plant spacing, and intercropping. Cassava responded positively to the application of N in short-term trials, but required relatively high applications of K for sustained high productivity. The crop responded to P application sporadically, and soil acidity, or lack of secondary or minor nutrients were seldom significant limitations in Asia. Practices such as green manuring, intercropping, cover cropping and alley cropping generally reduced cassava yields, but they may be beneficial for improving the long-term productivity of the soil. Considerable additional research will be needed to integrate erosion control practices, judicious fertilizer use, crop rotations, green manuring etc. in order to manage the crop and the soil for sustained high yields while protecting the natural resource base.

Africa

Broadening the cassava germplasm base

A collaborative project between CIAT and IITA is dedicated to the broadening of the cassava germplasm base of Africa through introduction of germplasm from the Americas adapted to specific agroeconomical conditions. It commenced in 1990 with the introduction of nearly 90,000 botanical seeds representing 400 families. A new seed lot was introduced in 1991. A total of 130,000 seeds (750 families) have now been transferred to Africa being evaluated under humid, sub-humid, semi-arid and mid-altitude conditions in Nigeria.

Results obtained from the material introduced in 1990 at Ibadan (sub-humid), Onne (humid) and Kano (semi-arid) show that progenies derived from crosses between Latin American germplasm and IITA's mosaic-resistant clones TMS 30001 and TMS 30572 are more resistant to the disease under conditions of high pressure observed at Ibadan.

Progenies of crosses involving CIAT germplasm adapted to the acid soil savannas of South America and IITA sources also showed a better reaction to an intense outbreak of CBB in the first 2 months after transplanting.

Resistance to cassava green mite was observed in progenies obtained from crosses involving CIAT elite materials adapted to the dry areas of Latin America and resistant to that pest.

The population evaluated under the semi-arid conditions of Northern Nigeria showed a remarkable performance in terms of root yields and growth, after enduring a 6 months dry season which started two months after transplanting. A recuperation period of 3 months after the dry season enabled the seedlings to recover and produce yields comparable to those obtained at the humid and sub-humid environments. Selection in the semi-arid location reflects the degree of adaptation of the genotypes to the harsh climatic conditions since no biotic constraints were observed in 1990-1991.

Individual selected as promissory at Ibadan, Onne and Kano were cloned and are being evaluated in four location in Nigeria as part of the cassava breeding scheme of the Tuber and Root Crops Program of IITA.

The results obtained so far from this large scale germplasm introduction support the feasibility of such a program and suggests that a preselection of parents based on their agroecological adaptation is a step forward in a germplasm-exchange program.

Collaborative Study of Cassava in Africa (COSCA)

The Collaborative Study of Cassava in Africa (COSCA) is a joint project, managed by IITA, which aims to provide basic information about cassava in Africa, to increase the relevance and impact of research related to the crop, and to help increase income and food security for people in Africa.

Implicit in the objectives of COSCA was a geographic characterization of how cassava production and utilization varied across the countries involved in the study. CIAT's Agroecological Studies Unit participated in the design of a spatial sampling frame for the project. To do this it mapped cassava distribution in Africa and constructed a geographic database of climatic, demographic and infrastructural information. A member of the Unit assisted in training and data analysis for the project's first phase. This consisted of a village level questionnaire to elicit qualitative information. National teams were trained in sampling and mapping techniques. Later the Unit participated in analysis of some of the data, including a description of the distribution of bitter and sweet varieties and relationships between varietal characteristics and environmental conditions.

The Unit has used the information that it compiled for the geographic sampling frame to construct a statistical model of the distribution of cassava in Africa. This uses population density, modified by climatic and edaphic factors, to predict cassava distribution in the year 2000, and to identify areas where cassava production is notably higher or lower than might be expected. This information has formed the basis for the preparation of an Atlas of Cassava in Africa which will be available in 1992.

CASSAVA PROGRAM STRATEGIC PLAN 1992-2002

In the 1990s the Program will continue to promote the integration and consolidation of national cassava research and development systems in tropical America and Asia, and to facilitate linkages between these systems and institutes undertaking advanced research on cassava through the Biotechnology Network. Closer collaboration will be sought with IITA to help meet the needs of African programs. While maintaining a commodity system perspective, the program will emphasize germplasm resource development. Crop management, utilization and market research will concentrate on strategic issues of global importance. Applied research in these areas will gradually be devolved to national organizations, with horizontal cooperation encouraged between countries at the regional level. The Program will focus primarily on technology development for the subhumid, semiarid and subtropical ecosystems of the Americas and Asia, interacting closely with CIAT's new Resources Management Research Division on hillside, savanna and forest margin ecosystems where an estimated 25%-30% of cassava is produced in tropical America.

Overall core resources are projected to decline slightly over the period in terms of actual staff positions, and significantly in terms of positions approved by TAC for 1989-1993.

ACKNOWLEDGEMENTS

This report was written by the principal scientists of the Cassava Program and those of the Germplasm Resources, Virology Research, Biotechnology Research, Seed and Agroecological Studies Units with which the Program closely interacts. We wish to acknowledge the very significant contribution made by our support staff. The achievements reported in the document would not have been possible without their hard work and dedication to the objectives of the Program.

We are indebted to the Training and Communications Support Program for their assistance in the organization and execution of numerous activities which facilitated the exchange of information between the Program and our partners in national institutions. We also acknowledge the invaluable support of Data Services Unit in data management and experimental design and analysis.

We wish to express our appreciation for the generous collaboration of many people in both developing and developed country institutions with whom the Program interacts. Apologies are given should their contributions not be fully recognized in the text of the report.

Finally, we thank the secretaries who typed the individual sections. In particular, acknowledgement is due to Trudy Brekelbaum, Maruja Rubiano and Miguel Angel Chaux who were responsible for assembling the component parts into what we hope is a coherent document.

INTRODUCTION

1. THE CIAT CASSAVA PROGRAM

In the tropics, cassava (*Manihot esculenta*) is the most important root crop, ranking fourth after rice, sugarcane and maize as a source of calories for human consumption. It is a major carbohydrate food for 500 million people, and in tropical Africa it is the single most important source of calories in the diet. Total world production has increased from 70 million t in 1960 to an estimated 150 million t in 1990. Of this total, 43% is produced in Africa, 35% in Asia and 22% in Latin America. The crop is principally used as a human food, either fresh or in a processed form; however, it is of growing importance both as an animal feed and as a raw material for producing starch and starch-based derivatives.

Cassava, which originated in Latin America, has a number of attributes that have contributed to its reaching this level of worldwide importance and that have made it an attractive crop for small farmers with limited resources in marginal agricultural areas:

- It is one of the most efficient carbohydrate-producing crops.
- It is tolerant of low soil fertility and drought and has the ability to recover from the damage caused by most pests and diseases.
- The roots can be left in the ground for long periods as a food reserve, providing an excellent insurance against famine.
- The crop is well adapted to traditional multispecies agricultural systems and subsistence cultivation in which farmers seek to minimize the risk of total crop failure.

Cassava is one of the few major food crops that is not grown to any significant extent in the developed world; thus until recently there had been a historic underinvestment in research both nationally and internationally. Over the last twenty years, however, there has been mounting recognition of the contribution that cassava can make to increasing incomes and generating employment opportunities in the rural sector; and this has led to a greater flow of funds for research. The research programs at CIAT and the International Institute of Tropical Agriculture (IITA), established in the early 1970s, have provided stability and continuity for the formation of what can now be considered as a global cassava research and development (R&D) system, which links institutions in both the developing and developed world.

1.1 History of CIAT's Cassava Program

1.1.2 The first ten years, 1973-1982

The Cassava Program at CIAT was formed at the time of the Green Revolution of rice and wheat. The wave of enthusiasm that followed the great success with these two commodities not only led to the establishment of the CGIAR (Consultative Group on International Agricultural Research)system but also defined its overall strategy: to apply modern science to the production of new varieties of broad adaptability that would greatly increase yields. The Green Revolution in wheat and rice was based on a large backlog of research, principally from Asia, Europe and the Americas. In the case of cassava, however, the scientific base for crop improvement was rudimentary. Nevertheless, the strategy of CIAT's Cassava Program evolved in the spirit of the times, revolving around increased understanding of the crop and using this knowledge to provide a genetic solution to the problems encountered in the field.

By the end of the seventies, a great deal had been achieved in improving understanding of the plant; however, the goals of providing broadly adapted varieties to farmers and increasing production were not achieved. The underlying reasons for this were:

- Cassava was grown under such heterogeneous conditions (in contrast to irrigated rice and wheat) that an ecosystem approach to varietal improvement and concomitant agronomic practices was needed.
- The principal constraint to increased production was often not in the area of production technology per se, but rather in the area of incentives for the farmers to produce more.

Strategies were altered accordingly, with emphasis on determining potential markets for cassava and on postharvest handling of the crop to ensure that marketable goods could be produced. Furthermore, a more holistic viewpoint was taken of the role of the crop in the overall context of rural development. The question became not **"what can CIAT's Program do for cassava?"**, but **"what can cassava do for the poorer segments of the population in the developing world?"** and **"what can CIAT as an institution do to ensure that it effectively plays that role?"**

In the early eighties therefore, research on cassava utilization was initiated as a core-funded activity, the Program became involved in the first pilot integrated production, processing and marketing project, and a senior breeder was outposted to Asia to provide a link with national breeding programs and broaden the region's germplasm base.

Concurrently with this period of internal reflection and realignment of strategies within the Cassava Program itself, questions were raised both by CIAT Board and Management and by the Technical Advisory Committee (TAC) of the CGIAR about the future demand for cassava. The basis of this skepticism related to the observed decline in per capita consumption of the crop in Latin America and the possibility that the experience on this continent might be a portent of the future for Asia and Africa. It was argued that there would be little demand for improved production technology for a crop with a declining market.

1.1.3 The cassava demand studies

During the 60s and 70s, economies of Latin American countries experienced a significant structural change, mainly caused by strong expansion of the industrial and service sectors, and rapid urban growth as a result of high rural-urban migration rates and an annual 2.8% population growth. Rising income and urbanization implied a rapid increase in demand for food products, with changing consumption patterns, especially in urban areas.

Despite the fact that agricultural production grew at 3.1% per year during this period, the ever-growing demand could not be satisfied. The resulting undersupply (or overdemand) led to an upward pressure on food prices and a negative trade balance. The majority of Latin American countries became even more dependant upon cereal imports.

This issue stimulated government policies to focus on (and favor) primary products, among them cereals. As a consequence traditional energy providers like cassava (and other roots and tubers) had to compete increasingly with grains, at a substantial disadvantage and at a high social cost. This--together with the shifting consumption patterns of a predominantly urban society in which traditional staples such as cassava were being replaced by more convenient cereal-based foods such as rice and wheat-based products--led to an overall decline in cassava production of 1.3% yearly during the 1970s.

The assessment of this situation was translated by the 1984 External Program Review of the Cassava Program into a recommendation that "studies be undertaken to assess the future demand of cassava and cassava products; that the future direction and scope of the Program should be reviewed after completion of these studies". While supporting current and future cassava research activities as important, TAC endorsed the need for cassava demand studies as "the future demands for cassava were unclear," especially in Latin America.

Between 1984 and 1986 the Economics Section of the Program, aided by several postdoctoral fellows and collaborating national social scientists in several Asian countries, embarked upon a series of studies (known as "The Cassava Demand Studies") to assess the current importance and future potential of cassava in the most relevant areas of Asia (India, the Peoples' Republic of China, Indonesia, Malaysia, Philippines and Thailand) and Latin America (Colombia, Brazil, Paraguay, Peru, Venezuela, Dominican Republic, Mexico and Panama). At the same time a proposal was developed for similar studies in Africa, which became known as "The Collaborative Study of Cassava in Africa", COSCA. This project got under way in 1989, and the final results are expected by 1992.

The preliminary results were presented to TAC in mid-1987. Overall the studies demonstrated a strong market potential for increased cassava production, depending on usage and region. There were six major conclusions:

- The observed decline in fresh consumption in Latin America is due primarily to the urbanization process. High marketing costs have shifted relative prices of cassava and grain staples between rural and urban areas, resulting in lower consumption in urban Latin America. Fresh cassava has a positive income elasticity and consumption can be expected to grow modestly. New preservation technology is likely to reduce marketing costs and accelerate this growth.

- Where human consumption of processed cassava has declined, this has largely been the result of government subsidies of competing cereals. These trends are already being reversed as these subsidies are removed, and demand for cassava in processed form can be expected to grow. These products will continue to serve as an important source of inexpensive calories to the very poor.

- Starch, much of which is used in the production of various foods, is expected to provide a growing demand for cassava, especially in Asia.

- A major potential for growth in demand for cassava is as a component of animal feed, chiefly for domestic use in Latin America and for both domestic use and export in Asia.

- The growing market for cassava in Asia has already reached the point where production cannot keep up with demand.

- Cassava is an important tool for equitable development. Its characteristics are such that the benefits of new technology can be targeted to the very people who have normally been left out of the development process--the poorer segments of the population.

The demand studies clearly demonstrated that, firstly, there is sufficient potential demand for cassava production; secondly, that because of its unique qualities, cassava earns an important place in the CGIAR basket of commodities; and thirdly, that its different end uses under different socioeconomic and agroecological conditions imply a decentralized R&D strategy. The nature of consumption patterns, marketing requirements and multiple end uses imply that the traditional germplasm approach alone will neither be sufficient nor effective for cassava R&D to maximize social benefits. Production research must be integrated with activities on processing, utilization, marketing and policymaking. In the light of this assessment, the Program revised its research strategies for the 1987-1992 period.

1.2 Cassava Program 1987-1991

1.2.1 Goal, objectives and areas of activity

The activities of the Cassava Program over the period 1987-1992 were set within the framework of the document titled "Global Cassava R&D: The Cassava Demand Studies and Implications for the Strategies for the CIAT Cassava Program" (1987). The goal of the Program is stated as follows:

> "To contribute materially to increased income and food supplies of small farmers and to improve food availability in tropical developing countries."

Furthermore, it is made clear that the Cassava Program is not in a position to reach this goal on its own; rather that it forms part of a global network dedicated to exploiting cassava as an important traditional rural and urban staple and to developing new forms of utilization for changing economic circumstances. It is within this context that the Program, in close collaboration with national and international agencies, set itself the objectives presented in Box 1.1.

The Program's efforts to attain the foregoing goal and objectives have been centered around the execution of a set of activities governed by the five operational principles that have guided all CIAT's activities; namely, Relevance, Equity, Complementarity and Cooperation, Comparative Advantage and Sustainability (see Box 1.2). The specific activities undertaken can be grouped into ten broad areas of endeavor:

- Assembly of a body of basic knowledge on the crop. This has included the generation of knowledge on basic biology and growth processes; reactions to different environmental conditions; interactions with pests and diseases, their biology and epidemiology; and the physicochemical characteristics of the plant.

- Genetic conservation and improvement. CIAT has continued to fulfill its mandate to collect, characterize and conserve the world's cassava germplasm. Efficient use of this germplasm has been achieved by concentrating the desirable characters--for specific ecosystems or end uses--in elite gene pools that are made available to national breeding programs.

- Integrated pest management. The importance of individual pests or pest complexes in terms of losses caused and the potential area over which they can cause damage has been evaluated. For the most important pests and diseases, integrated pest management programs are being devised around alternative strategies including phytosanitary control, biological control, host plant resistance and appropriate cultural practices.

BOX 1.1 OBJECTIVES OF THE CASSAVA PROGRAM

1. Develop components of production technology that form the basis for stable, cassava-based cropping systems with low costs per unit output.

2. Develop technology that allows cassava to be grown on presently underexploited lands.

3. Develop processing technology that makes cassava a low-cost, high-quality, convenient food.

4. Develop both production and processing technology that is cost-competitive, increases farmer income, and is sufficiently labor intensive to generate employment for landless labor.

5. Develop marketing strategies for cassava that reduce the marketing margin.

6. Stimulate the development of markets for cassava that provide a stable price floor for the raw material, thus providing farmers the incentive to increase production, thereby reducing price fluctuations for the consumer.

7. Assist in the development of novel uses of cassava that increase the overall demand for the crop.

8. Develop waste-reducing technology that increases the percentage of total production that is finally consumed.

9. Stimulate other agencies to play an active role in the cassava R&D process.

10. Increase the capacity of national programs to carry out cassava R&D projects.

- Sustainable agricultural production systems. Measures to reduce and control soil erosion and to counteract soil depletion have been researched, together with the interaction of cassava with other species--both in multiple cropping systems and in rotation.

- Improved root quality. Research has been undertaken to elucidate genetic, agronomic, environmental and process variables that affect the quality of different end products. Simple, effective methods for screening germplasm for desired quality traits are being developed.

- Improved preservation and processing technology. The Program has taken a lead role in developing small-scale processing technology for dried cassava, flour and starch, and refining the technology for preserving fresh cassava.

- New products and alternative markets. Changing socioeconomic conditions lead to changes in people's consumption habits and preferences. The Program monitors these changes as a means of identifying new markets for cassava-based products or new ways of bringing traditional products more effectively into the changing market structure.

- Development of an appropriate policy environment for cassava. Information is provided to national policymakers about the contribution that cassava can make to achieving economic development goals and about the effects that certain policy decisions can have on supporting or stifling that contribution.

- Institutional models for development with equity. Through integrated R&D projects in selected countries, the Program has fostered the vertical integration of national cassava R&D systems and the horizontal integration of production, processing and marketing activities. These are considered vital elements for achieving the adoption of new cassava technology and provide the basis for bringing about equitable development in cassava-growing regions.

- National program capacity. Training of national program personnel, the realization of joint projects and information exchange--through a newsletter, workshops, regional networks and the provision of bibliographic material--have been the principal elements for strengthening national programs' capacity to implement relevant cassava R&D activities.

1.3 Program Organization

The Cassava Program has organized the activities contemplated within these ten areas of endeavor into three general groups (1) Strategic and applied research, (2) regional programs and (3) networks.

BOX 1.2 OPERATIONAL PRINCIPLES OF THE CASSAVA PROGRAM

Relevance. Program efforts are directed toward increased food production that favors the poorer segments of the population, rather than increasing the body of scientific knowledge per se. Research is focused on solving the most important problems in the major cassava-growing regions served by the Program.

Equity. In seeking to contribute to increased food production, the Program orients its efforts toward benefiting primarily the small, resource-poor farmer, as well as the low-income urban and rural consumers.

Complementarity & cooperation. The Program's activities represent only one segment on the cassava R&D spectrum. Consequently, all activities are designed to complement those of other organizations. Of particular importance are the efforts in support of cassava by national agricultural R&D agencies in countries that the Cassava Program seeks to serve. The Program maintains strong linkages with these agencies and coordinates its work program closely with those of collaborating national programs.

Comparative advantage. The Program concentrates on resolving those problems and developing those techniques and methodologies for which it has a clear comparative advantage in relation to other agencies, be they international or national, public or private. The comparative advantage arises from certain characteristics of commodity research programs in international centers, including: (a) the ability to bring a critical mass of scientists to bear on problems; (b) the facility to move information, biological control agents, and genetic materials across borders; (c) a high degree of continuity of effort; (d) location in the tropics; (e) being in a position to coordinate activities of different entities on a regional or international level; (f) the ability to capitalize on economies of scale; (g) and the ability to take a long-term view of the overall R&D process.

Sustainability. The Program, in its endeavor to make a major and lasting contribution to cassava production and consumption, emphasizes long-term cumulative gains over dramatic short-term impacts. Hence it seeks to develop production technology that promises environmental harmony; relatively broad adaptation to important production constraints; and relatively low requirements for purchased inputs.

1.3.1 Strategic and applied research of global significance

These activities have been carried out, principally at headquarters (HQ), by a critical mass of cassava researchers supported by CIAT's Germplasm Resources Unit (GRU), Biotechnology Research Unit (BRU), Virology Research Unit (VRU), Agroecological Studies Unit (ASU) and Data Services Unit (DSU). Collaborative research is also carried out with research agencies in both developed and developing countries. This effort has been directed toward nonlocation-specific research in the following areas:

- Physiology of the crop and identification of desired characteristics
- Germplasm collection, characterization, development and distribution
- Cassava diseases and arthropod pests
- Cassava-based cropping systems
- Socioeconomic studies of cassava production and marketing
- Cassava quality and utilization

1.3.2 Regional programs

Cassava as a commodity plays a different role at different stages of a country's economic development, and this has been reflected in the Program's approach with regard to the types of activity carried out in collaboration with national programs in Africa, Asia and Latin America. The Program receives support from the Training and Communications Support Program (TCSP) in the execution of these activities.

1.3.2.1 <u>Africa</u>. CIAT's support for cassava development in Africa is channeled exclusively through IITA, which has regional responsibility for the crop on that continent. The Program's strategy is therefore to (a) complement the IITA research program in those areas where research based in Latin America has a comparative advantage over that undertaken in Africa itself and (b) support IITA in those areas of expertise generated from experience with problems similar to those encountered in Africa. The areas of collaborative activity have covered:

- Broadening of the genetic base of cassava in Africa through the introduction and preliminary screening of materials from the Americas

- Identification, characterization, multiplication and shipment of biological agents for controlling the cassava mealybug and green spider mite

- Participation in the organization and execution of COSCA

- Development of varietal screening methodologies for tolerance to water stress

1.3.2.2 <u>Asia</u>. In most Asian countries a multiple market structure for cassava has already developed, and opportunities exist for absorbing increased cassava production--either in existing or new markets--if prices are maintained competitive with alternative carbohydrate sources for food, feed and industry. In addition, the majority of countries have human resources dedicated to cassava R&D, both in the production and postharvest spheres. Consequently, the Program's efforts have been directed toward establishing an effective regional cassava research network, which includes:

- Generation, distribution and evaluation of improved germplasm
- Development of improved cropping systems incorporating soil fertility maintenance and erosion control practices
- Training of national program personnel in research techniques and methodologies
- Socioeconomic studies of cassava production and marketing, adoption and impact in selected countries
- Assessment of needs for horizontal collaboration in postharvest research

1.3.2.3 Latin America. The demand for cassava in Latin American countries still relies chiefly on food markets and on-farm consumption. The demand studies showed that cassava can compete in alternative markets, the development of which has been constrained by the nature of price formation in the cassava food market and government price and subsidy policies, which have favored other carbohydrate sources, especially cereals. In addition, national cassava programs have on the whole been underfinanced and have suffered from a relatively high turnover in personnel. Furthermore, there is a very limited capacity at the national level for undertaking activities in the areas of cassava processing and marketing research. To overcome these constraints, CIAT has based its activities on:

- Strengthening national cassava research and extension programs through training, technical support and collaborative research
- Developing projects with national programs that integrate production, processing and marketing activities in specific cassava-growing regions
- Consolidating the Panamerican Breeders' Network for the testing and evaluation of CIAT and local germplasm
- Creating a network for cassava R&D in the subtropics

1.3.3 Networks

The continued progress in cassava technology development, the consolidation of national cassava programs, and an increased interest in the crop by advanced labs have laid the groundwork for CIAT to catalyze and participate in the formation of a number of networks on cassava:

- The International Cassava R&D Network. Members include international, regional and national R&D agencies, individuals in national agencies and advanced research institutions in developed and developing countries that are either working or interested in the crop. Communication among members of the network is maintained through the Cassava Newsletter, the information/documentation service on cassava, and contacts made during international scientific meetings.

- Biotechnology Research Network. This recently formed network will provide the mechanism for involving and integrating developed and developing country institutions in cassava-related biotech research through joint projects, scientific meetings and a newsletter.

- Regional and subregional cassava R&D networks. These include the germplasm exchange networks in Asia and Latin America, the agronomy network in Asia, the Southern Cone (subtropics) cassava R&D network in Latin America and the Integrated Projects Network also in Latin America. These networks are providing the basis for defining regional priorities for research and opportunities for horizontal collaboration among countries.

1.4 Human and Financial Resources

The activities undertaken by the Cassava Program have been financed by resources from CIAT's core budget and through complementary funding of special projects. The BRU, VRU, GRU, ASU, DSU Seed Unit and TCSP have all contributed with human and financial resources for cassava-related activities.

Table 1.1 shows the projected and actual core-funded staffing pattern of the Program during the period 1987-1991. Although the staffing projections were approved by TAC, the positions of an additional HQ breeder, a second utilization specialist to work on quality and an economist in Asia have not been filled for lack of funding. The activities that were to have been covered by the breeder/agronomist position in Brazil are now being largely undertaken through a collaborative project with the Centro Nacional de Pesquisa em Mandioca e Fruticultura (CNPMF) Cruz das Almas (Bahia). Previous and ongoing special projects are listed in Table 1.2.

Table 1.1. Cassava Program: Projected and actual core-funded staffing pattern during the period 1987-1991.

	1987		1988		1989		1990		1991	
	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual
Headquarters										
Leader	1	1	1	1	1	1	1	1	1	1
Physiologist	1	1	1	1	1	1	1	1	1	1
Pathologist	1	1	1	1	1	1	1	1	1	1
Entomologist	1	1	1	1	1	1	1	1	1	1
Breeder(s)	1	1	1	1	1	1	2	1	2	1
Economist	1	1	1	1	1	-	1	1	1	1
Agronomist	1	1	1	1	1	1	1	1	1	1
Utilization Specialist(s)	1	1	1	1	1	1	2	1	2	1
Africa										
Specialist at IITA	-	-	1	-	1	1	1	1	1	1
Asia										
Breeder	1	1	1	1	1	1	1	1	1	1
Agronomist	-	1 F	-	1 F	1	1	1	1	1	1
Economist	-	-	-	-	-	-	-	-	1	-
Latin America										
Agronomist/Breeder (Brazil)	-	-	-	-	1	-	1	-	1	-
TOTAL	9	10	10	10	12	10	14	11	15	11

F = Funding from extra-CG resources.

Table 1.2. Cassava Program: Previous and ongoing complementary activities financed through special projects, 1987-1992.

Activity	Duration (yr)	Termination Date	Donor
Soil conservation research	3	Mar. 1993	Germany
Green spider mite research	7	Mar. 1992	UNDP/IFAD
Cassava quality research	3	Dec. 1989	UK
Cassava flour R&D	2.5	Dec. 1991[1]	IDRC
Cassava starch R&D	4	Dec. 1992	France
Germplasm development, semiarid & subtropical	5	Jul. 1995	IFAD
Collaborative study of cassava in Africa[2]	2	Dec. 1990	Rockefeller
Human resource development	4	Dec. 1991	UNDP
Ceará cassava development, Brazil	3	Feb. 1992[1]	Kellogg
Manabí cassava development, Ecuador	2	Mar. 1992[1]	FUNDAGRO
Atlantic Coast cassava development, Colombia	10	Mar. 1992[1]	Fondo DRI[3]
Cassava development, Colombia	2.5	Nov. 1991	PNR[3]

[1] Extension sought.
[2] Covering CIAT's contribution only.
[3] DRI = Integrated Rural Development Fund of the Colombian Govt.;
PNR = National Rehabilitation Plan of the Colombian Govt.

HEADQUARTERS-BASED RESEARCH

2. GERMPLASM MANAGEMENT AND IMPROVEMENT

Germplasm resource management and development has been one of the most important activities within the Cassava Program at CIAT. The Cassava Breeding Section has complemented national and international institutions in the development of components for sustained improvement of cassava varieties and for promoting them to farmers. This has involved a multidisciplinary effort within the Cassava Program, with other units in CIAT, and close linkages with collaborating national and international institutions.

Germplasm resources represent a major component of the natural resources base exploited in agriculture, justifying the Program's major focus on them. New cassava varieties developed from improved gene pools have proved to be one of the most attractive basic components of production technology for stable, cassava-based cropping systems. Improved germplasm can be easily adopted by farmers at a low cost and with a long-term contribution toward sustainable agricultural systems. The emphasis of the Breeding Section has been to improve the level and stability of cassava production and root quality, with efficient use of nutrient and water resources, and agrochemical inputs.

Priorities and modus operandi at the continental level have been determined by a combination of factors such as the importance of cassava production, characteristics and strength of national programs, available genetic diversity, presence of IITA with responsibility in Africa and funding opportunities. Virtually all national cassava programs have identified varieties as a crucial part of the new production technology they want to develop--an area where CIAT has contributed significantly during the last four years.

Improved germplasm generated over 15 years, together with the long-standing presence of CIAT and the readiness with which germplasm can be moved to countries in Latin America and Asia, made it possible to pursue the following objectives: help organize national breeding programs based on the most important constraints and production areas; channel improved germplasm to the levels of advanced experimental and/or on-farm trials, resulting in an increased number of released varieties; and stimulate the more developed national programs to take an active role in cassava breeding with a regional scope.

In the case of Africa, CIAT cooperation with IITA's ongoing cassava improvement efforts has led to an effective flow of information between the centers and the introduction of broad genetic variability. The expansion of the germplasm base to backstop IITA will result in a more efficient breeding program for the most important agroecosystems where cassava is grown in Africa, as well as the possibility of developing cassava for semiarid regions.

Within the worldwide responsibility for cassava germplasm management and development, the main objectives at CIAT have been to:

- Maintain a representative reservoir of genetic variability for *M. esculenta* and the related wild species; characterize it and evaluate it across different agroecosystems of relevance for the crop.

- Develop improved gene pools for specific edaphoclimatic zones (ECZs), taking into consideration the most important biotic and abiotic constraints, and market requirements.

- Study the physiological and agronomic bases of root yield (RY), stress adaptation, and root quality, and the best way to incorporate related screening techniques within cassava breeding programs.

- Develop a model for farmer participatory research and the improved adoption of new varieties.

- Support national programs through the interchange of cassava germplasm and related information, training in breeding, and promotion of networking activities among national and international institutions.

2.1 Breeding Strategies and Technical Advances

During the 20 years of work in cassava breeding at CIAT, a broad genetic base has been assembled in a germplasm collection, which has also been evaluated across a range of agroclimatic conditions. A breeding scheme was established in the mid-70s, including genetic recombination among complementary parental material, selection within segregating progenies, and recurrent utilization of elite clones, resulting in gene pools with specific adaptation to biotic and physical constraints.

2.1.1 Edaphoclimatic zone definition

Given the broad range of conditions under which cassava is grown and the difficulty of obtaining single genotypes with adaptation to all the production situations, the Section has worked on developing broad-based gene pools directed to particular regional needs. The components used to define the ECZs were: world importance of the agroecosystem, climatic conditions, predominant soil type and related constraints, pest and disease problems, and use of end product. Seven major ECZs were identified, some of which were further subdivided by utilization criteria. Table 2.1 presents a description of gene pools for defining cassava germplasm development, representative regions within each subdivision, and the sites where major breeding activities are conducted.

Two basic modifications were made to the original gene pool description. Based on the recognition of the growing importance of semiarid regions for expanding cassava production and the available genetic variability for enhanced water use efficiency (WUE), combined with findings in cropping systems that maximize the use of limited water

Table 2.1. Revised description of gene pools for defining cassava germplasm development.

No.	Description	Representative Countries/Regions	Main Sites for Breeding Work
1	Subhumid tropics	Mexico (Yucatan Peninsula); NE Brazil; NE Thailand; Domin. Rep.; N. Venezuela	Media Luna (Colombia)
1LC	Subhumid tropics; low HCN	Colombia (Atlantic Coast & Santanderes); Panama (Coclé); subhumid belt of Africa; Ecuador (NW coast)	Media Luna (Colombia)
2	Acid soil savannas	Mexico (Tabasco); Plains of Colombia & Venezuela; Brazil (Cerrado)	Villavicencio (Colombia)
2LC	Acid soil savannas; low HCN	Cuba; W Africa savannas; Philippines; Panama (Ocu)	Villavicencio (Colombia)
3	Humid tropical lowlands	Amazon basin (Brazil, Colombia, Peru); West Java & Sumatra; Malaysia; S. Vietnam	Villavicencio (Colombia)
3LC	Humid tropical lowlands; low HCN	Equatorial West Africa	Villavicencio (Colombia)
4LC	Mid-altitude tropics; low HCN	Andean zone; central Brazilian highlands; mid-altitude areas of Nigeria, Cameroon, East Africa	Palmira (Colombia)
5LC	High-altitude tropics; low HCN	Andean zone; Rwanda; Burundi	Popayán (Colombia)
6	Subtropics	S Brazil; Argentina; China; N Vietnam	Santa Catarina (Brazil)
6LC	Subtropics; low HCN	Cuba; Paraguay; S Africa	Santa Catarina (Brazil)
7	Semiarid	NE Brazil	NE Brazil
7LC	Semiarid; low HCN	NE Colombia; (Guajira) semiarid belt of West Africa; Tanzania; Mozambique; Ecuador (Coast)	NE Brazil

Note: Low HCN gene pools can also move to equivalent ECZs indicated for low/high HCN pools, but not vice versa.

resources, led to a major emphasis in gene pool development for those conditions. Research for this ECZ will have high priority within the Cassava Program as it comprises some of the poorest and highest food-demanding regions of the world.

The second modification relates to the growing concern about the effects of hydrocyanic acid (cyanide) on human health. Most gene pools have been divided into a low-cyanide population and one for which cyanide is not considered for parental selection. Low cyanide can not be generalized as a selection criterion given, on the one hand, the restricted available genetic variability within this type of gene pool and, on the other, the preference for high-cyanide varieties for certain processed food.

2.1.2 Germplasm conservation and evaluation

Germplasm management--which involves the activities of collection, conservation, characterization, documentation, distribution and research aimed at improving the efficiency of germplasm conservation and use--has been one of the main responsibilities of the Breeding Section and the GRU, with cooperation from the BRU and DSU.

The Section has focused on Latin American germplasm, given that a large proportion of the total genetic variability exists in this hemisphere. Nevertheless, selection for local adaptation in both Africa and Asia has resulted in new genetic combinations that should also be preserved.

The Section has gathered a representative sample of the genetic variability of the species in its reservoir. Collecting germplasm had a lower priority during the last five-year period, with greater emphasis on characterization, documentation, identification of duplicates, definition of a core collection, and the initiation of a broad germplasm collection for wild *Manihot* relatives.

2.1.2.1 Status of germplasm collection. Started in 1969, the cassava germplasm collection has grown gradually, with a total of 5035 accessions assembled in the field gene bank (Table 2.2). There will soon be a significant increase with the forthcoming introduction of 800 accessions from Brazil, giving proper representation to one of the most important centers of diversity for cassava. Other important contributions have come from Asian and Nigerian introductions. Asian clones have represented a source of broad adaptation, as well as being one of the bases for our cooperation with Asian national programs. Clones from IITA are already being used as parents for the germplasm introduced to Africa, providing a greater chance for immediate adaptation.

There are several gaps to be filled in order to complete a world collection. For some countries of intermediate to high importance in cassava production, there are no accessions, or common landraces are missing among the few accessions available. The absence of a centralized African germplasm collection has restricted representation from that continent. IITA's efforts to compile information on national collections and to consolidate an African cassava germplasm collection, together with recent advances in virus indexing techniques, will make it possible to have a better representation of the genetic variability available in Africa in the near future.

Table 2.2. Descriptive information available on the CIAT cassava germplasm collection.

Origin	No. of Accessions	% with Passport Data[1]		% with Agronomic Evaluation[2]	% with Isozyme Characterization	% with Morpholog. Character.
		Basic	Complete			
Argentina	16	0	0	100	0	94
Bolivia	3	0	0	100	0	67
Brazil	1085	25	0	73	72	50
China	2	0	0	100	50	100
Colombia	2010	50	30	90	56	100
Costa Rica	147	0	0	100	93	90
Cuba	74	0	0	100	100	100
Dom. Rep.	5	0	0	100	100	100
Ecuador	117	90	0	100	97	100
Fiji	6	0	0	100	100	100
Guatemala	91	0	0	100	85	90
Indonesia	51	0	0	100	100	88
Malaysia	68	0	0	100	97	96
Mexico	100	70	0	100	81	55
Panama	42	50	0	100	95	95
Paraguay	192	10	90	95	68	83
Peru	405	40	0	95	59	88
Philippines	6	0	0	100	100	0
Puerto Rico	15	100	0	100	100	100
Thailand	8	100	0	100	100	100
United States	9	0	0	100	89	89
Venezuela	240	50	0	100	98	100
CIAT clones	324	-	-	100	68	100
IITA clones	19	-	-	100	84	11
Total	5035	40[3]	17	98	69	90

[1] Basic: origin; date of collection; complete: origin; date of collection; site description; qualities and uses.
[2] Evaluation in at least one major ecosystem.
[3] Excluding clones.

The present status of the wild *Manihot* species collection is given in Table 2.3. This represents the starting point of a long-term strategy for exploiting these potentially valuable genetic resources. Crossability studies, preliminary evaluation and biochemical characterization have begun, resulting in much greater polymorphism than that observed in cultivated cassava. Isozyme characterization and DNA fingerprinting will provide the basis for clarifying some of the evolutionary patterns within the genus *Manihot*.

2.1.2.2 An integrated germplasm conservation strategy. The main responsibility of CIAT, as curator of the world cassava germplasm, is to assure long-term conservation at low levels of risk of loss, contamination by pests or pathogens, or genetic modifications. The collection is maintained in the field, and 95% of the accessions have been transferred to in vitro culture for maintenance under slow-growth conditions. Not only is the in vitro

Table 2.3. Wild *Manihot* species maintained in vitro at CIAT.

Species	Abbreviation	Genotypes (No.)
M. aesculifolia	aes	3
M. alutacea	alt	9
M. anomala	an	2
M. brachiloba	bra	1
M. caerulescens	cae	35
M. carthaginensis	cth	185
M. chlorosticta	chl	9
M. cecropiaefolia	cec	6
M. crassisepala	cra	12
M. epruinosa	epr	1
M. filamentosa	fmt	5
M. flabellifolia	fla	41
M. fruticulosa	fru	2
M. glandulifolia	gld	1
M. glaziovii	gla	4
M. grahami	grh	12
M. guaranitica	gua	48
M. hastatiloba	has	4
M. irwinii	irw	2
M. jacobinensis	jac	29
M. longipetiolata	lon	7
M. michaelis	mic	6
M. orbicularis	orb	9
M. peltata	pel	1
M. pentaphylla	pnt	2
M. pilosa	pil	3
M. pseudoglaziovii	pse	11
M. purpureo-costata	pur	1
M. sparsifolia	spr	3
M. triphylla	tph	24
M. tristis	tst	41
M. rubricaulis	rub	21
M. violacea	vio	4
M. violacea spp. *recurvata*	vio	2
Others (taxonomically undefined)		
6047-75663		1
167-71323		1
666.10-470.80		1
595-075698		1
Total: 34 species		509

collection a safer means of conservation but it also facilitates international germplasm exchange.

At present only about half the accessions are duplicated in national program collections, the most problematic case being the Colombian collection, with very few of the accessions maintained by ICA, the Colombian Agricultural Institute. Duplication of the collection in another institution will have high priority as a future germplasm conservation strategy.

Recent developments in cryopreservation of shoot tips, true seed (TCS) and pollen promise to become routine procedures for backup reserve of genetic diversity in cassava. A core collection representing a high proportion of the original genetic variation from the germplasm collection was recently defined. The possibility of eliminating duplicates is based on preliminary grouping using highly reliable biochemical and morphological descriptors. This will be completed next year, reducing the present number of accessions by about 20 to 25%.

All the previous concepts have been integrated into a strategy for conserving cassava genetic diversity (Table 2.4) based on the core collection, duplication in an other institution, and in vitro and cryopreservation.

2.1.2.3 Germplasm characterization and duplicate identification. Descriptive information available on the CIAT cassava germplasm collection is presented in Table 2.2. Evaluation based on the morphological descriptors defined by the International Board for Plant Genetic Resources (IBPGR) was completed for all accessions. In terms of biochemical characterization, the αß-esterase isozyme system has demonstrated the highest degree of polymorphism in cassava. To date, 70% of the germplasm collection has been characterized for banding patterns on polyacrylimide gels, and the whole collection will be fingerprinted by 1992. Every electrophoretic isozyme pattern is analyzed quantitatively by means of a laser densitometer and quantitatively by codifying the presence/absence of each of the 22 bands. From a replicated analysis of a representative sample (Table 2.5), the 12 highest confidence bands were detected (< 10% error in terms of presence/absence of a band). Based on this analysis and the grouping work conducted on a set of 175 clones from the North Coast of Colombia, in which a high degree of duplication was suspected, an empirical two-stage procedure was developed.

The first stage took into account grouping based on identity for those descriptors whose expression is least influenced by the environment or measurements errors. The second stage involved a cluster analysis within the identified groups with more than 10 accessions based on bands of less confidence and other morphological descriptors. After studying 1574 accessions with a complete set of morphological and biochemical descriptors, 831 different groups were identified, 544 of those represented by single-clone groups in the collection. Supposedly duplicate accessions within groups were planted together in the field at high density, and the morphological descriptors are being recorded again, but under uniform environmental conditions. It is expected that between 20 and 25% of the accessions will be confirmed as duplicates.

Table 2.4. Proposed strategy for conserving genetic diversity in cassava.

Implementation[1]	Description of Germplasm	Type of Conservation	Responsible Institution[2]	Estimated No. of Accessions
Actual	Total (LA & Asia)	Field	CIAT	5035
		In vitro	CIAT	4602
Short term	Reserve (LA & Asia)	Field	CIAT	5477
		In vitro	CIAT	4900
	Core (LA & Asia)	Field	CIAT	600
		In vitro	CIAT	600
Medium term	Reserve (LA & Asia)	Cryo.[4]	CIAT	4000
		In vitro	CIAT	4000
		Seed/pollen	CIAT	2000
	Core (global)	Cryo.[4]	CIAT	700
		In vitro	CIAT	700
		Seed/pollen	CIAT	500
		Field	CIAT	700
		In vitro or cryo.	Other	700
Long term	Reserve (global)	Cryo.[4]	CIAT	4500
		In vitro[5]	CIAT	4500
		Seed/pollen	CIAT	3000
		Cryo.[4]	Other[3]	3000
	Core (global)	Cryo.[4]	CIAT	700
		In vitro	CIAT	700
		Seed/pollen	CIAT	500
		Field	CIAT	700
		Cryo.[4]	Other[3]	700
		In vitro and Field	Other[3]	700

[1] Short term = 1-2 yr; medium term = 3-5 yr; long term = > 5 yr.
[2] Excludes conservation activities in Africa related to core and noncore collections.
[3] Duplicated at 2 other sites (e.g., IITA, CENARGEN, CTCRI, VISCA, CATIE).
[4] Assuming successful development of cryopreservation in the medium term.
[5] Assuming cryopreservation is not developed in the medium term.

2.1.2.4 Core collection definition. A core collection representing the total diversity of the species (including 13% of CIAT's total collection) was selected. It is anticipated that the core collection will be the first part of the collection to be duplicated at another institution, to be placed in cryopreservation, and to be evaluated intensively for specific new traits.

Table 2.5. Evaluation of αB-esterase bands for consistency across repeated samples.[1]

Band	Frequency in Sample (No.)	Frequency in Sample (%)	Frequency in All Germplasm	No. of Groups with Inconsistencies	No. Inconsistent Band Frequency	Ranking
1	85	11.1	6.4	12	14.1	16
2	56	7.3	10.1	35	62.5	20
3	334	43.8	44.3	30	9.0	11
4	253	33.2	33.4	19	7.5	10
5	114	14.9	20.2	27	23.7	17
6	345	45.2	48.2	48	13.9	15
7	474	9.7	6.7	23	31.1	19
8	430	56.4	47.2	49	11.4	13
9	306	40.1	34.8	21	6.9	8
10	519	68.0	71.2	19	3.7	4
11	0	0.0	0.1	0	-	-
12	42	5.5	5.5	0	0.0	1
13	55	7.2	8.8	1	1.8	3
14	35	4.6	2.1	2	5.7	7
15	363	47.6	50.9	33	9.1	12
16	0	0.0	0.1	0	-	-
17	24	3.1	1.5	7	29.2	18
18	125	16.4	13.8	16	12.8	14
19	177	23.2	28.1	13	7.3	9
20	262	34.3	22.6	13	5.0	6
21	183	24.0	29.4	7	3.8	5
22	528	69.2	66.4	5	0.9	2

[1] Data from 763 samples with 314 clones (avg of 2.43 reps/clone).

Criteria for selecting accessions for the core collection fell within four major groups: (a) geographic origin (the most important); (b) diversity of morphological descriptors; (c) diversity of αB-esterase banding pattern; and (d) a priori selection of accessions based on a predetermined criterion of specific interest. Table 2.6 presents a description of parameters and weighting factors used in determining the no. of accessions chosen from each country of origin.

2.1.2.5 Germplasm screening. Agronomic evaluation of cassava germplasm across a wide range of growing conditions provided information for detecting sources of resistance to physical and biological stresses common to cassava-producing areas worldwide, and for selecting high-potential and/or widely adapted clones for crossing blocks and for national programs. The great majority of accessions from Asia, all the clones from IITA, and small parts of the collections received from Brazil, Colombia and Peru were evaluated over the last five years. Table 2.7 summarizes characteristics of the most distinguished clones. Asian clones excelled for their broad adaptation, high resistance to thrips and moderate resistance to cassava bacterial blight (CBB). African clones were characterized by their susceptibility to mites, profuse branching, low dry matter (DM) and intermediate

Table 2.6. Description of parameters used in determining no. of accessions to be chosen from each country of origin.

Origin	No. Access.	Local Landrace Var. (%)	Est.Level of Dupl. (%)	Base No. of Landrace Access.	Importance as Center of Diversity: Scale	Importance as Center of Diversity: Wt	Country's Total Diversity in CIAT Collection: %	Country's Total Diversity in CIAT Collection: Wt	Diversity of Ecosystems: Scale	Diversity of Ecosystems: Wt	Correct. Factor[1]	Sum of Wts[2]	No. of clones for distinct parameters: Geographic Origin[3]	Morphological Diversity[4]	Diversity of Esterase	A Priori Selection[5]	Final No. in Core[6]
Argentina	16	40	10	8	1	1.00	25	0.75	2	0.40	1.00	2.15	2	4	0	3	8
Bolivia	3	100	0	3	1	1.00	5	0.95	2	0.40	1.00	2.35	1	2	0	3	3
Brazil[7]	1637	95	20	1244	1	1.00	40	0.60	5	1.00	0.20	0.52	110[8]	13	15	20	101
China	2	100	0	2	3	0.50	25	0.75	3	0.60	1.00	1.85	1	0	0	2	2
Colombia	1907	95	20	1449	1	1.00	75	0.25	5	1.00	0.20	0.45	111	15	13	14	146
Costa Rica	147	40	20	47	2	0.75	80	0.20	2	0.40	0.80	1.06	9	7	5	4	23
Cuba	74	90	20	53	2	0.75	80	0.20	2	0.40	0.80	1.06	10	5	1	2	18
Dom. Rep.	5	100	10	5	2	0.75	10	0.90	3	0.60	1.00	2.25	2	2	0	4	5
Ecuador	117	100	25	89	1	1.00	50	0.50	3	0.60	0.80	1.66	25	8	0	4	32
Fiji	6	100	10	5	3	0.50	50	0.50	1	0.20	1.00	1.20	1	0	0	2	2
Guatemala	91	100	50	46	2	0.75	80	0.20	2	0.40	0.80	1.06	8	8	0	2	15
Indonesia	51	10	15	4	3	0.50	10	0.90	3	0.80	0.80	1.80	1	0	2	5	7
Malaysia	68	70	15	40	3	0.50	50	0.50	2	0.40	0.80	1.12	8	0	1	6	15
Mexico	100	95	30	67	2	0.75	75	0.25	3	0.60	0.80	1.26	14	8	0	2	20
Panama	42	100	20	34	2	0.75	75	0.25	2	0.40	0.80	1.12	6	2	0	2	9
Paraguay	192	100	20	154	1	1.00	80	0.20	2	0.40	0.60	0.96	25	6	3	7	40
Peru	405	95	20	308	1	1.00	60	0.40	2	0.80	0.60	1.20	83	10	3	2	78
Philippines	6	30	0	2	3	0.50	5	0.95	2	0.40	1.00	1.65	1	0	0	2	2
Puerto Rico	15	40	15	5	2	0.75	60	0.40	2	0.40	1.00	1.55	1	2	0	4	7
Thailand	8	10	0	1	3	0.50	75	0.25	2	0.40	1.00	1.15	0	0	0	4	4
USA	9	0	0	0	3	0.50	100	0.00	1	0.20	1.00	0.70	0	0	0	4	4
Venezuela	240	95	20	182	1	1.00	60	0.40	4	0.80	0.60	1.32	41	9	3	3	55
CIAT clones	317	0	0	0									0	3	5	27	33
IITA clones	19	0	0	0									0	0	0	3	3
TOTALS	5477			3744									440	100	51	121	830[9]

[1] Correction factor for collection size:
> 1000 = 0.2
> 400 - 1000 = 0.4
> 100 - 400 = 0.6
> 20 - 100 = 0.8
1 - 20 = 1.0

[2] Sum of wts 1, 2 and 3 X correction factor for collection size.

[3] No. of accessions for core = (sum of wts X base no. of landrace accessions X constant), where constant = 0.17.

[4] Clones included in CIAT/IBPGR In Vitro Pilot Genebank (IVAG).

[5] Criteria:
a = Included in CBN studies on basis of diversity of geographic origin and agronomic value.
b = Common landrace var.
c = Elite clones from CIAT and IITA.

[6] Final may be less than the sum of columns as the same clone may be repeated for different criteria.

[7] Including 800 accessions to be introduced in 1991-92.

[8] Sixty accessions to be included prior to introduction of 800 new accessions.

[9] Actual total will likely be lower after testing for and eliminating duplicates within the core.

to low RY potential. Accessions from Brazil with stable performance were selected as elite clones for ECZ 1.

2.1.3 Breeding methodology development

The breeding scheme implemented by the Section (Fig. 2.1) allows for selecting genotypes adapted to specific ECZs while offering the possibility of screening for genotypes with broad adaptation across the main ECZs. Several clones selected independently in ECZ 1 and ECZ 2 over the last four years constitute an important genetic base to be transferred to national programs working in transitional or highly variable conditions, and to be used in building gene pools for enhancing broad adaptation.

Other strategies are being developed in order to improve the chances of selecting genotypes for other regions within an ECZ, outside CIAT's gene pools. An ideal breeding scheme for cassava would include the development of segregating progenies at CIAT and their subsequent evaluation within the same ECZ in different regions of the world. With the information on avg performance, parental material maintained at CIAT could be selected for recombination and families produced for the following cycle. The strategy will also allow breeding for constraints present on one continent but with the potential of being introduced into others (e.g., African cassava mosaic virus, ACMV).

Broad-sense heritability and realized response to selection were estimated using information from the performance of sets of clones in consecutive years from 1981-90. Traits such as HCN content, % DM and reaction to superelongation disease (SED) can be used as primary selection criteria at early stages of a cassava breeding program, given their relatively high heritability (Table 2.8). Other traits, which are highly affected by the environment (RY), by inoculum pressure (CBB), or complex traits (foliage and root evaluation) need to be selected for under replicated and preferably multisite evaluation trials.

Figure 2.2 A&B shows the genetic progress for RY at the main selection sites for the principal ECZs. The trend has been more consistent for ECZ 1 than for ECZ 2. The decline observed for the later period in ECZ 2 is possibly related to the change in selection site from a high-disease pressure site (Carimagua) to a less stressful environment (Villavicencio).

Emphasis has been on selecting elite, but not closely related parental clones for gene pool construction. A small number of clones with high RY potential and relatively broad adaptation have been used as parents; many of the elite clones selected by the Section have them in their pedigree (Table 2.9). Recombination among clones that have common ancestors may lead to considerable levels of inbreeding depression in subsequent generations.

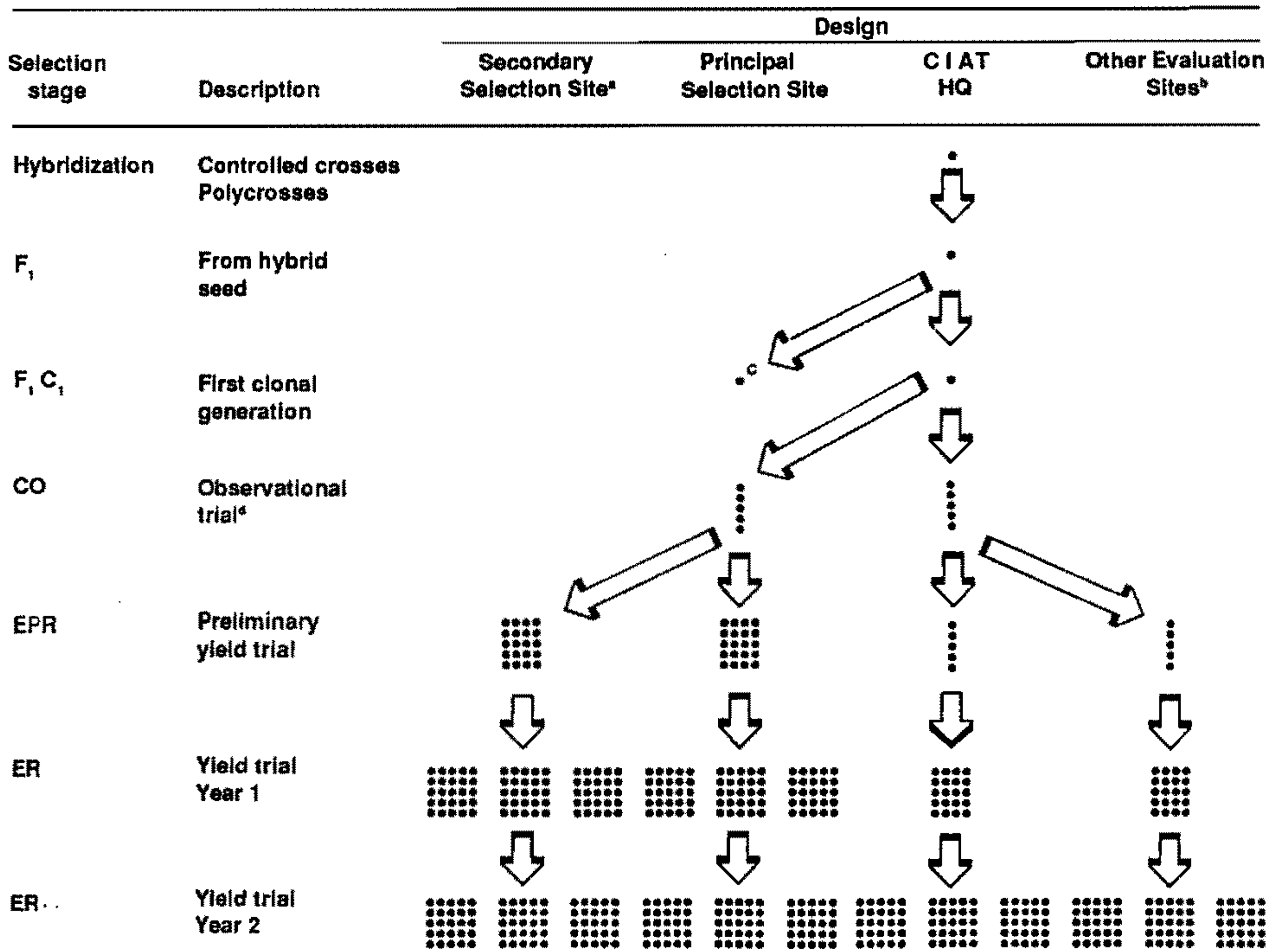
Table 2.7. Avg performance of selected germplasm accessions evaluated in common trials at different ECZ sites.

Clone	RY (t/ha)	HI	Commer. Roots/pl	%DM	HCN	Thrips	CBB	SED
a. ECZ 1 (Media Luna)[1]								
M Bra 191	13.4	0.50	3.0	34.6	6.0	1.0	-	-
M Bra 383	13.3	0.61	3.6	31.2	8.0	1.0	-	-
M Bra 390	13.6	0.53	3.5	34.8	8.5	1.0	-	-
M Bra 589	22.1	0.52	5.0	31.9	8.0	2.0	-	-
M Ind 8	16.0	0.54	4.2	30.8	5.0	3.0	-	-
M Tai 5	19.1	0.64	4.4	35.3	9.0	2.0	-	-
M Tai 8	20.0	0.64	4.9	30.8	9.0	2.0	-	-
Checks	13.8	0.54	2.9	29.9	7.2	2.5	-	-
b. ECZ 2 (La Libertad)[2]								
M Arg 7	22.0	0.53	3.0	35.0	6.0	-	2	1
M Arg 13	25.2	0.60	3.2	33.8	9.0	-	2	1
M Bra 97	24.9	0.60	3.2	34.3	9.0	-	3	1
Checks	16.1	0.59	2.7	31.0	6.4	-	3	1.8
c. ECZ 1 and 2[3]								
M Ind 39	19.0	0.53	3.1	35.0	6.0	1.5	2	1
M Mal 37	22.4	0.60	3.3	33.8	9.0	1.0	2	1
M Mal 48	23.4	0.60	3.4	34.3	9.0	1.0	2	1
Checks	15.8	0.59	2.7	31.0	6.5	2.5	3	1.6

[1] Means of trials GY8755, GY8810, GY8924, GY9024
[2] Means of trials GY8715, GY8819, GY8910, GY9015
[3] Means of trials GY8917, GY8924, GY9015, GY9024

2.1.4 Gene pool development for edaphoclimatic zones

Because of the wide range of conditions under which cassava is grown, the strategy of the CIAT Breeding Section has been to develop gene pools with adaptation to the main biological and physical environmental stresses for each of the ECZs. The strategy is based on the homology among environmental conditions found at particular sites in Colombia and those conditions in the predominant cassava-production areas of the world. Selected clones for a particular ECZ are used as parents for the next cycle of selection, and they are also shipped in vitro to national programs in order to be evaluated as potential new varieties. The link between cassava breeding at the national program level and population improvement at CIAT is the interchange of germplasm and information about its performance.



a Same ECZ as principal selection site
b ECZ for different principal selection site
c Selection at principal selection site but stakes for CO from CIAT HQ
d Accessions from germplasm collection enter at this stake

Figure 2.1 Stages of selection in CIAT Cassava Breeding Program

Table 2.8. Broad-sense heritability estimates for different ECZs, 1981-90.

Environment	RY	HI	% DM	HCN Content	Foliage Evaluation	Root Evaluation	CBB Resistance	SED Resistance
ECZ 1 Sem. A	0.27 [1] (0.058) [2]	0.56 (0.068)	0.47 (0.066)	0.44 (0.046)	0.30 (0.066)	0.10 (0.075)		
ECZ 1 Sem. B	0.51 (0.147)	0.69 (0.142)	0.35 (0.167)	0.56 (0.152)	0.56 (0.116)	0.33 (0.136)		
ECZ 2 Sem. A	0.28 (0.066)	0.44 (0.072)	0.51 (0.062)	0.63 (0.051)	0.28 (0.066)	0.26 (0.088)	0.33 (0.100)	0.39 (0.061)
ECZ 2 Sem. B	0.29 (0.121)	0.58 (0.126)	0.43 (0.118)	0.67 (0.132)	0.19 (0.092)	0.14 (0.109)	0.19 (0.073)	0.51 (0.174)

[1] Pooled estimate.

[2] SD (0.05).

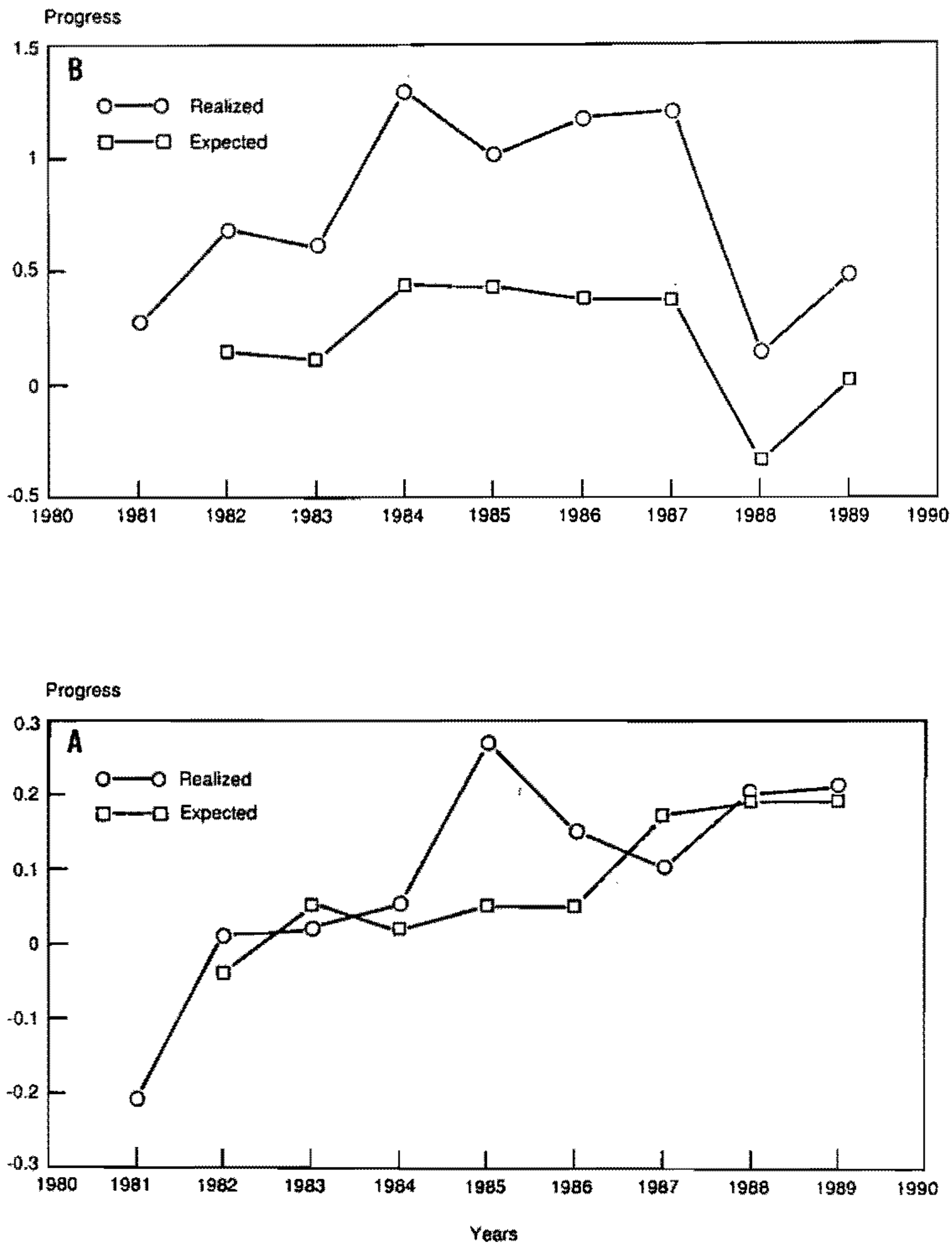


Figure 2.2. Genetic Progress in root yield: (A) ECZ 1- Semester A and (B) ECZ 2- Semester A

Table 2.9. Frequency of use of germplasm accessions as parents in elite clones (including multiple crosses).[1]

Germplasm Accession	ECZ	Frequency (%)
M Col 22	I-IV	27.7
M Col 1684	I-IV	20.9
M Bra 12	I-IV	7.2
Subtotal for ECZs I-IV		55.8
M Col 647	II-III	16.3
M Col 1438	II-III	13.3
M Col 638	II-III	10.4
M Ven 77	II-III	7.4
Subtotal for ECZs II-III		47.4
M Col 2060	V	22.9
M Col 1522	V	17.8
M Ecu 169	V	14.7
M Col 113	V	13.1
Subtotal for ECZ V		68.5

[1] Total of 283 elite clones analyzed.

2.1.4.1 Lowland tropics with low to intermediate rainfall and long dry season (ECZ 1). Media Luna (Magdalena) is the principal selection site for ECZ 1, with El Carmen (Bolívar) being a secondary location and the main site for interaction with ICA's cassava program. The ideotype sought for ECZ 1 includes the combination of good plant type, high RY, high DM and adequate levels of resistance to diseases (CBB and anthracnose) and pests (mites and thrips). Table 2.10 presents the elite clones selected from 1987-91 and their main characteristics. Local check M Col 2215 represents a high standard in terms of DM production and stability, and cooking quality. With a combination of superior RY potential and similar DM content, elite clones significantly outyielded the check in DM production/ha. Greater emphasis is being given to cooking quality in advanced yield trials (ERs) in order to prevent losing valuable genetic variability for that complex trait when selecting for just RY and DM production potential.

2.1.4.2 Lowland tropics with acid soil savannas and high rainfall (ECZ 2). Cassava breeding activities were moved from Carimagua (inner Eastern Plains) to ICA-La Libertad (Piedmont) in 1987. The new site is characterized by relatively high pressure from dry-season pests (green mites and mealybugs) and erratic incidence of CBB and SED. The strategies implemented to enhance disease pressure involved susceptible spreader rows, artificial inoculation and crop rotation. Until reliable high disease pressure is achieved, the Section risks selecting elite clones that will succumb under heavy disease pressure; or conversely, eliminating clones of avg productivity that could be a valuable source of disease resistance.

Table 2.10. Adjusted performance of elite clones for ECZ 1, selected from 1987-91.

								Resistance to:[3]	
Clone	Parent Clones Female x Male	RY (t/ha)	HI	No. Commer. Roots/pl	% DM	HCN[1]	Cooking Quality[2]	Thrips	Mites
CM 3320- 4	M Bra 20 x CM 523- 7	19.4	0.60	3.8	32.7	9.0	4.0	1.0	1.0
CM 3992- 9	CM 681-2 x M Col 1468	15.0	0.61	4.0	33.3	6.0	2.8	1.2	1.2
CM 3997- 1	CM 681-2 x CM 849- 1	12.9	0.41	2.0	30.4	8.5	3.0	1.5	1.2
CM 4013- 1	CM 922-2 x CM 728- 2	16.5	0.55	3.7	32.0	8.0	3.4	1.0	1.3
CM 4042- 4	CM 1015-13 x CM 180- 5	20.8	0.62	2.6	30.1	8.2	3.2	1.0	1.1
CM 4063- 6	CM 1015-42 x CM 849- 1	20.6	0.62	3.2	29.3	8.8	4.2	1.1	1.3
CM 4365- 1	CM 976-15 x M Col 2207	17.0	0.58	2.2	35.9	4.8	1.3	1.5	1.2
CM 4733- 2	M Bra 12 x M Col 72	15.3	0.58	3.3	33.9	6.3	2.0	1.4	1.0
CM 4772- 4	M Col 22 x M Mal 3	17.3	0.56	4.0	32.1	4.2	1.8	1.0	1.2
CM 4777- 2	M Col 72 x CM 523- 7	14.8	0.63	2.3	37.6	6.0	1.6	1.0	1.2
CM 4919- 1	M Col 2207 x SM 301- 3	19.7	0.71	3.8	33.7	8.5	3.2	1.2	1.0
CM 5586- 1	CM 681- 2 x M Col 2215	16.0	0.55	4.5	35.2	5.5	1.3	1.0	1.3
M Col 2215		10.2	0.47	3.0	34.2	5.2	1.8	1.6	1.3

[1] 1 = very low; 9 = very high
[2] 1 = excellent; 5 = very poor
[3] 1 = highly resistant; 5 = highly susceptible

Recently selected elite clones for ECZ 2 are presented in Table 2.11, along with their main characteristics. Most of the clones combine good RY with quality, representing an adequate genetic base for the developing cassava in the piedmont region.

2.1.4.3 High-altitude tropics (ECZ 5). Breeding activities have been developed in the region of Popayán (alt. 1800 m). Due to the potential importance of CBB in this ecosystem, greater efforts are being made to incorporate resistance to that pathogen. Elites clones are also being evaluated in Carimagua for their resistance to the disease. The genotype X altitude interaction has been recognized as being very important when breeding cassava for high-altitude tropics. In order to incorporate that factor into the breeding scheme and broaden the range of adaptation of the developed gene pools, two strategies were developed: Elite clones for middle- (ECZ 4) and high-altitude (ECZ 5) zones are under evaluation at an intermediate site (alt 1400 m) in Mondomo (Cauca) to determine their adaptation range. The second strategy includes the simultaneous evaluation of segregating material at Popayán and at CIAT-HQ (alt. 1000 masl), selecting only genotypes that show good performance at Popayán and at least reasonable adaptation at CIAT HQ. Table 2.12 gives the main characteristics of the elite clones selected for ECZ 5. These clones represent the basis for future cooperation with cassava-production areas in high-altitude tropics, particularly the Eastern Africa highlands.

2.1.5 Varietal evaluation with farmers

Evaluation of cassava varieties with the participation of farmers during 1987-91 has provided information for defining a methodological model for participatory research and refining selection criteria for varietal improvement. Based on the results from ERs, CIAT breeders and ICA scientists selected elite clones to be evaluated in regional and farmer-managed trials on the North Coast of Colombia. Open interviews provided relevant information at the farm level on production, market, technology demand and farmers' criteria for choosing/rejecting different alternatives.

CIAT's DSU combined common regression, principal component and stability analyses in an integrated approach to qualify the relevance of different evaluated traits for cassava growers. Farmers gave major emphasis to criteria related to the fresh root market such as root no., size and external color. Table 2.13 presents results for 26 clones evaluated by 379 farmers. Several experimental clones resulted with higher acceptability than the local varieties. In particular CG 1141-1 and CM 3306-4 always received high and stable qualifications at both early and late harvest. Many farmers in the region have been adopting these clones before release as a result of their outstanding trial performance.

The farmer participatory research model and means for improving the adoption rate of new varieties were discussed in a three-day workshop held at CIAT in September 1991. It was concluded that new varieties should be selected according to farmers' preferences and that the release process must be accompanied by an organized system for multiplying planting material and a proper followup of adoption rate. To extend the use

Table 2.11. Adjusted performance of elite clones for ECZ2; selected from 1987-91.

Clone	Parent Clones Female x Male	RY (t/ha)	HI	No. Commer. Roots/pl	% DM	HCN[1]	Cooking Quality[2]	Resistance to:[3] CBB	SED
CM 3311- 3	M Col 1468 x CM 523- 7	31.5	0.59	3.5	34.1	7.5	2.2	2.7	1.7
CM 3380- 7	CM 586- 1 x CM 523- 7	16.6	0.55	2.3	31.0	6.8	3.0	2.7	1.6
CM 4157-34	CM 586- 1 x M Bra 12	23.0	0.62	2.5	33.1	7.0	2.2	2.5	1.0
CM 4402- 4	CM 1335- 4 x M Ven 77	25.8	0.58	2.3	32.0	4.0	1.8	2.2	1.3
CM 4484- 2	M Col 1468 x M Cub 74	20.5	0.47	2.0	33.9	5.7	2.0	2.0	1.5
CM 4729- 4	M Bra 5 x M Cub 31	18.7	0.57	2.0	35.5	6.0	2.1	2.5	1.3
CM 4793- 1	M Col 72 x M Ven 77	18.6	0.60	2.3	32.1	6.0	2.2	2.7	1.0
CM 5253- 1	CM 1223-11 x CM 523- 7	27.9	0.57	3.0	38.2	6.0	1.4	2.0	1.3
CM 5286- 3	CM 1335- 4 x CM 1223- 1	23.1	0.62	3.0	32.6	7.5	2.3	2.6	1.3
M Ven 77		7.4	0.51	2.0	30.4	6.2	2.0	2.3	1.4

[1] 1 = very low; 9 = very high
[2] 1 = excellent; 5 = very poor
[3] 1 = highly resistant; 5 = highly susceptible

Table 2.12. Elite clones selected under highland conditions (ECZ 5).

Clone	Common Names or Parents	No. of Trials	Yield (t/ha)	% DM	HCN[1]	Cook. Qual.[2]	HI	Branching Levels	Resistance to:[3] Thrips	CBB	SED	Phoma
CG 354- 2	M Col 309 x M Col 1468	4	21.7	35	4	1	0.51	3	3	4	5	3.3
CG 358- 3	M Col 335 x M Col 2060	5	18.0	36	3	4	0.36	4	3	3	5	2.7
CG 401- 3	M Col 1522 x M Col 340	6	21.5	33	6	4	0.42	3	2	4	4	2.9
CG 402- 11	M Col 1522 x M Col 647	6	27.3	32	6	3	0.63	3	2			2.9
CG 406- 6	M Col 1522 x M Ecu 169	6	23.5	36	4	1	0.49	4	1	4	5	2.9
CG 481- 3	M Col 2060 x M Ecu 169	6	27.0	36	4	2	0.57	4	4			3.0
CG 501- 2	M Ecu 169 x M Col 2060	6	26.9	36	4	2	0.58	3	1			3.1
CG 501- 18	M Ecu 169 x M Col 2060	4	23.1	37	4		0.51	4				3.1
CG 1116- 32	M Col 2017 x M Col 2060	3	21.5	36	5		0.39	4				2.7
CG 1118-118	M Col 2017 x M Col 2060	4	30.3	37	3	2	0.49	4	2			2.7
CG 1118-121	M Col 2017 x M Col 2060	4	31.8	37	3	2	0.53	3	1			2.7
CG 1231- 3	M Col 1522 x M Col 2017	4	27.0	34	4	2	0.55	2	1			3.3
CM 4488- 4	M Col 1522 x M Col 2060	4	29.4	34	3	3	0.43	4	2			2.9
SG 350- 23	M Col 1522	4	23.6	34	4	3	0.39	2				3.1
SG 350- 42	M Col 1522	4	26.9	35	5		0.56	3				3.1
SG 427- 87	M Col 2060	4	37.7	37	6	3	0.52	4	2			3.0
SG 629- 4	M Col 1486	3	24.0	34	5		0.47	2		4		3.1
SG 638- 6	M Col 2061	4	32.1	35	5	4	0.55	3				3.0
SM 524- 1	M Col 1522	2	22.7	32	5		0.53	3		2		3.7
M Col 1522	Algodona	19	22.9	32	4	3	0.42	4		4	5	2.5
M Col 2059	Satadovio Satica	15	16.3	32	3	2	0.31	4	2	5	5	2.7
M Col 2060	Regional Amarilla	17	16.9	33	3	4	0.32	4	1	4	4	2.5
M Col 2061	Regional Morada	15	15.0	31	3	2	0.47	3	2	4	5	3.1
M Col 2261	Panameña	4	23.2	34	4	2	0.47	4	1			2.6

1) 1 = very low; 9 = extremely high
2) 1 = excellent; 5 = very poor
3) 1 = highly resistant; 5 = highly susceptible

Table 2.13. Proportion of total variation, explained by the first three principal components, 1987-91.

Variables	Evaluation by Researcher	Farmer Evaluation	Components	Comparative Proportion of Explained Variation
Root color:				
- External	0.646	0.932	1	17.54
- Flesh	0.743	0.552		
Plant height	0.4791	-		
Branching	0.5405	-	2	34.58
General evaluation		0.457		
Root no. (field)	0.497	0.4389	3	45.91

of participatory research methods in the selection of improved varieties, training of personnel participating in integrated projects with a varietal component and of scientists who play key roles within regional networks will have high priority over the next few years.

2.1.6 True seed propagation

The Cassava Program has developed a project to study the potential for and to conduct research on the major constraints to developing a TCS alternative for commercial cassava production. Comparisons between stake and seed progenies derived from the same parental clone showed comparable potential for TCS in terms of root production, but disadvantages in terms of early crop development (Table 2.14).

Results from a factorial experiment involving different true seed populations and seed coating with two sources of P (rock and superphosphate) are presented in Table 2.15. The more soluble source of P seems to affect seed germination; whereas rock phosphate does not affect germination and increases seedling vigor, improving the crop's ability to compete with weeds. Seed germination under suboptimal conditions and early crop establishment are the most important constraints to be overcome in TCS research.

2.2 National Program Collaboration

Breeding work at CIAT is oriented toward helping national programs better meet their objectives in varietal development. Effective collaboration results in more efficient and productive national programs. The interchange of knowledge (training and network development) and germplasm with national and international institutions is a major form of institutional support and strengthening undertaken by the Program.

Table 2.14. Comparison between clone CM 340-30 and its open-pollinated progeny when seed propagated.

Group	Propagation System	LAI at 120 days	RY (t/ha)	Total Plant Yield (t/ha)	HI
CM 340-30	Vegetative	5.4	41	91	0.48
Progeny	TCS	2.4	43	78	0.54
LSD (0.05)		0.9	8.7	9.2	0.07

Table 2.15. Effect of seed coating with two sources of P on two seed populations.

Population	Source of P	% Germination	Vigor[1]
SM 1557	None	39.4	3.2
	Rock phosphate	48.7	4.3
	Super phosphate	11.7	3.5
	Mean	33.3	3.7
SM 1559	None	49.3	3.5
	Rock phosphate	40.2	4.6
	Super phosphate	7.2	3.6
	Mean	32.2	3.9

[1] 1: poor, 5: excellent.

2.2.1 Training

Most of the training in cassava breeding has been provided to those participants in general production courses who, having certain interest in breeding, undertake a period of in-service training. This type of training has become a valuable tool not only for imparting knowledge but also for exchanging information and defining common objectives and breeding methodologies.

2.2.2 Network development

The Panamerican Cassava Breeders Network met at CIAT in 1987 and at CNPMF (Brazil) in 1990. The main purposes of the meetings were to exchange information on the status of the crop and research related to cassava varietal improvement in each country; and to analyze and propose specific breeding activities to be conducted in a network approach. The most relevant proposed network activities are related to (a) characterization of the main environments for cassava in Latin America, using genotype by environment techniques; (b) establishment of guarantees for cassava germplasm movement; (c) development of a basic set of traits for characterization and agronomic evaluation of breeding material; (d) conceptualization of stake multiplication schemes for different continental situations; and (e) improvement of the communication channels within the network.

Developments in the Asian Breeders Network are detailed in Chap. 20.

2.2.3 Germplasm exchange

CIAT's cassava germplasm constitutes the main support for national program breeding activities and advanced research projects. Sexual seed from improved gene pools represents a broader range of genetic variability for selection than the introduction of a set of clones via in vitro culture or indexed stakes. Table 2.16 presents a summary of information about germplasm shipments from CIAT during 1987-91. There is renewed interest in introducing elite clones or basic germplasm with specific traits, either for evaluation as potential varieties or to be used as parental clones in crossing blocks. At a global level the continuous progress made by the Cassava Breeding Section at CIAT is reflected in an increasing list of improved varieties released for the most important cassava-production regions of the world (Table 2.17).

2.2.4 Project for semiarid and subtropical germplasm development

CIAT has developed mechanisms to take advantage of special strengths of individual national programs in order to benefit other programs in a network manner. A prime example of this is a five-year project by CNPMF/EMBRAPA in Brazil to develop germplasm for semiarid and subtropical ECZs, especially in Africa but also for other continents. The project, started in 1991, is already generating promising results. Clones combining good yield, DM content and mite resistance have been identified and included in polycrosses. Germplasm screening at four selected sites for semiarid zones is expected to provide more information for selecting parents with good yield potential and stability. For the first time in 1991, there will be a simultaneous evaluation of the same progenies in Nigeria, NE Brazil and on the Colombian North Coast. The resulting information will help determine the homology among the sites chosen by the three institutions for this collaborative project. It will also provide the opportunity for selecting broadly adapted genotypes as the basis for the next crossing stage.

Activities for the subtropics at the Brazilian State Agricultural Research Agency EMPASC in Santa Catarina included finding a breeder for the project. A germplasm collection has already been established with more than 700 accessions from neighboring states, a recent germplasm collection from Santa Catarina, and introductions from Paraguay, Cuba and CIAT elite clones. This collection is the basis for germplasm development for the subtropics. The subtropical branch of the project will also support the Southern Cone Cassava Development Network in germplasm development and varietal improvement activities (see Chap. 13, sec. 13.1.1).

Table 2.16. Summary of international germplasm shipments, 1987-91.

Region	Form	No. Shipments	No. Crosses	No. Seeds	No. Clones
South America	Seeds	10	681	36915	1089
	In Vitro	36			65
	Indexed stakes	7			10
	Stakes	1			
Mesoamerica	Seeds	12	515	26359	
	In Vitro	10			118
	Indexed stakes	6			65
North America	Seeds	9	46	6900	
	In Vitro	11			74
	Indexed stakes	3			17
Caribbean	Seeds	7	283	18242	
	In Vitro	6			75
	Indexed stakes	1			13
Africa	Seeds	13	1074	155290	
Europe	Seeds	15	126	40245	
	In Vitro	9			96
	Indexed stakes	7			16
	Stakes	1			13
Asia	Seeds	42	2622	155462	
	In Vitro	13			154
Middle East	In Vitro	1			6
South Pacific	In Vitro	6			62
Total		226	5347	439413	1873

2.2.5 Varietal development: The Colombian case studies

Close collaborative work between CIAT and ICA has resulted in the release of three varieties and the pre-release of another three experimental clones. In 1990 clones CM 523-7 and CM 2177-2 were released as new varieties under the names of **ICA-Catumare** and **ICA-Cebucán**, resp., for the Eastern Plains region. Clone CM 2766-5 is in the pre-release stage for the same region. The superiority of the three clones in dry RY with respect to the check M Ven 77 can be seen in Table 2.18. These varieties, together with five other elite clones, have participated in on-farm trials, confirming their potential and farmers' preference.

For the North Coast region, experimental clone CG 1141-1 was released as **ICA-Costeña** in 1991; while two other elite genotypes, CM 3306-4 and CM 3555-6, have been pre-

Table 2.17. Cassava clones developed with CIAT input, released as recommended varieties in Asia and Latin America.

Category/Name	Country	Year of Release	Clonal Code	Location of Hybridization	Location of Selection	Adaptation	Potential Uses	Main Features
Landrace and national program clones pre-selected at CIAT								
CMC 40	Cuba	1981	M Col 1468	IAC, Brazil	INIVIT	DLT, WLT,	FC, AF	Early maturity; high yield
Costeña	Mexico	1981	M Mex 59		INIA	ST	FC, AF	Drought tolerance high yield
Sabanera	Mexico	1981	M Pan 51		INIA	DLT	FC, AF	Disease resistance; acid soil adapt.
M Col 1468	Dominican	1982	M Col 1468	IAC, Brazil	CESDA	WLT	FC	High yield; resistant CBB
M Col 1684	Rep.	1982	M Col 1684		CESDA	DLT, WLT,	ST	High yield; resistant CBB
Mdme. Jacques	Dominican	1983	M Col 1468	IAC, Brazil		ST	FC, ST	Early maturity; casabe quality
M Col 1684	Rep.	1983	M Col 1684			WLT	ST	Casabe quality
Manihoica P-11	Haiti	1984	M Col 1468	IAC, Brazil	ICA	DLT, WLT,	FC	Early maturity; high yield
Manihoica P-12	Haiti	1984	M Col 1505		ICA	ST	FC, AF	High yield; *Diplodia* resistant
M Mex 59	Colombia	1986	M Mex 59		CNPMF	WLT	FC, ST	High yield
VC 2	Colombia	1988	M Col 1468	IAC, Brazil	PRCRTC	DLT, WLT,	FC, AF	Table use with high yield
M Col 1684	Brazil	1989	M Col 1684		PRCRTC	ST	ST	High yield
Porto 1	Philippines	1991	M Col 2215		INIAP	DLT	FC, ST	High DM
	Philippines					DLT		
	Ecuador					DLT, WLT,		
						ST		
						WLT		
						DLT		
CIAT clones introduced to national programs								
VC 1	Philippines	1986	CM 323-52	CIAT	PRCRTC	WLT	ST, AF	High yield
Nanzhi 168	China	1987	CM 321-188	CIAT	SCIB	ST	ST, AF	High yield
Dayana	Panama	1990		CIAT	IDIAP	DLT	FC, AF	High yield
ICA-Catumare	Colombia	1990	CM 523-7	CIAT	ICA	WLT	FC, ST	High DM; resistant CBB
ICA-Cebucan	Colombia	1990	CM 2177-2	CIAT	ICA	WLT	FC, ST	High yield; resistant CBB
ICA-Costeña	Colombia	1991	CG 1141-1	CIAT	ICA	DLT	FC, AF	High yield and DM; resistant
CM 3306-4	Colombia	1991 [1]	CM 3306-4	CIAT	ICA	DLT	FC, AF	*Diplodia*
								High yield and DM
Selected from CIAT seed introduction								
Rayong 3	Thailand	1984	CM 407-7	CIAT	RFCRC	DLT	ST, AF,	High starch content
Rayong 2	Thailand	1985	CM 305-21	CIAT	RFCRC	DLT	FC	For snack food
Perintis	Malaysia	1988	CM 982-7	CIAT	MARDI	WLT	FC	High yield on peat soils
CNPMF 8339/11	Brazil	1989	CM 3997	CIAT	CNPMF/EPA	DLT	AF, ST	High yield
CNPMF 8347/19	Brazil	1989	CM 3291	CIAT	CE	DLT	ST	High yield
VC 3	Philippines	1990	CM 3590-1	CIAT	CNPMF/EPA	WLT	ST	Dual purpose
CGM 1322-12	Mexico	1991 [1]	CG 1322	CIAT	CE	WLT	FC, ST	High yield; resistant to CBB
					PRCRTC		AF	
					INIFAP			
Selected from local x CIAT crosses								
Rayong 60	Thailand	1987	CMR 24-63-43	RFCRC	RFCRC	DLT	AF, ST	High early yield
Rayong 5	Thailand	1990	(CMC 76 x V43)21-1	RFCRC	RFCRC	DLT	ST, AF	High starch content
Selected from local crosses								
Adira	Indonesia	1986	M-31	BORIF	BORIF/UJF	WLT	ST, AF	High starch yield

[1] Tentative for late 1991.

Table 2.18. Avg yield for three pre-released clones and two checks at different experimental sites.

Clone	CIAT HQ RY (t/ha)	Carimagua RY (t/ha)	La Libertad RY (t/ha)
CM 523-7 (ICA-Catumare)	26.0	15.0	24.3
CM 2177-2 (ICA-Cebucan)	30.0	21.0	22.4
CM 2766-5	29.2	23.4	25.3
M Col 1438 (check)	18.3	12.7	11.0
M Ven 77 (check)	16.0	7.6	15.8

Table 2.19. Comparative performance of three pre-released clones and two local checks under participatory research with farmers.

Clone	No. of Trials	Farmers' Preference[1]	RY (t/ha)	Commer. Roots/pl	% DM	Cooking Quality[2]
CG 1141-1 (ICA-Costeña)	49	3.1	21.6	5.0	36.3	1.4
CM 3306-4	54	3.7	20.1	5.2	36.2	1.5
CM 3555-6	48	5.0	21.5	5.0	34.0	1.7
M Col 1505 (check)	38	4.9	19.8	4.9	34.6	1.3
M Col 2215 (check)	35	5.0	14.4	4.3	36.1	1.2

[1] 1 = highly preferred; 10 = rejected
[2] 1 = excellent; 5 = very poor

released. Superior RY, DM content and cooking quality, comparable to the check M Col 2215, are the main characteristics of the three elite clones (Table 2.19). **ICA-Costeña** and CM 3306-4 stood out in on-farm trials for their superiority in nearly all traits and generalized acceptance by farmers in the region.

All the aforementioned clones were highly resistant to the principal diseases and pests in the region of adaptation. The demand for good-quality stake material for planting was further evidence of a high level of acceptability to farmers.

2.3 Future Perspectives for Germplasm Development

The Breeding Section will continue to support national and international institutions by providing components for sustained improvement of cassava varieties and for promoting these varieties to farmers. Within this mandate, the main objectives for the period 1992-96 are to:

- Play a leading role worldwide for cassava and wild *Manihot* germplasm management activities, especially conservation and characterization

- Build upon the knowledge base necessary for sustained genetic improvement, in areas of genetics, physiology, pest and disease management, crop and soil management, and root quality

- Develop improved germplasm through genetic recombination, in the form of broad-based gene pools, from which national programs can directly select superior new clones or, alternatively, use selected clones as parental material in further breeding

- Provide training to national program personnel and mechanisms for networking among programs

- Develop a production technology based on TCS

These objectives necessarily involve a multidisciplinary effort within the Program and with other Units at CIAT, as well as close linkages with collaborating national and international institutions.

3. PHYSIOLOGY

The goal of the Physiology Section is to conduct strategic and applied research in order to improve yield potential and stability, and the adaptation of cassava to the different agroecosystems where it is grown. To accomplish this goal, a wide range of research problems have been addressed in the past five years:

- Evaluation of cassava germplasm under prolonged water stress and identification of mechanisms that underly tolerance to stress

- Basic research to characterize the photosynthetic potential of cassava in relation to crop productivity

- Plant nutrition and soil management research to evaluate cassava germplasm adaptability to poor soils in the tropics (e.g., a collaborative research project with the Swiss Government focused on elucidating mechanisms associated with adaptability to low-P soils)

- Soil conservation in cassava-based cropping systems on hillsides continued through a collaborative research project with the University of Hohenheim, Germany, oriented toward collecting fundamental data on soil erosion to assess long-term effects on soil degradation and evaluating different crop management systems in relation to soil erosion.

Results of these research efforts, which are highlighted here as well as elsewhere in this report (see Chap. 10 & 11), have important practical implications for cassava breeding strategies and for developing technologies to improve production systems and to conserve natural resources.

3.1 Yield Stability During Prolonged Midseason Water Stress

Most cassava production occurs in the tropics where rainfall distribution is not uniform, with prolonged dry and wet cycles. Farmers usually plant cassava after the onset of a wet cycle, which allows the crop to get established with 3 to 4 mo of sufficient rain. The crop then has to endure a period of up to several months with no rain. Cassava adapts to water shortage by reducing its leaf canopy (CIAT Annual Reports 1986-89), thus limiting crop water use. Moreover, the plant reacts to soil and atmospheric water stress by partially closing leaf stomata (CIAT Annual Reports 1984-89). Although the combined effect of reduced leaf canopy and stomatal closure would improve crop WUE through a slow depletion of the limited soil water, it would also lead to reductions in total biomass and RY (CIAT Annual Reports 1986-89). Reduction in RY would depend on variety, intensity and duration of water stress. Varietal differences in response to water stress were found to be related to vegetative vigor and to leaf area duration during the growth cycle (Fig. 3.1). Varieties such as CM 507-37, which maintain relatively higher than optimal LAI under wet conditions, were found to produce well under both favorable and stressful environments.

In this report some results are presented on the effect of prolonged water stress during the growth cycle on productivity and on certain physiological characteristics. This information is of paramount importance in understanding the mechanisms underlying drought tolerance in cassava.

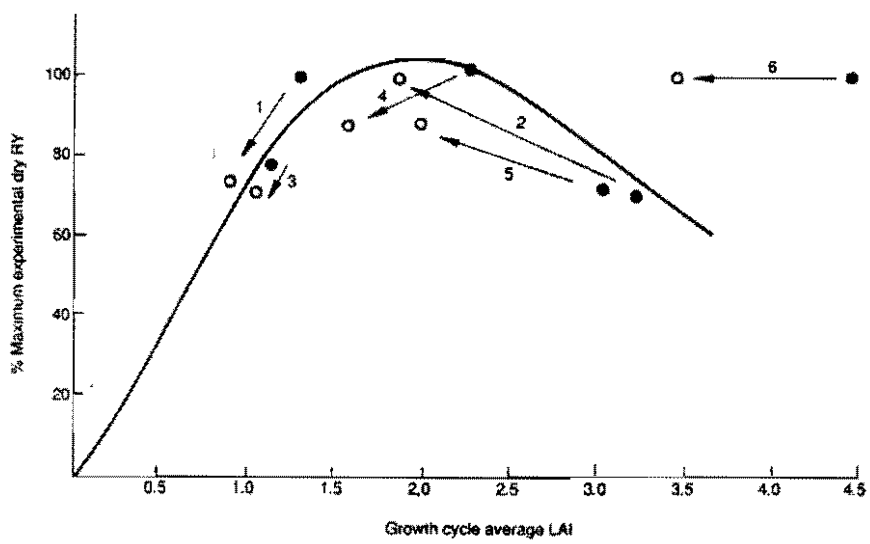


Figure 3.1. Relationship between yield and avg LAI as affected by midseason water stress. (1) and (2) represent var. M Col 22 and M Mex 59 (1980-81); (3) and (4) represent var. M Col 1684 and CM 507-37 (1984-85); (5) and (6) represent var. M Col 1684 and CM 507-37 (1986-87). Arrows indicate changes from well-watered to stress conditions.

3.1.1 Canopy development, biomass production and RY

Patterns of leaf canopy development, as shown by changes in LAI, are presented in Figure 3.2. It is apparent that in the first 3 to 4 mo clone CM 507-37 produced higher LAI than M Col 1684. At that stage, specific leaf area (leaf area/unit leaf dry wt) and leaf area ratio (leaf area/unit dry wt of leaf + petiole + stem) were also higher in CM 507-37 (186 ± 11 SD) cm^2/g for specific leaf area, and 98 ± 7 cm^2/g for leaf area ratio) than in M Col 1684 (147 ± 8 cm^2/g, and 73 ± 6 cm^2/g). Both var. reached peak LAI at 160 days after planting (DAP) in the unstressed crops, with the highest value in CM 507-37. Thereafter leaf canopies of both var. declined over time. Reduction in LAI was particularly pronounced in M Col 1684 between 160 and 222 DAP; whereas CM 507-37 maintained higher LAI and shed fewer leaves (Fig. 3.2), which may indicate better leaf retention.

Compared with the unstressed crops, water stress significantly reduced leaf canopy in both var. Reduction in leaf canopy could not be attributed solely to leaf fall as the stressed crops shed fewer leaves than the unstressed ones (Fig. 3.2). After release from stress, CM 507-37 recuperated rapidly and formed more new leaves than M Col 1684.

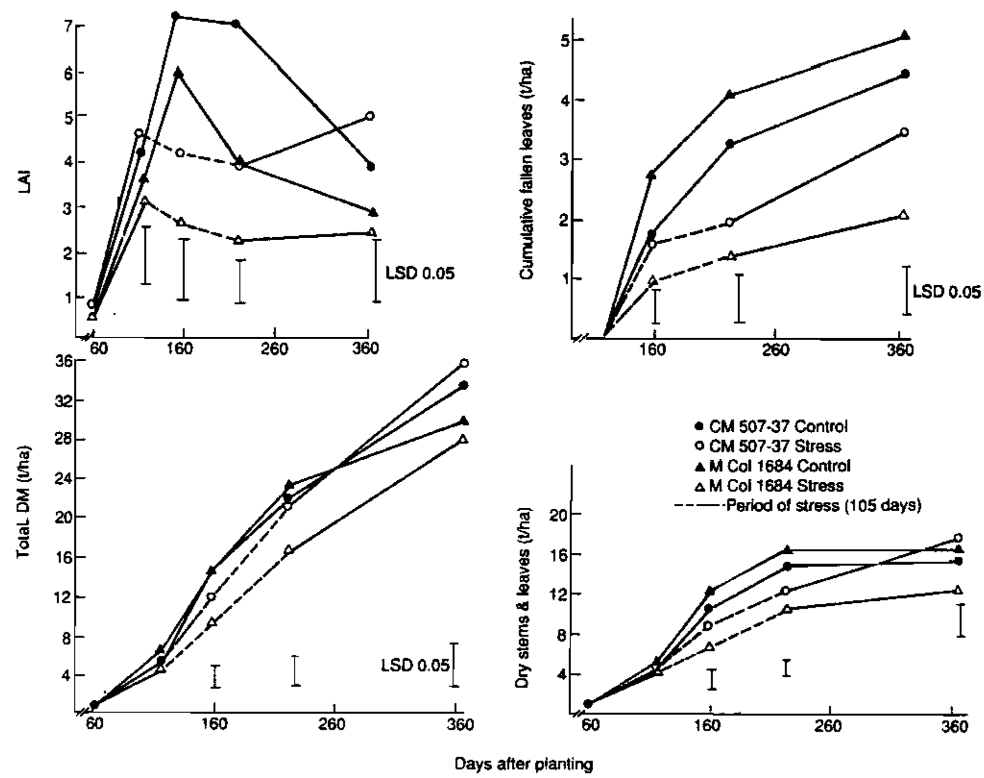


Figure 3.2. Canopy development, biomass and yield as affected by midseason water stress.

In the unstressed crops, midseason (222 DAP) RY (Table 3.1) and total biomass production (Fig. 3.2) were similar in both var. At final harvest (364 DAP), however, CM 507-37 had significantly higher RY and more total biomass than M Col 1684. In the stressed crops, CM 507-37 still produced higher RY and total biomass than M Col 1684 in midseason as well as in final harvests. Final yields in the previously stressed crops of both var. were not significantly different from the controls. Irrespective of water regime, CM 507-37 significantly outyielded M Col 1684.

When subjected to stress after establishment of full canopy, the plants reacted by reducing top growth (Fig. 3.2). The level of reduction in top growth, relative to that of the well-watered crop, was so high in M Col 1684 that it had led to significant reduction in total biomass by end of stress (Fig. 3.2). Reduction in top growth of CM 507-37 was compensated for by the increase in dry RY (Table 3.1) so that total biomass remained unchanged (Fig. 3.2). Upon release from stress, CM 507-37 showed considerable recovery in top growth, which resulted in significantly higher top weight at final harvest than M Col 1684.

3.1.2 Leaf water status and gas exchange

Figure 3.3 illustrates data of morning leaf water potential (Ψ_L), net photosynthesis and stomatal conductance as monitored throughout the stress period. Differences in Ψ_L due to water regimes were not marked except in the last 40 days of stress. Both predawn and midday Ψ_L showed few differences between treatments (data not shown). However, midday Ψ_L of M Col 1684 was about 0.15 MPa higher than CM 507-37, irrespective of water regime. These data suggest that cassava conserves water under prolonged stress. It is unlikely, however, that cassava leaves adjusted to stress osmotically as Ψ_L remained relatively unchanged. The ability of cassava to maintain Ψ_L under stress was aided by large decreases in stomatal conductance (Fig. 3.3), hence less water loss.

Table 3.1. Dry RY (t/ha) at 3 sequential harvests, with and without midseason water stress for clone CM 507-37 and the parent M Col 1684.

	M Col 1684		CM 507-37		
Harvest	Control	Stress	Control	Stress	LSD 5%
(160 DAP)	2.27	2.76	4.13	3.07	0.86
(222 DAP)	7.15	6.53	7.53	9.14	1.43
(364 DAP)	13.52	15.84	18.43	18.57	3.14

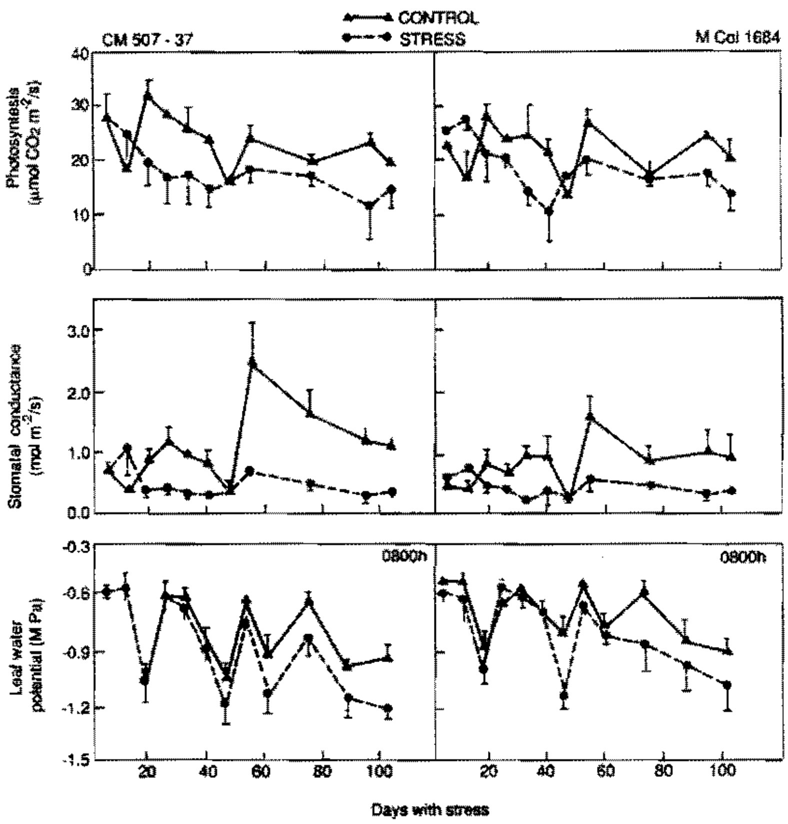


Figure 3.3. Leaf water status and gas exchange as affected by midseason water stress.

Compared with the unstressed leaves, leaf CO_2 uptake rates were about 25% lower in the stressed leaves of both var. throughout the stress period. The same trend was observed in stomatal conductance; however, the magnitude of reduction in stomatal conductance due to stress was more pronounced in CM 507-37 than in M Col 1684. Instantaneous leaf WUE (CO_2 uptake/H_2O loss) was the same in both stressed and unstressed leaves of both var. These data (not shown) indicate that leaves remained active in terms of gas exchange under the prolonged stress. The absence of a large decrease in Ψ_L of stressed leaves (Fig. 3.3) might partially explain the relatively high and consistent CO_2 uptake rates. Another factor that might have enhanced CO_2 uptake of stressed leaves is the notable decrease in their specific leaf area. At 43 days of stress, specific leaf areas were 197 ± 11 cm^2/g (mean ± SD) and 185 ± 5 cm^2/g for CM 507-37 and M Col 1684, resp.; whereas the respective values for the unstressed crops were 233 ± 16 cm^2/g and 206 ± 14 cm^2/g.

3.1.3 Water uptake in stressed crops and crop WUE

Patterns of water uptake of the stressed crops are shown in Figure 3.4. The two varieties extracted a major portion of the available soil water during the first 35 days of stress

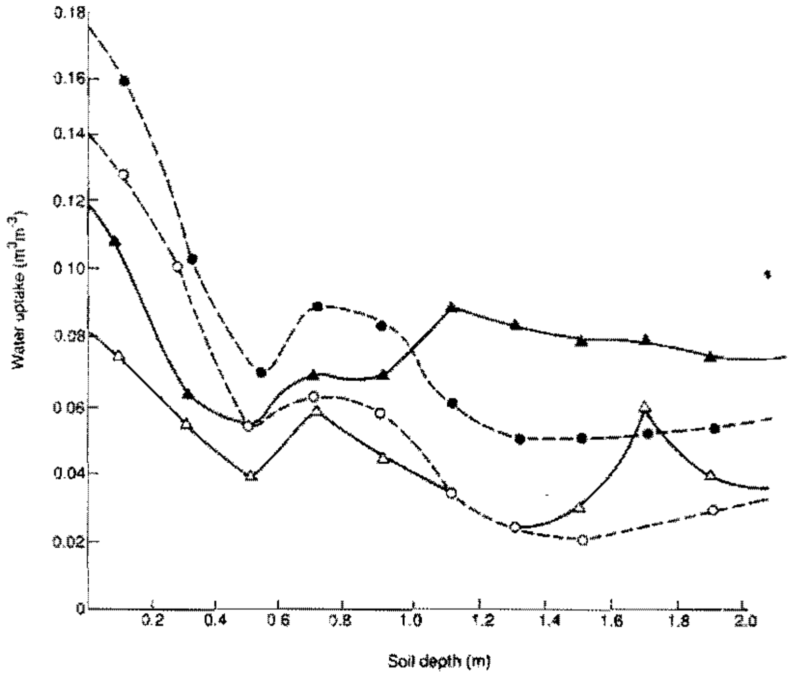


Figure 3.4. Patterns of water uptake during midseason water stress. (△), (▲) = M Col 1684; (○), (●) = CM 507-37. Open symbols = 35 days; closed symbols = 96 days.

(about 109 mm for CM 507-37 and 93 mm for M Col 1684). At 96 days of stress, total water uptake was about 160 mm in both var., which is equivalent to 70-75% of the water available in 2 m of this soil. M Col 1684 extracted less water from the upper soil layer and more from the lower layer than CM 507-37. These patterns of water uptake suggest that rooting systems and their distribution in the soil profile differed between the two var.: CM 507-37 appears to have more fibrous roots in the surface layer than M Col 1684.

Total dry biomass production (excluding fibrous roots) between 117 and 160 DAP, when crop growth rate was at max., was used to estimate crop WUE (Fig. 3.2). At that stage of growth, LAI was near max. for both stressed and unstressed crops (Fig. 3.2); hence radiation interception was high. Total DM increments over 43 days were 9176 kg/ha (213 kg/ha/day) and 8320 kg/ha (194 kg/ha/day) for the unstressed crops of CM 507-37 and M Col 1684, resp. As actual water uptake by the unstressed crops was not determined, a max. water use equivalent to pan evaporation of 190 mm (4.4 mm/day), recorded at a nearby weather station, was assumed. The resulting values of crop WUE in this case were 0.0048 and 0.0044 kg biomass/kg water for CM 507-37 and M Col 1684, resp. For the stressed crops during the same period, increments in total DM were 6410 kg/ha (149 kg/ha/day) and 4574 kg/ha (106 kg/ ha/day) for CM 507-37 and M Col 1684, resp. The estimated water uptake from regular soil sampling in 43 days was 132 mm for CM 507-37 and 125 mm for M Col 1684. These estimates excluded evaporation from the soil, which was covered with plastic, so actual water use might have been underestimated; nevertheless, the crop WUE should be taken as a rough estimate in this case. Resulting values were 0.0049 kg biomass/kg water for CM 507-37 and 0.0037 kg biomass/kg water for M Col 1684. These estimates are similar to those for the unstressed crops. Max. growth rate of cassava with nonlimiting water approaches the lower limit of C_4 crops such as maize and sorghum, and its short-term WUE is equivalent to these crops. Because of its long growth cycle and low LAI, which prevails during a significant portion of the growing season, however, the avg growth rate and the seasonal WUE of cassava are reduced.

The results presented herein with two genetically related clones (M Col 1684 is a parent of CM 507-37) subjected to prolonged midseason water stress reveal that certain physiological and morphological characteristics are apparently associated with tolerance to water stress and yield stability. Most notably, the ability to form rapidly and maintain leaf area to intercept enough solar radiation during the growth cycle is of paramount importance. Second, genotypic characteristics related to better partitioning of biomass between leaf and stem such as high specific leaf area (leaf area/unit leaf dry wt) and a high leaf area ratio (leaf area/unit dry wt of leaves and stems) may lead to higher levels of LAI without an adverse effect on RY. Clone CM 507-37 maintained higher LAI and higher RY under both well-watered and water-stress conditions than the parent M Col 1684 (Fig. 3.2 & Table 3.1). It also shed fewer leaves under well-watered conditions (Fig. 3.2) despite high LAI, which might indicate better leaf retention. However, evaluation of a wider range of genotypes under favorable and water-stress conditions (midseason as well as terminal stress) is warranted.

Cassava appears to tolerate prolonged drought through some stress-avoidance mechanisms. In addition to reduction in leaf canopy and top growth upon onset of stress, the leaves close their stomata partially while maintaining reasonable CO_2 uptake rates, thereby reducing water loss and continuing to accumulate DM into storage roots. Moreover, cassava is capable of extracting deep soil water slowly when available. This is an advantageous characteristic under prolonged drought or with sporadic rainfall normally encountered in cassava-growing regions in the tropics such as Sub-Saharan Africa and NE Brazil.

3.2 Screening for Drought Tolerance and Low HCN Content

Given the fact that most cassava varieties show increases in HCN under stress and become less suitable for human consumption in fresh form, research continued to identify genotypes with low levels of HCN under stress. Few clones were identified that tended to keep their HCN at reasonably low levels (CIAT Annual Report 1989). These clones were grown at the Quilichao Station for two years to determine, besides yield performance, some physiological parameters related to photosynthesis efficiency as affected by prolonged drought. The clones were grown in the field; and commencing 100 days after planting, half the experimental area (≈ 2000 m^2) was subjected to 3 mo water stress by covering the soil surface with white plastic sheets. The other half of the experimental area received natural precipitation as well as supplementary irrigation in periods with rainfall less than the potential evapotranspiration (≈ 4.4 mm/day). Data on leaf water potential (as an indicator of stress), canopy light interception (as an indicator of leaf area), and leaf gas exchange (as an indicator of leaf photosynthetic capacity) were collected during the entire stress period (Figs. 3.5-3.8).

Predawn leaf water potential (Fig. 3.5A) remained around -5 bars throughout the stress period for all four genotypes, with virtually no differences between the stressed and unstressed crops. Midday leaf water potential (Fig. 3.5B) was 1 to 2 bars less in the stressed crops, except for CM 1335-4. Midday leaf water potential for both stressed and unstressed crops oscillated between -8 to -15 bars, depending upon measurement dates. These values are higher than those observed for other field crops under stress, indicating that cassava conserves water. This characteristic is of a paramount importance for the crop's tolerance to prolonged drought. Such a "stress-avoidance mechanism" underlies the plant's ability to endure several months of little or no rainfall in seasonally dry and semiarid regions. Coupled with this mechanism is the large reduction in light interception through reduction in leaf area under stress--a factor of great importance in water consumption (Fig. 3.6). Although reduction in leaf area would lead to water conservation, it would also lead to reductions in total biomass and RY (Fig. 3.7). Nevertheless, cassava can recover rapidly, once released from stress, by forming new leaves, which increases light interception and compensates for yield losses during stress (Fig. 3.6).

Cassava leaves also remain reasonably active during water stress (Fig. 3.8). The stressed leaves are capable of maintaining photosynthetic rates around 40 to 60% of that of the nonstressed leaves during the entire 3-mo stress period. Upon recovery from stress, the old leaves can approach the efficiency of the nonstressed leaves. Furthermore, the new formed leaves of the previously stressed crop showed even higher photosynthetic rates than those of the nonstressed crop (Fig. 3.8). There are apparent genotypic differences in tolerance to stress as indicated by the magnitude of reduction in photosynthesis. Clone CM 489-1 appears to maintain higher photosynthesis during the entire stress period than other clones.

Yield, top and total biomass, HI, HCN content and percent starch in storage roots at final harvest are presented in Table 3.2. Across all varieties, reductions due to water stress were 9% in dry RY, 28% in top growth and 15% in total biomass. On the other hand, water stress increased HI by 6%. These data suggest that prolonged midseason water deficit does not seriously limit cassava productivity and confirm that cassava is a highly productive crop where a long dry season occurs.

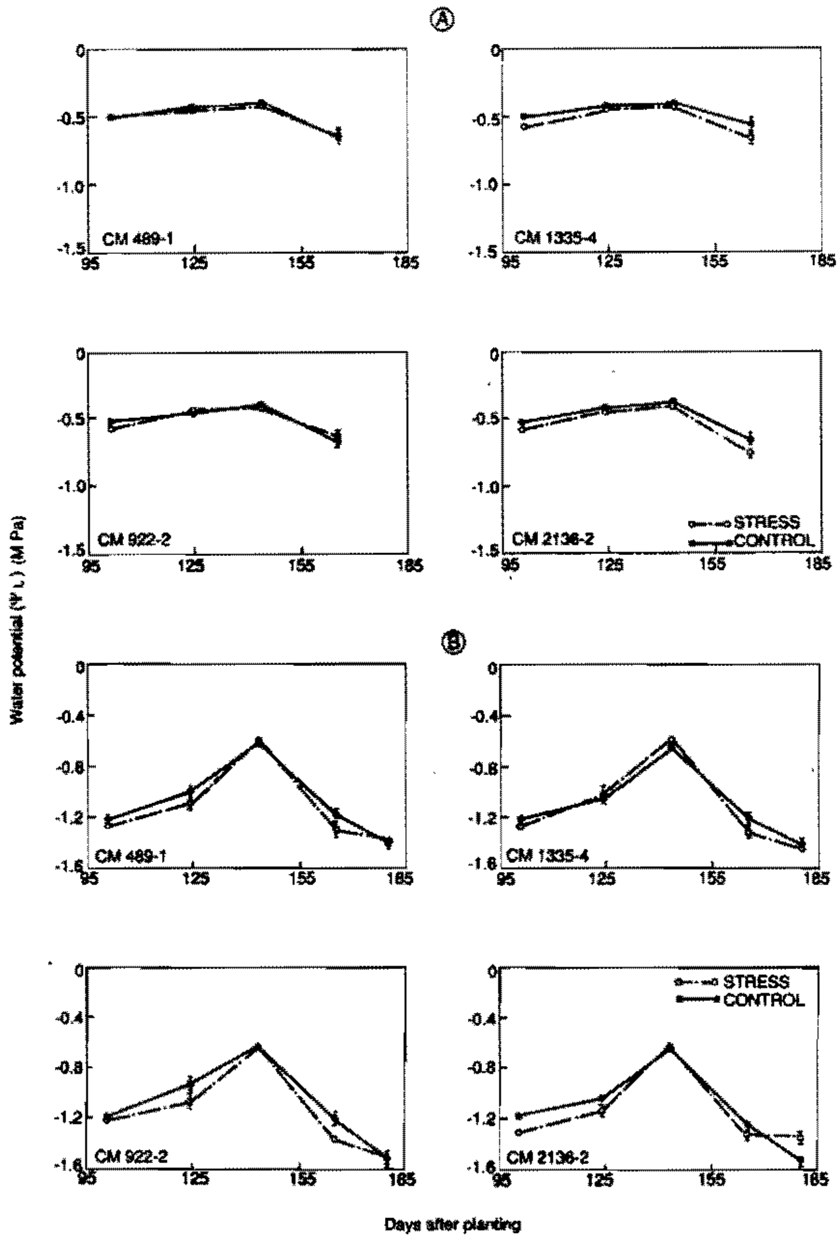


Figure 3.5. Leaf water potential in water-stressed and well-watered cassava: (A) predawn and (B) midday.

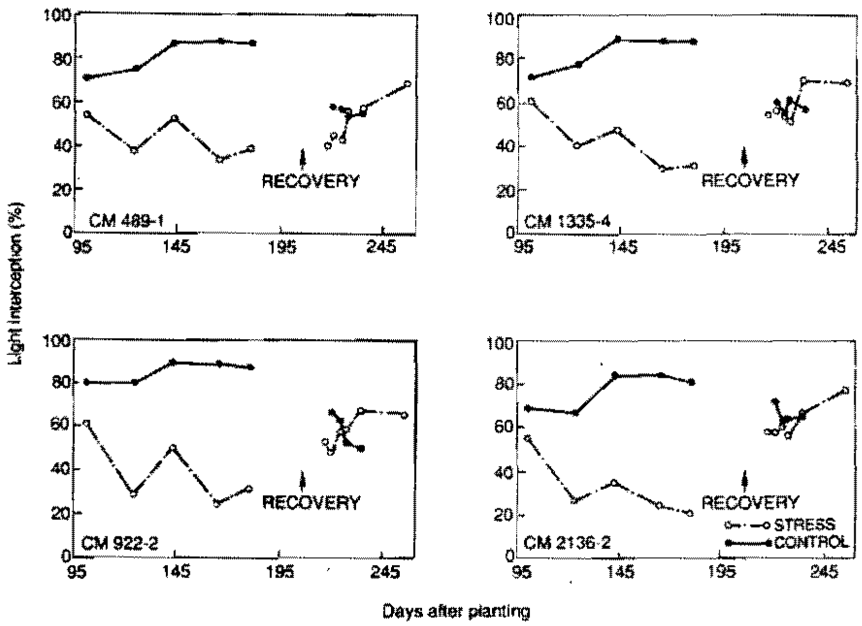


Figure 3.6. Light interception in water-stressed and well-watered cassava.

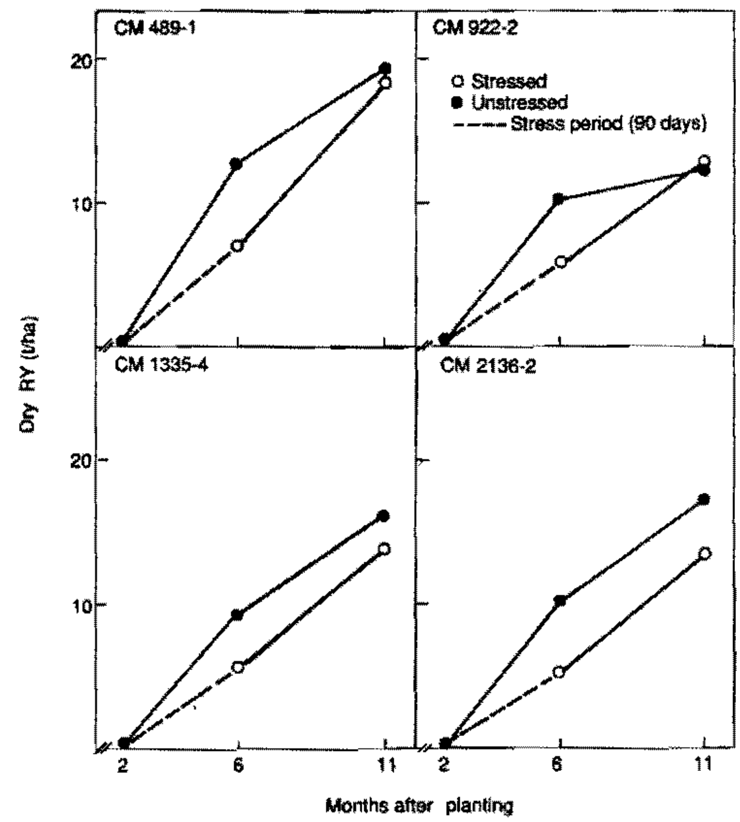


Figure 3.7. RY as affected by midseason water stress.

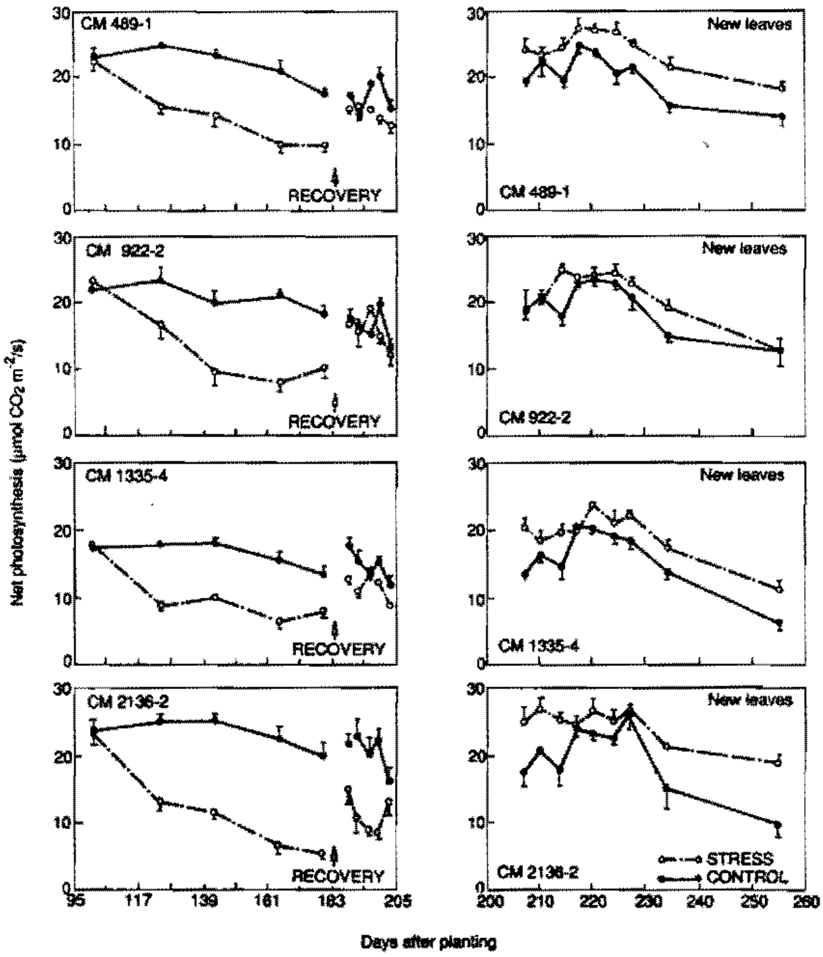


Figure 3.8. Leaf photosynthesis as affected by midseason water stress. Note the higher rates in the newly formed leaves of previously stressed plants.

Genotypic differences in response to water stress also exist. Clone CM 489-1 had high yields under both wet (19 t dry RY/ha) and stress (18 t dry RY/ha) conditions. This clone also maintained the highest leaf photosynthetic rates during the entire stress period (Fig. 3.8), suggesting that high photosynthetic capacity during stress could be used as a selection criterion for high yields. Previous findings (CIAT Annual Reports 1988, 1989) have shown significant positive correlations between leaf photosynthesis and both yield and total biomass among a wide range of cassava varieties grown under stress in the Patia Valley, Cauca, Colombia.

Table 3.2. Yield, biomass (dry t/ha), starch and HCN content at final harvest (11 mo) as affected by 3 mo midseason water stress commencing 90-100 DAP; avg. of 1987-89 seasons.

	Unstressed						Stressed					
Variety	Roots	Tops	Total	HI	% Starch	HCN ppm (dry wt.)	Roots	Tops	Total	HI	% Starch	HCN ppm (dry wt.)
CM 489-1	19.1	7.2	26.3	0.73	77	214	18.0	7.1	25.1	0.72	80	401
CM 922-2	14.8	7.6	22.4	0.66	83	142	15.0	5.9	20.9	0.72	81	190
CM 1335-4	18.1	7.8	25.9	0.70	83	107	16.5	5.1	21.6	0.76	82	123
CM 2136-2	19.3	12.4	31.7	0.61	87	166	15.5	7.3	22.8	0.68	81	338
Avg	17.8	8.8	26.6	0.68	82.5	157	16.2	6.4	22.6	0.72	81	263
% change due to stress							-9	-28	-15	+6	-2	+68
LSD 5%												
Var. (V)	1.25	1.51	2.44	0.024	3.1	59						
Treatment (T)	0.88	1.07	1.73	0.017	-	42						
V X T	1.76	2.1	3.44	0.034	-	84						

The highest reduction in RY among this group of genotypes was 20% for CM 2136-2; whereas CM 922-2 showed no change in yield due to stress. Under stress, HCN content remained at low levels (123-190 ppm on dry basis) in two clones (CM 1335-4 and CM 922-2), but was much higher (ca. 340-400 ppm on dry basis) in two others (CM 2136-2 and CM 489-1). Maintaining low HCN under stress is of a paramount importance when fresh cassava is used for human consumption in drought-prone regions such as NE Brazil and Sub-Saharan Africa.

3.3 Potential Photosynthesis of Cassava and its Relation to Productivity

3.3.1 Effect of growth environment

Environmental conditions under which leaves are developed are of paramount importance in determining potential photosynthesis of cassava. Studies were conducted to evaluate potential photosynthesis in a few cassava varieties from contrasting habitats. Three Colombian var.--M Col 22 (collected in Córdoba, elevation 100 m, mean annual temp, 28°C; habitat: hot, dry), M Col 1684 (collected in Amazonas, elevation <150 m, mean annual temp 28°C; habitat: hot-humid), and M Col 1522 (collected in Cauca, elevation 1500 m, mean annual temp 20°C; habitat: cool-humid)--were used as test materials. Stem stakes (0.2 m) were planted in plastic pots, (0.33 m wide x 0.46 m deep), filled with a mixture of 40% (w/w) top soil, 33% compost and 27% sand. The pots, which were adequately fertilized with 15:15:15 NPK at the rate of 15 g/pot 15, 45 and 65 DAP, were kept well watered and left in the open at a high-altitude site near Cali, Colombia (elevation 2000 m, mean annual temp, 17°C). Two months after planting, the pots were brought to CIAT HQ in Palmira (elevation 965 m, mean annual temp 24°C), where gas exchange measurements were conducted on the same day. Prior to measurement, some leaves were removed at every other node to balance source (leaves) with the confined and limited sink (roots). Then the plants were left outdoors for 7 days at this site to acclimate to the higher temp. Gas exchange was measured again on leaves having the same age as those previously measured. Four weeks later the fully expanded and newly developed leaves at the warmer site were used for further measurements.

Photosynthesis was substantially reduced in leaves of all varieties developed in cool climate (Fig. 3.9). This reduction was most pronounced in M Col 22, particularly at low leaf temp (Fig. 3.9A). The leaves that developed in cool climate and were then acclimated in warm climate for 7 days partially recovered their photosynthetic capacities, with the highest recovery (compared to rates before acclimation) in var. M Col 22; however, the rates were much lower than for the newly developed leaves. The max. rates in newly developed leaves were highest in M Col 22 and lowest in M Col 1522. Another apparent difference was the notable upward shift in optimum temp in M Col 1522 from 25°C in leaves developed in cool climate to 35-40°C in acclimated and newly developed leaves (Fig. 3.9C). Varieties from hot climates had broad and stable optimum temp ranges between 30° to 40°C in all sets of leaves (Fig. 3.9A,B).

The depression in photosynthesis at high leaf temp in leaves of M Col 1522 developed in cool climate was not due to stomatal closure as both leaf conductance and internal CO_2 were increased at that temp range (Fig. 3.9D). The higher rates and the upward shift in optimum temp in the acclimated leaves might indicate the influence of biochemical factors. After 7 days of acclimation in warm climate, changes in biochemical components of photosynthesis are more likely than changes in stomatal characteristics; moreover, the rates in cool-climate leaves of all varieties were much lower at all light levels and had a lower saturation light than both the acclimated and newly developed leaves (Fig. 3.10, for var. M Col 1684). The differences in light saturation rates among these sets of leaves can be attributed mainly to differences in CO_2 fixation capacity.

The response of photosynthesis to intercellular CO_2 in warm-climate grown plants of var. M Col 1684 is shown in Figure 3.11. It is evident that at the lowest CO_2 concentration used (50 μLL^{-1} CO_2), the rates of CO_2 uptake were positive. The CO_2 compensation point, as estimated from the regression line, was about 20 μLL^{-1} CO_2 under the conditions of these experiments. This relatively low CO_2 compensation point indicates that cassava has low photorespiration.

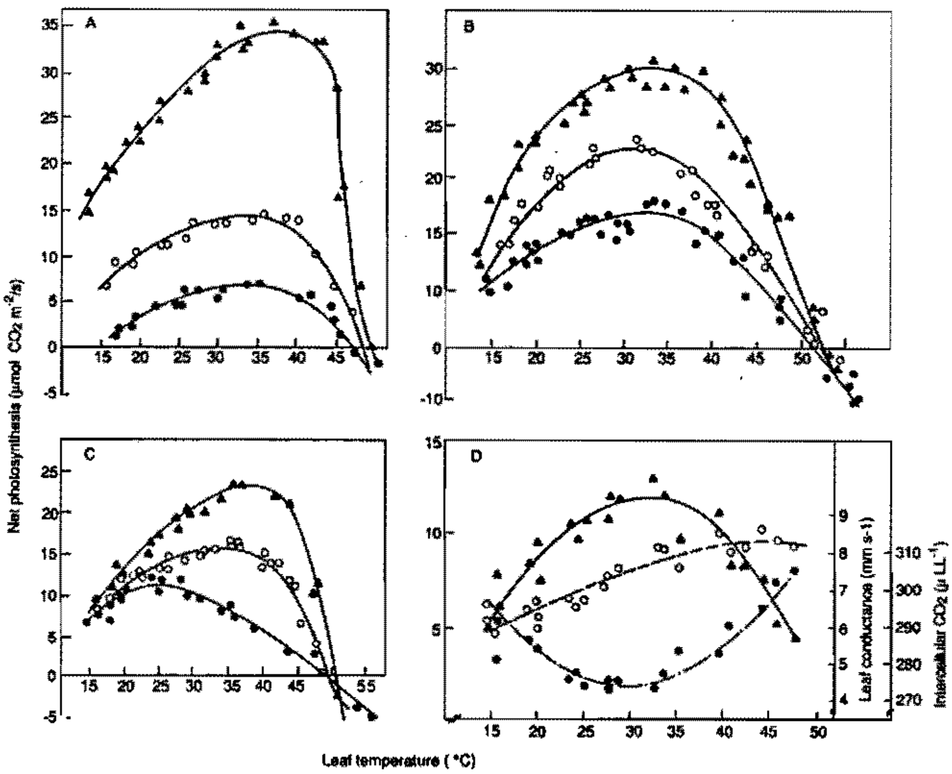


Figure 3.9. Responses of leaf photosynthesis to leaf temp as influenced by growth-temp: (A) M Col 22 (habitat: hot, dry); (B) M Col 1684 (habitat: hot-humid); (C) M Col 1522 (habitat: cool-humid); (●) leaves developed at 2000 m, daily mean temp, 17°C; (○) acclimated leaves (7 days) at CIAT HQ, daily mean temp, 24°C; (▲) leaves developed at CIAT HQ; (D) M Col 1522; (▲) net photosynthesis; (○) leaf conductance to water vapor; (●) intracellular CO_2. Note the apparent upward shift in optimum temp in acclimated leaves of var. M Col 1522.

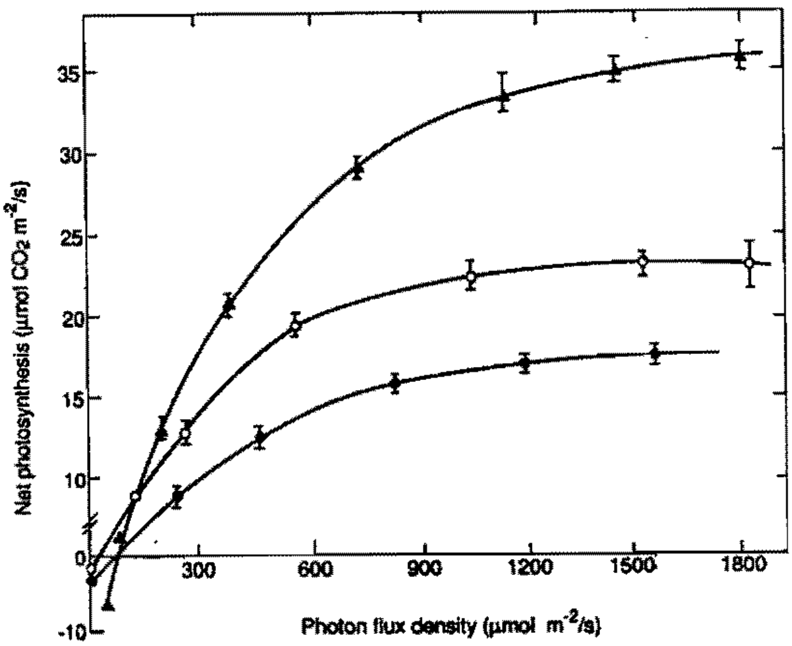


Figure 3.10. Responses of leaf photosynthesis (var. M Col 1684) to light as affected by growth-temp. Symbols as in Figure 3.9.

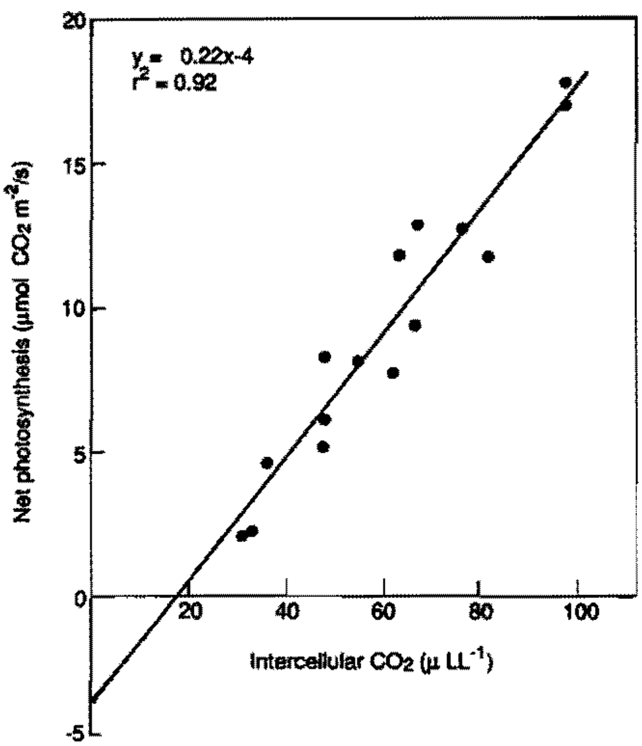


Figure 3.11. Response of leaf photosynthesis to intercellular CO_2; plants (var. M Col 1684) grown outdoors at CIAT HQ. Measurements made with 5 leaves at leaf temp of 28 ± 0.5°C and photon flux density of 1500 μ mol m^{-2}/s.

3.3.2 Photosynthesis of field-grown cassava

Photosynthetic potential in relation to productivity was evaluated in 15 var. and breeding materials from CIAT, grown under rainfed conditions at the Santander de Quilichao Experiment Station, Cauca, Colombia (alt. 990 m; lat. 3°30'; long. 76°31'W; mean annual temp 24°C) during the 1990-91 growing season.

Measurements of leaf gas exchange (CO_2 uptake and H_2O loss) were made with a portable infrared gas analyzer (LCA-2) on several occasions from 23 July to 25 November 1990. Across all reps, 30 fully expanded upper canopy leaves were measured per var. All measurements were made from 08:00 to 11:00 h with a solar irradiance of 1200-2000 µmol m^{-2}/s. Normal air (325 ± 10 µLL CO_2) was drawn from above canopy using a vertically mounted 4-m glass fiber probe connected to a pump. A small leaf chamber connected to the infrared gas analyzer was clamped over the middle portion (6.25 x 10^{-4} m^2 surface area) of the central lobe of the measured leaves and held toward the sun for 30-60 sec to obtain steady-state gas exchange.

In field-grown cassava, the photosynthetic rates of upper canopy leaves measured in wet soils were not light saturated up to 1800 µ mol m^{-2}/s (Fig. 3.12); moreover, the max. rates varied from 39 to 50 µmol CO_2 m^{-2}/s (Table 3.3). These rates are higher than the max. rates observed in well-watered potted cassava grown outdoors under similar levels of solar radiation, photoperiod and ambient temp. The calculated ratio of the intercellular to ambient CO_2 concentrations (Ci/Ca) varied between 0.37 to 0.45 (Table 3.3). These values are similar to those in C_4 species (≈ 0.4) but are lower than those in C_3 species (≈ 0.7). These data illustrate that the photosynthetic potential of cassava is high but can be fully expressed only in near optimum environment.

The seasonal avg net photosynthesis in upper canopy leaves ranged from 26 to 36 µ mol CO_2 m^{-2}/s (Table 3.3). These rates are relatively high, taking into consideration that most measurements were conducted during the dry season when water deficit was largely coupled with hot, dry air (Table 3.4). The known closure of stomata in reaction to soil water stress or to low atmospheric humidity can lead to high leaf water status (CIAT Annual Reports, 1982-90).

Maintaining leaf water status near normal levels reflects positively on leaf photosynthesis. Studies at CIAT have shown that leaf photosynthesis under stress remained ca. 50 to 60% of the well-watered crop even with an extended stress of more than 3 mo (see also CIAT Annual Reports, 1988-90).

Biomass and RYs were relatively high in this group of varieties (Table 3.3). Avg dry RY and biomass were 17 and 23 t/ha, resp. This productivity under rainfed conditions with prolonged water deficit commencing early in the growth cycle (Table 3.4) illustrates the capacity of cassava to withstand drought. Under stress, cassava restricts its leaf canopy and extracts soil water slowly (see Section 3.1).

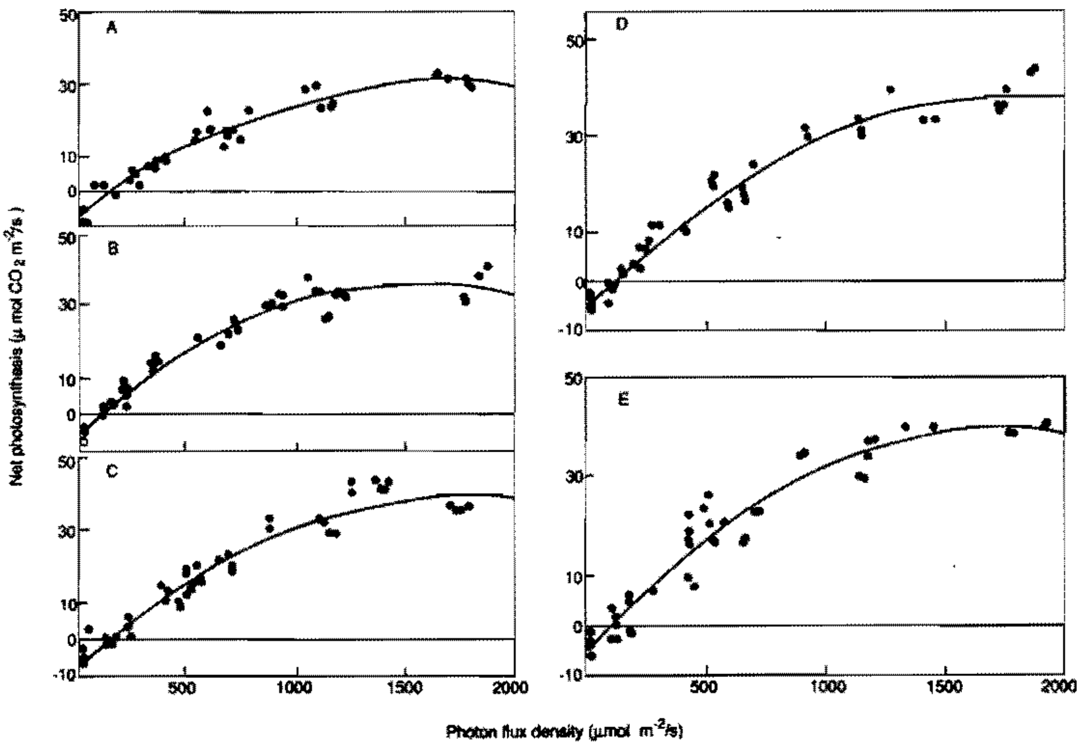


Figure 3.12. Responses of leaf photosynthesis to light in field-grown cassava. Measurements made on upper canopy, fully expanded leaves during the rainy season. (A) CG 927-12; (B) CG 996-6; (C) CM 507-37; (D) CM 523-7; (E) CM 3456-3.

These mechanisms allow the crop to maximize WUE over a longer period while maintaining good yield.

Max. photosynthesis was correlated with biomass and storage roots/pl (Table 3.5). The highly significant correlation with root no. suggests that expression of potential photosynthesis is partially dependent on sink capacity (CIAT Annual Report 1990), which might explain the much lower rates always observed in potted cassava. It must be noted that these high rates were obtained in 5- to 6-mo-old cassava when root bulking was in a linear phase and demand for assimilates was high. Moreover, at this stage of growth, LAI was near max. (see section 3.1), and shoot demand for assimilates was minimal.

Table 3.3. Leaf net photosynthesis, yield and biomass of field-grown cassava.

Variety	Max. Net Photosynthesis (n=6)	Ci/Ca* (n=6)	Seasonal Avg Net Photosynthesis (n=30)	Dry RY	Total Dry Biomass	Storage Roots/Pl
	μ mol CO_2 m^{-2}/s		μ mol CO_2 m^{-2}/s	t/ha		
CG 996-6	49.7	0.37	33.8	18.00	23.64	14
M Bra 191	47.4	0.37	35.5	16.50	24.00	14
CM 4864-1	45.1	0.39	34.0	19.22	25.55	13
CM 4145-4	43.9	0.40	31.7	17.42	22.44	7
CM 3456-3	43.7	0.43	31.9	17.97	23.12	9
CM 507-37	43.7	0.38	28.7	19.02	24.30	11
CM 4716-1	43.6	0.42	31.8	16.23	25.30	10
M Col 1684	43.0	0.42	30.9	17.11	22.20	7
CM 4575-1	42.8	0.39	33.2	17.95	21.90	7
CM 4617-1	42.8	0.46	31.4	17.20	22.67	8
CM 523-7	42.3	0.45	30.1	18.06	23.78	11
M Col 1468	42.3	0.44	30.3	14.63	21.67	9
CM 4701-1	42.2	0.45	30.9	18.08	24.00	9
CM 4711-2	41.3	0.45	30.9	17.21	24.61	8
CG 927-12	39.3	0.43	26.2	12.15	15.74	8
Mean of all var.	43.5	0.42	31.4	17.12	23.00	10
LSD 5%	1.7	0.08	1.8	1.74	2.38	2

* Ci/Ca = Intercellular CO_2 / Ambient CO_2; calculated from max. leaf gas exchange measurements.

Table 3.4. Meteorological data at Santander de Quilichao during the 1990-91 season.

Mo/ Yr	Rainfall	Evaporation	Solar-Radiation	Temperature Max.	Temperature Min.	Temperature Mean	Relative Humidity Mean	Relative Humidity Min
	mm	mm	MJ m^{-2}	°C	°C	°C	%	%
May/1990	134	109	465	28.7	18.8	23.6	80	54
June	36	120	515	29.8	18.5	24.3	75	47
July	97	131	595	29.8	17.5	24.0	71	41
August	55	149	567	31.5	17.2	25.2	64	39
September	79	151	618	31.4	18.2	24.4	74	36
October	245	118	518	28.6	18.7	23.2	77	49
November	197	127	555	29.2	18.7	24.0	78	50
December	200	121	495	29.4	18.7	23.6	77	50
January/1991	33	144	585	30.9	19.0	24.7	70	39
February	72	134	548	31.3	19.4	25.1	70	40

Seasonal average photosynthetic rates were also correlated with yield, biomass and storage roots\pl (Table 3.5). These findings again confirm previous reports (CIAT Annual Reports 1989, 1990) showing a direct relationship between photosynthesis as measured in the field and productivity and suggesting that leaf photosynthesis, leaf area duration and storage roots/pl are useful criteria for parental selections.

The two components of leaf gas exchange--that is, stomatal and mesophyll conductances--were also correlated with yield and biomass. The negative correlations with intercellular CO_2 (Table 3.5) suggest that nonstomatal factors were more important, especially as correlations with leaf WUE (CO_2 uptake/H_2O loss) were positive.

These data indicate that cassava has high photosynthetic potential, which is associated with productivity when grown under natural and near optimum conditions. Cassava requires high ambient temp and high solar radiation for optimal leaf development and for the expression of its photosynthetic potential; thus, when grown in environments--natural or artificial--that deviate from these fundamental climatic requirements, its photosynthetic potential would not be fully expressed.

Compared to the efficient C_4 crops such as maize and sorghum and to warm-climate C_3 crops such as cotton and sunflower, cassava is highly efficient, considering its thin, hypostomatous leaves. Furthermore, cassava has low photorespiration and elevated activities of the key C_4 enzyme, phosphoenolpyruvate carboxylase (Table 3.6), but lacks Kranz-anatomy, typical of C_4 species (CIAT Annual Report 1986). These physiological and biochemical attributes can be advantageous to cassava photosynthesis, particularly when the crop has to endure a long period of drought coupled with dry, hot air in the regions where it is grown.

Moreover, these findings have practical implications for the strategies adopted in cassava breeding programs for different production ecosystems:

- The high sensitivity of photosynthesis to ambient temp points to the need for genotypes more tolerant to low temp, which could be used in the highland tropics and in the subtropics where cassava is an important staple for resource-poor populations.

- The positive association of photosynthesis with productivity suggests that selection for high photosynthesis in parental materials may lead to higher yield when combined with other yield determinants.

- The relatively high photosynthesis under prolonged water deficit indicates the potential of cassava as a food crop in dry regions such as NE Brazil and Sub-Saharan Africa. In these drought-prone areas, very few other food crops would survive and produce reasonable yields. Breeding and selection for drought tolerance in this ecosystem are already in progress (see Chap. 2).

Table 3.5. Correlations among cassava leaf gas exchange characteristics and RY, biomass and storage root no. of field-grown cassava.

	All-Season Gas Exchange Measurements					
	Max. Net Photosynthesis	Avg Net Photosynthesis	Stomatal Conductance	Mesophyll Conductance	Intercellular CO_2	Leaf WUE (CO_2/H_2O)
Dry RY	0.41 (NS)	0.58 *	0.58 *	0.44 (NS)	- 0.39 (NS)	0.42 (NS)
Total dry biomass	0.54 *	0.61 **	0.51 *	0.55 *	- 0.54 *	0.52 *
Storage roots/pl	0.75 **	0.51 *	0.57 *	0.57 *	- 0.37 (NS)	0.51 *

NS = Not significant
* = Significant at 5%
** = Significant at 1%

Table 3.6. Activity of PEP carboxylase in leaf extracts of cassava, maize and common beans; values are means of 4 leaves ± SD.

Species & Photosynthetic Type	PEP Carboxylase Activity	
	μ mol NADH/min. gfw	μ mol NADH/min. mg chl
Maize - C_4 var. CIMMYT 346 Swan laposta C 848	14.9 ± 1.8	6.8 ± 3.55
Cassava - C_3 - C_4		
M Mex 59	3.2 ± 0.6	2.2 ± 1.0
M Bra 534	3.0 ± 0.4	2.1 ± 1.0
M Nga 2	1.3 ± 0.1	0.4 ± 0.1
M Ven 77	2.4 ± 0.2	1.5 ± 1.0
M Col 22	2.3 ± 0.4	1.0 ± 0.6
M Col 1684	1.8 ± 0.4	0.6 ± 0.1
M Col 2264	2.6 ± 0.6	2.3 ± 1.6
M Bra 309	1.8 ± 0.4	0.6 ± 0.05
M Ven 331	1.5 ± 0.2	0.4 ± 0.2
Common Beans - C_3 var. Calima G 4494	0.2 ± 0.07	0.3 ± 0.1

In conclusion, it can be stated that cassava has high photosynthetic potential, which underlies its high productivity under optimum conditions as well as its tolerance to stressful environments.

4. QUALITY

Quality is a complex issue for cassava research, given the variable nature of the raw material and the large number of actual and potential markets/products, each with specific quality requirements. End-product quality is a function of raw material (itself a result of genetics, crop management and environmental factors), the process, and storage and handling conditions. The research presented here focuses on the raw material; i.e., genetic and other factors affecting the composition and characteristics of the fresh root. Process-related factors are covered in the chapter on process and product development (Chap. 12).

4.1 Objectives

The general objective is to improve the quality of cassava for diverse end uses.

Specific objectives are to:

- Characterize the physicochemical and functional properties of cassava roots, and to relate these to end-user requirements
- Evaluate the genetic diversity for all important quality characteristics within the *M. esculenta* species and the *Manihot* genus
- Provide plant breeders with rapid and reliable screening methodologies for important quality characteristics
- Evaluate the potential of crop management, especially soil fertility, to improve root quality
- Study relationships between important root-quality characteristics

4.2 Research Priorities

Given the complex matrix of quality characteristics and products, it is necessary to identify the most important priorities in order to focus the limited resources available. Table 4.1 attempts to summarize current knowledge about the relative importance of each quality characteristic across products.

The main fresh root characteristic of relevance for producing dried cassava for animal feed is root DM content. This is crucial in determining the fresh:dry product conversion ratio and hence the economic feasibility of drying cassava for this market. CN content is important only if the final content is <100 ppm. The feed concentrate industry is

Table 4.1. Relative importance of cassava quality characteristics across products.

	Dried (Animal Feed)	Fresh (Human Food)	Flour (Human Food)	Starch (Human Food)
DM	+++	++	+++	+++
Starch content (% DM)	++	++	+++	+++
Amylose (% starch)		?	?	?
Functional properties starch		?	++	+++
HCN	+	++	+++	
Physiological Deterioration	+	+++	+++	++
Eating quality		+++		
Fiber	+	+	++	+
Protein			+	+
Ash	++		++	++
Microbial	++	++	+++	+++

+++, ++, + : Relative importance of each quality characteristic (high, moderate, low).
? : Relationship between this variable and product quality is unclear; further research required.

concerned about product purity (ash content) and the presence of fungi and mycotoxins; these are more process-related quality issues.

The main characteristics of importance for fresh cassava for human consumption are eating quality and postharvest storage life (physiological deterioration). This latter problem has been addressed through postharvest technologies (see Chap. 12). Fresh root chemical composition is important only as it relates to eating quality. CN is not a high priority as low CN varieties rarely result in bitter tasting roots. In Africa, use of high CN varieties for fresh or poorly processed root products can be a source of toxicity, especially under drought conditions.

Cassava flour for human consumption requires a high-quality product as regards purity (low ash, fiber, etc.) and hygiene (microbial standards). DM content is important for economic feasibility; starch physicochemical and functional properties are important and depend on the derived product to be made from the flour. CN content is more important than in cassava for animal feed as the acceptable levels for human consumption are lower (50 ppm) and the artificial drying process results in less efficient elimination of CN than in natural drying. High-quality flour also has industrial uses for which microbial quality is not relevant.

The main characteristics of cassava starch are those related to the physicochemical composition of the starch and its functional properties under different processes. Root DM content is also crucial in determining process efficiency. Root CN content is not important as the starch is obtained by wet extraction and has only trace amounts of residual CN. Pollution from CN in the waste water is a problem, however.

Finally, across all processed products, fresh root deterioration is a quality problem as it reduces process yields and the quality of the end product. The postharvest technology developed for the fresh market is not economical for ensuring fresh roots of good quality for processing: a genetic solution would be preferable.

Research priorities have therefore been identified as:

- CN content - for processed products and to resolve African-specific human toxicity problems
- Starch quality - to develop flour and starch suitable for different industrial end uses
- Eating quality - for the fresh market

From 1987-89 most attention was placed on eating quality as a result of the issues raised by the fresh cassava conservation projects. From 1989 to date increasing emphasis has been placed on CN. In 1991 the methodologies were in place to permit research on starch quality to initiate.

This report first details the methodologies developed for quality evaluation, then presents results obtained from research on varietal and crop management effects on quality, concluding with a look at future research priorities.

4.3 Methodologies

4.3.1 Cyanide

4.3.1.1 Improvement of analysis method. Cooke's enzymatic method for determining total CN and HCN has been used at CIAT for over 10 yr. Modifications to the method, developed at the Natural Resources Institute (NRI), have now been introduced. These modifications consist of a different extraction medium, a decrease in amount of toxic pyridine used, and the determination of the cyanohydrin intermediary between the glucoside and free HCN. The new extraction medium permits an increase in the time between sampling and analysis from 4 to 30 days, making the method much more flexible for use away from a central lab facility.

4.3.1.2 Correlation of enzymatic and qualitative methods. Studies were undertaken to correlate the enzymatic method with the rapid picrate qualitative method used by many cassava breeders. Although picric acid gives an intense color reaction with HCN, it is not specific. False positive and negative results can be obtained. In 3 experiments both methods of CN determination were carried out on the same samples. In two cases there was no significant correlation between the results. Although the correlation was significant (0.578***, N=112) in the third experiment, only 30 samples fell within the theoretical range expected for the picrate method. Low qualitative scores consistently underestimated the amount of CN in the root tissues, while high scores tended to overestimate CN content. As a result of this study, the development of an improved rapid methodology for estimating CN content of cassava root tissues has become a high priority for the Cassava Program: Without an improved method the selection of low CN germplasm cannot be undertaken with the required degree of confidence.

4.3.2 Starch

4.3.2.1 Starch content analysis. The analytical method for starch content determination in cassava was based on acid hydrolysis of the starch to sugars and the determination of the glucose liberated using a copper reagent. This was compared with an enzymatic method for both starch hydrolysis and glucose determination. The enzymatic method gave higher values with a smaller SD than the acid hydrolysis method; acid hydrolysis was probably not completely hydrolyzing all the starch. The enzymatic method is now standard at CIAT, resulting in a 50% cost saving/sample.

4.3.2.2 Starch quality evaluations. As cassava moves into more diversified industrial and other uses, the physicochemical and functional properties of the starch component of the root become ever more important. These quality characteristics are of equal or greater importance than price and availability factors for many products. Starch properties are determined by a range of complex factors related to the physicochemical structure of the starch granules and their behavior during baking and other processes.

The following methods have been developed by the Utilization Section at CIAT in collaboration with the Universidad del Valle (UNIVALLE) in Cali and the Universidad Industrial de Santander in Bucaramanga.

Microscopic technique: Determines the size and shape of starch granules and the mode of attack by microorganisms and enzymes.

X-ray analysis: Characterizes the crystalinity of starch granules according to the classification of X-ray diffraction patterns (types A, B or C).

Amylose content: One of the main factors determining starch quality is the amylose:amylopectin ratio. Amylose is essentially starch composed of glucose units linked in straight chains; amylopectin linkages permit ramification of the starch chains. This results in very different functional properties, especially of starch pastes subjected to heat. During 1991 a standard method for amylose determination was tested at CIAT and has now been included in the routine quality lab procedures. The method consists of dispersing starch grains in ethanol, then gelatinizing them at ambient temp for 24 h.

A color reaction between iodine and acidified amylose permits the spectrophotometric quantification of the amylose content against a standard curve prepared from known proportions of amylose and amylopectin. Results to date have proved highly reproducible, with amylose values between 16 and 25% of total starch. Significant differences between varieties and treatments are starting to become apparent.

Differential Scanning Calorimetry (DSC): Provides information on the thermal properties of starch. DSC detects the heat flow associated with phase transitions, giving a quantitative measure of gelatinization (transition enthalpy, gelatinization temp).

Viscoamylograms: Determines the mechanical properties of starch pastes (5% w/v) during heat treatment using a Brabender viscoamylograph, now available at CIAT. A viscosity/time curve is plotted, using the following program: Heat from 25 to 90°C at 1.5°C/min, hold at 90°C for 20 min, cool to 50°C at 1.5°C/min, and hold at 50°C.

Solubility and swelling power: Methods for evaluating these quality variables over a range of temp (30-95°C) are still being tested at CIAT for later routine use.

As the evaluations and analytical methods under study become available for routine use this coming year, the quality lab, together with collaborating institutions in Colombia, will be able to carry out complete characterizations of cassava starch samples. This is essential if the Program is to identify and develop germplasm with potential for use in a number of growth markets.

4.3.3 Eating quality

4.3.3.1 Expert taste panel. For detailed studies of fresh root eating quality, an expert taste panel was formed, with assistance from NRI personnel. The panel was comprised of 15 people selected for their sensitivity to acid, sour, sweet and bitter tastes. Initial group discussions identified 15 visual, olfactory, taste, texture and aftertaste characteristics of the fresh, boiled root for evaluation. Panel sessions were held regularly once or twice a week. At each session, three replicates of each of two different root samples (boiled in unsalted water until judged as done) were evaluated using the Quantitative Descriptive Analysis methodology, in which the intensity, not preference, of each characteristic is recorded on a continuous scale. This permits the analysis of results by ANOVA. Cooking time was also recorded.

4.3.3.2 Rapid evaluation. For evaluating the eating quality of a large number of samples, the expert panel is not suitable. For these cases a rapid method was standardized, in which only the salient characteristics are evaluated by one trained lab worker. Root pieces are boiled in unsalted water, and the time taken to reach optimum texture is recorded. Each piece is then evaluated for taste (sweet, bitter) and texture (hard, glassy, starchy) on a 0-3 scale of intensity.

4.4 Results

4.4.1 Characterization of starch quality

Starch from different varieties used for sour starch production was characterized at different plant ages. The following var. were studied: CMC 40, M Col 8, M Col 1684, CM 523-7 (short cycle) and M Col 1522 (long cycle).

4.4.1.1 Structure. Under light and scanning electron microscopy, starch granules from all var. were round with a truncated end and a well-defined excentric hilum. Granule size was 5 to 35 μm. The X-ray diffraction pattern found for CMC 40, M Col 8, M Col 1684 and CM 523-7 was type A (usually observed in cereals, as opposed to the B type found in tubers), with generally low amylose content and small starch granules. M Col 1522 was, however, identified as type C: intermediary between A and B types.

4.4.1.3 Amylose content. The changes of amylose content with plant age are shown in Fig. 4.1:

- M Col 1684, M Col 1522 and CM 523-7 increased in amylose content during the growth period, but CMC 40 and M Col 8 showed significant variations with age (16-20%).
- M Col 1522 showed a lower amylose content (ca. 16%) than the other var.

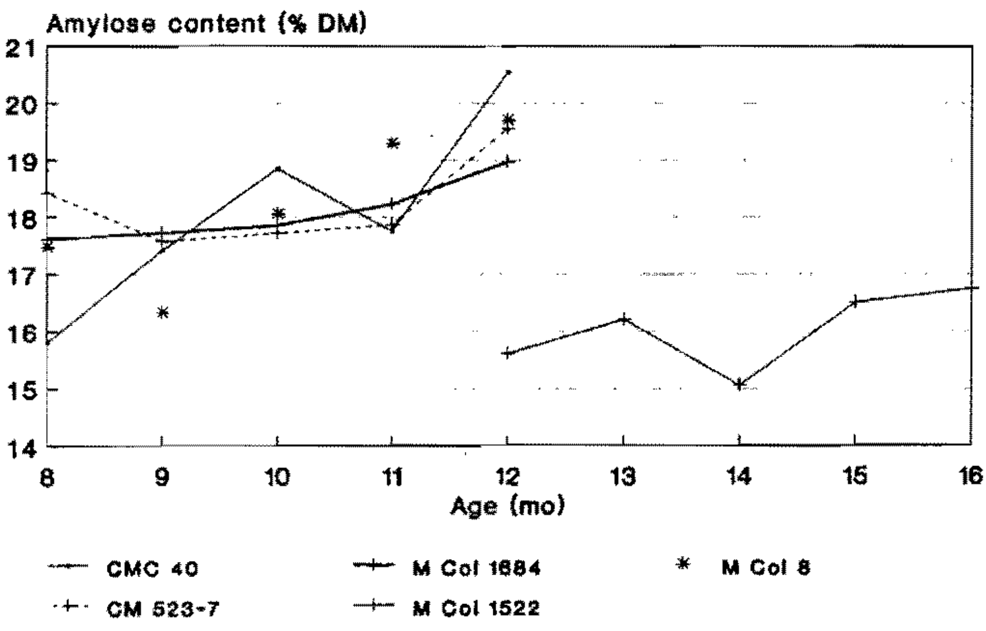


Figure 4.1. Amylose content of cassava native starches.

4.4.1.4 Functional properties. The different characteristic values of Brabender amylograms of 5 var. are given in Table 4.2. The amylograms show the same tendency of all high amylopectin-content starches, with a high peak viscosity, good ease of cooking, a high viscosity breakdown of the paste at high temp, a low viscosity setback produced by cooking after cooling, and a good viscosity stability of the cooked paste. Nevertheless, there are some varietal differences:

- The initial gelatinization temp is lower for M Col 1522 (ca. 58° C) than for the other var. (61-63° C).
- Starch paste behavior differs among the var. at both the 10- and 12-mo harvest. M Col 8 and CM 523-7 present similar curves, with a decrease in setback value for CM 523-7, but increased viscosity for M Col 1684.
- A decrease in the viscosity peak for CMC 40 with the appearance of a shoulder on the amylogram, probably due to alteration of the starch produced by root deterioration before processing.
- All var. except M Col 8 increased in cooking time (Te) with plant age.

Table 4.2. Characteristic values of amylograms of cassava starch.

Variety	Age (mo)	Tg °C	Vm BU	Vr BU	Ve BU	Tc min	Ve-Vr BU	Vm-Ve BU
CMC 40	10	63.5	745	325	465	10.0	140	280
	12	62.7	655	315	440	14.5	125	215
M Col 1684	10	61.2	880	290	370	7.5	80	510
	12	61.2	960	370	560	10.0	190	400
M Col 8	10	62.7	1020	400	615	8.5	215	405
	12	62.7	1085	380	580	8.5	200	505
CM 523-7	10	61.2	805	320	460	11.0	140	340
	12	61.2	810	370	565	13.5	195	245
M Col 1522	16	58.4	690	245	400	11.0	155	290

Tg = Initial gelatinization (pasting), temp
Vm = Peak viscosity
Vr = Viscosity after 20 min at 90°C
Ve = Viscosity on cooling to 50°C
Tc = Time to reach max viscosity from start of gelatinization
Ve-Vr = Gelatinization index
Vm-Ve = Setback value
BU = Brabender units

4.4.1.5 Thermal properties. All the DSC thermograms carried out from 30 to 130°C showed only one endotherm between 47 to 62°C, which corresponds to the gelatinization phase change; thus there is no formation of an amylose complex with lipids for these cassava starches. The specific values of thermograms obtained by DSC at different plant ages for each var. are given in Fig. 4.2, showing the three characteristic temp of phase transition--onset (To), peak (Tp) and end gelatinization (Te)--and the enthalpy of gelatinization. Results show that during the growth period of all var., the values were optimum at their respective time of maturity.

The thermogram values varied among varieties:

- Gelatinization temp (To, Tp, Te) increased in the following order of var.: M Col 1522 (47.8, 51.0, 57.5), CM 523-7 (51.9, 55.6, 62.0), M Col 1684 (52.1, 55.8, 62.0), M Col 8 (53.6, 56.4, 62.0) and CMC 40 (54.3, 57.9, 63.8).

- The enthalpy of gelatinization was significantly different between M Col 1522 (avg of 9.3 J/g) and the other var. (6.1-7.4 J/g).

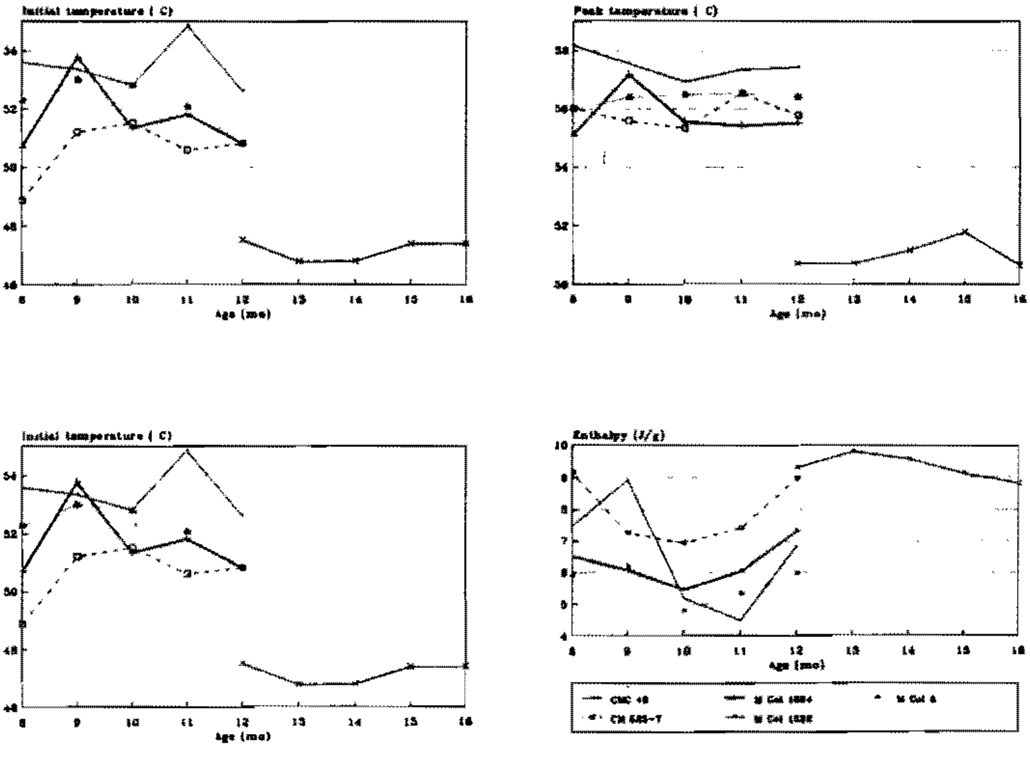


Figure 4.2. Characteristic parameters of DSC thermograms.

4.4.1.6 Conclusions. M Col 1522 had structural, functional and physical properties very different from the other var. and also gave the best sour starch quality (see Chap. 12, sec. 12.7). A direct relation between the raw material and sour starch quality thus seems likely. In the future more emphasis will be placed on the influences of native starch properties on sour starch quality.

4.4.2 Characterization of fresh cassava eating quality

The expert taste panel was used to characterize what is meant by good eating quality of fresh cassava. Roots from two varieties, independently evaluated as of good and poor eating quality, were evaluated by the panel (Fig. 4.3). The good-quality sample had higher values for starchiness, freshness, "cassava taste" and consistency of texture than the poor-quality sample, which was of glassy appearance, hard in texture and with a moister mouth feel.

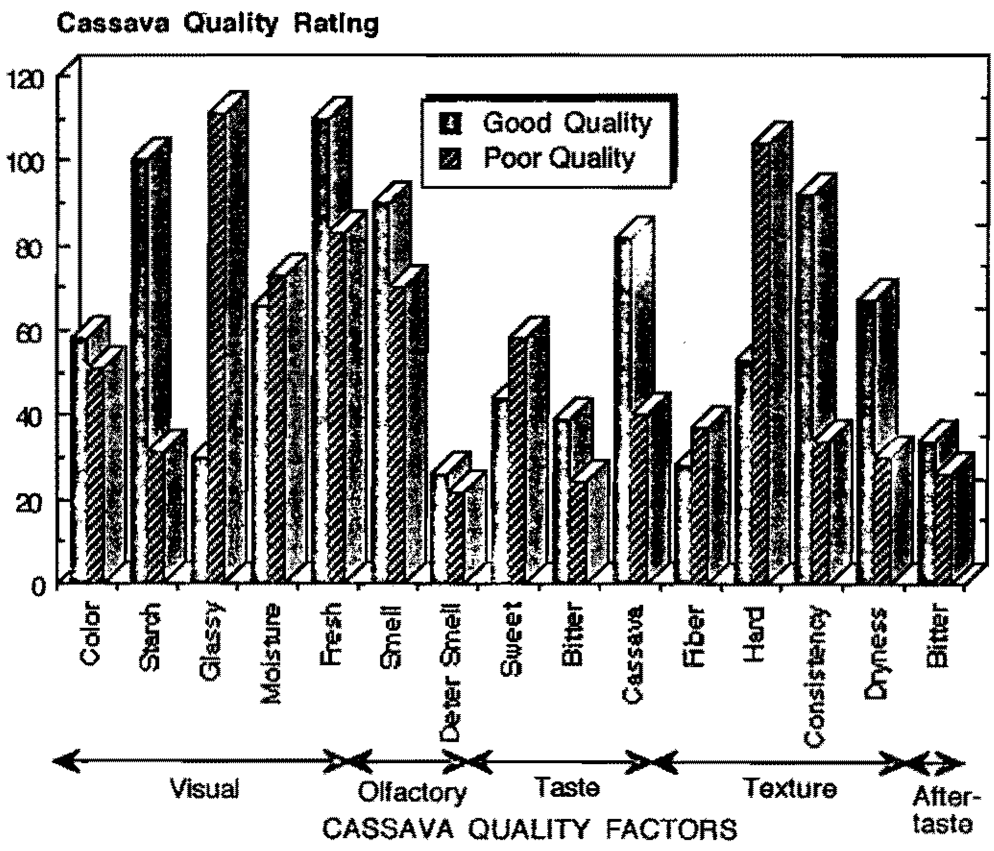


Figure 4.3. Profile of good- and poor-quality fresh cassava according to results of expert taste panel.

Multivariate analysis of a no. of samples from different varieties helped identify which characteristics of the fresh root were most related to like/dislike of the same samples (Table 4.3): cassava taste and hard texture. The importance of a "cassava taste" factor in acceptability of fresh cassava has not previously been recognized and merits further research to identify the volatile flavor components involved. Hard texture had been reported as a crucial characteristic affecting fresh root quality in previous annual reports, both as a result of lab studies and consumer surveys. Specifically, the occurrence of a hard, glassy texture in boiled roots as a universally perceived negative quality factor has been evident for some time.

4.4.3 Characterization of germplasm

Numerous experiments have demonstrated that considerable variation for many of the important quality characteristics exists within cassava germplasm. Table 4.4 shows the range of values encountered for the principal chemical constituents of the fresh root.

Table 4.3. Multivariate regression analysis of expert taste panel results: Determination of quality characteristics most significantly associated with like or dislike of samples from 6 cassava var.

Quality	Level of Significance (%) of Each Character					
Characteristic	HMC 1	CM 681 2	CM 1559-5	CM 489-1	CMC 40	M Col 22
Color	85	4*	58	38	7*	80
Starch	83	54	21	3*	0*	17
Glassiness	16	13	1*	0*	0*	65
Moisture	85	68	37	24	59	39
Freshness	76	29	5*	0*	10*	4*
Smell	68	0*	7*	0*	95	75
Deterioration smell	43	47	26	49	64	65
Sweet taste	20	59	4*	9*	7*	14
Bitter taste	10*	84	93	11	60	53
Cassava taste	3*	0*	2*	0*	13	3*
Fibrousness	78	53	91	64	79	7*
Hardness	0*	7*	0*	2*	5*	9*
Consistency	68	94	51	72	0*	42
Dryness	48	92	27	67	5*	69
Bitter aftertaste	38	87	10*	30	31	54

Note: Level of significance (%) taken from the probability of the T-value for each characteristic. Values below 10 (*) are significantly related to like/dislike evaluation.

Table 4.4. Range encountered in the principal constituents of cassava parenchyma and peel.

	Percent (Dry Wt)	
Constituent	Parenchyma	Peel
DM (% fresh wt)	23-44	15-34
Starch	70-91	44-59
Total sugars	1.3-5.3	5.2-7.1
Crude fiber	3.0-5.0	5.0-15.0
Ash	1.0-2.5	2.8-4.2
Protein	1.0-6.0	7.0-14.0
Fat	0.3-1.5	1.5-2.8
Total CN (ppm)	30-1350	60-550

Knowledge of the variability of starch characteristics in cassava is especially weak, with only a few reports available in the literature. The Program intends to characterize the core germplasm collection germplasm for CN content and starch quality factors.

4.4.4 Characterization of wild *Manihot* species

The few (9) species available thus far in the wild *Manihot* collection at CIAT have been characterized for total CN content in leaves and roots, and for the presence of physiological deterioration--characteristics where it is known that the cassava germplasm evaluated to date does not hold sufficient variability to permit selection for desired characteristics. All species had high levels of CN in leaves and roots (Table 4.5), and all showed susceptibility to physiological deterioration. As over 100 species exist in the *Manihot* genus, it may still be possible to find an acyanogenic species or one without physiological deterioration.

4.4.5 Effect of plant age and climate on quality

The perennial cassava plant has no fixed maturity time; harvests are therefore fixed by a number of factors; for example, the farmer's need for land, price in the market, yield and root quality. The plant responds dynamically to changes in the environment, especially as regards starch deposition and mobilization. These factors result in extremely variable root quality with plant age, and by season and location. Figure 4.4 shows the variability in root DM and starch content and eating quality over a 4-mo period for a variety harvested weekly at CIAT. This variability is typical of the crop, making it difficult to decide on the optimum harvest time for agronomic experiments. The effects on eating quality can be seen in one experiment in which the same variety was harvested on 7 different occasions over a 2-yr period at CIAT, always at the same plant age (10 mo).

Table 4.5. DM and CN contents of 9 species of *Manihot*.

		Total CN (ppm, DM basis)		
Manihot Species	% DM	Parenchyma	Peel	Leaf
M. aesculifolia	40.2	582	2818	636
M. carthaginensis	19.7	1443	2811	1519
M. crassisepala	43.8	314	912	2123
M. grahami	48.3	260	1564	3537
M. michaelis	32.9	442	6106	2943
M. pseudoglaziovii	38.1	1082	6006	3196
M. flabellifolia	42.2	733	1584	1622
M. rubricaulis	-	-	-	3064
M. chlorosticta	-	-	2636	2969

Note: Missing data due to absence of storage roots in the plants sampled.

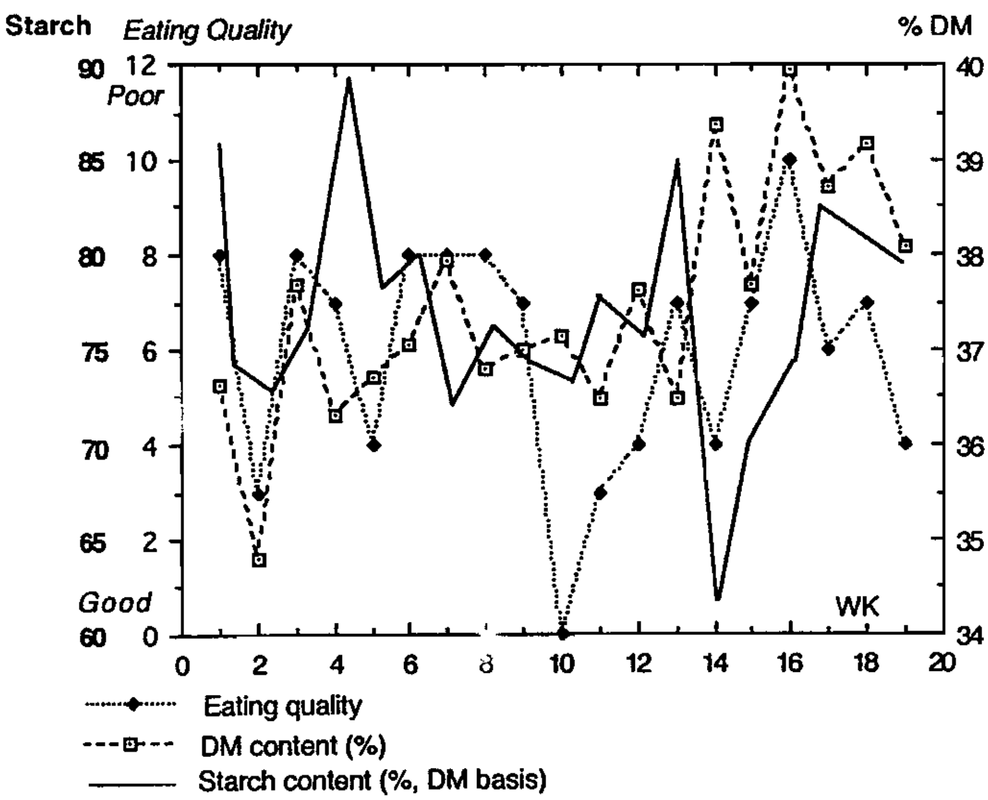


Figure 4.4. Variability in root DM and starch contents and eating quality (rapid evaluation method) of HMC-1, harvested at weekly intervals from 6 to 11 mo at CIAT.

Eating quality, as evaluated by the expert panel, varied significantly in the 3 most important quality characteristics: hardness, glassiness and cassava taste (Table 4.6).

4.4.6 Crop management effects on root quality

The foregoing section showed how variable the quality of cassava can be, depending on plant age and certain climatic factors. Experiments with other preharvest variables--such as fertilizer applications, water stress regimes and stake selection--have shown significant effects on RY and are leading to the development of crop management strategies for cassava. However there has been relatively little information available on the effects of these variables on root quality characteristics. Advantage has therefore been taken of experiments conducted by other sections of the Cassava Program during the last four years. Collaboration has been especially fruitful with the Physiology Section, with samples being taken from experiments in Santander and Pivijay, Colombia. Samples from 25 field experiments have been analyzed for root chemical composition and eating quality. These show that the effects of different treatments on root quality can be very significant.

Table 4.6. **Taste panel evaluation of hardness, glassiness and cassava taste for boiled cassava sample varieties, grown at CIAT and harvested at 10 mo of age on 7 occasions between 1987 and 1989.**

Quality		Variety			
Characteristic	Harvest	HMC 1	CM 681-2	CM 1559-5	CM 489-1
Hardness	1	39^{ef}	53^{d}	55^{cd}	57^{b}
	2	77^{b}	92^{ab}	47^{d}	94^{a}
	3	60^{cd}	82^{bc}	88^{a}	90^{a}
	4	71^{bc}	102^{a}	69^{bc}	53^{b}
	5	52^{de}	56^{d}	73^{b}	98^{a}
	6	108^{a}	74^{c}	70^{bc}	86^{a}
	7	36^{f}	46^{d}	50^{bcd}	57^{b}
Glassiness	1	49^{b}	75^{c}	58^{bc}	51^{de}
	2	50^{b}	109^{b}	57^{bc}	78^{a}
	3	33^{cd}	109^{b}	71^{ab}	75^{ab}
	4	38^{bcd}	130^{a}	49^{cd}	44^{d}
	5	26^{d}	59^{d}	33^{e}	63^{bc}
	6	76^{a}	80^{c}	75^{a}	59^{c}
	7	44^{bc}	32^{e}	36^{de}	26^{e}
Cassava taste	1	85^{de}	76^{cb}	71^{c}	77^{bc}
	2	77^{e}	53^{d}	84^{cb}	72^{c}
	3	109^{ab}	66^{c}	72^{c}	76^{bc}
	4	89^{dc}	49^{d}	92^{ab}	87^{b}
	5	115^{a}	85^{b}	98^{a}	65^{c}
	6	49^{f}	67^{c}	71^{c}	76^{bc}
	7	99^{bc}	97^{a}	102^{a}	102^{a}

Notes: 1. Values with different letter superscripts were significantly different ($P = 0.005$, DMRT); the main effect of harvest date was significant at $P = 0.001$ in all cases.

2. Evaluation scale: 0-150 with 0 = absence of character; 150 = intense expression of character.

4.4.6.1 Soil fertility. Most results have been obtained from experiments in the area of soil fertility improvement. Comparisons of fertilized and unfertilized plots are not consistent; experiments at Pivijay and Patia showed no effect of fertilization (NPK, 15-15-15) on DM, starch, total CN or eating quality. A similar experiment at Santander, however, did show a significant effect, with fertilizer treatment increasing DM content of the roots and improving their eating quality. Response to fertilization is probably related to the nutrient status of the soil involved as another experiment showed that root quality (DM and starch contents) were significantly higher on plots after fallow than on plots with several successive cassava crops.

Similarly, annual applications of fertilizer resulted in better root quality (higher DM, lower HCN) than in plots reliant on the residual effects of previous fertilizer applications in two experiments in Santander. Nevertheless, a further experiment in Santander produced roots with higher DM but also higher total CN after annual fertilizer applications.

Differences in the effects of NPK root quality have also been found. K seems to be especially important in determining root quality. In three separate NPK trials at Santander, the zero-K treatment produced roots with significantly less DM and with higher total CN contents. At Pivijay, two NPK trials showed no differences between different treatment levels although a separate K experiment did give a significantly higher total CN content with zero K as at Santander (Table 4.7). Ongoing experiments in collaboration with the Physiology Section should provide more information on the role of K in determining root quality in cassava.

In contrast, the role of P appears to be negative: Two varietal screening trials at Santander have both demonstrated that higher levels of P increase root total CN content significantly, while DM content and eating quality declined. Nevertheless, there are varietal differences: Although most varieties increase in total CN, a few remain constant and some decrease in content (Table 4.8).

Table 4.7. Effect of K application on root DM and total CN content (mean of 8 clones harvested at Pivijay).

Treatment	DM (%)	Total CN (ppm, DM basis)
Level of K (t/ha)		
0	34.5	350 [a]
50	34.2	286 [b]
100	35.0	277 [b]
200	35.3	256 [b]
Significance	NS	0.01%

Note: Different letter superscripts represent significant differences in values, DMRT.

Table 4.8. Effect of P application on root DM and total CN content of 33 clones harvested at Santander.

	P Application (t/ha)			
	0	75	0	75
Cassava Clone/Var.	% DM		Total CN Content (ppm DM basis)	
CG 927-12	36.1*	33.8	187	206
CG 996-6	38.8*	34.3	131	163*
CG 1374-2	40.0	39.3	128	154
CM 305-41	32.0	31.8	286	411*
CM 2718-1	35.9*	35.1	286	360*
CM 2774-11	37.3	36.7	96	119
CM 3285-7	37.8*	35.3	139	192*
CM 3401-2	37.7*	36.3	172	208*
CM 3456-3	36.4*	34.7	158	219*
CM 3654-3	40.1*	37.7	138	154
CM 3667-1	37.1	37.2	251*	220
CM 3750-5	37.6	37.6	278*	249
CM 4145-4	37.1	36.9	124	177*
CM 4575-1	37.1	36.9	234	285*
CM 4617-1	35.8	35.5	424	477*
CM 4701-1	38.5	38.2	102	132*
CM 4711-2	37.6	37.2	418*	262
CM 4716-1	40.2	39.7	123	154*
CM 4793-1	38.7*	36.7	257	354*
CM 4830-3	35.0*	31.0	184	343*
CM 4864-1	38.3*	35.3	152	189*
M Bra 191	35.6	35.9	168	227*
M Bra 383	37.4	37.2	350*	305
M Col 2215	38.5*	34.9	291	382*
M Pan 51	36.6*	33.7	148	293*
SG 104-264	37.0*	35.7	193	260*
SG 104-284	35.3	34.7	125	253*
SG 106-59	33.6	35.8*	168	150
SG 250-3	37.5*	33.3	145	181*
SG 302-1	36.1*	35.2	232	270*
SG 455-1	39.5*	38.2	166	214*
SG 545-7	33.9	33.5	207	198
SM 414-1	33.7	37.0*	132	204*
	LSD = 0.8		LSD = 29	

Note: * Denotes significant (5%) difference between means, placed next to the highest value of the pair.

Finally, two experiments at Pivijay have looked at the effect of increasing N levels on root quality. In both experiments DM and starch contents increased but total CN content decreased as N levels increased from 0 to 200 t/ha. Eating quality also improved.

Future experiments will continue the attempt to clarify the roles of the different soil fertility factors on root quality, with more emphasis on identifying germplasm that provides good quality under poor conditions and also responds to fertilizer applications and other management strategies.

4.4.6.2 Effects of cover crops. One recent experiment carried out at Pivijay has demonstrated the potential for improving root quality using a mulch cover. The use of mulch resulted in roots with a significantly lower total CN content while DM content remained unchanged. These results (Table 4.9) could be due to the lower soil temp under the mulch or to the extra nutrients provided by this treatment. Starch samples were also analyzed for their amylose content, using the new routine methodology; and the results showed the significant effect that the use of mulch can have on this important quality factor as well. Roots from plants treated with mulch had lower amylose percentages than the control plants (Table 4.9). This is the first instance of a significant effect of the preharvest environment on starch quality in cassava.

4.4.6.3 Effect of water stress. Three experiments have been carried out in which plants have been subjected to water stress during the growth cycle, for periods of up to 4 mo. Water stress significantly increased the total CN content of roots although differences in varietal response to the stress were found (Table 4.10). Root DM and starch contents were significantly reduced by water stress in some varieties, but not in others. The potential for developing varieties in which quality is not adversely affected by drought stress has been identified. This could be important for Africa, where drought stress has frequently been cited as a factor contributing to CN toxicity problems.

Table 4.9. Effect of mulch application on total CN and on starch quality of roots of M Col 1505 harvested at Pivijay, Colombia.

	DM	Total CN (ppm, DM)	Amylose (% Starch)
Mulch application	33.6	139	16.7
Control	32.7	208	20.0
Significant difference at P<	NS	0.001	0.001

Table 4.10. Effect of a 3-mo period of water stress, followed by 2 mo of recuperation, on total CN and starch contents of 4 cassava var.

	Starch (%, DM basis)		Total CN (ppm, DM basis)	
	Control	Stress	Control	Stress
CM 1335-4	80	78	123	108
CM 922-2	80	77	146	155
CM 2136-2	87	80*	162	340*
M Col 1684	89	76*	723	930*

Note: * Denotes significant difference between means at P<0.05.

4.4.6.4 Other preharvest factors. This series of experiments has also shown that root quality was unaffected by association of cassava with maize or maize and yams. In a crop rotation experiment, the only treatment that resulted in poorer quality (lower DM content) was planting cassava after two crops of maize. Planting cassava after beans resulted in improved DM content. Two experiments comparing root quality in plants derived from selected and treated stakes, compared with unselected and untreated stakes, were carried out at CIAT. Stake treatment had no effect on root quality; selection resulted in significantly lower total CN content in one experiment. In one experiment where plants of 2 var. were subjected to differing levels of mealybug infestation, root quality was severely affected. Root DM and starch contents and eating quality decreased as the intensity of the mealybug attack increased; there was no consistent effect on total CN content.

4.4.7 Relations between eating quality and starch quality

In Section 4.4.2 the importance of the glassy texture problem was highlighted. Roots that become hard and glassy when boiled, rather than soft and floury in texture, are negatively evaluated by consumers in all urban markets surveyed in Latin America. The impossibility of determining whether a root will be glassy or not before boiling, makes purchasing cassava risky from the consumer's viewpoint, even if the deterioration problem has been solved. The body of field observations and experimental results also point to the extreme variability of glassy texture phenomenon: Eating quality may vary greatly among plants of the same variety in one field or even among the roots of one plant.

To resolve this problem, greater quality stability over time and over edaphoclimatic variables is required. Research in this area is hindered by the lack of a simple, objective evaluation method for glassy texture: All root samples must be boiled and tasted. Over the last four years, a collaborative project between the NRI and CIAT sought to identify the causes of this texture problem; i.e., to relate root texture to a chemical or physical characteristic of the root tissues. No simple relationship was found between eating quality and DM content (Table 4.11). It was hypothesized that changes in the starch component of the parenchyma (80-90% of total DM) was responsible for the changes in boiled root texture. To this end, 4 var. were selected for study, one (HMC 1) of good eating quality and 3 of variable quality (CM 681-2, CM 1559-5 and CM 489-1). In order to determine variability in eating quality due to seasonal factors, each clone was harvested on 7 separate occasions over a 2-yr timespan, always at 10 mo of age. All samples were evaluated for eating quality by the expert taste panel at CIAT; extensive variation was found (Table 4.6).

It is noteworthy that even the variety selected as being of consistently good eating quality was in fact highly variable. All samples were also subjected to a complete proximal analysis, and starch samples were exhaustively characterized by the NRI, together with Nottingham University. The results of the starch characterization work were surprising in that there was very little variation in any of the starch quality variables examined. There

Table 4.11. Cooking time and eating quality of cassava roots with different DM contents.

Clone	% Root DM	Cooking Time (min)	Eating Quality	
			Taste	Texture
M Per 245	26.1	20	good	soft
M Col 1522	25.4	36	poor	hard
CM 91-3	30.4	15	good	soft
CM 849-1	30.1	31	poor	hard
HCM 1	35.8	20	good	soft
CM 922-2	35.1	40	poor	hard

was no relation between eating quality--specifically root texture--and any of the starch characteristics.

Although the study did not therefore advance the specific objectives for which it was designed, it did provide an opportunity to carry out a comprehensive characterization of the properties of cassava starch. However, the problem of identifying the causes of glassy texture in cassava remains unsolved. Further studies are required, concentrating on other root components that could affect texture (e.g., cell wall pectins and hemicelluloses). The lack of understanding of the biochemical aspects of cassava eating quality is now a severe constraint to improving this quality through breeding: currently only advanced lines can be screened for eating quality.

4.5 Future Priorities

- Complete the standardization of methods for starch quality evaluation, including Brabender viscoamylograph
- Develop a rapid and reliable method for CN determination for use by breeders
- Characterize the core cassava germplasm collection and the available wild species of *Manihot* for all salient quality factors
- Continue research on the physicochemical causes of variation in eating quality of fresh cassava
- Continue research on the effects of preharvest variables on root quality, concentrating on water stress and soil fertility, and on CN and starch quality

5. BIOTECHNOLOGY

Early work on cassava biotechnology focused on tissue culture techniques for virus elimination, germplasm exchange and conservation. Following the organization of the Biotechnology Research Unit (BRU) at CIAT in 1985, research was undertaken on genetic characterization, cryopreservation and plant regeneration, and later on genetic mapping and transformation. BRU cooperation with the Cassava Program focuses on integrating biotechnology into the Program's ongoing research activities. Table 5.1 shows the research activities in cassava biotechnology at CIAT, the type of project, and the current state of technology development.

Developments in cassava biotechnology over the last four years will be highlighted, with emphasis on three interrelated areas of application:

- Analysis and conservation of genetic diversity
- Crop productivity research
- Institution-building activities

Table 5.1. Cassava biotechnology research activities at CIAT (1987-91).

Research Activities & Technologies	Type of Project: Core	Type of Project: Special	Status of Tech. Development
1. Analysis & conservation of genetic diversity			
1.1 Isozyme fingerprinting	X	X	In use[1]
1.2 DNA fingerprinting		X	Advanced
1.3 In vitro active gene bank	X	X	In use[1]
1.4 Cryopreservation		X	Advanced
2. Crop productivity research			
2.1 Pathogen-free clones	X		In use[1]
2.2 Immature pollen culture	X		Initiating
2.3 Genetic transformation	X		Initiating
2.4 Molecular mapping		X	Initiating
2.5 Starch quality and CO_2 assimilation	X	X	Initiating
3. Institution building			
3.1 Training/biotechnology issues	X	X	Underway
3.2 The cassava biotechnology network		X	Underway

1 Technologies shifted from the BRU to the GRU and the Cassava Program in 1989-90.

5.1 Analysis and Conservation of Genetic Diversity in *Manihot*

5.1.1 Isozyme fingerprinting

The fingerprinting of cassava by α,β-esterase (EST) isozyme electrophoresis was developed through a collaborative project with the U. of Manitoba, Canada. In 1988, the BRU improved the methodology with the addition of 4 systems: Diaphorase (DIA), acid phosphatase (AcP), peroxidase (PrX) and glutamate oxaloacetate (GOT). It was demonstrated that EST patterns discriminate morphologically similar varieties (Fig. 5.1A), with practical applications for sorting mixtures and eliminating duplicates from the cassava collection.

Studies on the genetics of isozymes can assist in determining linkages for constructing the cassava genetic map. Some 300 progenies from 11 crosses have been analyzed to determine the EST-1 locus, the fastest cationic bands of this isozyme. Results indicate that the EST-1 locus comprises 5 multiple alleles, including one null allele (Ao, A1, A2, A3, A4). There are 11 observable phenotypes and 5 nonobservable null alleles. This locus behaves as a monomer and its inheritance pattern is compatible with a diploid model.

5.1.2 DNA fingerprinting

In contrast to other methods, DNA fingerprinting covers the genome extensively, detects variation in coding and noncoding regions of the genome, and is insensitive to developmental and environmental variations. In a collaborative project with IBPGR, the BRU has been developing DNA-based techniques for analyzing the genetic diversity of *Manihot*. Techniques for DNA extraction and for constructing a genomic library have been implemented using the var. M Col 22. DNA was digested with each one of the restriction enzymes (Pst I, Eco RI, Bam HI, Xba I and Hind III), then ligated into pUC 19 and the constructs transformed into *Echerichia coli* DH5a; insert size ranged from 0.2-7 Kb.

DNA, isolated from var. M Col 22, M Col 1505 and CM 507-35, was digested with the enzymes Apa I, Bam HI, Dra I, Eco RI, Eco RV, Hae III, Hind III, Hinf I, Hpa I, MspI, Pst I, Taq I and Xba I. It was found that methylation-sensitive enzymes such as Apa I and Pst I cut cassava DNA very ineffectively. Polymorphisms were detected with several clones; one Hind III clone was able to discriminate among the 3 var.

Other probes have also been used for detecting polymorphism in cassava. The human minisatellite probe (Jeffrey's probe) resulted ineffective in detecting polymorphism; however, the phage M13 probe and several random amplified polymorphic DNA markers (RAPD) yielded sufficiently variable band patterns to differentiate the varieties tested (Fig. 5.1B & C). These probes are being tested for morphological and isoenzymatic analysis of similar varieties and clones that have been in in vitro storage for over 10 yr.

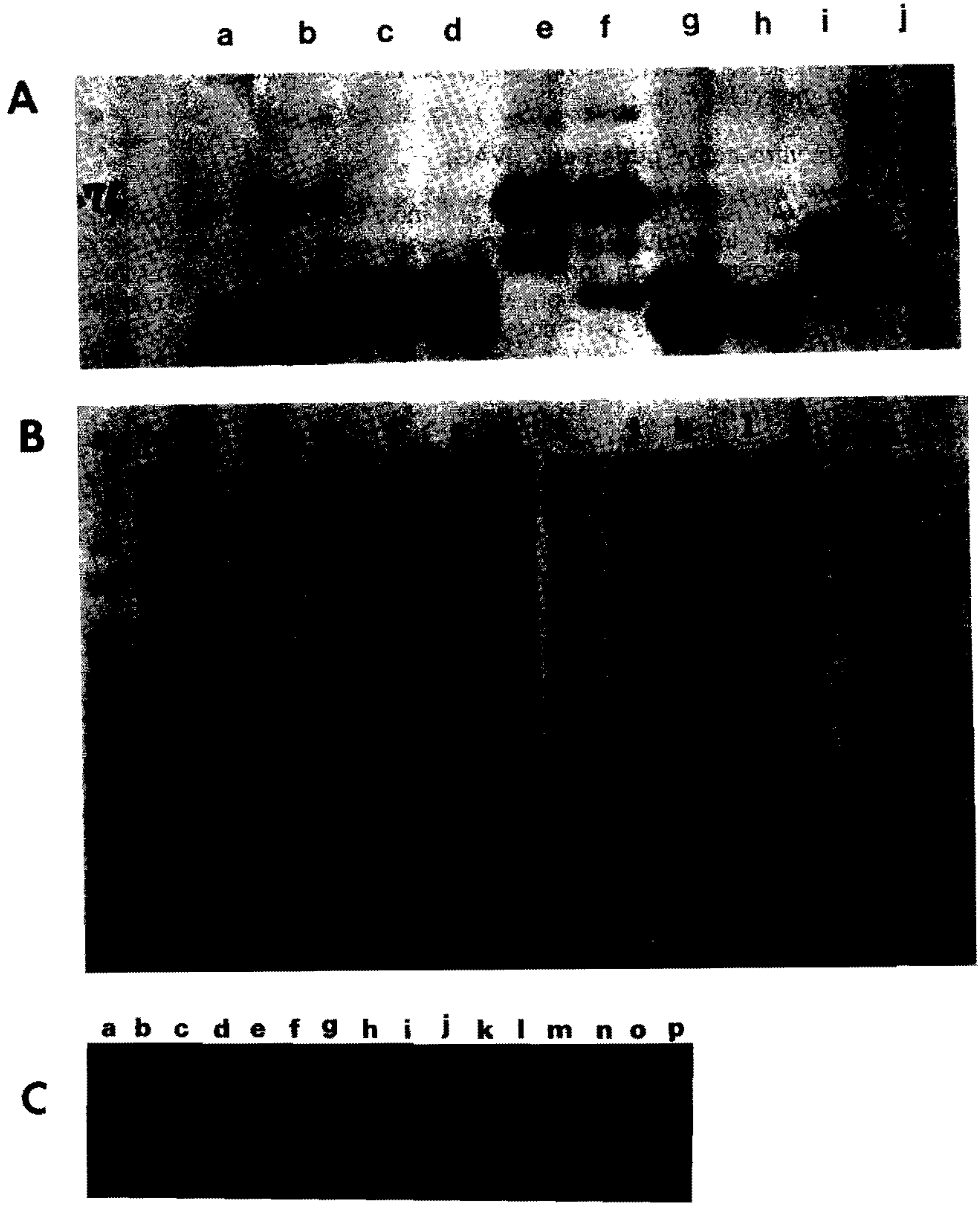


Figure 5.1. Molecular fingerprinting of cassava var.: (A) EST isozyme fingerprints of 10 varieties (a-j); (B) M13 probe DNA fingerprints of 15 var. (a-o); and (C) RAPD fingerprints of 16 var. (a-p).

Genotyping of cassava by isozyme and DNA fingerprinting techniques will be useful in assessing genetic variability, defining gene pools and contributing to the construction of the cassava molecular map.

5.1.3 The in vitro active gene bank (IVAG)

The cassava IVAG is probably the largest and most complete in vitro collection for any crop in the world. In the IVAG, plantlet cultures derived from meristem tip culture are available for micropropagation and distribution at any time. IVAG conditions are: 22-24°C, 1000 lx illumination and 12-h photoperiod; the subculture period can be extended to 15-18 mo. Up to 1989 the IVAG comprised over 4300 clones in a 6x7 m room. The estimated operating cost of the CIAT cassava IVAG is US$30,000/yr, which covers the salaries of five technicians, reagents and other consumable items.

Given the experience acquired on in vitro conservation at CIAT, a collaborative pilot project with IBPGR was undertaken from 1987-89. The objective of the project was to evaluate critical technical and logistical aspects of establishing and running an IVAG, using cassava as a model. The Pilot-IVAG project has provided valuable information on procedures for:

- Entry of material to storage from the field, in vitro exchanges, including pathogen tests, no. of samples/accession

- Monitoring cultures (viability and stability) and facilities for in vitro conservation

- Managing data including passport, fingerprinting, pathogen tests, subculturing, and distribution of cultures

5.1.4 Cryopreservation of shoot tips

Cryopreservation provides a means to the long-term storage of cassava clones, seed and pollen. With the collaboration of the IBPGR, which provided support for a postdoctoral fellow and technical aid, research was conducted on cassava cryopreservation from 1988-90.

Given the impossibility of reproducing previous cryopreservation reports, it was decided to use seeds as specimens for freezing experiments. In 1989, 90-100% seed germination was obtained after rapid immersion of whole seeds into liquid N. Thawing had to be slow to prevent seed shattering. In 1988 very few shoot tips survived cryopreservation, but in 1989 shoot tips consistently survived freezing to -25 to -35°C. Only toward the end of 1990 was it possible to obtain an avg of 70% shoot-tip survival and 20% plant formation from cryopreserved shoot tips in liquid N (-196°C).

The BRU's strategy was to develop first a protocol with var. M Col 22 and then test the system with other cassava genotypes. Every single step of the process was studied, paying special attention to conditions that can prevent or minimize growth of ice crystals within the tissue, such as composition of the culture medium and the kind and amount of cryoprotectant used prior to freezing. Use of sorbitol, sucrose and dimethyl sulfoxide (DMSO) in the preculture medium, and the elimination of water from the surface of the explants contributed to increase tissue survival to 90% and shoot formation to 50% (Fig. 5.2A).

The use of small shoot tips and purified cryoprotector increased shoot formation. Interestingly, direct immersion into liquid N gave both a higher recovery rate and higher shoot formation than slow freezing (Table 5.2).

The cryopreservation response of 14 cassava genotypes, with M Col 22 as a check, was tested. Viability and shoot formation varied from 4-80% and 0-50%, resp. Work in 1991 focused on improving the preculture, cryoprotection and after-freezing culture conditions. The BRU has significantly increased the response of low-responding genotypes and obtained shoot formation from nonresponding ones. It seems that genotypic differences in response are not due to the actual freezing step, but to the culture conditions prior and after freezing. Recently, the Unit also succeeded in the cryopreservation of cassava pollen. This concerted effort should lead to the development of a cassava base gene bank.

5.2 Crop Productivity Research

5.2.1 Tissue culture for producing clean planting material

Significant increases in yield have been reported as a consequence of eliminating viruses from cassava varieties. The technique consists in the culture of 0.1-0.2 mm meristem tips from terminal buds grown on stakes at 40-42°C and 35°C day/night for 3-4 wk. Indexing by cassava virologists has confirmed the elimination of FSD, CCMV, CsXV and latent viruses.

International germplasm exchange has been facilitated by the use of pathogen-tested material. Up to 1989, nearly 2000 clones were introduced to CIAT from 13 countries in the form of in vitro cultures, and CIAT distributed many pathogen-tested clones in vitro to 35 countries.

At Guangzhon, China, CIAT clone CM 321-188, selected and named "Nan-Zhi 188," has been propagated massively using in vitro techniques and the planting material distributed to 15 sites. Similarly, national agricultural programs in Panama, Venezuela, Mexico, Peru and the Philippines have advanced cassava micropropagation to the field-testing stage.

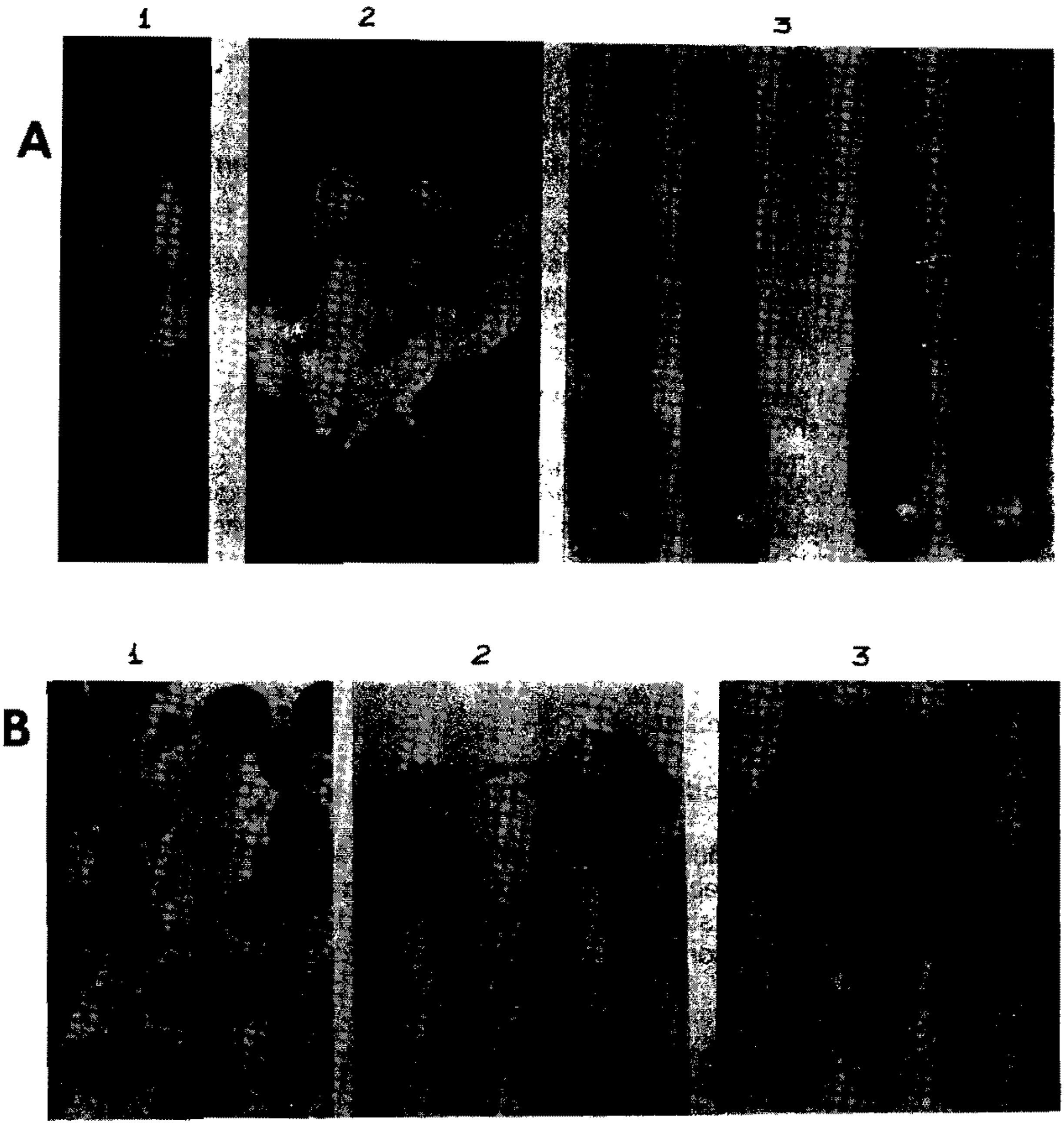


Figure 5.2. (A) Cryopreservation of cassava shoot tips: (1) shoot tip retrieved from liquid N (-196°C), (2) growth after 1 wk in post-freezing medium, and (3) plantlets from frozen shoot tips after 1 mo; and (B) toward a haploid method in cassava: (1) isolated tetrad-stage microspores (arrow), (2) mitosis in tetrad microspores (arrow), and (3) microcallus from microspore.

Table 5.2. Effect of shoot-tip size, cryoprotection and freezing rate on viability and shoot formation after freezing in liquid N (var. M Col 22).

Treatment	Avg Values (%)[1]	
	Viability	Shoots
Shoot tip size		
small (0.5-1 mm)	71A	57A
large (2-3 mm)	14B	0B
Cryoprotection		
sterile DMSO (ampules)[2]	90A	44A
standard DMSO[2]	83AB	33A
without cryoprotection[2]	60B	11B
cryoseeds	67AB	0B
Freezing rate[3]		
fast	86A	57A
slow	68B	29B

1 Avgs with the same letter are not significantly different at 0.05 level.
2 Shoot tips were dried prior to freezing.
3 Fast = direct immersion in liquid N;
Slow = 0.5°C/min.

5.2.2 Toward a haploid method: culture of immature pollen

Haploids and double haploids will be of significant value to cassava as a research tool with various applications in genetics, evolution, expression of important recessive genes and a breeding system for TCS.

Initially, background research was conducted on the reproductive behavior of cassava, including in situ and in vitro pollen germination, pollen tube growth, and isolation and culture of young zygotic embryos. The microsprogenesis of cassava was also characterized, and macroscopic parameters have been defined that correlate with critical microspore developmental stages.

The in vitro culture of whole anthers has led only to the formation of callus; therefore in the last year, the emphasis has been on devising a technique for culturing isolated immature pollen. The technique utilizes some 50 flowers; i.e., 50,000 microspores in hanging droplets, per petri dish.

Immature pollen at the mitosis stage did not divide in culture as expected; rather it rapidly formed exine components that rendered it impermeable to medium components. Thus work has shifted to the culture of microspores at the tetrad stage (Fig. 5.2B). Optimal culture density was 10^5 microspores/ml medium. Tetrad-stage microspores cultured in high osmotic concentration and then transferred to a medium with a lower osmotic concentration were able to divide mitotically and gradually pushed their way out of the tetrad callose. Outside, the tetrad division continued, but at a slow rate. Microcalli then become visible (Fig. 5.2B). Microspores, isolated from highly fertile varieties responded better than those from highly sterile ones.

In summary, it has been possible to change the gametophytic fate of cassava microspores to initiate sporophytic development. This is the first necessary step toward androgenetic development. Future activities will focus on enhancing callus induction from tetrad microspores and monitoring this development cytologically.

5.2.3 Genetic transformation

A basic requisite for genetic transformation is the ability to regenerate plants from cell culture. The regeneration of cassava plants by somatic embryogenesis on immature leaves or apical meristems was demonstrated earlier (Fig. 5.3B).

Development of genetic transformation requires the availability of:

- A genetic construct containing appropriate selectable and/or reporter markers, a housekeeping or tissue-specific promoter

- A transfer vector or the technology for direct DNA transfer

- An efficient plant regeneration protocol

- Technology to monitor the transcriptional and posttranslational products of gene expression and the inheritance of the introduced gene

5.2.3.1 <u>Agrobacterium-mediated genetic transformation</u>.

- Because the efficiency of *Agrobacterium* infection of plant tissues is genotypic dependant, 4 cassava var. (M Col 22, M Col 1505, M Mex 55 & M Cub 74) were first screened with 25 *A. tumefaciens* strains. M Col 1505, which also regenerates well through somatic embryogenesis, resulted highly susceptible to strains 1182, 1183, C58C, B6S3 and EHA 101.

- The plasmid construction pGV 1040, provided by Plant Genetics System (PGS), Belgium was used. It contains two selectable markers (bar gene & NIPTII gene) and one reporter gene (gus A), which are driven by strong promoters (NOS & CMVS 35).

- Even at the lowest X-glu concentration (Jefferson's method), cassava somatic embryos produced endogenous GUS (ß-glucuronidase) activity, which did not occur in leaves and stems. Using Kosugi's technique, somatic embryos were still GUS + with 2x and

3x X-glu concentrations; but endogenous GUS activity was not detectable at the lowest X-glu concentration.

- Leaves and stems were much more susceptible (8 mg/lt) than somatic embryos (32 mg/lt) to the product of the bar gene (herbicide BASTA = phosphinothricin).

- The antibiotic Kanamycin resulted highly detrimental to somatic embryogenesis.

The conditions for efficient *A. tumefaciens* infection of M Col 1505 will now be defined in order to initiate work on transformation and regeneration. Both single vector strains as well as the binary vector approach will be used.

5.2.3.2 Genetic transformation by particle bombardment. The particle gun available in the BRU accelerates DNA-coated metallic microproyectiles to high speed in such a way that they can penetrate cell walls, thus being a vehicle for transformation with foreign DNA.

- Transient GUS activity was demonstrated in cassava tissues 3 days after bombardment.

- The vacuum for effective particle acceleration with minimum cell damage was < 550 mm Hg, and the distance of the specimen to the gun, 22 cm.

- Freshly prepared plasmid DNA solution produced stronger GUS transient expression on cassava tissue.

- Recently GUS expression was obtained on the tips of somatic embryos 3 days after bombarding embryogenic callus at the globular stage (Fig. 5.3A).

Work continues on increasing the frequency and intensity of GUS expression on somatic embryos. This work should lead to experiments on stable genetic transformation of somatic embryos using herbicide resistance as a selection factor.

5.2.4 Molecular mapping

With the support of the Rockefeller Foundation (RF), a research project was begun to construct highly saturated molecular and physical maps of cassava using random genomic, cDNA and YAC libraries. The project involves cooperation among the U. of Georgia, Washington U., IITA and CIAT.

The maps will be useful for analyzing the genomic structure of cassava and its wild relatives and for tagging agronomically important traits, simply and quantitatively inherited. Eventually the map will be useful to isolate and clone cassava genes.

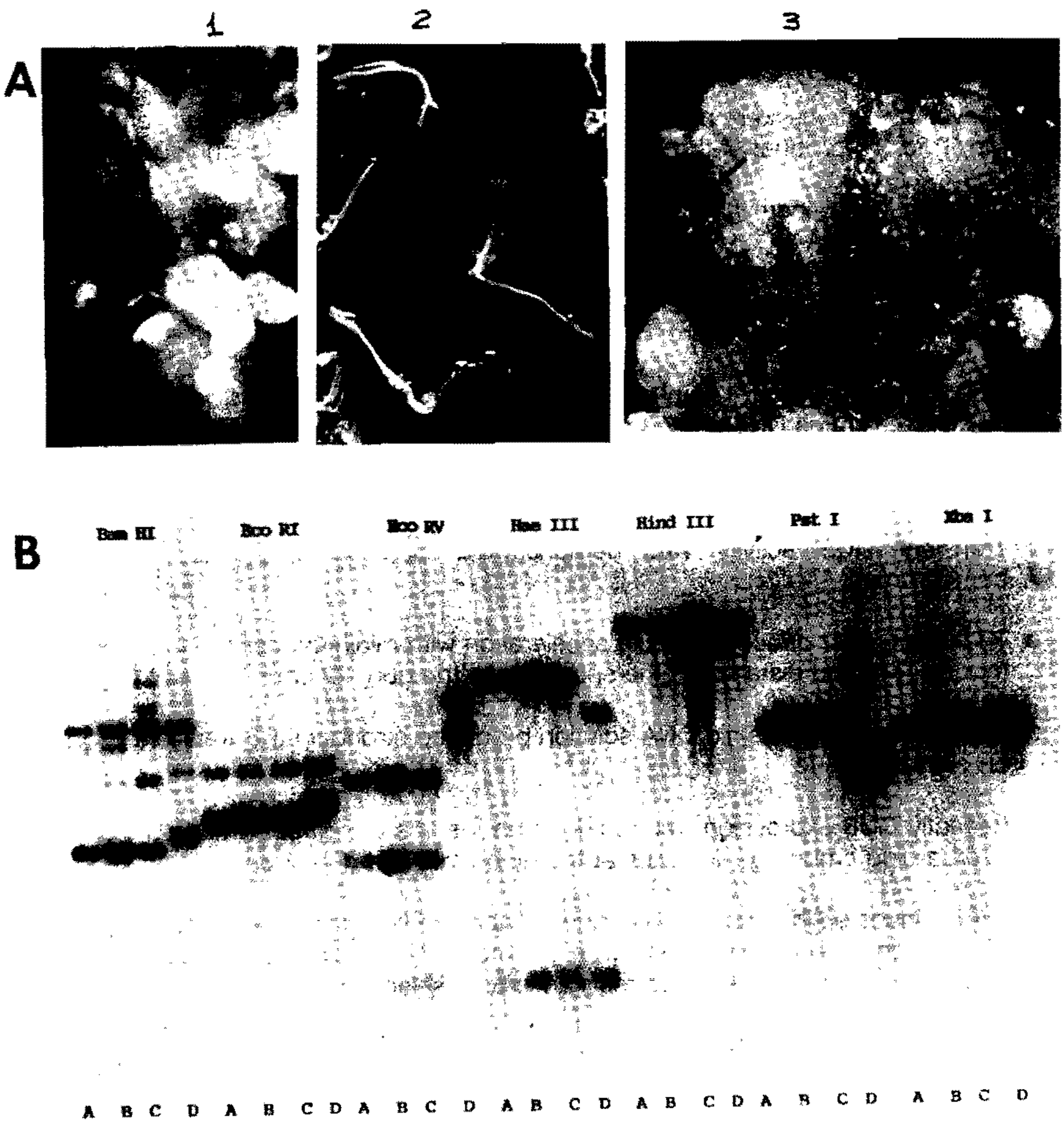


Figure 5.3. (A) Genetic transformation of cassava somatic embryos: (1) somatic embryos induced on meristem tips; (2) plantlets regenerated through somatic embryogenesis; (3) transient GUS expression on globular somatic embryos (arrow); and (B) restriction fragment length polymorphism (RFLP) with 7 restriction enzymes between A = M Thai 8, B = M Col 1505, C = M Nig 5 and D = *M. aesculifolia*. Note polymorphisms only with *M. aesculifolia*.

The project has built upon the experience gained at CIAT in the last year. Thus protocols for DNA extraction, digestion and hybridization have been implemented. A Pst I random genomic library was generated using var. M Col 22. Some 200 single-copy clones of a total of 500 have been characterized; insert size ranges from 0.2 to 3 Kb.

Recent developments in this project include:

- Cassava DNA digested with Eco RI, Eco RV, Xba I and Hind III libraries provide probes with highest polymorphisms.

- Polymorphism between var. M Col 22 and its wild relative *M. aesculifolia* was dramatically higher than the polymorphism found between two cultivated genotypes (Table 5.3, Fig. 5.3B). Four cutter restriction enzymes displayed less frequency of polymorphism then six cutter enzymes for cultivated genotypes.

- Polymorphism displayed by Dra I was extremely low, indicating that regions rich in adenine and thymine may not be spots for mutations in cassava.

5.2.5 Starch quality and CO_2 assimilation

- Cassava sour starch, obtained by natural fermentation, presents quality fluctuations that relate to the fermentation process itself. Previous research in Cassava Utilization described the fermentation mechanisms and the role of the microorganisms involved.

  Because the main substrate for these microorganisms is starch, amylolitic activities must play a central role. A methodology is needed to determine and differentiate the enzymatic systems of the microbial activity and to measure the production of excreted enzymes.

Table 5.3. Degree of polymorphism detected with at least one restriction enzyme[1] using five random genomic libraries as source of probes.

Library	M Col 22 vs. M Col 1505	*M. aesculifolia* vs. M Col 1505
Pst I	60%	85%
Xba I	60	85
Hind III	55	95
Eco RI	40	60
Bam HI	30	45

[1] Best restriction enzymes, in order of polymorphism, are: Eco RV, Xba I, Eco RI, Hind III.

In collaboration with the Cassava Program, an electrophoretic methodology was developed to determine amylolitic activities. The method will be useful for selecting and characterizing amylolitic microorganisms by their respective electrophoretic patterns. These patterns in turn will make it possible to monitor the development of the amylolitic activities throughout the fermentation process. The causes for quality fluctuations will be identified and strategies for improving the microorganism activities through genetic manipulation will be proposed.

- Certain cassava photosynthetic parameters lie between C3 (e.g., bean) and C4 (e.g., maize) plants. This suggests that cassava might have developed mechanisms for efficient photosynthesis, especially under drought and high temp conditions. Early work at CIAT has shown enzymatic indications of this behavior, for which there is a wide range of genotypic variability. Now, it remains to be established what are the actual mechanisms underlying these characteristics. The final objective is to use this knowledge for developing screening methodologies that can be incorporated into breeding programs.

  One approach that is being initiated is to develop in situ hybridization techniques on leaf tissue using photosynthetic gene probes to assess their compartmentalization patterns. Homologous genes from cassava have to be used; therefore, these genes must first be isolated from cassava gene libraries using heterologous probes from maize (provided by Yale U.). The genomic library is being constructed. High homology has been observed between the maize genes and cassava total DNA, which indicates that these genes are highly conserved, thereby facilitating the task of isolating the cassava genes. The genes being working are: RUBISCO (rbcs), malate dehydrogenase (mdh), malic enzyme (me) and PEP-carboxylase (ppc). Another target would be the glycine carboxylase, an enzyme involved in CO_2 recycling--a mechanism that may be related to cassava's C3-C4 behavior.

5.3 Institution Building

5.3.1 Training/biotechnology issues

Over the last four years 40 people from developing countries have participated in various training activities in cassava biotechnology.

As a result of the training and follow-up activities, tissue culture facilities for cassava micropropagation have been implemented in China, the Philippines, Panama, Venezuela, Cuba, Peru, Brazil and Mexico. National agricultural research institutions such as CNPMF in Bahia (Brazil) have also requested and received training on cassava isozyme fingerprinting.

In 1990-91 CIAT developed its Biosafety Guidelines and established the Institutional Biosafety Committee (IBC). The guidelines comprise peer-approved norms for the adequate and safe handling of R-DNA research in the lab and the testing of genetically engineered organisms in the greenhouse and the field.

5.3.2 The cassava biotechnology network (CBN)

With the collaboration of IITA and many national and international organizations interested in cassava, the CBN was founded in a workshop held at CIAT in September 1988. The objective of the CBN is to facilitate the implementation of modern biological approaches and tools to contribute to the solution of priority problems in cassava production and utilization that are recalcitrant to traditional methodologies.

The CBN will facilitate:

- The organization of meetings on cassava biotechnology and more basic research
- Effective mechanisms for developing country access to genetic resources, genetic constructs, technologies and information
- Participation of developing country scientists in biotech training activities
- Discussion and actions on critical issues such as biosafety and intellectual property protection

The network approach to cassava biotechnology has received wide acceptance by the scientific community and national and international funding agencies. Since its foundation, the number of projects funded has steadily increased; currently 22 projects dealing with research constraints and technical bottlenecks in cassava are under way (Table 5.4).

The CBN Steering Committee (SC), elected at the founding meeting at CIAT, has met twice. Because of the interest demonstrated by the Dutch Govt. in biotech developments (particularly in cassava) for developing countries, the SC recommended approaching the DGIS, Ministry of Foreign Affairs, the Netherlands with a proposal for funding the activities of the CBN for five years.

The proposal seeks financial support for:

- A full-time coordinator/scientist
- Organization of scientific network meetings every 2 yr and ad hoc SC meetings
- Training of developing country scientists
- Bridging funds for critical research areas requiring attention
- Newsletter and brochure for the network

Table 5.4. Research projects under way in cassava biotechnology in developed and developing country institutions (October 1991).

Subject	Institutions	Funding
Cyanogenesis	U. of Newcastle Upon Tyne	RF/EC/ODA
	Royal Vet.Agric.U., Copenhagen	RF/EC
	Mahidol U., Bangkok	RF/EC
	Ohio State U. Colombus	USAID
	Free U., Amsterdam	
Virus resistance	Washington U., St. Louis	ORSTOM/RF/USAID
Insect resistance	Washington State U., Pullman	RF
Photosynthesis	Australian Nat. U., Canberra	AIDAB
	U. of Georgia, Athens	USAID
Plant regeneration	U. Paris, Orsay	EC
	U. of Bath	ODA
	U. of Zimbabwe, Harare	
	CIAT	Core
	South China Inst. Botany, Guangzhou	RF
Genetic transformation	U. Nottingham	RF
	U. of Guelph, Canada	RF
	CENARGEN, Brazil	
	CIAT	Core
Radiation induction	IAEC, Vienna	Core
DNA fingerprinting	Washington U., St. Louis	RF
	CIAT/IITA	RF
Molecular mapping	U. of Georgia, Athens	RF
	CIAT	RF
Cryopreservation	CIAT	Core
Other activities at CIAT & IITA		Core

The Dutch Govt. has reacted very favorably to the proposal, and the profile of the CBN Coordinator is currently being discussed with the DGIS prior to advertising the position worldwide.

6. PATHOLOGY

Early work on cassava pathology dealt with the etiology of cassava pathogens and identification of epidemiological features for disease severity. This led to an understanding of the strong interaction between cassava and the bioconstraints and edaphoclimatic factors characteristic of each cassava-growing area. Consequently, research of the Pathology Section centered on defined ECZs, and research priorities were set according to economic losses caused by diseases in each ECZ. This report summarizes research carried out over the last 5 yr, including production recommendations found appropriate for controlling important cassava diseases causing epiphytotics in the target areas. Etiologic and epidemiological studies on previously unreported pathogens and diseases are also presented. Research on novel biological control strategies is presented, envisaging practical applications. The existence of unknown endophytes, potentially dangerous to cassava, was demonstrated. A system for the effective storage of cassava stakes was also designed to solve problems of establishment and production in those areas where this agronomic practice is necessary. A new method for interchanging virus-indexed vegetative planting material of cassava was developed to assure establishment of introduced genotypes. By extrapolating data on epidemiology, surveys and climatology, the geographical distribution and areas of potential risks are also presented for the six most important diseases of cassava in Latin America. This information will assist scientists in planning research projects or quarantine regulations.

6.1 Etiological Studies

6.1.1 Unreported pathogens of cassava

The following two fungal species were found inducing severe stem and root rots in several cassava plantations of Colombia and Brazil: *Scytalidium* sp. and *Verticillium dahliae*.

6.1.1.1 *Scytalidium* sp. Damage induced by this pathogen appears at the onset of the rainy seasons. It commonly appears in association with *Diplodia manihotis*. It has caused losses of up to 85% RY in the state of Paraiba (NE Brazil) and on the North Coast of Colombia.

The pathogen affects stems showing black necrosis of vascular strands and disease symptoms similar to those induced by *D. manihotis*. Symptoms differ in that there is no pycniocarp formation on the bark of stems and roots. The epidermis of *Scytalidium*-affected stems swells and breaks longitudinally, releasing a mass of charcoal-like blackish conidia, which are easily disseminated.

Colonies on potato-dextrose-agar (PDA) are effuse, dark blackish-brown; mycelia, immersed and superficial; hyphae, smooth with dark brown septa. They do not produce stroma; conidiophores are micro- or mononematous, branched. Conidiogenous cells fragment and form arthroconidia. Conidia, which are catenate, simple and smooth, are of two kinds: colorless, thin-walled and medium or dark brown, thick-walled.

6.1.1.2 *Verticillium dahliae*. This fungus, commonly found at the onset of the dry season, is also able to affect both the stems and roots of young or old plants, inducing black necrosis along vascular strands where it produces black microsclerotia. Affected plants suddenly wilt and die. The cortex of the swollen roots shows necrotic spots similar to those of the "smallpox" disease, but without signs of insect or wound damage on the epidermial and cortical tissues surrounding the spots. The fungus penetrates the stem or root peduncles through wounds induced by environmental stresses, insects or physical/mechanical damage.

The fungus grows well on PDA and lima bean-agar (LBA). The optimum temp for growing and spore production is 26°C. Hyphae are hyaline, whitish to cream after 1 wk, later turning black upon the formation of microsclerotia. Conidiophores are abundant, erect, hyaline, verticillately branched. Phialides are variable in size; conidia, which arise singly, are subcylindrical, hyaline, mainly simple but occasionally 1-septate. Dark brown resting mycelia form only in association with microsclerotia, each of which arises from a single hypha by repeated budding. They range in size and shape from elongate to irregularly spherical.

6.1.2 Taxonomic investigations

Several *Phytophthora* and *Fusarium* species have been reported in the literature inducing root rots on cassava, but their characterization is confusing. Taxonomic and pathogenic studies with isolates of *Phytophthora* and *Fusarium* species collected in different cassava-growing areas have thus far shown that the following species are true pathogens of cassava:

6.1.2.1 *Phytophthora erythroseptica*, *P. cryptogea*, *P. drechsleri* and *P. nicotianae* var. *nicotianae*. Of these species the last two are widely distributed (especially in Brazil, Colombia and Mexico), inducing severe damage in endemic regions. The other two species have been found sporadically affecting cassava in Africa and India, but are not considered of importance in the Americas. These species can be differentiated by structure, optimum growth temp and fungicide sensitivity. Symptomatologically, their differentiation is difficult as symptoms are quite similar.

6.1.2.2 *Fusarium solani* and *F. oxysporum* were identified as true cassava pathogens able to affect both the stem and roots. They can be differentiated morphologically as well as for certain cultural characteristics: optimum growth for *F. solani* is obtained on PDA under light; for *F. oxysporum,* in darkness. For better spore production, the former should be grown on acid media (pH = 3-4); the latter on alkaline media (ca. 8.0). Growth of both species was slightly affected by both glucose and cassimine acid in Park media.

6.2 Epidemiological Studies

6.2.1 Mycorrhiza-Phytophthora relationships

The controversial interaction between vesicular-arbuscular mycorrhizal (VAM) fungi and soil-borne pathogens affecting a given host was investigated by using the VAM species *Glomus manihotis* and *Entrophospora colombiana*, and the pathogen *P. nicotianae* var. *nicotianae* (*P.n.* var. *nicotianae*) to inoculate cassava plants under controlled conditions. Only *G. manihotis* had a beneficial effect on root/shoot ratio (dry wt), fine roots and swollen root initials, and leaf weights, compared to the nonmycorrhizal controls. VAM infection showed a protective effect against *Phytophthora*; protected plants showed only slight damage levels as compared with *P. n.* var. *nicotianae*-inoculated plants.

6.2.2 Flooding-Phytophthora relationships

Studies on hydroponic plantings of several cassava clones showed the following:

- Tolerance of cassava to flooding is due to the quick formation of a secondary root system on the upper, unflooded base of the stem; tolerance to *P. n.* var *nicotianae* appears to be due to inhibitory biochemical effects on the pathogen in the root system as well as the ability to form a secondary root system, after roots have rotted. These two mechanisms appear to be independent.

- None of the clones evaluated showed simultaneous tolerance to both flooding and *P. n.* var. *nicotianae*.

- The effect of *P. n.* var. *nicotianae* infection was additive to the effect of flooding: plantings on pathogen-infested soils will possibly show severer root rots after flooding.

Based on the foregoing it is concluded that programs aimed to overcome the two problems should direct research to (a) improving genetic resistance to *Phytophthora* spp., and (b) preventing flooding, either by using improved cultural practices (planting on ridges, improving drainage; timing planting to escape heavy rainy periods; etc.) or by selecting for early-maturing genotypes, which can be harvested before flooding.

6.3 Witches' Broom (WB) Disease

In 1985, a severe outbreak of a WB-like disease on cassava was reported affecting 4000 ha in 8 municipalities of the Ibiapaba Sierra (states of Piaui and Ceará, Brazil). A 1987 survey indicated that losses were up to 95%, with an avg of 40% of the total root production of cassava in the affected area. In 1986 research was initiated in cooperation with the Ceará Department of Agriculture, the CNPMF of EMBRAPA and the CIAT VRU. Thus far the following results have been obtained:

- Ultra-thin sections under electron microscopy revealed pleomorphic membrane-bound bodies (characteristic of mycoplasmlike organisms, MLO) in vascular strands of diseased plants.

- Dissemination through the use of infected stakes taken from diseased plants was 100%; when diseased scions were grafted onto healthy stakes, disease transmission 3 mo after grafting was 100% and 60%, or vice versa. No motile vector was found; but the existence of field-resistant clones and the high percent of affected plants found 6 mo after planting stakes from symptomless plants of susceptible clones appear to indicate that this means of pathogen-dissemination occurs; the disease was also transmitted at very low rates (0.03%) by using infected machetes.

- When stakes are taken from a 25% affected plantation, losses induced by WB averaged 51% (range 23.5 to 80.1%, depending upon the level of infection of the mother plants). This indicates that WB-induced losses are related to the rate of infection of the mother plants.

- WB incidence was reduced drastically by planting selected stakes from symptomless plants, but percent disease reduction was related to the percentage of infection in plots from where mother plants were taken (Table 6.1). Thus the disease was controlled by selecting stakes from symptomless plants from moderately affected plantations in the endemic area.

- Percent remission of symptoms induced by the WB pathogen was reduced after planting stakes from infected plantations in a nonendemic neighboring area (Table 6.2). Thus the disease can also be controlled by planting selected stakes from affected plots in areas where ecological conditions restrict pathogen multiplication and invasion into the host.

Table 6.1. Reduction of WB symptoms over two cycles by planting selected stakes from visually symptomless plants.

		Disease Symptom Reduction (%)[1]		
% Infection	Total No. of	Cycle 1		
Source Pl	Evaluated Pl	6 Mo	12 Mo	Cycle 2
95	52	51.9	22.0	87.7
50	400	94.1	75.5	88.0
25	600	97.9	87.5	92.9
0	500	100.0	100.0	100.0

[1] Evaluation was at the peak of the epidemic in each cycle.

Table 6.2. Remission of WB symptoms and RY (t/ha) by planting infected stakes in a location with environmental conditions unfavorable for disease development.

	Symptom Expression (%) and RY (in parentheses) at Favorable Location	Symptom Expression (%) and RY (in parentheses) at Unfavorable Location	Symptom Expression (%) and RY (in parentheses) Back at Favorable Location
Clone	First Cycle	Second Cycle	Third Cycle
Cruvela Rastreira	93.3 (4.3)[1]	0 (8.4)	4.5 (10.0)
Cruvela Vicosae	27.4 (6.3)	0 (8.5)	10.0 (7.8)

[1] Avg data taken from more than 120 pl/treatment.

- A project to evaluate resistance to WB was initiated in 1990 with the introduction of 259 clones from the CNPMF and the states of Ceará and Pernambuco to Guaraciaba, a WB-endemic area in the Sierra de Ibiapava (Ceará). Results thus far have shown differences in symptom expression and reaction to WB, both of which were clonal related. However, the most striking results are related to: (a) existence of WB-resistant clones (at least 10 clones are highly resistant); and (b) identification of a group of field-resistant clones, which were susceptible to grafting and mechanical transmission, but showed a high rate of field resistance during three growing cycles; they are probably resistant to an unknown motile vector.

The following production system was defined for WB-endemic areas:

- Planting material (stakes) must be selected from field-resistant, symptomless 12- to 14-mo-old plants (because of cool temp the growing cycle of cassava is ca. 14 mo). Stakes should be 15 to 20 cm long and treated with maneb (3 g/lt) by dipping for 10 min before planting.

- Machetes and tools used during stake preparation and shipping should be disinfested by cleaning them with rags soaked in 2% Na-hypochloride solution.

- Cassava debris from previous plantings should be burned before planting new selected stakes to eliminate volunteer plants from affected stock.

- Suspected diseased plants as well as volunteer plants from previous plantings should be rogued. To facilitate disease identification, weekly inspections of plantations are recommended.

This production system and a description of disease symptoms were published as a pamphlet that has been distributed to farmers by extension agents and community leaders. Several demonstration plots have also been planted for field days. As a result disease incidence has been reduced and RY increases are starting to be shown in several locations of the area; for example, RY increases obtained by 4 growers who followed the recommendations and took selected material from a 25%-affected plantation averaged 51% (range 23.5 to 87.1%) (Table 6.3).

In addition to the above the following projects are in progress:

- A program has been implemented to produce planting material on a commercial scale in areas where ecological conditions restrict pathogen multiplication and invasion. Material will be distributed to growers during the 1992 planting season (Jan./Feb.).

- In cooperation with the Plant Science Institute (Microbiology and Plant Pathology Laboratory), the BRU and VRU at CIAT MLO-cassava probes will be used to develop a program to provide MLO-free planting stocks, identify naturally infected hosts, insect vectors, and various epidemiological features related to this MLO.

6.4 Superelongation Disease

Studies on genetic control of SED of cassava (caused by *Elsinõe brasiliensis*) covered the following areas:

6.4.1 F1 morphological resistance

Histological studies on 3-mo-old shoots of resistant (CM 523-7 and M Ven 77) and susceptible (M Col 22 and M Col 113) clones grown at different light intensities showed that the thickness values of the external layers of the stems of resistant clones were

Table 6.3. RY increase obtained by 4 growers who used selected planting material taken from symptomless plants from a 25% WB-affected plantation, compared with RYs of neighboring plots where planting material was not selected[1].

Grower	Fresh RY (t/ha)[2]		RY increase
No.	Selected Stakes	Unselected Stakes	(%)
1	16.3	13.2	23.5
2	15.6	10.0	56.0
3	16.5	12.0	37.5
4	17.4	9.3	87.1
$\bar{X}$	16.5	11.0	51.0

1 Machetes and tools used were disinfested with Na-hypochlorite (2%); debris from previous planting was burned and suspected plants were rogued.
2 Data taken from 15 pl/4 reps/grower.

significantly (5%) greater than those of the susceptible clones when the plantlets were incubated at 20,600 to 24,000 lx. This ratio decreases at low light intensities; e.g., at 7,200 lx or lower, the thickness values decreased dramatically, differences between resistant and susceptible clones disappearing. Temp and RH had no effect on these parameters. Similarly, measurements on other stem tissues showed no significant differences between susceptible and resistant clones. Further evaluation of 30 clones whose susceptibility/ resistance values were previously known showed the same results. This opens up the possibility of devising a rapid screening system for resistance to *E. brasiliensis*, which can replace the current field screening evaluation system.

6.4.2 Field evaluation

To determine the most appropriate location for field evaluation of genotypes for resistance to SED, genotypes belonging to 17 families were planted in three locations where the disease is endemic: Carimagua and Villavicencio (Colombia), and Huimanguillo (Mexico). Disease scores were recorded at the height of the epidemic, and the probability for finding resistant clones among genotypes of each family per location was calculated according to Grizzle, Starmer and Koch (1969)[6.1]. At Carimagua disease severity was highest, reducing the probability of finding plants with low disease damage in each family (avg disease scores were also highest). Consequently, this location appears to be the most appropriate for evaluating resistance to SED in the field.

6.4.3 Stability analysis

Stability of resistance to SED and CBB was investigated by planting clones of three families over a 5-yr period. According to Digby's modified joint regression method:

- The general response of the clones to SED and CBB was unstable.
- Despite this instability, differences in levels of resistance between families and among genotypes belonging to the same family were identified.
- Disease pressure differed each year, justifying clonal evaluation for several growing cycles.
- The families that showed the most stability for resistance were CG 890 (CM 723-3 x M Col 638) and CM 3581 (CM 849-1 x CM 523-7). These parents have intermediate to high resistance to both SED and CBB.

[6.1] Grizzle, J.E., Starmer, C.F., and Koch, G.G. 1969. Analysis of categorical data by linear models. Biometrics 25:489-504.

6.5 Cultural Practices to Control CBB

6.5.1 Mixed cropping

The effect of mixed cropping cassava with maize was evaluated at Media Luna (North Coast of Colombia) by planting plots where two cassava rows alternated with two rows of maize. Severity of two foliar diseases (CBB and brown leaf spot, BLS) was significantly (0.05 level) less in mixed cropping than monocropped plots. RYs were also significantly higher (Table 6.4), and there was a positive effect of mixed cropping in controlling root rots. Reduction of both CBB severity and incidence by mixed cropping cassava with maize was evident in commercial farmers' fields: 30% CBB incidence vs. 85% for monocropping (highest rating = 4.0).

6.5.2 Pruning

This cultural practice (CIAT Annual Report 1972) was validated on several commercial cassava plantations on the North Coast of Colombia (Table 6.5): Both disease incidence and severity were much lower on pruned plantations. On mixed cropped cassava-maize plantations, however, CBB incidence and severity were much lower. Consequently, pruning most of the aboveground portion of infected plants and burning infected debris in severely infected plantations are effective means of slowing down the spread of the pathogen and decreasing inoculum potential; however, this should be done only at the end of the rainy season to prevent new reinfection through rainfall splash.

6.5.3 Effect of CBB-infected stakes on RY

Dissemination of the CBB pathogen by stakes and botanical seeds taken from affected plants has been demonstrated (CIAT Annual Reports 1972 & 1980), but quantification of the effect of using CBB-infected stakes for planting on RY was not investigated until 1987. When planting 25% CBB-infected stakes of a susceptible clone, losses in RY can be ca. 72%; from a 100%-affected plantation, 26% RY reduction in resistant clones, although much lower, can be of significant importance (Table 6.6). This shows the importance of using CBB-free stakes for planting as an important cultural practice for controlling CBB.

6.6 Root Rot Problems

Root rots are the most important pathological problems of cassava, especially in those areas where the crop is planted during successive cycles or in flooded areas, badly drained soils and/or during abnormally heavy rainy seasons. The most important root rot problems are induced by species of *Diplodia* (*D. manihotis*), *Scytalidium* (*Scytalidium* sp.), *Fusarium*, (*F. oxysporum* and *F. solani*) and *Phytophthora* (*P. drechsleri* and *P. nicotianae* var. *nicotianae*). Each species requires certain edaphoclimatic conditions, which restrict their incidence to specific ECZ. Consequently, research directed to

Table 6.4. Effect of cassava (M Col 2215)-maize mixed cropping on fresh RY (t/ha) and severity of CBB and BLS.

Planting System[1]	Fresh RY (t/ha)	Root Rot (%)	Disease Severity CBB[2]	BLS[2]
Cassava-maize mixed cropping	16.7a	2.3b	2.4b	2.3b
Cassava monoculture	9.6b	13.7a	3.7a	3.5a

[1] Avg data taken from 4 plots/treatment with 400 cassava plants mixed cropped every 2 rows with maize and 800 cassava plants under monoculture. Data between planting systems followed by different letters are significantly different at 0.05 levels (DMRT).

[2] Disease severity: CBB: 1 = leaf spots; 5 = plant death or dieback. BLS: combined data on affected leaf area and percent of affected leaves/pl.

Table 6.5. Incidence and severity of CBB on 5- to 6-mo-old commercial plantations with cassava monocropping (pruned or unpruned) and cassava-maize-mixed cropping in Mandinga (Bolívar, North Coast of Colombia).

Cropping System	CBB-Severity[1] Min.	Max.	Avg	Incidence[1] (%)
Cassava monocropping (unpruned)	2.0[2]	4.5	3.6	100
Cassava monocropping (pruned)[3]	1.0	2.5	1.6	50
Maize-cassava mixed cropping[4]	1.0	2.0	1.1	10

[1] Disease severity: 1 = angular leaf spots; 5 = plant dieback or death. Incidence: % infected plants in the whole plantation.
[2] Avg data taken from plantations ranging from 0.5 to 2.0 ha.
[3] Pruning: most cassava plants aboveground were cut, collected and burned. [4] Mixed cropping: alternate rows of cassava and maize.

Table 6.6. RY reduction due to the use of CBB-infected stakes for planting in a CBB-favorable location.

% CBB-Infected Stakes	Susceptible Clone RY[1] (t/ha)	RY Reduction (%)	Resistant Clone RY (t/ha)	RY Reduction (%)
0	28.9	-	25.3	-
25	20.4	29.4	22.6	9.6
50	15.8	45.3	23.4	7.5
75	17.9	38.1	19.5	22.9
100	8.1	72.0	18.7	26.1

[1] Data taken from 6 reps/treatment, 30 plants each.

controlling root rot problems of cassava is location specific and tends to integrate cultural, chemical (only for stake treatments), biological and varietal resistance control measures. The following is a summary of the research directed to control root rots in several regions of Latin America.

6.6.1 Media Luna (North Coast of Colombia)

The Media Luna region is characterized by sandy soils with low OM (0.3%) and nearly neutral pH (6.8). The land has been used intensively for several decades (mostly for cassava production) under a traditional system characterized by very limited inputs. As a result, soils have been depleted of nutrients and have a high accumulation of inoculum potential of *D. manihotis* and *F. oxysporum,* which reduces crop establishment and plant vigor, and causes severe root rots (ca. 40% of total production). These two pathogens survive by affecting alternate host species (*D. manihotis* = *Vigna unguiculata, Crotalaria espectabilis, Sesamum indicum, Zea mays* and *Mangifera indica; F. oxysporum* = *C. espectabilis, V. unguiculata, S. indicum),* volunteer cassava plants, cassava debris or by infesting the soils.

Initial RYs were relatively high (>20 t/ha according to farmers' information) but have decreased sharply during the last decade, (avg of only 3-4 t/ha in 1988). Research developed by different sections of the Cassava Program led to the definition of the following cassava production systems for Media Luna:

- Land should be left fallow if cassava has been cultivated for more than 4 consecutive cycles or when root rot is higher than 3%. Debris from weeds must be incorporated into the soil before planting cassava by plowing once and disking twice.

- Stakes should be taken from 10- to 12-mo-old plants of high-yielding, root rot-tolerant clones. Stakes must be 15-20 cm long (containing at least 5 nodes/stake), selected visually and treated for 20 min in a suspension of dimethoate (1 cc/lt), benomyl and captan (3 g/lt each) before planting.

- Plots should be sprayed after planting with diuron (1 kg/ha) and alachlor (1.5 lt/ha) as a preemergent weed control practice. After 2 to 3 mo weeds can be controlled manually during the growing cycle (11 mo) as required.

- Plots should be fertilized (15-15-15 NPK at 300 kg/ha) at a rate of 100 kg/ha at 30, 60 and 90 days after planting.

This production package was validated with great success during 1988-89 by 12 cassava growers and in 2 demonstration trials. They obtained a RY increase of 208% when they planted a resistant clone and 300% when the clone was susceptible. More than 30 cassava growers were successfully growing cassava following this package in 1989-90.

6.6.2 Varzea region of the Amazon

Cassava is being planted in two different regions of the Amazon: (a) coastal or unflooded area (terra firme) with extremely acid (pH 4.0) and infertile soils; (b) varzea, or the flooded basin edges of rivers with alluvial, fertile and nearly neutral pH soils. On the former cassava RYs are ca. 6 t/ha/yr; in the latter > 20 t/ha after 6 mo. In 1983 a severe root rot outbreak was reported in the varzea area, causing 60% losses on almost 84,000 ha of cassava. A collaborative research project with CPAA-Manaos (Centro de Pesquisa Agroforestal da Amazonia Occidental), the CNPMF and CIAT included research on control of the cassava root rot problem (induced by *P. drechsleri* and *F. solani)* through varietal resistance, cultural practices (crop rotation, mixed cropping, planting on ridges and selection of planting material) and chemical treatment of stakes. This led to the definition of the following cassava production package for the region:

- Infested land (>3% root rot in previous harvest) should be rotated with maize or rice during the dry season.

- Soils must be plowed once, disked twice, and then ridges (about 0.3 m high) constructed; drainage canals should be constructed or improved.

- Twenty-cm stakes from lignified stems of 10- to 12-mo-old plants of tolerant clones should be selected for absence of rot or mechanical injuries. Planting material should be produced in the coastal area.

- Selected stakes must be treated by dipping for 10 min in a suspension of fosetyl-Al 80% at a concentration of 2 g/lt.

Experimental results using this system and the cumulative effect on RY induced by each component of this system are presented in Table 6.7. This production system was officially released during a field day that CPAA/CNPMF-EMBRAPA/CIAT organized in September, 1990, and is being evaluated by more than 200 cassava growers in 10 municipalities. Three resistant clones have been identified after screening more than 286 clones over a 5-yr period.

6.6.3 CIAT HQ

The Palmira Station is characterized by clayey soils with high OM content. Planting cassava for more than 4 consecutive cycles decreases RYs sharply, and populations of *F. oxysporum*, *F. solani* and *P. nicotianae* var. *nicotianae* increase to levels of around 10^6 cfu/g of soil. Crop rotation for one year with any crop combination of sorghum, maize, beans and even fallow recovered RY to original levels and were 3.2 times higher than controls.

Table 6.7. Cumulative effect on RY of one tolerant and 15 susceptible clones of various cultural practices for controlling root rots induced by *P. drechsleri* and F. *solani* in the varzea region of the Amazon.

Cultural Practices	Tolerant Clone	Susceptible Clones[1]
Traditional planting	6.5	0.1
Rotation with maize or rice	16.0	5.0
Drainage and planting on ridges	22.5	6.0
Selection of stakes	24.5	5.5
Fosetyl-Al 80% (2g/lt) treatment of stakes	29.3	6.5
Integrated system	29.3	7.3

[1] Avg data for 15 susceptible clones.

6.6.4 North and Northeast Brazil

The North and NE regions of Brazil produce 63.4% of the 21.6 million t of cassava roots that are produced on 1.76 million ha. Of this production 85% is directly or indirectly used as staple food for more than 45 million people. A severe outbreak of cassava root rot in 1986 affected around 350,000 ha. Initial etiological studies revealed that the problem was induced by *F. solani, F. oxysporum, P. drechsleri, D. manihotis* and *Scytalidium* sp., which are located in different cassava-growing areas.

A collaborative project is being developed with the CNPMF and the following state agencies: CPAA-Manaos, CPATU-Pará (Centro de Pesquisa Agroforestal del Tropico Umedo), IPA-Pernambuco (Instituto de Pesquisa Agropecuária), EMEPA-Paraiba (Empresa Estadual de Pesquisa Agropecuária), EPEAL-Alagoas (Empresa de Pesquisa Agricola), ENDAGRO-Sergipe (Empresa de Desenvolvimento Agrícola, Rural e Operacional) and AMIDOGLUCOSE-Sergipe (a private enterprise). The primary objectives are to develop technological packages for controlling the problem in each geographic area, promote their use, interchange resistant genotypes, and build up collections of native varieties as sources of resistance.

Experimental plots have already been planted and project status is as follows:

- **North Brazil**

  - **CPATU-Pará**. Appropriate cultural practices for the region are being defined. Twelve root rot-resistant clones have been selected, 2 of which have shown high RY potential and carbohydrate content, and low HCN content. These will be released to growers in 1993.

- **CPAA-Amazonas.** A production package for the varzea region was defined and 2 root rot-resistant clones were released for the first time in 1990 (see p. 6.11); a new resistant clone will be released in 1992. The technological package for the litoral region is under definition, and a collection from the Amazon is building up, part of which is under evaluation in the litoral region.

■ **NE Brazil**

- **CNPMF-Bahia.** Etiological and epidemiological work is under way. F_1 hybrids from root rot resistant genotypes are being produced.

- **Indiaroba Farm-Sergipe (a private enterprise).** Twenty-five selected clones are being evaluated for earliness with the aim of avoiding the root rot problem in the region, which normally attacks the swollen roots 10 mo after planting.

- **ENDAGRO-Sergipe.** Eighty-five clones are being evaluated for root rot resistance. The technological package is under definition.

- **EPEAL-Alagoas.** Five root rot-resistant clones, selected from among 50 clones evaluated in 1986, are in advanced field trials. Two clones will be released in 1992.

- **IPA-Pernambuco.** Root rot-resistant clones from Manaos were highly resistant in this state, but show susceptibility to *Scytalidium* root rot and to adaptation. F_1 clones from root rot-resistant genotypes are being produced.

- **EMEPA-Paraiba.** A disease survey for the state, as well as evaluation trials, is under way.

6.7 Biological Control of Cassava Diseases

Beneficial fluorescent pseudomonads and strains of *Trichoderma harzianum* (commonly found in most cassava-growing areas of the Cauca Valley and neighboring hillside areas) have been used in the biological control of cassava diseases. Pseudomonads were used because of their nutritional diversity, ability to grow under a wide range of environmental conditions, and ability to colonize the rhizosphere of many plant species.

6.7.1 Fluorescent pseudomonads

6.7.1.1 Isolation and survival of beneficial bacteria. Strains of *Pseudomonas putida* and *P. fluorescens* were isolated from soil or the plant rhizosphere of different cassava clones by using King's B (KB) medium incubated at 27°C for 24-36 h. Bacterial isolates showing fluorescence on KB under ultraviolet light were purified from single colonies after serial dilutions seeded on KB medium. High bacterial populations were found in the rhizosphere of cassava plants or rooted shoot tips 2 mo after inoculation. There were variations in bacterial populations among clones and between strains; but a clone X strain interaction was not found, which indicates lack of host specificity with the strain tested. Survival of fluorescent bacteria is probably dependant upon nutrient availability and/or space and cellular migration to new sites. Similarly, quality of exudates (e.g., production and quantity of specific amino acids or toxic compounds) may influence their survival in the rhizosphere, in which case these characters could be genetically controlled.

6.7.1.2 Effect on plantlets under glasshouse conditions. Isolates of beneficial fluorescent pseudomonads have been characterized according to their inhibitory effect in vitro on both bacterial and or fungal pathogens (I) and ability to promote root system growth of plantlets as related to pathogen inhibition in vitro (II). With method I four groups of isolates were identified: (a) those with no or very mild inhibition of pathogenic bacteria and fungi; (b) those that strongly inhibit pathogenic bacteria, with no or very mild inhibition of fungi; (c) those causing very strong inhibition of fungi, with no or very mild inhibition of bacteria; and (d) those inducing strong inhibition of both fungi and bacteria. Generally, there were more isolates able to inhibit pathogenic bacteria than fungi. Among all isolates collected, those of *P. fluorescens* showed broader in vitro inhibition of the bacterial and fungal species tested than *P. putida*. Isolates characterized by method II were also classified into four groups: (a) those that did not inhibit cassava pathogens in vitro or increased root growth of cassava plantlets; (b) strains showing a high inhibitory effect in vitro of cassava pathogens (both fungi and bacteria; some strains of group d in method I), but not promoting an increase in foliage or root system of inoculated clones (secondary metabolites may have phytotoxic or antibiotic activity); (c) strains that did not inhibit cassava pathogens but increased both the foliage and root system of inoculated clones (antagonistic interactions with pathogens in the form of nutrient competition or antibiotic effects may have resulted in the exclusion of pathogens from the rhizosphere); and (d) strains inducing a strong inhibitory effect on cassava pathogens and a significant increase in the aerial parts and roots of inoculated plantlets. It has been reported that some strains of fluorescent pseudomonads produce growth regulators for other crop species.

6.7.1.3 Practical applications. The following applications can be envisaged at various steps in systems of cassava aimed at increasing production:

- Biological control of foliar pathogens. Strains from method I group b, which induced the highest in vitro inhibition of *Xanthomonas campestris* pv. *manihotis* (causal agent of CBB), were used to spray plots of susceptible and resistant clones planted in an area where CBB is epidemic (Table 6.8). Both the no. of angular leaf spots/leaf and the no. of blighted leaves/pl were significantly reduced by foliar applications of a strain of *P. putida*. RY of the susceptible clone (M Col 22), but not of the resistant clone, increased 2.7 times.

Table 6.8. RY (t/ha), no. angular leaf spots/leaf and no. of blighted leaves/pl of CBB-susceptible (M Col 22) and resistant (M Ven 77) clones after foliar applications of *Pseudomonas putida* (strain F-44).

Clone	Scoring System	Sprayed Plots	Control Plots
M Col 22	No. angular leaf spots/leaf[1]	6.4 b	17.8a
	No. of blighted leaves/pl	1.3 b	5.5a
	RY[2]	6.8a	2.5 b
M Ven 77	No. angular leaf spots/leaf	1.2a	1.5a
	No. of blighted leaves/pl	1.7a	1.9a
	RY	9.6a	9.1a

1 Plants received 6 foliar applications of 0.5×10^{8} cfu/ml of a suspension of *P.putida* at 15-day intervals. Control plants were sprayed with distilled H_2O. Data represent avg no. of leaf spots/leaf of 15 leaves/plot of 36 pl with 3 reps; and avg no. of blighted leaves/pl of 20 leaves/plot.

2 RY recorded from 3 reps of 30 plants each (12 harvested plants). Data followed by the same letter are not significantly different (0.05 DMRT).

Control of other foliar pathogens of cassava by spray applications of specific strains of beneficial fluorescent pseudomonads has not been reported, but it is possible.

Practical and economic problems exist, such as base inoculum production, inoculum storage and preparation under aseptic conditions, and costs of spray applications. Further research is required to test the practical feasibility of controlling foliar pathogens of cassava.

- Biological control of preharvest root rots. When soils infested with *Pythium* spp. or *D. manihotis* were drenched with a bacterial suspension of *P. putida* (method I, group d) before planting cassava plantlets, satisfactory control of root rot was obtained. Strains of *P. fluorescens* (method I, group c) were also able to protect stakes against *D. manihotis* (Tables 6.9 & 6.10). The protective effect was evident when stakes were treated with the bacterial suspension before or after fungal inoculations. Protection was related to sprouting of buds and fungal establishment, as well as invasion through the tissues of the stakes (Table 6.9). This type of protection was also evident for three clones taken either from farmers' fields or from meristem-culture derived plants (MCP). Bacterial protection was nearly as efficient as that obtained with the best fungicidal treatment (Table 6.10).

Fresh RY increased when plants were watered with a 10-ml bacterial suspension of a beneficial strain of *P. fluorescens* (method II, group d). RY tended to increase with an increased no. of waterings (Table 6.11). However, levels of increase varied according to clone, suggesting differential clonal responses to bacterial strains used or differences in susceptibility of the pathogens to the beneficial bacteria. In another trial commercial plots of M Col 2215 (susceptible) and M Col 1505 (resistant) were planted in a *D. manihotis*-endemic area (La Colorada, North Coast of Colombia), where CBB

Table 6.9. Effect of *Pseudomonas fluorescens* (strain Pf. C5a) on sprouting of stakes (M Col 1684) after inoculation with *Diplodia manihotis* (*Dm.*)

Treatments[1]	Sprouting[2] (% of Stakes)	Stake Infection (% of Invaded Tissues)
10min in Pf. C5a 20 min in Dm.	100a[3]	16b
10 min in DH_2O 20min in Dm.	10c	97a
18h in *Dm.* 20 min in DH_2O	40b	85a
20min in *Dm.*	0c	100a
Controls[4]	100a	0c

[1] Dip treatment in suspensions of $1.1x10^9$ cfu/ml of *P. fluorescens* (strain Pf.C5a)in distilled water (DH_2O), followed by a dip treatment in a suspension of $5.8x10^4$ pycniospores/ml of *Dm.* or viceversa.
[2] Data taken 1 mo after planting in pots with sterile soils maintained in a glasshouse at 25°C (± 8°C), Dm. or vice versa.
[3] Data followed by the same letter are not significantly different at the 0.05 level (DMRT).
[4] Controls consisted of stakes dipped 20 min in DH_2O or in suspensions of strain Pf. C5a.

Table 6.10. Effect of *Pseudomonas fluorescens* (strain Pf-88) on bud germination of stakes of three clones collected from farmers' fields (FF) and from (MCP)[1] and inoculated with *Diplodia manihotis* (*Dm.*).

		Percent Germination in Relation to Treatments			
			10 min Pf-88	10 min Fungicidal Mixture[3]	
Clone	Stakes	20 min *Dm.*	20 min *Dm.*[2]	20 min *Dm.*	Controls
M Col 113	FF	80(48)[4]	100(29)	100 (5)	100(4)
	MP	0(100)	100(29)	100(26)	100(17)
M Col 72	FF	60(47)	90(22)	100 (0)	100(8)
	MP	10(93)	70(37)	80(15)	100(2)
M Col 1468	FF	20(87)	100(0)	100 (0)	100(0)
	MP	10(98)	100(2)	100 (1)	100(9)

[1] MCP were obtained originally from meristem cultures and propagated one cycle in the field to obtain stem stakes.
[2] Dip treatments in suspensions of $5.8x10^4$ pycniospores/ml of *D. manihotis* or $1x10^9$ cfu/ml of *P. fluorescens* (Pf-88).
[3] H_2O suspension of captan/BCM (carbendazim), 3000 ppm each.
[4] Data taken from 40 stakes/clone/source treated. The avg percent of tissue showing fungal invasion after treatments is given in parentheses. Readings were taken 1 mo after growing the stakes in pots with sterile soils maintained under glasshouse conditions.

and anthracnose normally occur at low levels; stakes were dip treated and plants sprayed monthly with a bacterial suspension. RYs increased 28 and 123% for the susceptible clone planted with stakes taken from commercial plantations or from MCP, resp. (Table 6.12). The lowest RY was obtained on plots planted with untreated stakes of the same susceptible clone obtained from MCP; the highest disease rating was also shown on untreated plants from stakes taken from MCP, indicating the efficiency of the protective effect asserted by the native microflora living on stakes taken from commercial plantations. Finally, the bacterial treatments did not significantly increase RY of the resistant clone because the intrinsic genetic resistance in this clone overcame pathogen-induced stress. Controlling root rots of cassava with beneficial bacteria, replacing fungicidal treatments of stakes, is feasible; however, further research is needed to define practical systems.

Table 6.11. Avg RY of fresh roots of several clones planted at Carimagua, Media Luna and CIAT in relation to treatments with *Pseudomonas fluorescens* (Pf-88).

		RY (t/ha) in Relation to Bacterial Treatments[1]			
Location	Clone	0	1	2	3
Carimagua	M Col 1914	12.1b[2]	14.5b	16.5a	17.6a
	M Col 1916	11.2b	14.5b	15.7a	17.7a
	M Pan 19	10.7a	10.1a	12.0a	12.3a
	M Ven 77	14.5b	14.5b	18.1a	21.6a
Media Luna	CM 342-170	9.0b	11.1ab	11.3ab	12.5a
	M Col 72	12.5b	16.0a	16.3a	18.3a
	M Col 2215	10.3b	11.3b	12.3ab	13.3a
CIAT-HQ	M Col 1468	38.1b	40.2b	44.5ab	49.3a
	M Col 72	42.1b	46.6ab	46.8ab	47.0a

1 Bacterial treatments: 10 ml of a bacterial suspension (1.1×10^9 cfu/ml) were poured at the base of each plant at: 1 = 1 mo; 2 = 1 and 2 mo; 3 = 1, 2 and 3 mo after planting.

2 Data taken from 3 reps of 30 pl/location/clone and treatment. Border plants were eliminated. RY data followed by the same letter(s), compared across bacteria treatments, are not significantly different at the 0.05 level (DMRT).

Table 6.12. Effect of *Pseudomonas fluorescens* (strain P.f. C5a) on commercial RY of fresh roots of 2 clones (M Col 2215 = susceptible; and M Col 1505 = resistant) planted in a *Diplodia manihotis*-endemic area, with moderate CBB and anthracnose infection during the growing cycle.

	RY (t/ha)/Clone	
Source of Stakes	M Col 2215	M Col 1505
Commercial plantations–bacterized[1]	23a[2]	20a
MCP–bacterized[1]	29a	20a
Commercial plantations–untreated	18ab	17a
MCP–untreated	13 b	18a

1 Bacterization: stakes dip treated in a bacterial suspension of 1×10^9 cfu/ml; and plots sprayed monthly with a bacterial suspension of 5×10^9 cfu/ml.

2 Plots harvested 10 mo after planting; results followed by the same letter not statistically different (DMRT).

shown on untreated plants from stakes taken from MCP, indicating the efficiency of the protective effect asserted by the native microflora living on stakes taken from commercial plantations. Finally, the bacterial treatments did not significantly increase RY of the resistant clone because the intrinsic genetic resistance in this clone overcame pathogen-induced stress. Controlling root rots of cassava with beneficial bacteria, replacing fungicidal treatments of stakes, is feasible; however, further research is needed to define practical systems.

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Location	Clone	0	1	2	3
Carimagua	M Col 1914	12.1b[2]	14.5b	16.5a	17.6a
	M Col 1916	11.2b	14.5b	15.7a	17.7a
	M Pan 19	10.7a	10.1a	12.0a	12.3a
	M Ven 77	14.5b	14.5b	18.1a	21.6a
Media Luna	CM 342-170	9.0b	11.1ab	11.3ab	12.5a
	M Col 72	12.5b	16.0a	16.3a	18.3a
	M Col 2215	10.3b	11.3b	12.3ab	13.3a
CIAT-HQ	M Col 1468	38.1b	40.2b	44.5ab	49.3a
	M Col 72	42.1b	46.6ab	46.8ab	47.0a

1 Bacterial treatments: 10 ml of a bacterial suspension ($1.1x10^9$ cfu/ml) were poured at the base of each plant at: 1 = 1 mo; 2 = 1 and 2 mo; 3 = 1, 2 and 3 mo after planting.

2 Data taken from 3 reps of 30 pl/location/clone and treatment. Border plants were eliminated. RY data followed by the same letter(s), compared across bacteria treatments, are not significantly different at the 0.05 level (DMRT).

Table 6.12. Effect of *Pseudomonas fluorescens* (strain P.f. C5a) on commercial RY of fresh roots of 2 clones (M Col 2215 = susceptible; and M Col 1505 = resistant) planted in a *Diplodia manihotis*-endemic area, with moderate CBB and anthracnose infection during the growing cycle.

	RY (t/ha)/Clone	
Source of Stakes	M Col 2215	M Col 1505
Commercial plantations--bacterized[1]	23a[2]	20a
MCP--bacterized[1]	29a	20a
Commercial plantations--untreated	18ab	17a
MCP--untreated	13 b	1da

1 Bacterization: stakes dip treated in a bacterial suspension of $1x10^9$ cfu/ml; and plots sprayed monthly with a bacterial suspension of $5x10^9$ cfu/ml.

2 Plots harvested 10 mo after planting; results followed by the same letter not statistically different (DMRT).

Table 6.13. Effect of 6 strains of *Pseudomonas putida* (*Pp.*), 2 of *P. fluorescens* (*Pf.*) and one of *Bacillus* sp. (*Bsp.*) on postharvest microbial deterioration of cassava.

	Percent Root Deterioration after Storage[1]								
Bacterial Strain	CMC 40		HMC-1		CMC 40		M Col 22		
No.	1	2	1	2	2	3	1	2	3
Pp. f-56	0.6[2]	30.5	7.0	18.0					
Pp. f-44	8.8	10.0	7.3	23.0					
Bsp.	15.2	32.5	15.3	25.0					
Bsp.+Pp. f-56	6.6	23.5	7.8	28.5					
Bsp.+Pp. f-44	7.0	9.0	7.6	16.0					
Pf. c-5a					0.0	10.0	4.5	9.9	38.0
Pp. c-7a					20.4				
Pp. c-4b					7.8	14.8			
Pf. c-88					11.0	47.3			
Pp. c-5b							7.0	16.5	
Pp. c-7c							5.0	18.0	
Thiabendazole	8.6	13.5	4.8	15.0	1.8	4.0	2.0	8.4	5.6
Control	10.3	34.5	13.8	74.5	32.5	77.0	18.0	64.0	100.0

[1] Readings taken after 1, 2 and/or 3 wk of storage.
[2] Avg score from 500 roots of approx 0.5 kg each; score of 0 to 100 refers to percent loss due to microbial deterioration.

6.7.3 Native microflora

The importance of native microflora in protecting cassava against pathogens has been demonstrated by the following findings: (a) MCP are more susceptible to pathogens than plants grown from stakes from the field; and (b) plants grown from sterilized stakes (dipped in Na-hypochloride) of clones with apparent resistance resulting from the effect of beneficial microflora are, in fact, genetically susceptible. Native beneficial microflora, especially bacteria belonging to species different from fluorescent pseudomonads, are responsible for such protection. The interaction of these microorganisms with pathogens merits intensive research.

6.7.4 Soil-borne beneficial residents

It is well known that the biological activity of beneficial microbial residents can be enhanced by implementing appropriate cultural practices. By using crop rotation and fallow at two different climatic and edaphic locations, the following was found:

6.7.4.1 CIAT HQ (a fertile clayey soil high in OM). Results showed that planting cassava for more than 4 consecutive cycles decreased RY sharply; best RY was obtained in rotations (avg 19.4 t/ha vs. 7.0 t/ha for controls). Bacterial populations on unrotated crops were quite low, while *Fusarium* and *Phytophthora* species populations were high. Rotation favored beneficial bacterial activity in these soils, resulting in RY increase due to root rot biological control.

6.7.4.2 Media Luna (a sandy soil low in OM). The highest cassava RY and NPK uptake (determined by leaf nutrient analysis) occurred after fallow. Similarly, microbial recovery at planting showed that the lowest concentrations of *Fusarium* spp. (soil-borne inhabitants capable of inducing root rot) were found in fallowed plots (Table 6.14). Moreover, the no. of earthworm castings was 4 times higher on fallowed plots than on either maize-sesame or maize-cowpea plots; microbial populations in the castings had a high concentration of bacteria, most of which can inhibit in vitro growth of *F. oxysporum* and *F. solani* cultures. The low root rot pathogen population may explain the higher RY in fallowed plots in addition to the improved nutritional effect provided by the earthworms. Results also explain growers' preference for fallow rather than crop rotation.

6.8 Cassava Endophytes

The existence of endophytes (microorganisms able to grow inside their host tissues without inducing visible necrosis) in cassava was suspected for the following reasons: (a) A wide range of variation in RY is frequent among disease-symptomless plants growing on the same plot; (b) RY of low-yielding, virus-free plants of traditional clones can be increased by meristem culture (CIAT Annual Report 1976); (c) the performance (i.e., RY) of MCP decreases sharply and uniformly under field conditions (CIAT Annual Report

Table 6.14. Effect of fallow and crop rotation at Media Luna (North Coast, sandy soils with low OM content) on RY, NPK uptake and *Fusarium* spp. concentration; plots not fertilized.

Cropping System	Fresh RY (t/ha)	Nutrient Uptake (kg/ha) N	P	K	*Fusarium* spp. (spores/g of soil)
Cassava-fallow-cassava	8.0a[1]	91.6	7.5	35.1	$2.2x10^1$
Cassava-cassava-cassava	7.2a	70.4	5.6	22.8	$1.1x10^2$
Cassava-maize/sesame-cassava	6.3a b	57.8	5.2	18.8	$5.8x10^3$
Cassava-maize/cowpeas-cassava	4.8 b	60.3	5.1	19.9	$2.4x10^4$

1 Data taken from 4 reps/treatment with 30 pl each. Data on fresh RY followed by different letters are significantly different at 0.01 (DMRT).

1988); and (d) the long growing cycle of cassava and its vegetative propagation allow infection and dissemination of these parasites.

Findings were as follows:

- Several fungal species were isolated from internal tissues of the epidermis, colenchyma and parenchyma of stems of symptomless low-yielding plants of various clones. The fungal species isolated and their frequency were: *Septoria nodurum, 52.1; Fusarium oxysporum, 7.2; Colletotrichum gloeosporioides, 5.8; C. graminicola, 4.3; Alternaria termissima, 2.9; Trichoderma sp., 2.9; Botrytis sp., 1.4; Torula sp., 1.4; Nigrospora sp., 1.4* and others 20.4. Most of these species have been reported as endophytes in literature.

- Inoculations on plantlets and callus tissues by spraying, puncturing or immersion in a fungal suspension of some of the isolated fungi did not induce visible symptoms, but inoculated fungal species were reisolated from internal tissues near the inoculated points 30 days afterward.

- Total root dry wt (t/ha) of plots planted with stakes taken from commercial fields and treated with a systemic fungicide were higher than for similar plots treated with a protectant fungicide or untreated controls (Table 6.15). However, differences were recorded among plots with plants derived from rooted shoots; this may be due to the existence of a higher probability of endophyte infections of stakes than shoots.

- Histological studies observing fungal invasion into the host tissues have shown hyphal growth in colenchyma and parechyma tissues of affected stems.

Table 6.15. Root dry wt (t/ha) of a plot planted with stakes taken from commercial fields and with plants derived from rooted shoots; both were treated with systemic or protectant fungicides every 2 wk, 3 mo after planting and for a 6-mo period.

Clone	Source of Planting Material	Treatment		
		Benomyl (systemic, 1500 ppm)	Chlorothalonil (protectant, 1500 ppm)	Control (Distilled H_2O)
M Bra 191	Rooted shoots	24.4[1]	19.7	17.1
	Stakes	25.5	15.0	14.7
M Col 1468	Rooted shoots	20.8	7.6	6.7
	Stakes	22.1	14.0	11.8
M Col 2215	Rooted shoots	21.8	15.6	12.4
	Stakes	17.7	12.8	13.2

[1] Avg data taken from 9 pl/plot, 3 reps; plants harvested at 10 mo.

The effect of 9 of the isolated endophytes was studied on 3 cassava clones (M Col 2215, M Bra 191 and M Col 1468) inoculated by spray, immersion and puncturing methods. Results were as follows (Fig. 6.1):

- Both detrimental and beneficial endophytes affect cassava, but most of the isolated species were detrimental.

- The detrimental/beneficial effect of some endophytes depended upon the inoculation method: on M Col 2215, *Curvularia* sp. was detrimental when spray-inoculated, but beneficial when inoculated by immersion or puncturing.

- Some fungal species behaved as endophytes in a given plant tissue but as pathogens in others: *Rhizoctonia* sp. did not induce symptoms in leaf and stem tissues, but induced necrosis when the roots were mechanically wounded, similar to any root pathogen.

- There were varietal differences in relation to the behavior of the endophytes on cassava, which could be of importance for genotype selection.

These findings stress the importance of selecting planting material from high-yielding plants of commercial plots and the need for genotype evaluations through several growing cycles under field conditions in order to eliminate susceptible clones showing low RY stability. On the other hand, the existence of detrimental endophytes in cassava may partly explain the gradual degradation of cassava clones over continuous growing cycles. Further research is needed to elucidate other interactions between cassava endophytes and genotypes of the crop, as well as epidemiological features related to this group of parasites before control/prevention systems can be devised. Special attention will be

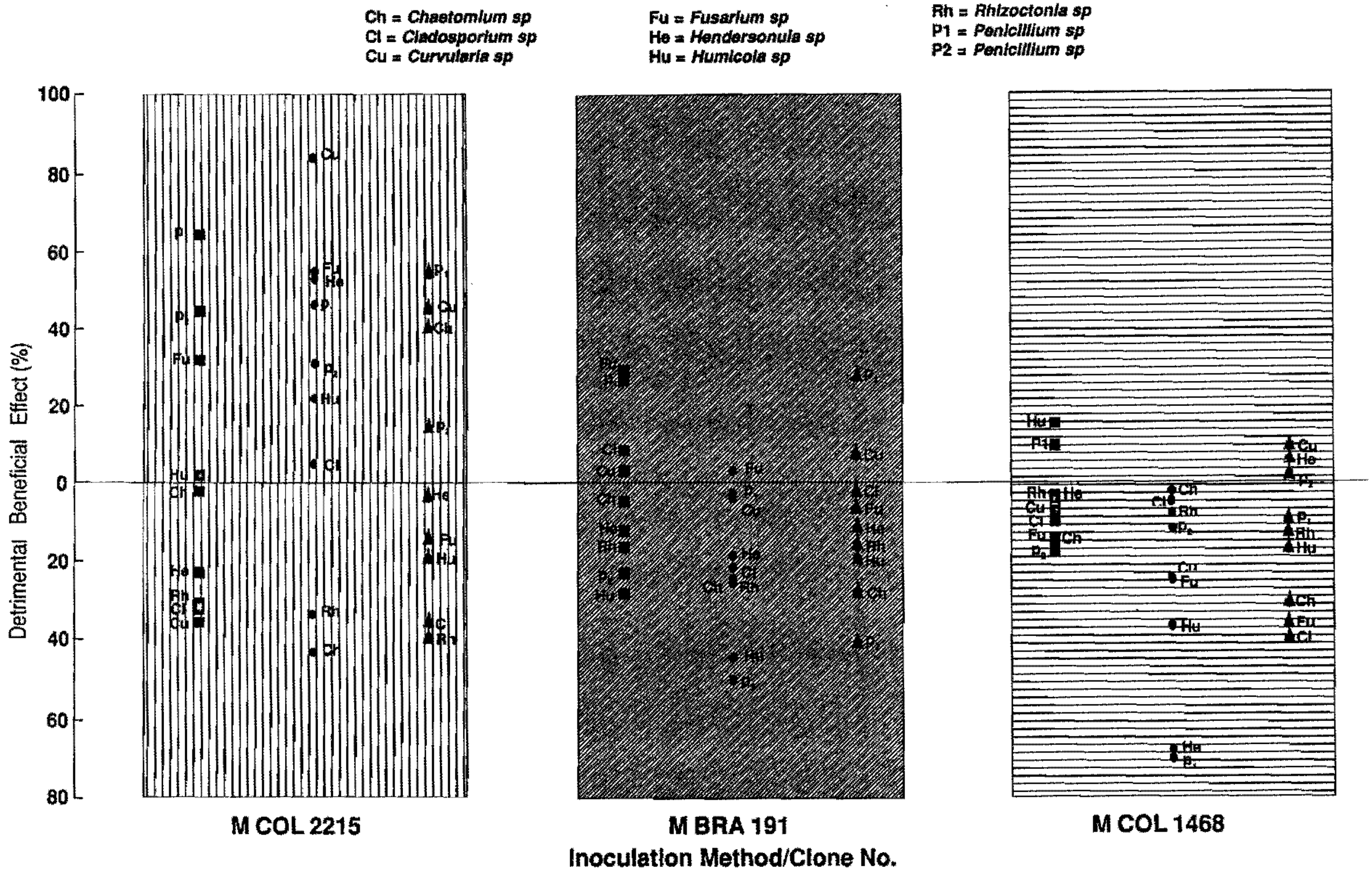

Figure 6.1 Effect of 9 cassava endophytes(inoculated by ■=spray, ●=immersion, and ▲=puncturing) on 3 cassava clones in relation to the percent of root weight of uninoculated controls.

given to the beneficial endophytes in order to increase biomass production or induce plant protection against detrimental parasites.

6.9 New Method for Interchanging Indexed Vegetative Planting Material of Cassava

The exchange of vegetative planting material of cassava is being done as MCP in test tubes. This material is subject to few quarantine restrictions; however, as the plantlets are weak, losses are common (up to 90%) and there are delays in obtaining adult plants (1 1/2 to 2 yr). To overcome these problems, the following system was developed: 30-day-old shoots from indexed mother plants (MCP previously tested for sanitary status) are cut into 10-cm sections and placed in a container with deionized H_2O to prevent dehydration. Shoot stakes are then removed from H_2O and dusted with Thiuram (mercuric mercurous chloride); each end (1-2 cm) is wrapped with parafin. Shoot stakes are then organized in bundles of 5, and their bottom half is wrapped with paper towels previously sprayed with a benomyl-captan (3 g/lt each) suspension, covered with a plastic bag and sealed with rubber bands. Bundles are then arranged in cardboard boxes, with several holes to allow air exchange during shipping. Shoot stakes have a shelf life of more than 15 days. At the recipient location, the stakes are planted in pots with sterile soil and covered with plastic bags with 4 to 6 holes to maintain a high RH and permit air exchange. Soil is kept moist but not saturated. When shoots have rooted and buds germinated (10-12 days), the plastic bags are removed. Two wk later the plantlets are planted in the field. Using this system it is possible to obtain 90 to 100% establishment 20 days after packing and adult plants 7 to 10 mo later. If mother plants are virus-indexed and maintained free from insect vectors of cassava viruses, quarantine risks can be minimized. This system was included in the FAO/IBPGR Technical Guidelines for the Safe Movement of Cassava Germplasm and several countries have accepted vegetative planting material using this system.

6.10 Storage of Vegetative Planting Material

Research on storage of vegetative planting material of cassava has identified the following factors that affect quality during storage:

6.10.1 Dehydration

This factor can decrease establishment when stakes are stored at RHs below 80%. Varietal differences in resistance have been found, but there do not appear to be sharp differences in the speed of H_2O loss from stakes stored at low RH. The highest percent of H_2O loss, which occurs during the first days, is related to the ambient RH at the storage site.

6.10.2 Light

Light intensity showed significant effects on establishment after long periods (4 mo) of storage of 1-m long stakes: at high light intensities (13,400 FC) establishment was as for the controls. Starch content in stakes decreases over time, independent of light intensity. Results also showed the existence of varietal differences in starch loss, but the relationship between starch content and establishment was not clearly shown, data suggesting a varietal X starch level interaction.

6.10.3 Chemical treatment

Chemical treatment of stakes prior to storing is essential for eliminating both insects and pathogens and preventing reinfestations during storage.

6.10.4 Effect of storage period and light intensity on RY

Generally RY is affected when using stored stakes for planting, RY decreasing as the storage period increases. Consequently, stakes should be stored only when necessary. A storage period of more than 2 mo can induce severe RY decreases in highly sensitive clones. Highly resistant clones exist, and this character appears to be genetically controlled.

The following storage system is advisable for tropical environments:

- Stems should be selected from visually healthy plants of unbranched clones showing satisfactory levels of resistance to storage (>80% establishment after 60 days); mother plants should be those that yielded most.

- Stems should be 1.20m long, taken from the first half of 8- to 11 mo-old mother plants. Stakes should be arranged in bundles (approx. 10 stakes) and treated with a fungicide-pesticide mixture (benomyl, 3 g/lt; maneb, 3 g/lt; and malathion, 1-2 cc/lt).

- Bundles should be stored vertically in the open field by planting the first 5-10 cm of the stakes in the ground and watering for the first 2 wk.

- The first 10 cm from each end, as well as shoots produced during the storage period, should be removed. Stakes should be 15-20 cm long and treated again with the fungicide-pesticide mixture before planting. Fertilization (based on soil or plant tissue analyses) should be implemented at 45 days.

This system was implemented in plots planted with stakes stored for 4 mo under very dry conditions (Pivijay, North Coast, 28°C avg; 60% RH). RYs were similar to those obtained on plots planted with unstored controls (Table 6.16). This system is now being validated

Table 6.16. RYs of plots planted with stakes[1] of 2 clones from Media Luna following a storage system[1] for tropical environments.

	Fresh RY (t/ha)/Clone			
	M Col 2216		M Col 2215	
Treatment	Unfertilized	Fertilized	Unfertilized	Fertilized
Unstored control	16.3	20.2	14.5	20.8
Storage in open field	15.2	17.9	15.6	20.8

1 Stakes taken from first half of stems of 11-mo-old plants; long (1.20 m) stem stakes stored 4 mo (Jan.-Mar., the driest period of the region).

in 4 different locations on the North Coast and has been adopted by several progressive cassava farmers at Media Luna.

6.11 Geographic Distribution and Potential Risk of Six Cassava Diseases

Extrapolating data on epidemiological studies, surveys on disease severity and climatology (with the cooperation of the ASU), the geographic distribution and potential risks of CBB, SED, WB, *Fusarium* and *Phytophthora* root rots, and *Diplodia* stem and root rot are presented for Latin American (Fig. 6.2). The data show the following:

- The highest potential risk for CBB and SED exists in areas with moderate temp during the wet season (20-26.5°C), more than about 1200 mm rainfall/yr, and prolonged periods of high RH (for SED), or where day/night temp fluctuate more than 8°C during the wet months (for CBB).

- The highest risk for *Fusarium* stem and root rot pathogens exists in areas with high temp (>25°C) and frequent heavy rainfalls during short periods of the rainy season. For *Diplodia* stem and root rot pathogens temp >26°C, annual rainfall <1000 mm and dry season >4 mo. If the temp is more than 20°C and the land is periodically flooded during the rainy season or badly drained, *Phytophthora* spp. can also be of great importance.

- The mycoplasm-induced WB is characteristically found in areas where the temp ranges from 20 to 24°C for at least 3 mo/yr. Symptoms are moderate to mild, and may disappear as temp increases. Consequently, WB can be a threat in areas where cool temp occur during the year or for more than a 3-mo period.

This information can be used to select appropriate clones in the different geographic areas of Latin America, as well as guide breeding programs for different ecological areas and defining strategies for controlling these diseases.

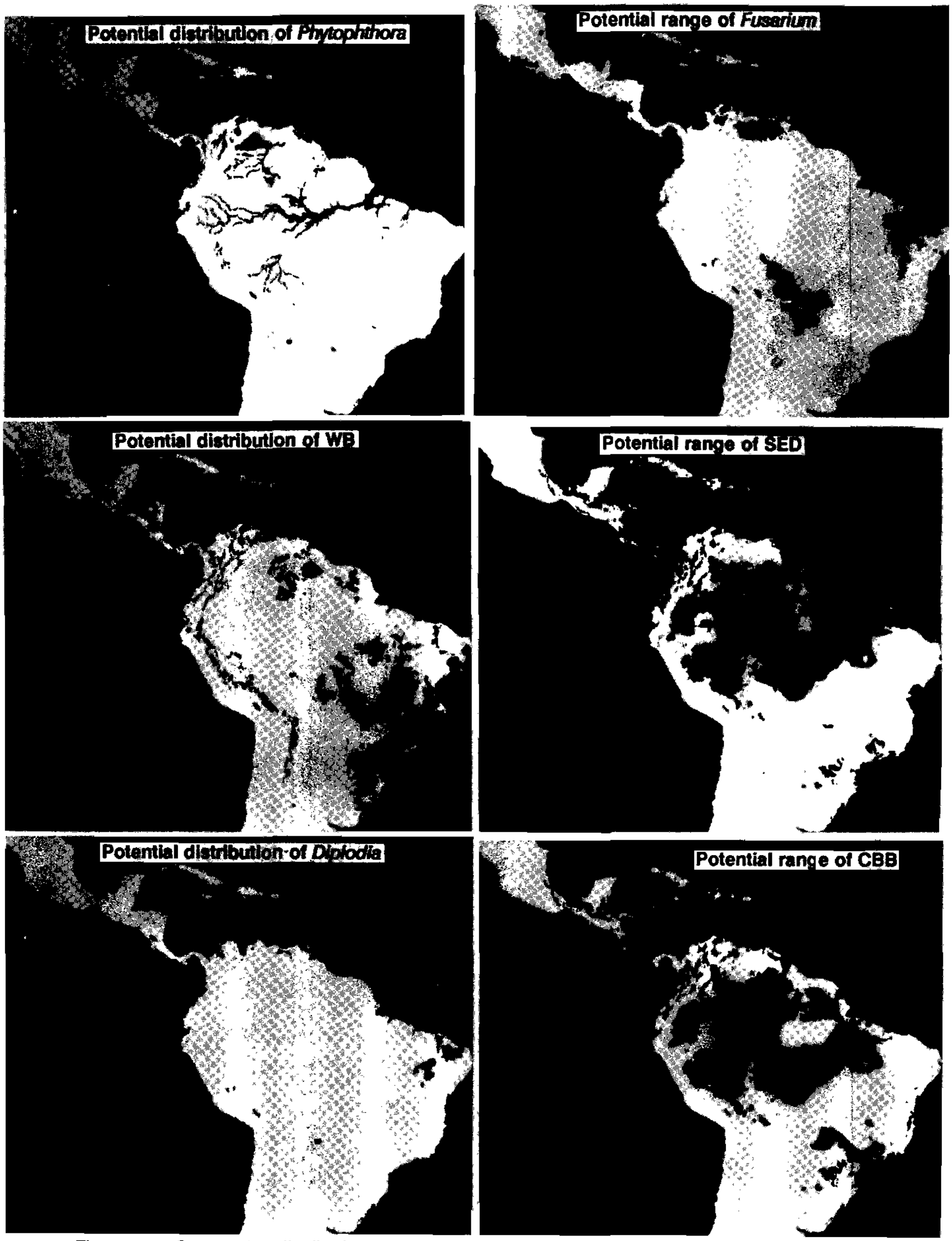

Figure 6.2. Geographic distribution and potential risk of six cassava diseases in Latin America.

7. VIROLOGY

The VRU is responsible for investigating the diseases of cassava caused by viruses or viruslike agents. The development of a methodology to assure the movement of virus-free cassava germplasm is a research priority. This is especially important because there are diseases of cassava of unknown etiology.

The control of viral diseases requires either the identification of resistant germplasm or the implementation of cultural practices that mitigate disease losses. Most viral diseases are controllable with the current technology; and continued development of rapid diagnostic techniques, together with the deployment of resistant germplasm, should further reduce the losses caused by viruses.

7.1 Frogskin and Caribbean Mosaic Diseases

Frogskin disease (FSD) is a viruslike disease of unknown etiology that was first reported in 1971 from southern Colombia. There are no leaf symptoms produced in most cassava clones affected by FSD, but there can be very severe root symptoms. The malady was named frogskin disease because the root periderm and corky layers enlarge to form characteristic raised lip-shaped fissures on the roots. The roots often show a zone of constriction where these fissures are prominent. In severely affected plants, the roots do not fill with starch, and there are yield losses of more than 90% in areas where the disease is endemic. A few cassava clones develop mosaic symptoms on the leaves and growth is stunted.

Caribbean mosaic disease (CMD) is a viruslike disease of unknown etiology, reported in 1981 from the northern coastal regions of Colombia. Susceptible cassava varieties affected with CMD show foliar mosaic symptoms and significant yield loss. Yield losses in susceptible cassava clones can be severe, but tolerant clones produce normal yields.

These two diseases have been reported as different because the root symptoms associated with FSD are either absent or mild in plants affected with CMD. While the root symptoms are apparently different, these diseases share many similarities. Both disease agents are transmitted by grafting and the cassava var. Secundina can be used in indexing programs to detect both CMD and FSD. The mosaic symptoms on the leaves of Secundina are expressed most prominently when the plants are kept in an area where the max. temp is kept below 30°C. Constant temp (> 28°C) suppresses the foliar symptoms of both diseases. Neither FSD nor CMD can be inoculated mechanically, and the only known host for both diseases is cassava. Insect vectors have been suspected for both diseases as they spread rapidly in the field.

7.1.1 Identification of a phytoreoviruslike agent associated with FSD and CMD

Isometric viruslike particles (70-80 nm in diameter) are found in thin sections of leaves, petioles, stems and roots of CMD-affected plants. Similar viruslike particles are also found in the same tissues of plants affected with FSD. These particles have been found in plants affected with all the FSD and CMD isolates that have been tested (Fig. 7.1A). Viroplasmlike bodies have also been found in FSD- and CMD-affected plants; they are often associated with the chloroplasts of the cells (Fig. 7.1B).

Double-stranded RNAs were purified from cassava plants infected with either CMD or FSD and run on both agarose and polyacrylamide gels. On the former, there appear to be 3 or 4 bands; but on the latter, there are 9 bands, which are consistently present in plants affected with FSD or CMD (Fig. 7.2). The ds-RNA segments are estimated to be 4000, 3800, 3400, 2600, 1900, 1800, 1700, 1100 and 1000 bases in length (Fig. 7.3).

Radioisotopic-labeled cDNA probes were prepared from the isolated ds-RNA for use in hybridization analyses to determine the relatedness of the various FSD and CMD isolates. Based on the limited studies to date, there appears to be a fairly high degree of similarity between the isolates. For example, FSD isolate 14 hybridizes with CMD isolate 80 (Fig. 7.2). This is further evidence that ds-RNAs associated with FSD and CMD are either identical or closely related.

The partial purification of the phytoreoviruslike particles has been attempted, but they are very labile. The particles have been banded on a cesium sulfate gradient, and then visualized with a transmission electron microscope (TEM). Some particles are complete, but the majority of them appear to have degraded into a 50-nm structure typical of the core virions of phytoreoviruses. To determine whether the isolated particles contained the ds-RNAs associated with CMD and FSD, a dot blot assay was performed using a radioisotopically labeled cDNA probe prepared from the ds-RNA. The dot blots were positive, indicating that the fraction containing the viruslike particles also contained the ds-RNA. This is evidence that these phytoreoviruslike particles contain a ds-RNA genome.

The viruslike particles and the ds-RNA bands present in cassava affected with FSD or CMD are similar to those reported for in phytoreoviruses. Neither FSD nor CMD has been mechanically transmitted despite many attempts; this is consistent with the causal agent being a phytoreovirus as these viruses are not mechanically transmitted.

7.1.2 Vector transmission experiments

Whiteflies have long been suspected as the vectors of FSD. For most of the transmission experiments to date, the indicator clone Secundina has been used. The mosaic symptoms in the leaves were used as the marker to determine successful transmission. Table 7.1 is a list of the FSD and CMD isolates for which transmission by *Bemisia*

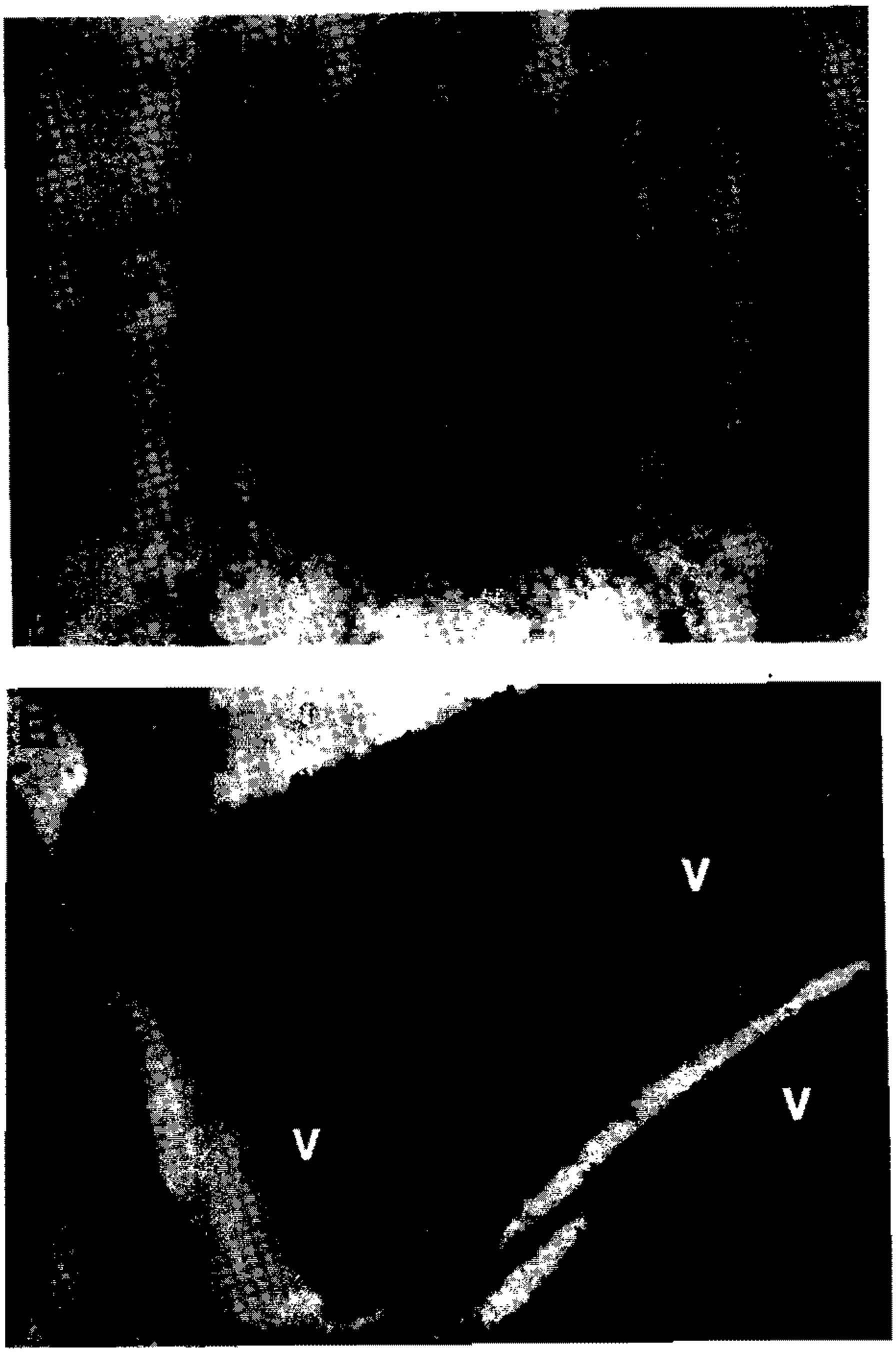

Figure 7.1. A: A group of viruslike particles found in a thin section of a leaf of the cassava clone Secundina affected with the mosaic symptoms associated with FSD.

B: Viroplasmlike bodies found in a similar section as the viruslike particles; **V** indicates the viroplasmlike bodies.

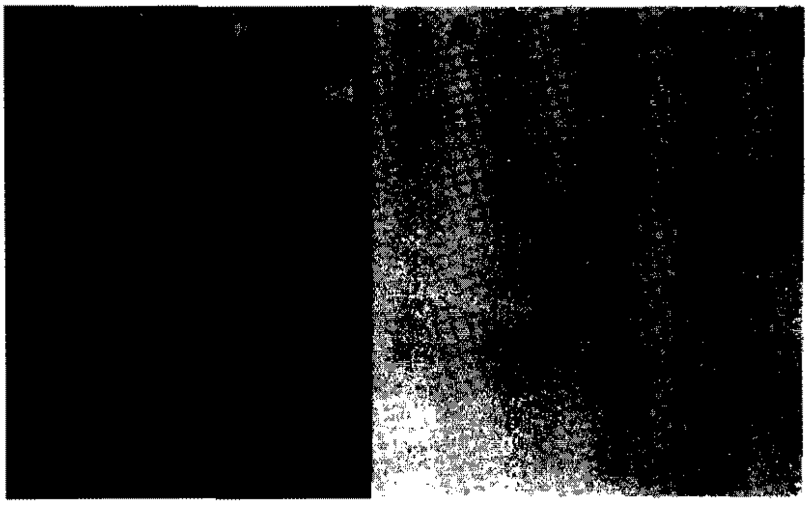

Figure 7.2. (1) An agarose gel showing the dsRNA segments extracted from plants infected with FSD and CMD; (2) blot hybridization using a first-strand cDNA probe prepared from FSD-dsRNA (isolate 14). A = dsDNA markers; B = FSD isolate 14; C = FSD isolate 24; D = CMD isolate 80.

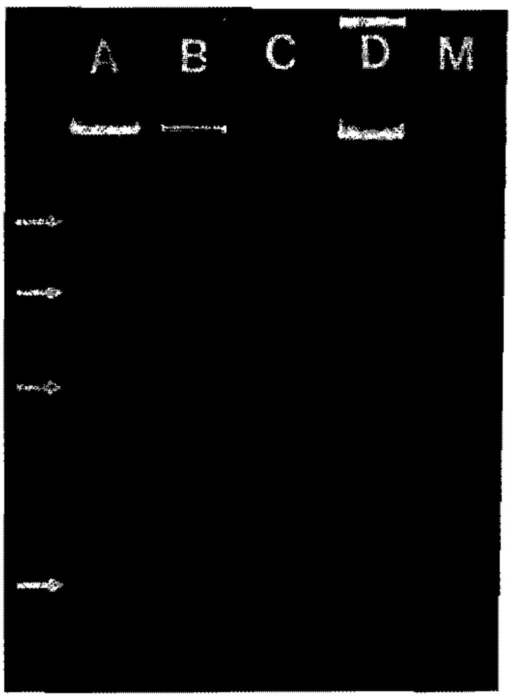

Figure 7.3. A polyacrylamide gel showing the dsRNA segments isolated from plants infected with FSD or CMD. A: FSD isolate 24, B: CMD isolate 5, C: FSD isolate Tolima, D: FSD isolate 29, M: dsDNA markers.

Table 7.1 List of isolates of FSD and CMD that have been transmitted to cassava by the whitefly *B. tuberculata*.

Disease	Isolate	Source Plant	Receptro Plant	Date Results
WF-mosaic	3	WF from field[1]	Secundina	1986
FSD	29	Secundina	Secundina	1990
CMD	80	Secundina	Secundina	1990
CMD	86	Secundina	Secundina	1990
FSD	24	M Col 72	Secundina	1991
FSD	Tolima	Secundina	Secundina	1991

[1] This isolate originated from whiteflies collected in the field; later experiments showed it was transmitted by *B. tuberculata*.

tuberculata has been shown. A one-day acquisition period gives the highest rates of transmission. There is a latent period during which the virus is not transmitted by the vector. The minimum period of inoculation that has resulted in transmission is 3 days.

Additional experiments must be done to characterize more accurately the transmission of the FSD agent, but preliminary results indicate that the agent is transmitted persistently, presumably in a circulative manner. There is no evidence at this time that the agent multiplies within the vector.

Plants that developed mosaic symptoms were transplanted in soil inside a screenhouse. The plants were grown for 6 to 8 mo, and then the roots were harvested and inspected for symptoms of FSD. Plants infected with FSD isolate 29 and CMD isolates 80 and 86 all showed mild but distinct FSD symptoms on the roots (Fig. 7.4).

The plants that developed the mosaic symptoms in the transmission tests were analyzed for the presence of ds-RNA species. In most cases, both the mother plants used as the source of inocula, and the plants infected in the transmission experiments had similar ds-RNA patterns. The exception has been FSD isolate 29, which loses some of its ds-RNA bands during the transmission experiments. Only the 9 bands consistently associated with FSD and CMD are present in the plants infected during transmission experiments either with isolate 29 or the others. This suggests that FSD isolate 29 may be co-existing with a second virus.

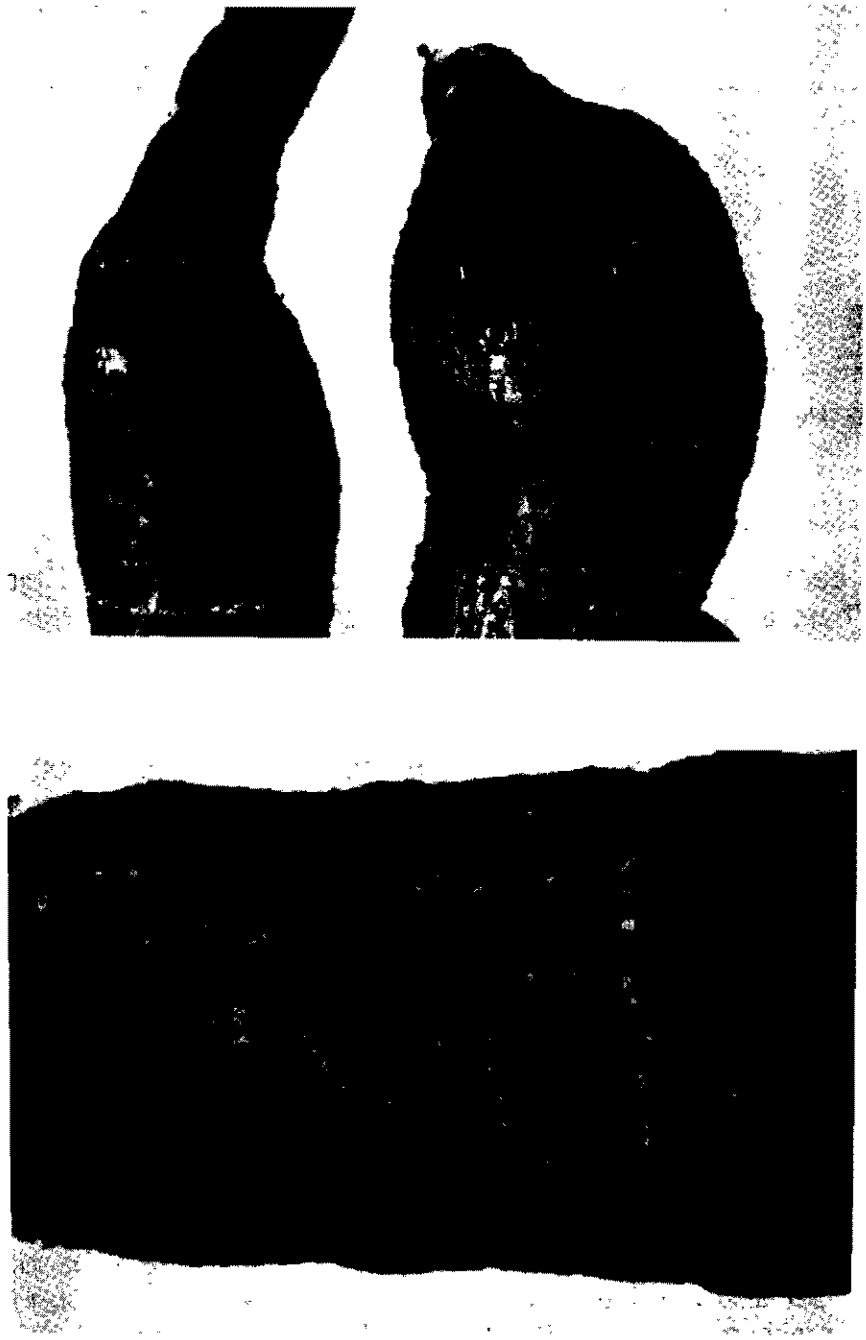

Figure 7.4. Roots showing mild symptoms typical of FSD. These roots were harvested from plants infected with the phytoreoviruslike agent using *B. tuberculata* as the vector. Plants were grown in a screenhouse to prevent other sources of infection.

Viruslike particles 80 nm in diameter, similar to those found in FSD- and CMD-infected plants, have been found in the newly infected plants from all isolates tested. Viruslike particles have been found directly in *B. tuberculata* individuals fed on infected plants; none was found in *B. tuberculata* individuals fed on healthy plants.

7.1.3 Control strategies

The damage caused by FSD can be limited by using clean stakes. In heavily infested fields, the old crop should be removed for at least a month and then the field should be planted with clean stake material. Use of the indicator clone Secundina can facilitate the selection of clean stakes. As the disease is not mechanically transmitted, no special care is needed when handling stakes. The key for sustainable yields is the continued selection of clean planting material. There are no leaf symptoms in most cassava clones; therefore, the selection of the planting material must be made at the time of harvest. The roots must be inspected carefully for symptoms of FSD. As many of the root symptoms are mild, care must be taken to recognize them and eliminate stakes from these plants in order to mitigate the losses caused by FSD.

7.1.4 Quarantine implications and diagnostic tests

FSD is the most serious viral disease that is endemic in Colombia. While progress has been made on identifying a phytoreoviruslike agent associated with the disease, there are still some unanswered questions concerning its etiology. Therefore, extra care must be taken to assure that the germplasm exported from CIAT is free of FSD agents. Currently, two tests are being used to detect FSD. The first method, in use for many years, is to graft the test plant to the indicator clone Secundina. The second method is to extract ds-RNA from the plants and confirm the presence of FSD either in a polyacrylamide gel or with a dot blot assay and hybridization probe. If either test is positive, the clone is assumed to be infected. Only clones that have no history of FSD will be considered for export.

7.2 Cassava Common Mosaic Virus

Cassava common mosaic virus (CCMV) is a member of the potexvirus group found throughout Tropical America from Mexico to Paraguay. The particle morphology is a semiflexuous rod approx. 15 X 495 nm. The viral particles contain a single coat protein with a relative molecular wt (Mr) of 25,000, and a ss-RNA genome of approx. 6400 bases. Nuclear inclusions typical of the potexvirus group can be found in cassava and *Nicotiana benthamiana*. Cassava plants infected with the virus have mosaic symptoms on the leaves and may suffer yield losses of more than 20%. In terms of total yield loss, CCMV is considered to be the most destructive viral disease in cassava in the Americas.

7.2.1 Molecular characterization

The sequencing of CCMV genome is nearly complete. The virus (6400 bases in length) is most closely related to potato virus X (PVX). CCMV has a genomic organization typical of other members of the potexviruses, whose genomic sequence is known. Most of the sequencing of CCMV was done at the VRU at CIAT--perhaps the first plant virus to be sequenced in Latin America.

The cDNA cloning and sequencing of CCMV coat protein was an essential element for the Cassava-Trans project, based at Washington U. The coat protein gene of CCMV was successfully introduced into *Nicotiana benthamiana*, and these plants show almost complete immunity to CCMV. Coat protein-mediated cross protection will be one method for developing resistant germplasm to CCMV. The major technical limitation is the transformation of cassava.

7.2.2 Quarantine implications and control.

Antisera against CCMV are available, and the virus is readily detected by ELISA. All germplasm from the Americas is routinely screened for the presence of CCMV before exportation from CIAT.

There are no reports of a vector for CCMV, and the leaf symptoms caused by CCMV are very distinct. The disease is controlled by selecting plants without foliar symptoms and using these stakes for propagation. If the area is heavily infested, cutting tools should be disinfected between plants.

7.3 Cassava Vein Mosaic Virus

Cassava vein mosaic virus (CVMV) is a member of the caulimovirus group, which has isometric virions approximately 50 nm in diameter and a ds-DNA genome of approx. 8000 bases. The only known host for CVMV is cassava, and the vector is unknown. Symptoms include chlorosis of the veins, which can either appear as a chevron pattern or coalesce to form a ring-spot pattern. Some leaves also show a mosaic pattern over the entire leaf. There is often leaf distortion and young leaves sometimes show epinasty. Symptoms are variable, being expressed better at high temp. The virus is reported in many states of Brazil, being most prevalent in the NE, especially in the hot semiarid zones where it is not unusual to find more than 50% of the plants infected. CVMV is not known to occur outside Brazil, and there is very little information on yield losses.

7.3.2 Quarantine implications and diagnostic tests

Initial characterization of CVMV was done by Drs. E. Kitajima and A. Costa (Brazil). An antiserum to the virus was made by Dr. M. Lin around 1980, but it is not known if it is still viable. Infected plants have distinctive symptoms, that can be confirmed by visualization of 50-55 mM isometric particles using TEM. Symptoms may not always be present; and as the virus can infect *in vitro* cultured plantlets, a rapid and reliable diagnostic test is needed. DNA clones to CVMV have been prepared at the U. of Kentucky, and one has been provided to the VRU. A polymerase chain reaction (PCR) test for rapid detection of CVMV should soon be available at CIAT. There is a need to prepare a new antiserum or transfer a PCR detection method to EMBRAPA/CNPMF to facilitate screening of cassava germplasm for CVMV in Brazil.

7.4 African and Indian Cassava Mosaic Viruses

African cassava mosaic geminivirus (ACMV), found throughout tropical Africa, and a similar virus, Indian cassava mosaic geminivirus (ICMV), found throughout India and Sri Lanka, cause the most destructive viral diseases of cassava. Symptoms include mosaic, yellowing, distorted leaves and stunted growth. The vector of these viruses is the whitefly, *B. tabaci*.. Resistant varieties exist, and in these plants symptom expression is erratic. It is presumed that distribution of the virus is restricted in these varieties.

7.4.1 Quarantine implications

Recently ACMV was introduced to the island Praia, Cape Verde. Losses were nearly 100% as the germplasm (of Brazilian origin) was not resistant to the virus. Similar losses can be expected if ACMV and an active vector are introduced into tropical America. In Asia these geminiviruses have not been reported outside India and Sri Lanka; therefore, much of Asia faces a similar threat. *In vitro* cultures of cassava received at CIAT from IITA (Nigeria) have all been tested for the presence of these geminiviruses at the Scottish Crop Research Institute (SCRI). Monoclonal antisera to these viruses have been produced at the SCRI. There are antisera and cDNA probes to ACMV available at CIAT that can be used to detect these geminiviruses.

While *B. tabaci* is common throughout the Americas, it does not normally colonize cassava. Recently a biotype of *B. tabaci*, which has become dominant in Florida, Puerto Rico and the Dominican Republic, has colonized cassava. As this biotype is a possible vector of ACMV, there is a need to monitor its distribution.

7.4.2 Control strategies

The use of resistant clones is the most effective method of mitigating losses caused by these geminiviruses. Resistant clones exist in Africa and in India. IITA has shipped clones with resistance to ACMV to CIAT, but these have severe agronomic and disease problems when grown in Colombia. The clones have been used in a breeding program as one source of resistance. Another means of identifying resistant germplasm is through the joint CIAT-IITA program (see Chap. 23). A third possible source of resistance could be obtained through the Cassava-Trans project, which is working on coat protein-mediated cross protection for both CCMV and ACMV. With the spread of the new biotype of *B. tabaci*, the threat introducing ACMV into tropical America has increased; therefore, additional emphasis will be placed on identifying ACMV-resistant germplasm adapted to tropical America.

7.5 Latent Viruses of Cassava in Latin America

There are several latent viruses known to infect cassava in Latin America. These latent viruses were discovered while working on other virus or viruslike pathogens of cassava. None of these viruses is known to cause disease in cassava or to have any effect on RY. There is only limited information on the distribution of these viruses. CIAT is committed to sending germplasm that is free of pathogens; therefore, the primary concern of the investigations on these viruses is to find methods of detection that make it possible to certify that germplasm does not contain these latent viruses.

7.5.1 Cassava X and cassava Colombian symptomless viruses

Cassava X (CsXV) and cassava Colombian symptomless (CCSpV) viruses are both potexviruses discovered during attempts to identify the causal agent of FSD or CMD. These viruses were discovered because they are mechanically transmitted to diagnostic hosts. Subsequent tests have shown that they are not present in most of the plants affected with FSD or CMD. Neither virus is known to cause symptoms or disease in cassava, either alone or in combination with other viruses.

With respect to quarantine implications and diagnostic tests, there are antisera to both viruses. All *in vitro* germplasm that originates from Colombia is checked for the presence of these viruses by ELISA before shipping.

7.5.2 Cassava American latent virus

Cassava American latent virus (CALV), a member of the nepovirus group, was discovered by Dr. B. Walters, who isolated it from cassava also infected with CCMV. The virus was isolated from samples from Guyana and Brazil (Manaus). While the vector of the virus is unknown, it is probably a nematode. It is also possible that this virus is seed transmitted. As no cassava plants infected with this virus have been found in the field, it is difficult to test whether the virus is seed and/or nematode transmitted.

As for quarantine implications and diagnostic tests, Dr. Walters has made an antiserum for CALV available. This antiserum, which has been used to test cassava in Colombia and Brazil, has been useful in certifying seed lots as free of CALV. Thousands of seeds and hundreds of plants grown at CIAT HQ, were assayed for CALV, all of which were negative. CALV does not appear to be present in the Cauca Valley; therefore, the further testing of materials grown at CIAT is not warranted. Of approx. 200 plants (18%) of the germplasm collection at EMBRAPA/CNPMF at Cruz das Almas tested for CALV, all tested negative. CALV does not appear to be present at the CNPMF farm in Cruz das Almas.

Some additional testing may be done on germplasm being developed for the semiarid and subtropical regions (see Chap. 2, sec. 2.4). The distribution of this virus is not known, and the only reported source of the virus is from the humid tropical regions of the Amazon. The virus has not been found at the main sites where true cassava seeds are produced for export; thus the risk that this virus is contaminating these cassava seed lots is extremely low.

7.6 Conclusions and Future Research Objectives

There are 4 main diseases caused by virus or viruslike agents. These are FSD, CVMV, CCMV and ACMV (ICMV). While the losses caused by these diseases can be mitigated through cultural practices, there is a need to continue efforts to identify and distribute cassava clones that are tolerant or resistant to these diseases.

Research on FSD continues, focusing on the confirmation of the association of the phytoreoviruslike agents and the entire complex of disease symptoms. Hybridization assays have been developed to detect the ds-RNAs associated with the disease, making it possible to screen cassava germplasm more effectively. Now that the assay is available, more emphasis will be placed on looking for resistance.

Additional research is also needed in NE Brazil to determine the losses caused by CVMV. The vector of this virus needs to be determined to understand its epidemiology. Control of this virus should be a part of the integrated pest management strategies developed for this area of Brazil.

There are excellent detection and control measures for CCMV. Some additional research is needed to identify resistant germplasm, but directly in those areas where the disease is causing losses. Screening CCMV-resistant material from the Cassava-Trans project can be done at CIAT.

The greatest need for ACMV is to identify additional resistant germplasm. As resistant germplasm is identified in the CIAT/IITA collaborative project, it needs to be transferred back to CIAT so that there are adequate sources of ACMV resistance in germplasm adapted to tropical America. A similar project is needed for those areas of tropical Asia in which the virus is not present.

Beside the major diseases, there are seven other known viruses that infect cassava. Although most of these viruses do not appear to cause disease, they are of quarantine significance because of their limited distribution. Diagnostic methods have been developed for both the viruses that cause diseases and the symptomless ones. These diagnostic methods help assure the safe movement of cassava germplasm, and a research objective will be to develop even more sensitive detection methods.

8. ENTOMOLOGY AND ACAROLOGY

Early research in cassava entomology and acarology defined the arthropod complex in cassava and identified key and potential pests. A large complex of pests was found, especially in seasonally dry lowland areas of the Neotropics. Extensive efforts for developing control strategies were made for species associated with significant yield losses.

Pests that attack the crop over a long period of time (3-6 mo) cause the greatest losses. These include mites, thrips, mealybugs, lacebugs, whiteflies and the burrowing bug. Some species such as shootflies, fruitflies, scale insects, gall midges, termites, leafcutter ants and stemborers occur sporadically, causing little or no yield reduction.

Cassava is produced primarily by small-scale, resource-poor farmers, and pesticide use is limited or negligible. In areas where cassava production is under intensification (e.g., Colombian North Coast, Coastal Ecuador, NE Brazil), however, increased agrochemical input as a means of increasing yields may eventually result, particularly in seasonally dry areas where arthropod pest problems are severest. In crops such as cotton, potatoes and rice, dependence on pesticide use with prophylactic applications has often led to the development of resistance to pesticides, negative environmental effects, and even to abandonment of the crop when the cost of pest control exceeded returns from production. Integrated pest management (IPM) is often implemented at this point in order to reverse this process.

The objective of the Cassava Entomology and Acarology Section is to implement ecologically sound crop protection practices while cassava production is in the intensification stage, before the use of pesticides becomes significant. Accordingly, research has focused on host plant resistance (HPR), biological control and cultural control practices.

Cassava Entomology and Acarology is a dynamic program that responds to changing needs in crop protection. Considerable basic information and improved technology components have been generated for control of pests such as mites, mealybugs and hornworms. Although substantial research is still needed, technology based on HPR and biological control for mites and mealybugs, and augmentative biological control of the hornworm are in the implementation stage. A major project for testing and refining this technology with farmers, and for training farmers and crop protectionists in ecologically sound pest and disease management has been developed for NE Brazil in collaboration with the Pathology section. As part of the same project, IITA will lead a similar effort in West Africa. UNDP funding is being sought for this undertaking.

Research on pests such as whiteflies, burrowing bugs and lacebugs is more recent; and considerable basic study is needed before sound technology can be recommended.

Some sources of HPR to whiteflies and lacebugs have been identified; however, these need to be evaluated against the various species found in the different cassava ECZs of the Neotropics.

Research on pests of dried stored cassava, true seed and wild *Manihot* species has been initiated recently to meet the future demands set out in the Cassava Program strategy for the 1990s. In addition the potential of wild *Manihot* species as sources of HPR to such pests as hornworm, lacebugs, burrowing bugs and certain whitefly species (*Bemisia tabaci*) will be evaluated.

8.1 Mites

The Cassava Green Mite (CGM, *Mononychellus tanajoa*), a major pest in some areas of the Neotropics, was accidentally introduced to Africa from the Americas in the 1970s. Control of CGM in Africa is one of the most important challenges facing crop protection today. CGM is a serious pest in the most important cassava-growing area of the continent--NE Brazil. A sibling species, *M. caribbeanae*, is a pest in subhumid areas of Venezuela, Colombia, Ecuador and the Caribbean basin. This report summarizes CIAT's contribution to IITA's classical biological control effort for Africa, describes the agroecological basis of the CGM problem in NE Brazil, and outlines a strategy for its solution.

8.1.1 Exploration for natural enemies of CGM in the Neotropics

In order to implement classical biological control of CGM in Africa, a collaborative, multinstitutional effort was organized by IITA. CIAT and EMBRAPA were engaged to explore for predatory phytoseiid mites, considered to be the most important natural enemies of CGM in South America; while IITA implemented the release and follow-up campaign in Africa. Other institutions including universities in developed countries and several African national programs were also involved in the effort.

Explorations for phytoseiid natural enemies of CGM were conducted by CIAT from 1983-90 in most cassava-growing countries of the Neotropics. CIAT conducted extensive surveys in Colombia, Venezuela and Ecuador, and smaller scale surveys in NE Brazil, Trinidad & Tobago, Guyana, Peru, Paraguay, Mexico, Cuba, Panama and Nicaragua, visiting 1261 cassava fields. In NE Brazil, a parallel exploration effort was conducted by EMBRAPA from 1988-90 covering 427 cassava fields. Explorations by both institutions involved qualitative and quantitative evaluation of CGM, other tetranychid mites, and natural enemy populations on cassava, and in neighboring vegetation. Agroecological criteria were used to prioritize the exploration efforts. High priority was given to seasonally dry and semiarid lowlands; humid lowland sites were also included in the surveys.

8.1.1.1 Geographic patterns of distribution, host plant range and abundance of CGM and related species in the Neotropics. Four species of *Mononychellus* were found in cassava. The most geographically widespread was *M. caribbeanae*, which occurred throughout Central and South America in all countries surveyed except Brazil, Peru and Paraguay. *M. mcgregori* was found in the inter-Andean valleys of Colombia, Ecuador and Peru and in the Colombian and Peruvian Amazon Basin. *M.tanajoa* was found in Panama, Colombia, Venezuela, Guyana, Trinidad, Ecuador, Paraguay and Brazil. *M. planki* was detected in 5 fields in Colombia and in one of 52 fields surveyed by CIAT in Brazil. In 778 samples taken from vegetation adjacent to cassava fields, *M. mcgregori*, *M. caribbeanae* and *M. planki* were found in 11, 6 and 1 plant species other than cassava (*M. esculenta*) resp. Although reported from wild *Manihot* spp. in Brazil, *M. tanajoa* was found only once on a host plant other than *Manihot* spp. (in Panama).

Avg *M. tanajoa* no./leaf were significantly higher in NE Brazil than in Colombia. Within NE Brazil significantly higher densities (P=.10) were found in areas with 365-700 mm rainfall/yr than in other rainfall zones; whereas in Colombia *M. tanajoa* was found in only 1 of the 15 sites sampled with 365-700 mm rainfall/yr. The sibling species *M. caribbeanae* was found in 4 of these sites. Higher population densities of *M. caribbeanae* (X=127/leaf; n=34) than *M. tanajoa* (X=66/leaf; n=34) were found in surveys of semiarid and seasonally dry areas of Venezuela; and *M. caribbeanae* was the only species found in seasonally dry and semiarid areas of Ecuador, suggesting this species is well-adapted to subhumid conditions.

8.1.1.2 Geographic distribution of phytoseiid natural enemies of CGM in the Neotropics. The phytoseiid complex on cassava in the Neotropics attained max. diversity in Colombia, where 40 species were identified. The composition of the complex in Colombia varied regionally (CIAT Annual Report, 1990). *Amblyseius limonicus sensu lato* was the dominant species in all areas surveyed, except in the seasonally dry to semiarid Guajira, where *M. tanajoa* was replaced by *M. caribbeanae* as the dominant species of *Mononychellus* and *A. idaeus* was the dominant phytoseiid. In other seasonally dry areas of Colombia, *M. tanajoa* was the predominant species of *Mononychellus*. Although considerable regional variation in the phytoseiid complex was observed within the seasonally dry zone, 3 species (*A. limonicus s.l., A. rapax, A. dentilis*) occurred consistently (CIAT Annual Report, 1990).

In Colombia, Venezuela and Ecuador up to 12 phytoseiid species were found per cassava field, and 29% of the fields contained 3 or more species. In Brazil, 22 phytoseiid species were reported on cassava (Source: EMBRAPA); however, only 2 of them were common. Only 3% of the fields contained 3 or more species, 56% contained only one species, and 28% were devoid of phytoseiids (CIAT Annual Report, 1990).

The no. of dry mo/yr was a useful agroecological criterion for separating Neotropical phytoseiid species ecologically. *Amblyseius chiapensis, A. peregrinus* and *Euseius*

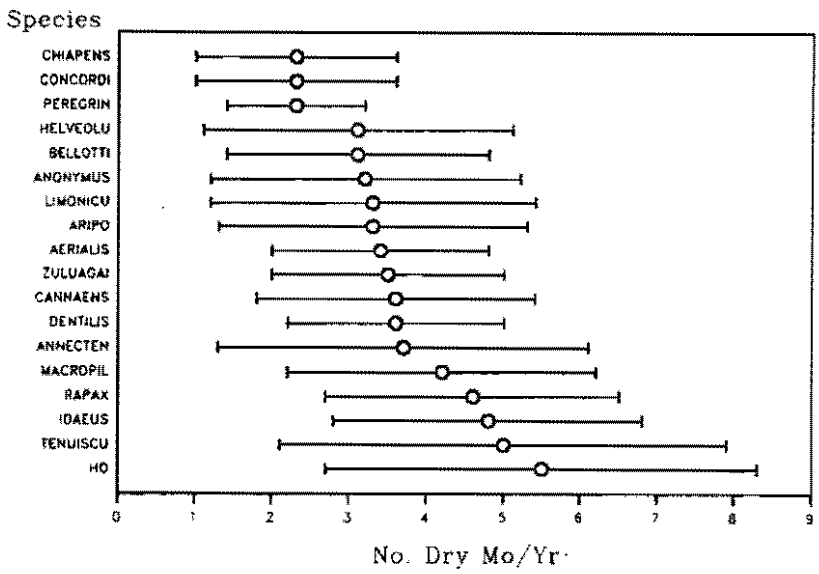

Figure 8.1. Distribution of Neotropical cassava-inhabiting phytoseiids along an agroecological gradient: No. of dry mo/yr. Open circles represent the mean no. of dry mo/yr for cassava fields where each species was present. Bars represent one SD from the mean. Only species found in ≥ 20 fields are shown (sample size from top to bottom: 24, 77, 38, 92, 20, 153, 628, 100, 84, 24, 47, 72, 99, 63, 54, 53, 62).

concordis were strongly associated with humid zones (< 3 dry mo/yr); whereas *A. rapax*, *A. idaeus*, *A. tenuiscutus* and *Euseius ho* were rarely found in humid zones (Fig. 8.1). The other species studied fell between these extremes.

Agroecological data for all phytoseiids detected in NE Brazil were compared with data for the 18 most frequently encountered species in the Neotropics as a whole. *A. limonicus s.l.* was the most frequently encountered species in the 3 principal agroecosystems considered in the survey (Fig. 8.2); however, the data from semiarid areas of NE Brazil were not consistent with this pattern (Fig. 8.3). In NE Brazil *A. idaeus* was the most frequently encountered species after *A. limonicus s.l.* in humid and seasonally dry lowlands and the only species found in more than 10% of the cassava fields in the semiarid lowlands of NE Brazil. In the Neotropics as a whole, *A. idaeus* was a relatively

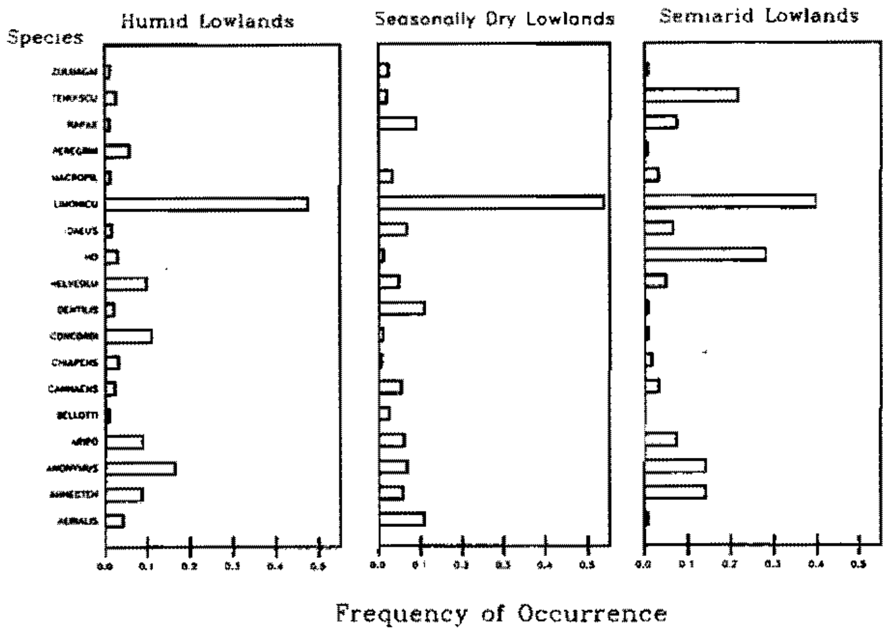

Figure 8.2. Frequency of occurrence of phytoseiid species in cassava in humid, seasonally dry and semiarid lowlands of Neotropics. The proportion of cassava fields where each species was present is given for each agroecological zone. 566, 538 and 121 cassava fields were sampled in humid, seasonally dry and semiarid lowland zones, resp. Species occurring in < 20 fields are not shown.

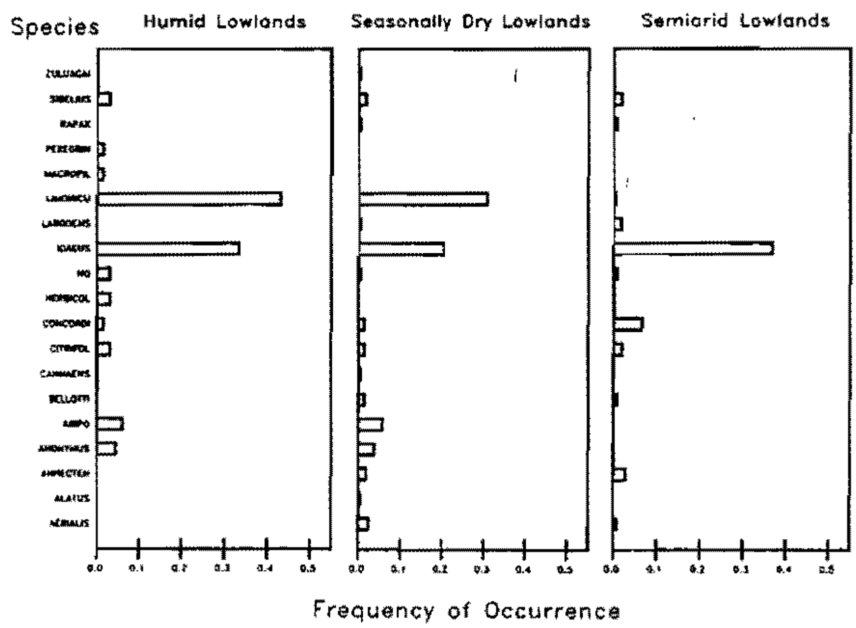

Figure 8.3. Frequency of occurrence of phytoseiid species in cassava in humid, seasonally dry and semiarid lowlands of NE Brazil. The proportion of cassava fields where each species was present is given for each agroecological zone. 66, 210 and 106 fields were sampled in humid, seasonally dry and semiarid lowland zones, resp. (Source: EMBRAPA).

rare species, occurring in less than 10% of the fields in each agroecosystem; however, *A. limonicus s.l.* occurred in more than 40%, *E. ho* and *A. tenuiscutus* in more than 20%, and *A. annectens* and *A. anonymus* in more than 10% of fields surveyed in semiarid areas. The presence of *A. idaeus* in more than 30% of the humid lowland fields in NE Brazil is a further exception to phytoseiid agroecological distribution patterns in the Neotropics as a whole.

8.1.1.3 Geographic distribution of fungal pathogens of CGM. In 1989 EMBRAPA reported epizootics of the entomopthoraceous fungus *Neozygites* sp. on CGM in seasonally dry areas of NE Brazil. This led to interest in assessing the feasibility of introducing the fungus to Africa for biological control of CGM. Although detection of microbial control agents was not contemplated when the exploration survey was designed, the collection of CGM and phytoseiid specimens from each field site for identification provided an indirect means of assessing whether phytoseiids are also affected by the fungus, and of estimating the frequency with which fungal pathogens were present in field populations of CGM and related mite species. Fungal structures were found in *M. tanajoa* specimens in 10% of the fields (n=77) sampled in Venezuela, Brazil, Trinidad and in the Colombian states of Santander, Atlántico, Caquetá and Valle. Of the fields sampled in Colombia (n=25), 32% contained infected CGM. Infected *M. caribbeanae* were reported from Venezuela, Cuba and the Colombian Guajira. The presence of zygospores in samples from Venezuela, Brazil and Atlántico, together with size differences in primary conidia, suggest that several species of *Neozygites* may be involved. No infected phytoseiids were observed.

8.1.2 Provision of phytoseiid natural enemies to Africa

In order to provide IITA with phytoseiid natural enemies, lab culture methods were developed. The standard insectary-style culture unit developed by McMurtry and Scriven, based on artificial substrate such as black plastic, with tetranychid mite eggs provided as food and cotton wool fibers as oviposition sites, did not give satisfactory results for a number of species of cassava-dwelling phytoseiids. A breakthrough was achieved by using cassava leaves infested with tetranychid mites as the rearing substrate. Some species could be reared successfully with either *Tetranychus urticae* or *Mononychellus* spp. as prey; other species required *Mononychellus* spp.. A standard unit employing cassava leaves as substrate was developed (Mesa-Bellotti Unit, see Cassava Newsletter, vol. 11(1), 1987), and quality control methods were devised to ensure that rearing units were not contaminated by other phytoseiid species. The periodic addition of wild-type individuals to cultures minimizes possible undesirable effects of lab selection. Packing and shipping methods were developed to permit the transfer of pure cultures of phytoseiids in large numbers to quarantine facilities at the U. of Amsterdam before transfer to Africa.

Ten species of natural enemies from the Neotropics have been sent to Africa since 1984. Shipments peaked during Oct. 1988-Oct. 1989, when over 25,000 individuals of 5 species were received in 14 consignments by the quarantine service (Source: International Quarantine for Mite Predators).

In addition methods were developed for multiplying phytoseiids with a minimum of resources and in the absence of infrastructure for control of light, temp and RH. A mean of 350 female *A. tenuiscutus*/rearing unit were produced every 4 days (the optimum harvest interval) in prototype units made from plastic canisters containing *Mononychellus*-infested leaves and maintained in a lean-to bamboo shelter. The use of field cages for multiplying *A. tenuiscutus* was feasible as a means of quickly increasing a small founder population for farm-level inoculative releases.

8.1.3 Ecological and biological characterization of natural enemies

8.1.3.1 Predatory phytoseiids. In order to provide basic information on their biological attributes, benchmark studies were made of each species put into culture. This information was intended to guide the adaptation of mass rearing techniques in Africa, to provide a baseline against which to monitor possible quality change in culture, and to aid in the selection of species for introduction to Africa. The benchmark studies consisted of a life table generated at 25±5°C, 75±10% RH, an olfactometer test (developed by the U. of Amsterdam) for ability to detect *M. tanajoa*, other prey-specificity tests and performance tests on nonacarine foods. Comparative life tables were constructed for each species with *M. tanajoa* and *T. urticae* as prey. Behavior with *T. urticae* as prey was intended as an indicator of feeding specificity. In other specificity tests, development and fecundity of selected phytoseiid species were measured with each of the major Neotropical species of cassava-dwelling tetranychids as prey.

Results of life-table analyses for 22 species of phytoseiids and other benchmark studies are reported elsewhere (CIAT Annual Reports, 1989, 1990; Mesa et al., 1990[8.1]; Janssen et al., 1990[8.2]). These data, together with information from exploration surveys and field impact studies, formed the basis for recommendations to IITA on species to be considered for introduction to Africa. *A. limonicus s.l.*, *A. tenuiscutus* and *A. idaeus* were highly recommended for their apparent specificity for *Mononychellus* spp.; in the case of *A. tenuiscutus* and *A. idaeus*, for their ecological adaptation to seasonally dry and semiarid evironments. Although these phytoseiids are believed to play a major role in biological control of *Mononychellus* spp. in the Neotropics, exploration data suggest that the presence of a complex of several species of phytoseiids may be important for successful control of CGM (CIAT Annual Report, 1990).

[8.1] Mesa, N.C., A.C. Bellotti and A.R. Braun. 1990. A comparison of *Mononychellus progresivus* and *Tetranychus urticae* as prey for five species of phytoseiid mites. Exp. Appl. Acarol., 9:159-168.

[8.2] Janssen, A.; Hofker, C.D.; Braun, A.R.; Mesa, N.; Sabelis, M.W.; Bellotti, A.C. 1990. Preselecting predatory mites for biological control: the use of an olfactometer. Bulletin of Entomological Research 80(2):177-181.

Experience with rearing phytoseiids of the same species collected from different locations was the first indication of significant biological and ecological differences among geographic subpopulations. Rearing difficulties with A. *limonicus s.l.* led to the development of the Mesa-Bellotti unit; however, *A. limonicus s.l.*, subsequently collected from the North Coast of Colombia, was multiplied much more easily than *A. limonicus s.l.*, collected from CIAT. Subsequent life-table analysis revealed variations in the intrinsic rate of increase among geographic subpopulations. The inclusion of different populations of *A. limonicus s.l.* and other species in development and reproduction studies on several prey species confirmed that geographic subpopulations or races of phytoseiids have evolved in the cassava system (CIAT Annual Report, 1990). Three *A. limonicus s.l.* populations from the North Coast of Colombia had significantly higher fecundities than the population from CIAT when *M. caribbeanae* was offered as prey, even though only one of the North Coast populations is associated with *M. caribbeanae* in the field. Likewise, *A. tenuiscutus* from Ecuador (Quevedo) had significantly higher fecundity than a population from Colombia (Las Córdobas) when *M. tanajoa* was offered as prey. The existence of intraspecific differences in growth rate and adaptation to prey type may strongly affect colonization ability, which may explain the difficulties experienced in Africa in establishing *A. limonicus s.l.* populations collected at CIAT.

Of 16 populations of *A. limonicus s.l.* obtained, 13 were from different sites in Colombia and one each from Brazil, Venezuela and Trinidad & Tobago. Based on multiple correspondence analysis of polymorphic esterase loci in polyacrylamide gels, these populations were grouped into 5 races. *A. limonicus s.l.* from the Colombian state of Meta (Villavicencio) and from Santa Isabel, Venezuela were distinct from each other and from all the other populations. *A. limonicus s.l.* from Tacarigua, Trinidad and Cruz das Almas, Brazil were indistinguishable and together formed a third group. Three populations from the Colombian states of Cauca (Santander de Quilichao) and Valle (Vijes, Caicedonia and CIAT-Palmira) formed a fourth race; however, the Vijes population showed evidence of divergence. Eight populations from the North Coast of Colombia (Las Flores, La Paz, Pivijay, Baranoa, Arjona, San Juan de Betulia, Cerete and Ciénaga de Oro) formed a fifth race with evidence of differentiation into two closely related subgroups (Fig. 8.4).

Crosses were performed between *A. limonicus s.l.* populations from Brazil and Venezuela, CIAT and Venezuela, Meta and Brazil and Pivijay and Brazil. Two reciprocal and two homogamic crosses were compared for each pair. Fecundity, % females ovipositing, development time, % eggs inviable, egg-to-adult survival and the proportion of females were determined for the F_1 and for progeny of reciprocal backcrosses. All crosses resulted in viable progeny, confirming that the 4 populations are conspecific; however, fecundity was consistently higher when the female parent was from the Brazilian population. The lowest fecundities were obtained in crosses involving the CIAT population. The proportion of females in the progeny was generally higher in crosses involving CIAT, particularly in the backcross progeny of the crosses between CIAT and Venezuela, where extraordinarily high sex ratios (57 females/male) were observed. In

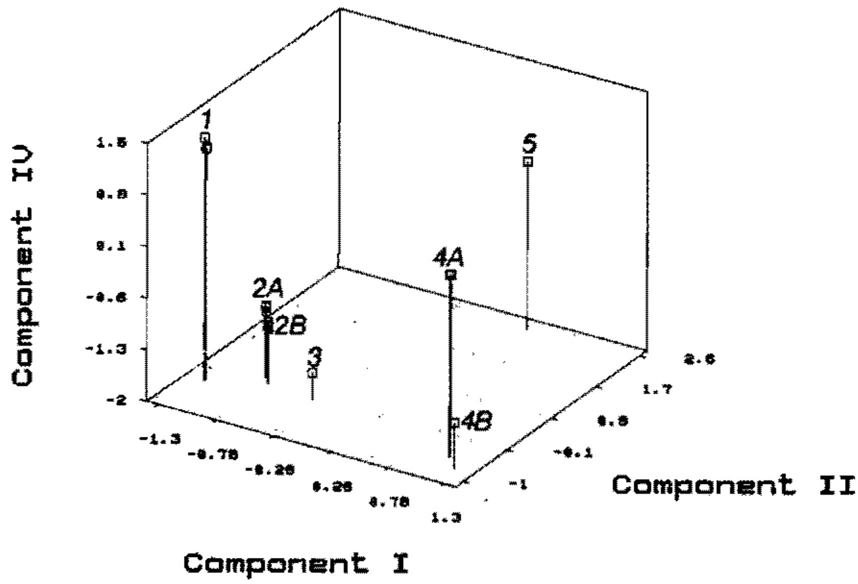

Figure 8.4. Position of 5 *A. limonicus s.l.* races on 3 principal component axes. Component III is not represented. (1 = Brazil, Trinidad; 2A = Betulia, Baranoa, La Paz, Clénaga de Oro; 2B = Arjona, Cerete, Pivijay, Las Flores; 3= Villavicencio; 4A = Santander, Caicedonia, CIAT; 4B = Vijes; 5 = Venezuela).

backcrosses, the % of eggs inviable was consistently lower, and egg-to-adult survival was consistently higher when the male rather than the female parent was an F_1 hybrid. The differences in reproductive parameters observed between the homogamic and hybrid crosses corroborate the existence of races deduced from the electrophoretic study. The status of *A. limonicus s.l.* as a true species distinct from that of *A. limonicus*, originally described from avocado and citrus in California, was confirmed through crossing experiments and electrophoretic analysis.

8.1.3.2 Fungal pathogens. *Neozygites* sp. is pathogenic to all mobile stages of CGM. No evidence was found for transovarial transmission of the disease. In tests involving exposure of *A. limonicus s.l.* to infected CGM, no evidence was found for pathogenicity of this fungus to phytoseiids. The disease cycle of the fungus was determined in CGM. Conidiogenesis does not occur at RHs below 65%; and the formation of anadhesive conidia, which are responsible for propagating the infection, is inhibited at RHs above 65%. The time between inoculation and appearance of symptoms was inversely related to temp in the range of 20-32°C; however, the infection rate of exposed individuals peaked between 24 and 28°C. Efforts to culture *Neozygites* sp. on artificial media involve extracting and transferring the hemocoel of live infected individuals to culture media. Thus far these have been unsuccessful; however, a method for provoking conidiogenesis directly onto culture media is under development. Cultures based on conidia obviate the extraction and transfer of hyphal bodies from the hemocoel--the steps associated with contamination.

8.1.4 Estimation of field impact of natural enemies

8.1.4.1 Phytoseiids. Several species of tetranychids may be present simultaneously on cassava in many areas of the Neotropics (CIAT Annual Report, 1990). Differences in development and fecundity have been demonstrated as a consequence of providing phytoseiids with diets composed of different tetranychid or nonacarine prey; however, ability to utilize a given prey type under lab conditions does not guarantee it will be consumed under field conditions. Electrophoretic analysis of gut contents of field-collected *A. limonicus s.l.* confirmed that this species preys on *M. tanajoa*, *M. caribbeanae* and *M. mcgregori*. *Oidium manihotis*, a fungus hypothesized as an alternative food source for *A. limonicus s.l.* during periods of low acarine prey densities, was not identified in the gut contents of 143 *A. limonicus s.l.* analyzed from 8 field sites in Colombia and Venezuela; neither were tetranychid species commonly associated with cassava (*Oligonychus gossypii*, *O. peruvianus* and *T. tumidus*). Analysis of 64 *A. idaeus* suggests that *M. caribbeanae* is the principal tetranychid prey consumed by this species in Colombia and Venezuela: 70% had consumed *M. caribbeanae*; 10%, *M. tanajoa*; and in the remaining 20%, no prey were detectable. In the Guajira (Fonseca), *M. caribbeanae*, *M. tanajoa*, and *O. peruvianus* comprised 60, 31 and 9% of the tetranychid population resp. *A. idaeus*, *Typhlodromus annectens* and *Euseius alatus* comprised 83, 8 and 5% of the phytoseiid population, resp. The protective effect of phytoseiids on yield was estimated by chemical elimination. Yields 8 mo after planting averaged 8.5 t/ha in plots where phytoseiids were eliminated compared to 18.3 t/ha in plots where they were present. Infestation intensity of *Mononychellus* spp. in plots with and without predators averaged 48,841 and 74,851 mite-days/leaf, resp. Phytoseiid densities accumulated to an avg of 456 phytoseiid-days/leaf in plots where they were excluded and 1342 phytoseiid-days/leaf in untreated plots. Yield declined by an avg of 1 t/ha of cassava per 2691 mite-days/leaf; conversely, 90 phytoseiid-days/leaf provided a protective effect equivalent to 1 t/ha, indicating that *A. idaeus* is an important biological control agent of *M. caribbeanae*.

In a second predator exclusion site, Ciénaga de Oro, where *M. tanajoa* was the predominant species of tetranychid (97%), avg yields of 25 and 21 t/ha (12 mo after planting) were obtained in plots with and without predators, resp. Although the yield difference was not significant, mite infestation intensity was 8,897 and 17,398 mite-days/leaf in plots with and without predators, resp.; and an avg of 1 t/ha was lost per 2125 mite-days/leaf. Conversely, 4.8 phytoseiid-days/leaf provided a protective effect equivalent to 1 t/ha. In this seasonally dry area, *A. limonicus s.l.* and *A. rapax* comprised 69 and 27% of the phytoseiid population, resp.

8.1.4.2 Fungal pathogens. Controlled studies of the impact of *Neozygites* sp. are not yet available; however, indirect evidence from field observations suggests that under certain conditions *Neozygites* may play an important role in biological control of CGM. In an epizootic of the fungus detected in Pivijay (Magdalena), 78% of *M. tanajoa* individuals were infected with *Neozygites* sp. on the sampling date immediately before the *M. tanajoa* population crashed (Fig. 8.5). Mortality due to *Neozygites* sp. and to rainfall (280 mm), which fell during the period preceding the fifth sampling date, may have been the key factors responsible for this.

8.1.5 Characterization of CGM in NE Brazil

During exploration in NE Brazil for natural enemies as part of the CGM biological control effort for Africa, CIAT and EMBRAPA observed that the severest CGM attacks occurred in semiarid areas. In surveys conducted by IITA in Africa, CGM attacks in semiarid areas were not observed; nor have they been frequently observed within the Neotropics (except in Brazil), possibly because *M. caribbeanae* rather than *M. tanajoa* predominates in such areas, except in Brazil, where *M. caribbeanae* does not occur.

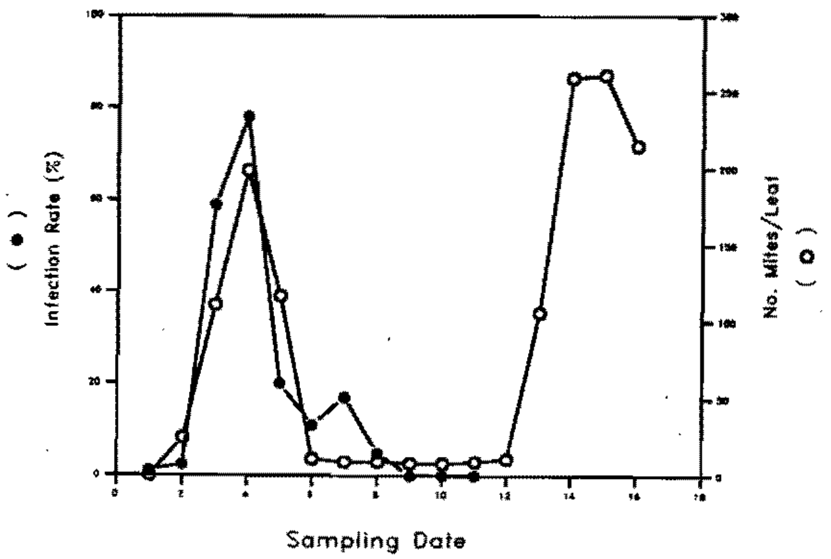

Figure 8.5. Dynamics of *Neozygites* sp. infection (% mites infected) in a field population of CGM; infection rate not available for sampling dates 12-16.

In an extensive biotaxonomic analysis of *M. tanajoa*, polymorphism was found with respect to the lengths of the dorsal setae, a character used in species identification. Polymorphism was found in all Neotropical regions where CGM occurs, except for NE Brazil, where 100% of 352 mites examined from 35 collection sites were classified into a single morph (very short) by cluster analysis, corroborating earlier taxonomic work done in Brazil. Similar work in Africa (Rogo et al. 1988)[8.3] demonstrated that the African CGM is polymorphic.

Mites of the genus *Mononychellus* are rarely found on hosts other than cassava and its wild relatives, and the species of the *Mononychellus* complex appear to have adapted to different cassava agroecosystems. *M. caribbeanae* occurs primarily in hot, dry areas in the Caribbean basin and along the Ecuadorian coast. *M. mcgregori* occurs in humid inter-Andean valleys and in the Amazon Basin of Colombia, Peru and Ecuador. *M. planki* is an extremely rare species. *M. tanajoa* has a broader agroecological range than its sibling species; however, it does not occur north of Panama or south of Colombia in the Andean Region. *M. tanajoa* is the only species of the complex present in Paraguay and Brazil. Although *M. caribbeanae* is well adapted to subhumid areas, it does not occur in NE Brazil.

These biotaxonomic and agroecological distribution data suggest that the trophic association between *Mononychellus* and cassava may have originated in the northern Neotropics. Outside Africa, the only regions where *M. tanajoa* occurs in the absence of other *Mononychellus* species are Brazil and Paraguay. In Africa, *M. tanajoa* has not invaded semiarid areas although the data from Brazil demonstrate that this is possible. The monomorphic character and semiarid adaptation of CGM in NE Brazil suggest that a race or subspecies of CGM has developed there. A possible explanation for this is that CGM was introduced to Brazil from the northern Neotropics; and it was able to colonize semiarid areas in the absence of competition from *M. caribbeanae* and predation by species such as *A. tenuiscutus* and *A. rapax* and strains of *A. limonicus s.l.* adapted to semiarid areas.

8.1.6 Estimated impact

The CGM has been the object of a pest management effort by EMBRAPA in NE Brazil since the 1970s. Losses have been estimated at 10-50%, depending on agroecological zone, variety, planting date, planting system and length of the crop cycle (Source: EMBRAPA).

[8.3] Rogo, L.M., Oloo, W. Nokoe, S. and Magalit, H. 1988. A study of the *Mononychellus* (Acari: Tetranychidae) species complex from selected cassava growing areas of Africa using principal component analysis. Insect Sci. Applic. 9, 593-599.

8.1.7. Strategy for managing CGM in NE Brazil

Several phytoseiid species and strains not detected in Brazil have been found in homologous seasonally dry and semiarid cassava-growing areas in northern South America, suggesting a potential for increasing the effectiveness of local natural enemies in NE Brazil through augmentation and conservation practices, and for improving the level of biological control through the introduction of exotic species. The CGM management strategy should also include the use of resistant clones, good-quality planting material, as well as agronomic practices that conserve soil fertility. The deployment of *Neozygites* sp. as a biological control agent will depend on selecting virulent strains adapted to the agroecological conditions of target areas and developing simple technology for multiplying and applying the fungus. Further investigation of culture methods, specificity and an analysis of possible risks to human health are necessary. This should be accomplished as part of an integrated effort involving farmers in the testing and adaptation of crop protection technology for CGM and other pests and diseases associated with targeted agroecological areas. Sites for crop protection pilot projects should be chosen in areas where farmers have access to markets for the additional production accruing from reductions in pest impact.

8.2 The Cassava Hornworm *Erinnyis ello* (L.)

The cassava hornworm is one of the most serious pests of cassava in the Neotropics. *E. ello* has a broad geographic range, extending from southern Brazil, Argentina and Paraguay to the Caribbean basin and the southern US. *E. ello* is polyphagous with at least 35 recorded food plants, including 21 species of Euphorbiaceae.

Larvae feed on cassava leaves of all ages, stems and leaf buds. Severe attacks result in complete plant defoliation, bulk root loss and poor root quality. In simulated damage studies, yield losses in fertile soils ranged from 0 to 25% for one attack and up to 47% after two consecutive attacks. On less fertile soils, losses were between 15 and 45% for one attack and up to 64% after two attacks. Losses in farmers' fields after one attack were 18%. Repeated attacks are most common when ill-timed pesticide applications do not destroy 5th instar larvae or pupae, but eliminate the natural enemies that build up during the initial hornworm outbreak. Control measures based on sound ecological principles are needed to avoid pesticide use.

8.2.1 Biology and ecology

The migratory flight capacity of *E. ello* is well documented. Adults migrating en masse will oviposit in cassava fields. Under conditions of high leaf area, up to 600 eggs/pl may be found; larval populations may exceed 100/pl. A 5-yr study of *E. ello* populations using light traps at CIAT showed that hornworms are present throughout the year and that peak activity coincides with the rainy season, during which the abundant foliage required for developing large hornworm populations is available. These data are supported by observations and data from other areas in Brazil, Colombia, Mexico and Cuba.

Current hornworm mass-rearing methods (CIAT Annual Report, 1989) yield 4000 to 5000 eggs/day and provide larvae of known ages for experimental purposes. Larval duration at 15, 20, 25 and 30°C averages 105, 52, 29 and 23 days, resp. Development is 5 times faster at 30°C than at 15°C. The minimum temp threshold (MTT) for development is 11.2°C and 398 degree-days (°D) are required for development to adulthood (CIAT Annual Report, 1987). These data suggest that peak hornworm activity should occur in lowland to middle altitudes (800-1200 m) in the tropics and during the summer periods in the subtropics.

8.2.2 Biological control

Research on the cassava hornworm natural enemy complex was initiated more than 15 years ago. Approx. 30 species of parasites, predators and pathogens have been studied, leading to the hypothesis that migratory capacity of hornworm adults is a mechanism for escaping from natural enemies, which greatly reduces the effectiveness of natural biological control. Because their rate of reproduction is limited, predators and parasites cannot usually compensate quickly enough to suppress dramatic hornworm outbreaks. Although well-timed pesticide applications can bring hornworm irruptions under control, they are costly, toxic to natural enemies and to the environment, and may cause outbreaks of other pests such as mites. For biological control to be effective under these conditions, native natural enemy populations must be augmented when adult invasions occur. An easily manageable natural enemy must be available for introduction during the early stage of larval feeding.

A granulosis virus of the family Baculoviridae infects hornworm larvae and is effective in managing hornworm populations. To determine pathogenicity, infected larvae were collected from the field, liquified in a blender and filtered through cheesecloth. The resulting liquid was diluted with water and applied to cassava plants. Within 72 h after feeding, larval mortality reached 100%. In a field trial in El Patía, Colombia, fresh virus preparation was applied to hornworm-infested fields. Hornworm numbers were monitored on 50 plants in treated and nontreated plots before and 48 h after application. Mortality at 48 h was 98% (CIAT Annual Report, 1988).

The effects of virus concn. and larval instar on mortality were evaluated after 72, 96, 120 and 144 h. At 0.9 ml virus/lt water ($1.5x10^{6}$ inclusion bodies/lt), 90% mortality was obtained. A sigmoidal relationship between concn. and mortality was found for the 1st, 2nd and 4th instars. In the 3rd instar the relationship was asymptotic, with higher mortality at a lower concn. than in other instars (Bellotti et al., 1991)[8.4]. Most 5th instar larvae reached the prepupal stage. At the lowest concn. (185x10^4 inclusion bodies/lt), 30% mortality occurred; 53% mortality was obtained at the highest concn. (4.5x10^6 inclusion bodies/lt) (Table 8.1). At the lowest concn., 60% of the prepupae reached the pupal stage; whereas only 28% pupated at the highest concn. Considerable pupal deformity was observed. Adult emergence from the pupal stage was 45% at the lowest concn. and 15% at the highest. Wing deformity was common in adults. Very few female adults emerged, dying without producing progeny. These results indicate that virus applications to 5th instar larvae at high concn. can effectively reduce populations of subsequent hornworm populations.

The lowest LC_{50} (0.06 ml virus/lt water) was found for first instar larvae. LC_{50} increased to 0.45 ml of virus/lt (Fig. 8.6) for 4th instar larvae, indicating that progressively higher concn. are needed for adequate control of each succeeding hornworm larval instar. This reinforces the importance of early detection of hornworm attacks so that virus preparations can be applied while larval populations are in the early instars, which are susceptible to low concn. of the virus.

Table 8.1. Effect of concn. of *Baculovirus* on survival of 5th instar larvae of *E. ello*.

(No. Inclusion Bodies/lt H_2O)	% Survival		
	Prepupa	Pupa	Adult
0	85	80	57.5
1.85 x 10^4	70	60	45
7.4 x 10^4	65	45	37.5
2.2 x 10^5	55	40	30
6.8 x 10^5	55	40	30
1.9 x 10^6	52.5	32.5	25
3.3 x 10^6	47.5	27.5	17.5
4.5 x 10^6	47.5	27.5	15

n = 40/stage

[8.4] Bellotti, A.C.; Arias, B.; Guzmán, O.L. 1991. Biological control of the cassava hornworm Erinnyis ello (L). Florida Entomologist. (In press).

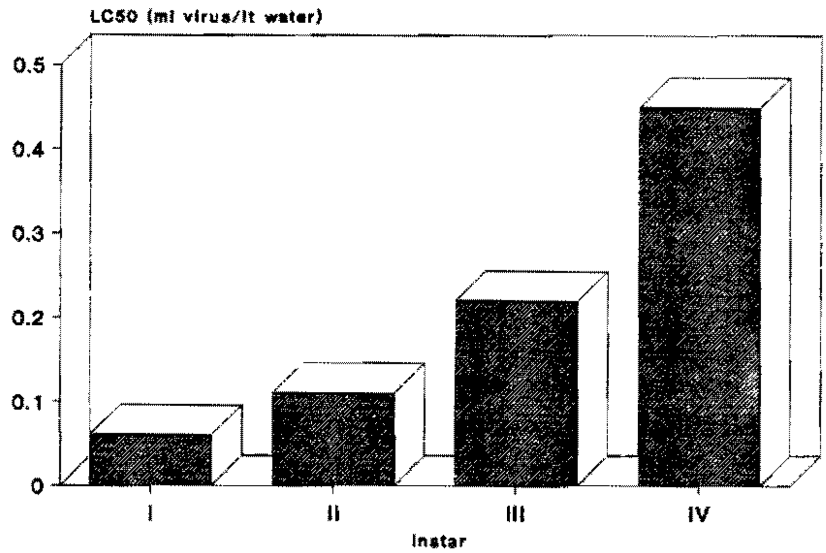

Figure 8.6. Susceptibility of larval instars of *E. ello* to Baculovirus.

Duration of pathogenicity was determined after applying a 20% virus solution to cassava fields. At 0, 1, 5, 9, 13 and 19 days after application, leaves were removed and placed in petri dishes in the lab and fed to first instar larvae. Mortality was measured 96 h later. At 24 h after application, mortality was > 96%, declining to 11% after 19 days. At 9.4 days after application, 50% mortality was attained (Fig. 8.7), indicating that in the case of prolonged attacks, the virus should be applied every 9 days to obtain optimal control. There was no significant difference in mortality between virus preparations applied with or without an adjuvant.

Hornworm attacks tend to increase in frequency in areas of intensive cassava production, such as coastal Ecuador and Colombia, and NE and southern Brazil. Natural biological control is ineffective in preventing outbreaks due to adult migration. The hornworm virus provides an attractive management option given its ease of manipulation and storage, and low cost. Research on improved storage and application of the virus is still needed. The virus is being used by farmers in some parts of Brazil.

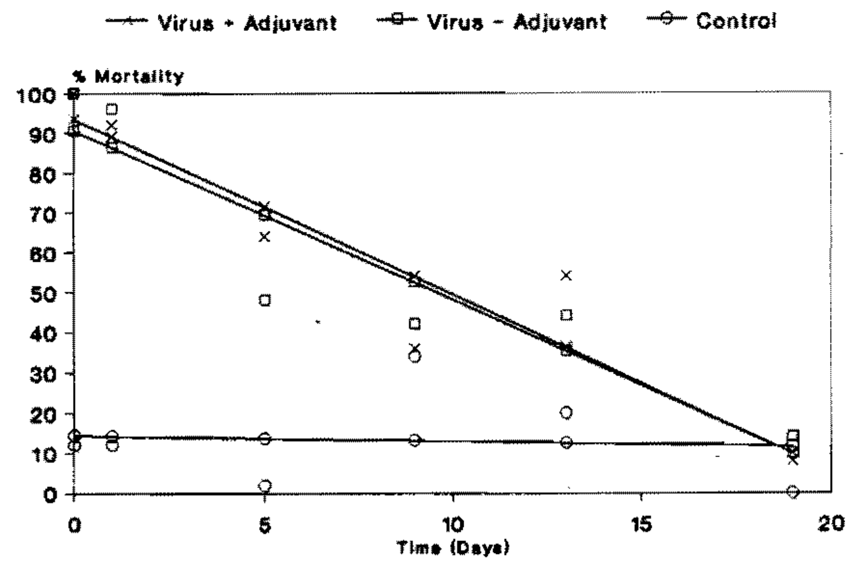

Figure 8.7. Persistence of Baculovirus, applied with and without adjuvant, to field populations of *E. ello*.

8.3 Cassava Mealybug

Numerous species of mealybugs attack cassava; however, only *Phenacoccus herreni* and *P. manihoti* are important economically. Both are of Neotropical origin; but *P. manihoti*, a major pest of cassava introduced to Africa, is confined to Paraguay, certain areas of Bolivia and the Matto Grosso area of Brazil.

P. manihoti, which has caused heavy yield losses in cassava in Africa, has been the object of a major classical biological control program. CIAT collaborated extensively with IITA in identifying the geographic origin of this pest and in studying its natural enemies. The hymenopteran parasite, *Epidinocarsis lopezi*, discovered in Paraguay, has become established in Africa and is bringing the mealybug under control. At present CIAT research is focused on *P. herreni*.

8.3.2 Damage yield losses

P. herreni, reported only from South America, causes damage similar to that of *P. manihoti*. It has been detected in certain areas of Colombia, Venezuela and the Guayanas, and is spreading through NE Brazil. Yield losses up to 80% have been estimated in farmers' fields. Yield losses in experimental plots have reached 88%, depending upon clone, plant age and duration of attack (CIAT Annual Reports, 1984, 1987, 1988 and 1990).

Mealybugs extract Ca from cassava leaves during feeding. Loss of Ca may result in weakened, less rigid cell walls, which may be responsible for the leaf curling characteristic of mealybug damage. Reduction in photosynthetic rate, transpiration, mesophyll efficiency and moderate increases in water pressure deficit, internal CO_2 and leaf temp were found in infested plants. A positive correlation was found between low photosynthetic rate and lower leaf Ca content, suggesting that Ca-rich clones may be more tolerant of *P. herreni* attack than Ca-poor clones (CIAT Annual Report, 1988).

8.3.2 Biology and ecology

P. herreni populations peak during dry seasons (van Driesche et al. 1990)[8.5]. Rains reduce pest populations and permit plant recovery. The development of *P. herreni* was studied under controlled conditions at 20, 22, 25, 30 and 35°C. Female development time was 90 days at 20°C, 38 days at 25°C, 39 days at 30°C and 59 days at 35°C. Optimal female development occurs between 25 and 30°C. The MTT for females was 17.5°C, and 331°D were required to complete development (Herrera et al., 1989)[8.6].

8.3.3 Mealybug control

A combination of HPR and biological control can offer stable control of mealybug populations. Partial resistance (low to moderate levels) may reduce *P. herreni* to levels that make biological control more effective. Where adequate numbers of natural enemies are present in cassava fields, high levels of HPR may not be required to maintain mealybug populations below economic injury levels.

[8.5] Van Driesche, R.G., A.C. Bellotti, J.A. Castillo and C.J. Herrera. 1990. Estimating total losses from parasitoids for a field population of a continuously breeding insect, the cassava mealybug *Phenacoccus herreni* (Homoptera: Pseudococcidae) in Colombia, S.A. Florida Entomologist. 73(1):133-143.

[8.6] Herrera, C.J., R.G. van Driesche, and A.C. Bellotti. 1989. Temperature-dependent growth rates for the cassava mealybug, *Phenacoccus herreni*, and two of its encyrtid parasitoids, *Epidinocarsis diversicornis* and *Acerophagous coccois* in Colombia. Ent., Exp. Appl. 50:21-27.

8.3.4 Biological control

Approx. 70 species of parasites, predators and pathogens of cassava mealybugs have been identified in the Neotropics. Current research efforts are primarily directed toward the natural enemy complex associated with *P. herreni*; however, collection, evaluation and provision of natural enemies to IITA for evaluation and possible release in African continues.

8.3.5 Parasites

Parasites of *P. herreni* identified in Colombia, include *Acerophagus coccois*, *Epidinocarsis diversicornis*, *Anagyrus putonophilis*, *A. insolitus* and *Apoanagyrus elgeri*. Recent explorations in Venezuela led to the identification of *Aenasius* sp. (*near vexans*) as an important parasite. *E. diversicornis* prefers 3rd instar nymphs; whereas *A. coccois* parasitizes male cocoons, adult females and 2nd instar nymphs with equal frequency. Ovipositor penetration by *E. diversicornis* caused 13.2% mortality of first nymphal instars (van Driesche et al., 1990). In-field studies, using trap plants with mealybug hosts set out in cassava fields, 54.9% mortality was estimated for the combined action of the two parasitoid species present (van Driesche et al., 1988, 1990)[8.7].

A. n. vexans, introduced to Colombia from Venezuela, is in culture and under evaluation in the lab and field. *A. n. vexans* is more specific for *P. herreni* than other parasitoid species evaluated. In a choice test offering the preferred stage of each host, *A. n. vexans* parasitized 36% of *P. herreni* vs. 2% of *P. madeirensis*. *A. coccois* collected from Venezuela parasitized *P. herreni* and *P. madeirensis* with equal frequency, whereas *A. coccois* collected in Colombia is highly specific to *P. madeirensis* (Table 8.2). Distinct biotypes of *A. coccois* may be involved; however, they were not distinguished through electrophoresis of esterases. In studies of host stage preference of *A. n. vexans*, *A. coccois* and *E. diversicornis*, all three species parasitized all host stages; however, within-species preferences for specific instars were identified. *A. coccois* (Ven.) prefers 2nd instar nymphs; *E. diversicornis* prefers 3rd instar and adult females; and *A. n. vexans* prefers 2nd and 3rd instar nymphs and adult females (Table 8.3). When *A. n. vexans* parasitizes 2nd instar nymphs, nearly all offspring are males. Parasitism of 3rd instar nymphs also results in a lower sex ratio; however, parasitism of adult female *P. herreni* resulted in 86% female offspring. *E. diversicornis* is parthenogenetic and no males are produced; however, reproduction was maximized when 3rd instar nymphs were the host. The fact that *A. n. vexans* females are larger than *E. diversicornis* and *A. coccois* females (0.47 mm, 0.43 mm and 0.23 mm, resp.) may influence progeny sex ratio and host stage preference. Although both species (*A. n. vexans* and *E. diversicornis*) will parasitize first instar nymphs, no offspring result (Table 8.4).

[8.7] Van Driesche, R.G., J.A. Castillo and A. C. Bellotti. 1988. Field placement of mealybug-infested potted cassava plants for the study of parasitism of *Phenacoccus herreni*. Entomol. Exp. Appl. 46:117-124.

Table 8.2. Preference of 4 parasitoids (Encyrtidae) in a choice test for *P. herreni* and *P. madeirensis*.

Parasitoid	% Parasitism[1]	
	P. herreni	*P. madeirensis*
Acerophagus coccois (Venezuela)	32	27
A. coccois (Colombia)	0	27
Aenasius n. vexans (Venezuela)	36	2
E. diversicornis (Colombia)	32	16

[1] Data taken from several experiments.

Table 8.3. Preference of three parasitoid species (Encyrtidae) in a choice test for life stages of *P. herreni*.

Stage	% Parasitism [1]		
	Parasite Species		
	A. coccois (Ven.)	*E. diversicornis*	*A. n. vexans*
Instar I	8.3 c	10.3 c	3.5 c
Instar II	63.3 a	19.0 b	35.1 a
Instar III	26.7 b	34.9 a	35.1 a
Adult female	1.7 d	35.8 a	26.3 b

[1] Data taken from several experiments.
(P = 0.05, DMRT)

Table 8.4. Comparison of parasitism rates *A. n. vexans* and *E. diversicornis* competing for different life stages of *P. herreni*.

Mealybug Stage[1]	N[1]	No. Mealybugs Parasitized		
		Species		
		A. n vexans		*E. diversicornis*
		Females	Males	Females
Nymph 1	250	0 d	0 d	0 d
Nymph 2	250	1 c	17 b	19 c
Nymph 3	250	17 b	24 a	32 a
Adult	250	37 a	6 c	21 b
	Total	55	47	72

[1] Five reps of 50 individuals from each mealybug stage.
[2] Five pairs of *A. n. vexans* and five *E. diversicornis*.

Egg-to-adult developmental time is 16 days for *A. n. vexans* and 18 days for E. diversicornis at 28°C and 60±10% RH. *P. herreni* develops in 39 days, indicating that there are at least 2 generations of the parasitoids per host generation, a favorable ratio in a biological control effort.

Field releases of *A. n. vexans* were made in cassava fields at ICA-Villavicencio, Meta, Colombia. Terminal buds and leaves were artificially infested with *P. herreni*. Parasites were released and % parasitism was compared in (a) terminals completely enclosed in sleeve cages, (b) enclosed terminals with cages open at one end, (c) uncaged terminals artificially infested with *P. herreni*, and (d) uncaged, uninfested terminals. Parasitism levels were measured 10 and 45 days after release of *A. n. vexans*. Considerable parasitism was obtained in uncaged terminals and on terminals in open cages, resulting in a lower rate of mealybug population increase than in the caged terminals. *A. n. vexans* persisted in natural mealybug populations in cassava plantings adjacent to the experimental field throughout the subsequent rainy season, indicating that establishment of this parasitoid may have occurred under field conditions.

8.3.6 Predators

A large complex of predators, mostly of the family Coccinellidae (Coleoptera) have been identified associated with *P. herreni*. Several of these have been evaluated to determine their potential for biological control (CIAT Annual Reports, 1987, 1989-90; Sullivan et al., 1991)[8.8]. Previous studies determined the development cycles and consumption rates of *Cleothera onerata* and *C. notata*. Present research has concentrated on *Hyperaspis* sp., a new species discovered during explorations in the Colombian Llanos.

Development time of *Hyperaspis* sp. was measured under controlled conditions at 20, 25, 28, 30 and 33°C. Female development time was 88 days at 20°C, 29.6 days at 25°C and 20 days at 33°C (Fig. 8.8). The MTT for female development was 15.5°C, and 251.4°D were required to complete development. This compares favorably to the development rate of the prey, *P. herreni* (17.5°C MTT and 331°D). *Hyperaspis* sp. mortality was highest at the lowest temp; 33% mortality occurred at 20°C, 6% at 28°C and no mortality occurred at 33°C, indicating adaptation to high temp conditions, which also favor *P. herreni* population growth.

Hyperaspis sp. prefers to feed on eggs, followed by the 1st, 2nd and 3rd instars and adult stages. Consumption capacity is greatest during its 4th instar, when it can consume 185 eggs/day (Fig. 8.9). These results are similar to those obtained for other cassava mealybug predator species.

[8.8] Sullivan, D.J., J.A. Castillo and A.C. Bellotti. 1991. Comparative biology of six species of coccinellid beetles (Coleoptera: Coccinellidae) predaceous on the mealybug *Phenacoccus herreni* (Homoptera: Pseucoccidae), a pest of cassava in Colombia, South America. Environ. Entomol. 20(2):685-689.

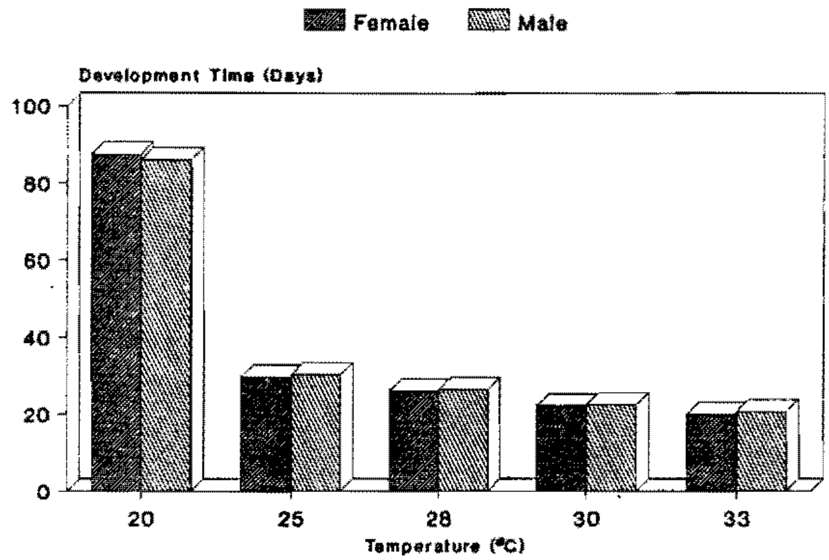

Figure. 8.8. Effect of temp on development time of *Hyperaspis* sp.

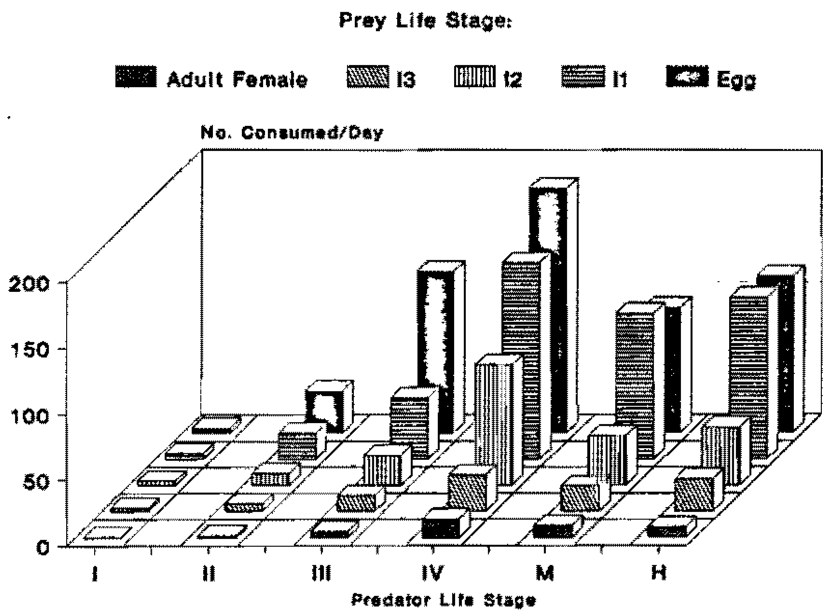

Figure 8.9. Consumption capacity of *Hyperaspis* sp. life stages for *P. herreni* eggs, immature stages and adult females.

Survey data from South America indicate that the *P. herreni* parasitoid and predator complex is large in Colombia and Venezuela, but smaller in NE Brazil, where *P. herreni* populations have caused severe crop damage. *P. herreni* may be of northern South American origin and may have been disseminated along the eastern coast of South America to NE Brazil, where it appears to be an introduced pest. Introduction of natural enemies from northern South America has potential for stabilizing *P. herreni* below economic damage levels in NE Brazil.

8.3.7 Host plant resistance

Approx. 3000 lines from the CIAT germplasm bank have been screened for *P. herreni* resistance at two selection sites over a 5-yr period. Artificial infestation was used to ensure uniform population density. Damage evaluations based on a scale of 1 (no damage) to 9 (necrosis of leaves and branches) were made periodically after infestation. In previous evaluations clones CM 6069-3, CM 2177-2, SM 540-8, SG 250-3, SG 106-54 and CM 2177-2 were selected as promising sources of resistance. The last three were evaluated in replicated trials with and without pesticide to determine yield depression as a resistance criterion. Yield reduction was 10.1, 9.3 and 34.2% for SG 250-3, CM 2177 and SG 106-54 resp. (Table 8.5; CIAT Annual Report, 1990). Adequate levels of resistance or tolerance were identified in the first two clones to justify their incorporation in a resistance breeding program. Clones CM 6069-3, CM 5263-1 and SM 5409-8 selected during 1990 are currently under evaluation for yield depression.

During the 1990-91 cycle, 243 clones were evaluated for *P. herreni* resistance in Carimagua and Villavicencio. CM 2600-2, CM 5948-1, CM 3581-17 and CM 5620-3 were selected to enter the yield depression evaluation scheme. Mealybug populations were higher and damage was severer at Carimagua than Villavicencio, indicating that the former site is superior for resistance screening. Additional greenhouse and lab studies have been initiated to determine whether the resistance expressed is tolerance associated with plant vigor or due to antibiosis mechanisms.

8.4 Cassava Root Mealybug: *Pseudococcus mandio*

Areas of Paraguay, Argentina and southern Brazil (especially the state of Sta. Catarina) have reported root damage due to the mealybug, *P. mandio*. This species feeds on underground plant parts including the swollen roots and below-ground stems, causing clorosis and defoliation of lower leaves and darkened spots on infested roots. Damage reduces commercial value of the roots, and culinary quality is affected. Continuous cassava cultivation results in increased mealybug populations.

A collaborative project, with research contracted with EMPASC, Itajai, SC (Brazil), is studying the occurrence, behavior, damage and control of this pest. Preliminary results are presented from 1989 to date.

Table 8.5. Yield of protected and mealybug (*P. herreni*)-infested plots in Carimagua yield-depression trials.

Clone	Protected Yield t/ha	Infested Yield t/ha	Yield Loss %
CM 2177-2	29.5 c[1]	26.7 d	9.3
SG 250-3	39.2 a	35.2 b	10.1
M Ven 77	30.3 c	20.4 e	32.6
SG 106-54	25.6 d	16.8 fg	34.2
CMC 40	14.2 g	4.6 h	67.0
M Col 22	18.6 ef	2.1 h	86.3

[1] Means with the same letter are not significantly different (P = 0.05).

8.4.1 Biology

Developmental studies of *P. mandio* were done in the lab (25±°C; 80± 5% RH). After eclosion, females complete 3 nymphal stages before adulthood. Males have 4 nymphal stages (the 3rd and 4th stages occur in the pupal cocoon); the 5th stage is the winged adult. Avg egg-to-adult development time for the female is 25 days; adults live an avg of 17.8 days. Avg development time for males is 17.9 days and adults live 1 to 3 days. Fertilization is necessary for reproduction; unfertilized females do not produce eggs.

8.4.2 Yield losses

Yield loss studies were done during two cropping cycles. During the first cycle yield reduction was 17% (significant, T-test; P = 0.05); during the second cycle there was no significant yield reduction.

8.4.3 Control

Research on control of *P. mandio* has been initiated with emphasis on crop rotation and biological control.

8.5. The Cassava Burrowing Bug

The cydnid burrowing bug *Cyrtomenus bergi* was first recorded as a pest of cassava in Colombia in 1980. *C. bergi* is reported from Colombia, Costa Rica, Honduras and Panama. Subsequently, several other species of Cydnidae, which cause similar damage to cassava were identified. This complex includes *Pangaeus piceato, P. aethiophs* (Colombia); *Tominotus communis*, *Prytidorsporus identatus* and *Dallsielus lugubres* (Cuba).

Surveys in Colombia and other areas have revealed that onions (*Allium fistulosum*), peanuts (*Arachis hypogea*), maize (*Zea mays*), sorghum (*Sorgum vulgare*), sugarcane, coffee, coriander, pasture grasses, potatoes and numerous weed species are also hosts of *C. bergi*. Yield losses in peanuts and onions are considerable, and repeated pesticide application are required for effective control as other control measures are not available. This pest apparently has the capacity to switch from a preferred host such as maize to other hosts such as cassava, making control of *C. bergi* a difficult challenge.

The insect feeds by inserting its stylet into the fleshy root (parenchyma). Feeding damage combined with infection by soil pathogens results in the appearance of brown to black spots 12 to 24 h after feeding is initiated. From 70 to 80% of the root may be affected, and a ≥ 50% reduction in starch content is common, resulting in serious reduction in commercial value.

8.5.1 Biology, ecology and behavior

Development and behavior studies were initially hindered because of the inability to rear *C. bergi* in the lab. This problem has been solved by replacing cassava with maize as a culture medium. Lab colonies of 10,000 to 12,000 individuals of all life stages (egg, 5 nymphal instars and adults) have been established.

C. bergi feeding behavior can be studied on "artificial" cassava roots--pellets consisting of low-HCN cassava flour encased in paraffin wrap. These pellets can be used to evaluate nutrient requirements or pesticide effectiveness. *C. bergi* develops faster on maize than on cassava and prefers maize over cassava in free-choice feeding tests (78 vs. 22%). Oviposition was 300 times greater on maize than on cassava (105 vs 0.4 eggs/female); intermediate on onions (CIAT Annual Report, 1990). The LD_{50} on maize was 95 days, compared to 69 on onions and 66 and 64 days, resp., on a sweet (CMC 40) and bitter (M Col 1684) cassava clone. Nymphal development was shortest on maize (92 days), longest on onions (119 days), and intermediate on cassava (111 days) (CIAT Annual Report, 1989).

Field trials suggest that *C. bergi* feeding preferences may be related to the HCN content of the root. Previous lab studies showed that adults and nymphs fed on a high HCN clone had longer nymphal development, reduced adult longevity, reduced fecundity and increased mortality compared to insects fed low HCN clones. Recent studies under controlled conditions compared nymphal mortality and feeding on a low (CMC 40) and a high HCN (M Col 1684) clone. On CMC 40 nymphal mortality was 56%, occurring during the first 2 instars. Nymphal mortality on the high HCN clone in two trials was 94 and 84%, resp. (Table 8.6). All mortality occurred during the first 3 instars, with highest mortality in the first two. On CMC 40, 50% mortality occurred at 35 days (r^2=0.96); for M Col 1684, at 28 days (r^2=0.98). The earliest instars are most susceptible to root HCN content, and even low HCN levels cause considerable mortality. Nymphal development time for the 1st through 3rd instar was 43.5 days on CMC 40 and 81.7 days on M Col

Table 8.6. Mortality of *C. bergi* nymphs feeding on low- (CMC-40) and high- (M Col 1684) HCN cassava roots.

	% Mortality	
	Clone	
Instar	CMC-40	M Col 1684
I	26	40
II	30	42
III	0	2
IV	0	0
V	0	0
Total % Mortality	56	84

n = 50
X^2 test of independence for instars I and II significant, $P \leq 0.05$

1684. This supports previous observations that cassava is not a preferred host for *C. bergi* and that an additional host must be available for population growth to occur in the field. Survival is highest when *C. bergi* feeds on the small storage roots of sweet varieties and lowest when feeding on the root peel.

Field studies also show an increase in swollen root damage following rain events. This is supported by lab studies, which indicate greater *C. bergi* survival and more activity during moist conditions. It is possible that *C. bergi* migrate deep into the soil and diapause during dry periods until conditions become more favorable. The use of ground covers or mulches, which increase soil moisture conditions, could increase *C. bergi* activity in cassava.

In field trials on the Colombian North Coast, *C. bergi* damage recorded on 7 clones averaged 24.3% during the May-to-May vegetative cycle when rains occur during the first 6 mo. Root damage during the Oct.-to-Oct. (dry season) cycle was only 0.6%. These results support observations that soil moisture may influence *C. bergi* attacks.

8.5.2 Control of *C. bergi*

8.5.2.1 Crop management. Previous research has shown that intercropping of *Crotalaria* sp. (sunne hemp) with cassava is an effective means of controlling *C. bergi* through allelopathy. Lab studies comparing feeding behavior on several crops showed that *Crotalaria* was least preferred. Trials in farmers' fields showed that when *Crotalaria* is sown between each cassava row, root damage was only 8%; whereas in control plots of cassava monoculture, damage was 77%. Pesticide applications are less effective than intercropping with *Crotalaria* (CIAT Annual Reports, 1988-89). As *Crotalaria* has little or no commercial value and as the intercrop results in reduced cassava yields, farmers are not inclined to adopt this technology. Nevertheless, allelopathy may eventually contribute to the control of *C. bergi* if a commercially acceptable system can be developed.

8.5.2.2 Chemical control. The insecticide chlorpyriphos was incorporated in cassava pellets (see previous description) at 4 concn. (2.5, 5, 10 and 20%) and placed in plastic boxes in the lab. First, 3rd and 5th instar nymphs and *C. bergi* adults readily feed on these. At the 3 highest concn., 100% mortality of all instars and adults occurred within 24 h of initiating feeding. At the lowest concn. (2.5%), 100% mortality occurred for the 1st and 3rd instars during the first 24 h and for the 5th instars and adults at 72 h. The use of cassava pellets containing pesticides as poison baits may be feasible for controlling *C. bergi*, eliminating the broadcasting of soil pesticides presently employed in certain areas.

8.5.2.3 Biological control. The potential for biological control of *C. bergi* with nematodes is under investigation. *Steinernema carpocapeae* was evaluated for pathogenicity to *C. bergi* under controlled conditions in the lab. Plastic containers with soil and maize kernels were infested with 70 *C. bergi* nymphs and adults. The soil was inoculated with approx. 20 nematodes previously reared on artificial media. Six days after inoculation, 20% mortality of *C. bergi* was observed with a mean of 19 nematodes recovered per dead insect. Analysis of soil samples revealed considerable numbers of *S. carpocapeae*. These results suggest potential for using entomopathogenic nematodes to control *C. bergi*. Other nematode species will be evaluated and field trials will be designed.

8.6 Whiteflies

Numerous species of whiteflies are reported on cassava. The predominant species in the Americas are *Aleurotrachelus socialis*, *Trialeurodes variabilis*, *Bemisia tuberculata*, *Aleurothrixus aepim* and *Bemisia tabaci*. In recent years high whitefly populations have been reported from Paraguay (*B. tuberculata*), Brazil (*A. aepim*), Colombia (*T. variabilis* and *A. socialis*, and the Dominican Republic (*B. tabaci*). Results from early research show a correlation between duration of whitefly attack and yield loss; an 11-mo attack resulted in a 79% yield loss. These and other results have provided an estimate of probable yield losses in areas of high whitefly populations. This has justified a continual although moderate effort in whitefly research, with emphasis on identifying resistant germplasm and developing resistant clones. Recent developments including increased whitefly populations in several areas and the appearance of a new biotype of *B. tabaci* has led to an increase in research efforts.

8.6.1 *Bemisia tabaci*

Whiteflies are known to transmit several virus diseases (see Chap. 7). *B. tabaci* transmits African Cassava Mosaic (ACMD) in Africa, a disease of considerable importance, which has not yet been reported in the Americas. Although *B. tabaci* is present in the Americas and is a major pest in several important crops (beans, soybeans, etc.), until recently it had not been reported feeding on cassava, suggesting the existence of a distinct biotype from that feeding on cassava in Africa. The absence of ACMD in the Americas is thought to be related to the inability of its vector, *B. tabaci*, to colonize cassava. In recent years, *B. tabaci* has been reported feeding on and transmitting virus diseases on numerous crops that it did not previously colonize. It has been reported feeding on cassava in the US (Florida), Puerto Rico and the Dominican Republic. This indicates the possible development or introduction of a new biotype in this area. If this biotype is capable of transmitting ACMD and this disease enters the Americas, it could devastate cassava production. Whiteflies collected from cassava in a 1991 survey of Florida were identified as *B. tabaci* (Source: Louise Russell, USDA) and verified by electrophoretic studies at CIAT. These findings warrant an increased emphasis on whitefly research.

8.6.2 Whitefly control

HPR studies with *A. socialis*, *T. variabilis* and *B. tuberculata*--the most economically important species in Colombia--were initiated nearly 10 yr ago. More than 2000 clones have been evaluated. Clones M Ecu 72, M Col 336, M Bra 12 and M Col 339 were selected as resistant or tolerant to whitefly attack. M Ecu 72, which has consistently expressed the highest level of resistance, were used in a crossing program with other selected clones to produce whitefly-resistant, high-yielding clones. Using estimates of yield depression and plant damage ratings to compare resistance levels, 4 clones were selected (CG 489-34, CG 489-23, CG 489-31 and CG 489-4) (Table 8.7). These studies, done in collaboration with ICA-Nataima, Tolima, should eventually lead to the official release of these clones.

More recent evaluations of elite cassava germplasm have identified several additional source of resistance (CG 959-1, CM 2156-3, M Bra 191, CM 1203-13, CG 1141-1, CM 2136-2, CM 4042-4, CM 4157-34, SM 301-3 and CM 2156-13). These clones are under evaluation for yield depression, and an additional 300 clones are being screened as possible sources of resistance. Resistant materials have been sent to IITA for evaluation for resistance to *B. tabaci*, the predominant species attacking cassava in Africa.

Crop resistance to whiteflies has not been frequently reported and is not easily achieved. Results with cassava are encouraging, and it is hoped that HPR will be a useful mechanism for reducing the incidence of virus diseases.

Reports on cotton suggest a relationship between resistance and low leaf-tissue pH. Thirty cassava clones were evaluated for leaf pH; three fully expanded leaves were removed from 5-mo-old cassava plants. From 25 to 30 g of leaf tissue were macerated and mixed with deionized water (2X the wt of leaf tissue), and allowed to stand for 1 h; pH readings were made at 5, 10 and 15 min.

Table 8.7. Yield reduction in 10 cassava clones caused by whitefly attack at ICA/Nataima, Tolima, Colombia.

Clone	Yield with Insecticide Protection (t/ha)		Yield Without Pesticide Protection (t/ha)		% Reduction in Yield
CG 489-34	30.3	fg[1]	29.3	gh	3
CG 489-23	39.1	c	35.4	de	9
CG 489-31	27.9	ghi	24.9	ijk	10
CG 489-4	32.9	ef	27.1	hij	17
CMC 76	22.8	k	15.8	l	31
Reg. Quind.	25.1	ijk	17.3	l	31
M Mex 59	36.3	d	24.1	jk	33
CMC 40	53.5	a	25.7	ijk	52
CMC 57	33.1	ef	7.7	m	76
H 305-122	42.1	b	8.6	m	79

Data extracted from several experiments.

1 Means with the same letter are not significantly different ($P = 0.05$).

Six resistant clones identified through field evaluations had pHs below 6.0 (range of 5.51 for M Ecu 72 to 5.72 for M Bra 12); the other 24 clones had pHs > 6. These results indicate that leaf pH may be an indicator of whitefly resistance and could be a useful tool in screening procedures.

8.6.3 Intercropping

Traditionally grown cassava is often intercropped with other species. Many evaluations have been made of insect populations under these conditions (see section 8.5 on *C. bergi*). The most recent have examined the effect of intercropping maize and cowpeas on whitefly populations. Intercropping cassava with cowpeas reduced egg populations of two whitefly species (*A. socialis* and *T. variabilis*), relative to those in monoculture. These effects were residual, persisting up to 6 mo after harvest of the intercrop (CIAT Annual Report, 1987). Intercropping cassava with maize did not reduce egg populations. High populations of cassava whiteflies led to significant reductions in growth and yield. Yield losses in cassava/maize, cassava monoculture and mixed variety systems were ca. 60%; whereas in cassava/cowpea intercrops yield losses were 12%, and yields were superior to those obtained in the other systems. Intercropping may offer the small-scale farmer a valuable means of reducing pest problems, especially in areas where cowpeas have a high commercial value as in NE Brazil.

8.6.4 Biological control

Natural enemies of cassava whiteflies include the predator *Delphastus pusillus* and the parasites *Amitus aleurodinus* and *Eretmocerus aleurodiphagus*. Predators play a minor role in whitefly population dynamics (Gold et al., 1989)[8.9]; however, parasitism of *A. socialis* by *A. aleurodinus* and *E. aleurodiphagus* ranged from 49.1 to 54.3% in experimental plots, indicating that parasites may be an important mortality factor (CIAT Annual Report, 1989). Biological control of whiteflies will be given more attention in future research.

8.7 Insects Attacking Sexual Seed

The Cassava Program recently decided to invest in research on the potential of sexual seed for propagating the cassava crop. In order to identify potential pest problems in seed storage and field germination, experiments were initiated in 1991. Measured quantities of untreated cassava seed were placed in paper bags and stored in unprotected facilities at CIAT. Seeds were inspected at 15-day intervals. After 6 mo, no insects or insect damage was detected. These studies will be continued in cassava-production areas.

The ability of *Tribolium castaneum*, *Sitophilus granarius*, *Acanthoscelides obtectus* and *Zabrotes subfasciatus* to feed on cassava seed was evaluated. Fifty sexual seeds were placed in plastic containers and infested with 40 adults of each species. Oviposition on the seed coat was observed after 2 to 3 wk. Although eclosion was observed, none of the species was able to penetrate the seed coat although *Z. subfasciatus* caused some rasping damage. These preliminary results indicate that the cassava seed coat provides considerable protection against insect attack. These trials will continue.

8.8 Insects Attacking Dried Cassava

The increased utilization of processed cassava for animal feed has resulted in the commercial storage of dried cassava for 1 to 3 mo. Dried cassava as flour or chips is vulnerable to numerous stored products pests.

8.8.1 Pest infestations

Cassava chips are susceptible to insect attack while the chips are exposed on drying surfaces and during storage. To evaluate the first case, 500 g samples of bitter (M Col 1684) and sweet (CMC 40) cassava were removed from the drying patio at 1-h intervals, placed in glass containers, and stored in the lab for 30 days. Samples removed while the

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[8.9] Gold, C.S., M.A. Altieri and A.C. Bellotti. 1989. The effects of the intercropping and mixed varieties of predators and parasitoids of cassava whiteflies (Hemiptera:Aleurodidae) in Colombia. Bull. Ent. Res. 79, 115-121.

humidity was above 14% were susceptible to mold; those from 11 to 14% showed no mold damage. No insects or insect damage were detected in any of the samples.

Cassava chips and flour produced from CMC 40 and M Col 1684 were evaluated in 4 packing materials: sisal, paper, cloth (cotton) and polypropylene. Of the 18 species of arthropods found in the dried cassava products, the most frequently recovered from large chips were *Araecerus fasciculatus*, *T. castaneum* and *Rhyzoperta dominica*. From small chips, the major species were *T. castaneum*, *Lasioderma serricorne* and *Dinoderus minutus*. Cassava flour was primarily infested with *T. castaneum*, *L. serricorne* and *Sitophilus orizae*. Pest populations were not significantly different in the 2 var. The best packing material for avoiding storage pests was polypropylene.

During 1991 several drying plants on the Colombian North Coast were surveyed to determine the extent and nature of arthropod pest infestations. Samples taken from drying plants were infested with *T. castaneum* (most common), *Sitophagus holopteloides silvanus* sp., *Psocoptera* sp. and *Sitophilus orizae*. Significant infestations were found in cassava stored for more than 20 days.

9. CROPPING SYSTEMS

Due to the widespread practice among small-scale farmers of intercropping cassava and maize, the Agronomy Section has dedicated substantial effort to gain more knowledge and develop better technology that can contribute to improving the productivity and sustainability of this association. Some research activities are carried out on farms with farmer participation in the design, implementation and evaluation of technology; other activities are conducted on experiment stations.

The development of methodology to evaluate the performance of new maize and cassava var. in intercropping systems has been an important activity for the last six years. Results on the performance of new varieties and on nutrient cycling in the maize/cassava intercrop are presented.

In several regions where cassava is an important crop, fallow is practiced to maintain soil fertility. Population pressure and new market opportunities for cassava have increased demand for roots. High demand means more production and consequently a more rapid depletion of soil nutrients. Given the socioeconomic characteristics of the farmers who grow cassava, a long-term, low-cost strategy should be developed to sustain production. Meanwhile low levels of fertilizers applied to the most common cassava-based cropping systems will help sustain yields. A summary of results obtained in farmers' field using fertilizers for the cassava/maize association is presented here.

Land preparation and weed control are closely related. These are among the most labor-demanding activities in cassava production. Reduced tillage is an alternative to mechanized land preparation that should help reduce soil erosion and production costs. This research is long term in nature; preliminary results corresponding to the first three years of research are reported.

In NE Brazil, cowpeas are commonly intercropped with cassava. Although there were some available research results that could be applied immediately to improve the performance of this crop combination, some specific characteristics of the cropping patterns used in the semiarid areas of the world have not been studied. Results are given of an experiment station with the cropping pattern used in NE Brazil.

Technology components developed by the Cassava Program and/or national programs should be validated under farmer management and across a wide range of socioeconomic and environmental conditions to assess their viability. This activity will provide feedback to research and speed up the technology development process, as well as the transfer of this technology to farmers. Results are given of pre-production trials and of a study to validate selection and chemical protection of stakes before planting.

9.1 Intercropping Cassava and Maize

9.1.1 Intercropping cassava with improved and traditional varieties of maize

In most countries where cassava is an important crop, maize is one of its most common intercrops. Cassava is seldom grown as a sole crop in NE Brazil, coastal Ecuador, the Atlantic Coast of Colombia, or several other important cassava-producing areas.

In Latin America, national programs release improved maize var. more frequently than improved cassava var. Therefore in regions were the cassava/maize association is cultivated, a few traditional cassava clones are generally intercropped with several local and improved maize var. The increasing availability of improved maize var. bred originally for monoculture justifies the inclusion of field experiments to test their performance when intercropped with cassava.

To develop a generally applicable methodology for testing maize var. with cassava, a set of field trials was conducted from 1985-90 in collaboration with the ICA on-farm research team in the North Coast of Colombia. Newly released maize var., mainly V-156 and V-109, were compared with the traditional or local maize var. A 5-yr experiment using a split-plot design with association and sole crop as main plots and maize var. as subplots was conducted on more than 30 farms. The local cassava var. "Venezolana" was used as a check. Researchers planted and harvested the plots; all other aspects of crop management were the farmers' responsibility.

For both maize and cassava, either in association or in sole crop, differences in yields between years were highly significant. Yields also differed significantly between locations (farms). More variability in yields of cassava and maize in pure stand and in association is expected between years than between farms in rainfed areas. Avg cassava RYs in monocrop were always higher (± 2t) than in association with maize (statistically significant). Yields of maize in association with cassava or in monocrop were not significantly different (Table 9.1).

If maize is as important as cassava to farmers, this small difference between yield in monocrop and yield in association justifies the widespread practice of intercropping. There was a significant interaction between types of maize and association or not with cassava, indicating that cassava does not respond equally in terms of yield when intercropped with different types of maize. This interaction, significant at the 10% level for maize, means that all maize var. do not perform equally when intercropped with cassava. The avg yield of the 2 improved maize var. was significantly higher than that of the traditional one.

Table 9.1. Avg yields (t/ha) of improved and local maize var. and cassava as sole crop and intercropped with maize.

	Cassava Yield	Maize Yield
Cropping Season		
First	14.10 a[1]	1.68 b
Second	13.75 a	2.10 a b
Third	8.60 b	2.67 a
Cropping pattern		
Monocrop	12.34 a	2.32 a
Association	10.59 b	2.25 a
Maize varieties[2]		
V-156		2.51 a
V-109		2.42 a
Criollo or local		1.91 b
Maize cv X Cropping system[3]		
Cassava/V-156	10.91 a	
Cassava/V-109	10.97 a	
Cassava/Criollo or local	9.91 b	

[1] Amounts followed by the same letter are not statistically different ($P < 0.05$ DMRT).
[2] Means of monocrop and associated maize.
[3] Maize var. are considered as nested in plots where cassava was associated with maize.

The Competitive Ratio Index (CRI)[9.1] provides an estimate of the relative ability of one crop to compete with another when planted in association. This index was in favor of maize in 74% of the 134 cases analyzed, indicating that cassava RY depends heavily on the performance of the intercropped maize. The environmental conditions during maize development and/or the agronomic management of the maize determine the performance of the intercropped cassava. As 75% of the cases involved improved maize var., the management of improved varieties is a key factor determining cassava RY on the North Coast of Colombia, where more than 39% of the farmers were using improved maize var. in 1990. If farmers continue to grow this crop combination, the system can be modified most easily through maize management. This is probably also true in other regions where this crop combination is common. The slow initial growth of cassava and the comparatively rapid early development of maize, particularly of the improved varieties, probably account for maize predominance when these two species grow together.

Land Equivalency Ratio (LER)[9.1] values above 1 were obtained in 93% of the cassava/maize plots, indicating more efficient use of land by the cassava/maize intercrop than by either species planted in pure stand. In regions where farmers have limited

[9.1] Leihner, D. 1983. Management and evaluation of intercropping systems with cassava. CIAT, 70 pp.

access to land, land use efficiency is of great importance; e.g., the North Coast of Colombia and many other regions of the world where cassava is an important crop.

Improved maize var. yielded significantly more than the traditional var., both in monocrop and in association with cassava; conversely, cassava in association with improved maize yielded significantly more than in association with the traditional var. (Table 9.1). This represents an additional benefit of new maize var., which were originally developed to perform better as a monocrop. No significant differences in yield were registered between the two improved maize var. tested, but on avg they significantly outyielded the traditional ones.

The stability of different cassava/maize intercrops across various environments was tested, and the sensitivity of these cropping systems was estimated using methods developed by Eberhart & Russell[9.2]. Cassava monocrop is less sensitive to environmental variations than cassava associated with any of the maize varieties tested. Monocrop cassava RYs, which were always > 10 t/ha even in the less favorable environments, did not respond positively in the more favorable ones (see the almost horizontal line corresponding to cassava RY in Fig. 9.1). Both traditional and improved maize var. performed well in favorable environments, but their performance under less favorable conditions was relatively poor (Fig 9.2).

The general performance of maize as sole crop and in association with cassava is similar in terms of environmental sensitivity[9.3]. Within the range of varieties tested, their performance in intercropping can be predicted from performance as a sole crop; however, lower yield can be expected in association with cassava than in monoculture.

From the standpoint of cassava, association with maize increases its sensitivity to the environment. In less-favorable environments, yields of cassava in association with maize are significantly lower than in monoculture. In more favorable environments, yields of cassava in association with maize could be higher than yields of cassava in monocrop. In favourable environments expected differences in yields between cassava monocrop and cassava in association with maize may be lower than in less favourable environments. (Fig. 9.1).

Improved maize var. have high HIs and thus allocate more DM to the grain. They are frequently planted at high densities to achieve their full yield potential. If traditional maize is replaced by improved var., nutrient balance within the farm will change as more nutrients will be exported from the farm system (Fig. 9.3). When soil fertility is restored

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[9.2] Eberhart, S.A.; Russell, W.A. 1966. Stability Parameters for comparing varieties. Crop Science 6(1):36-40.

[9.3] Cortes, M.H. 1991. Análisis de ensayos con el intercultivo de yuca (*Manihot esculenta* Crantz) y maíz (*Zea mays* L.) en la costa norte de Colombia. B.Sc. Thesis. Universidad del Valle, 139 pp.

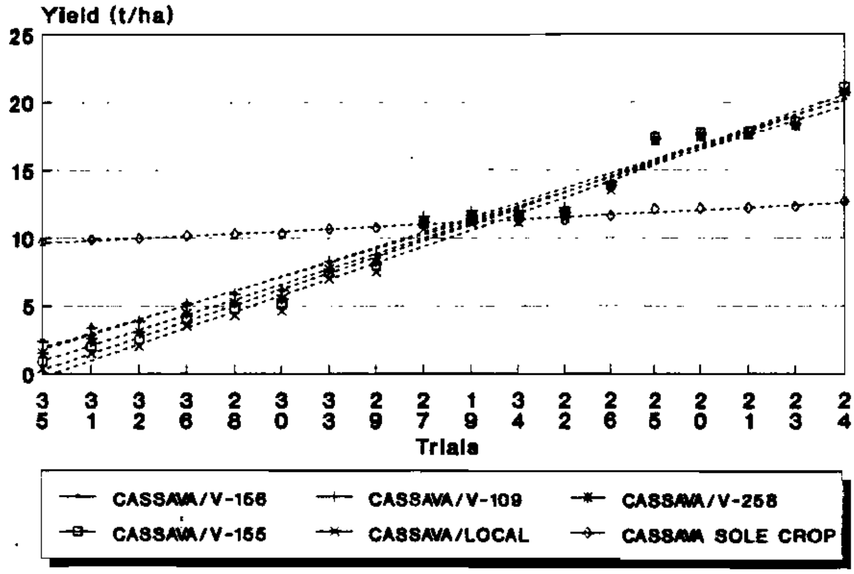

Figure 9.1. Estimated yields of cassava monocrop and associated with different maize var. in favorable and less-favorable environments.

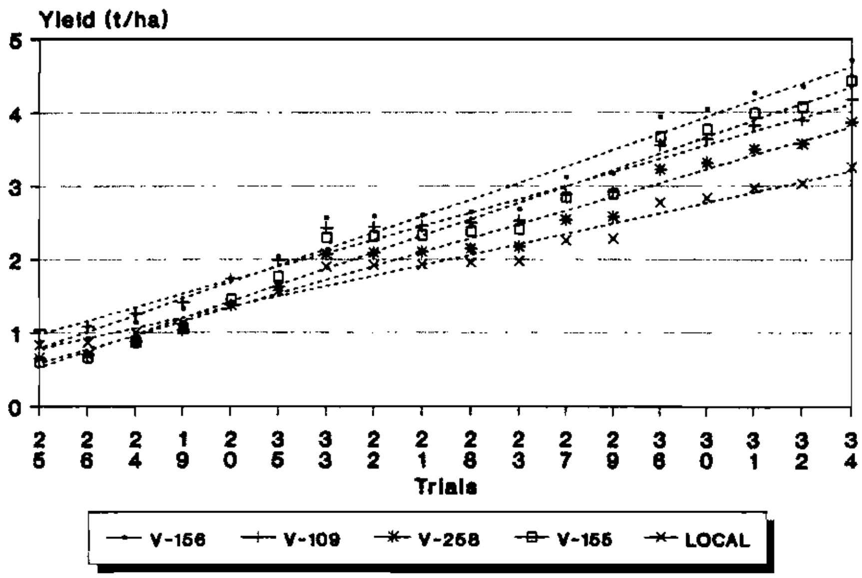

Figure 9.2. Estimated yields of maize monoculture in favorable and less-favorable environments, maize var. frequently intercropped with cassava.

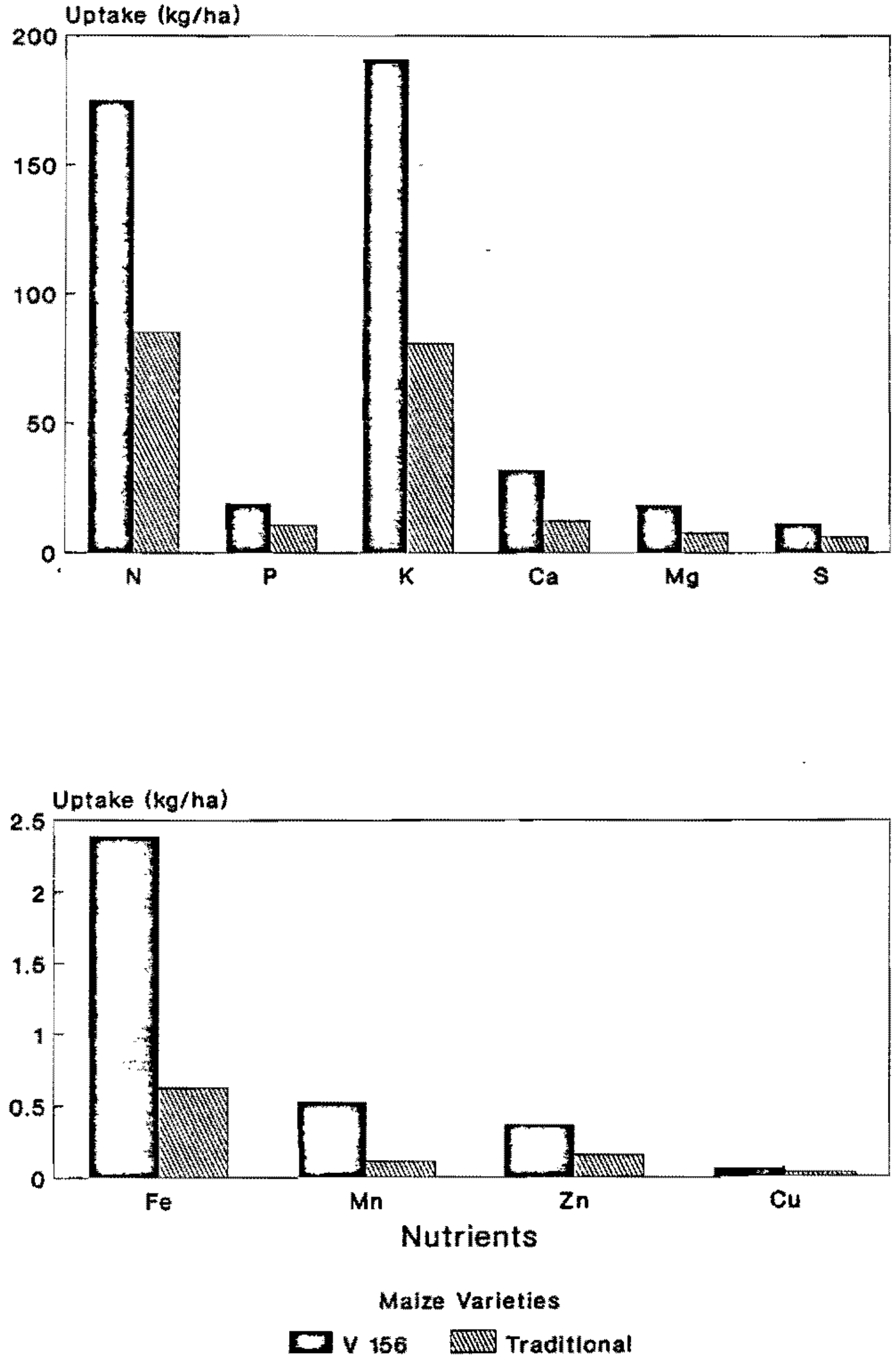

Figure 9.3. Nutrient uptake from the soil by improved and traditional maize var. on the North Coast of Colombia.

Table 9.2. Biomass produced by cassava var. CMC 40 and uptake of nutrients in association with different types of maize and as sole crop at CIAT HQ.

	Biomass (t/ha)				
Intercropped maize	Total	Leaves	Stems	Roots	
H-211[1]	18.9	0.68	8.63	9.68	
V-258[1]	17.48	0.44	7.19	9.85	
Clavo[2]	17.54	0.64	6.90	9.99	
Limeño[2]	20.48	0.55	7.75	12.18	
Sole crop	22.07	0.72	9.12	12.23	
	Nutrients (kg/ha)					
	N	P	K	Ca	Mg	S
H-211	111.9	19.6	118.6	82.2	63.7	14.6
V-258	101.8	17.3	94.0	72.6	58.1	13.7
Clavo	102.6	17.5	104.0	72.2	57.2	13.4
Limeño	124.4	20.3	121.6	80.8	66.0	15.2
Sole crop	130.9	21.1	128.6	98.8	83.0	18.5

[1] Improved maize var.
[2] Local maize var.

mainly through fallow, more nutrients leaving the farm means either a longer fallow recovery period or lower yields. The total amount of nutrients removed by improved maize var. was significantly greater than in local var.

Total biomass production and nutrient removal and distribution in a cassava/maize association were studied at CIAT HQ for traditional and improved maize var. grown as sole crop or intercropped with a single cassava var. Removal of nutrients by cassava monoculture was higher than cassava in association with maize (not statistically significant). No influence of the type of maize (traditional or improved) was found on removal of nutrients by the intercropped cassava. Total cassava biomass production was also higher in cassava monoculture than in association with maize (no significant difference due to the maize var.). No difference in total biomass accumulation was found between maize varieties intercropped with cassava (Table 9.2).

Maize var. differed significantly in the amount of biomass and nutrients allocated to the grains, improved var. allocating more nutrients to the grains (42% of total) than local var. (21% of total). Improved var. were similar in terms of nutrient and biomass allocation to the grain, but there were statistically significant differences between the traditional var., probably because of their genetic backgrounds. Association with cassava did not affect the ability of improved var. to allocate more resources to the grain. High grain-formation capacity was more evident in hybrids than in open-pollinated var. Hybrids performed well in terms of grain yields when they were intercropped with cassava in alternate rows.

Intercropping hybrids in the same row with cassava did not result in good maize yield. It is not known whether this is a general characteristics of all clones or specific to those reported here. Traditional var. allocated relatively more nutrients to leaves and stems. If leaves and stems are left in the field after harvesting the cobs, recirculation of more nutrients would be expected with traditional than improved maize var. A similar situation would be expected if manure from animals fed leaves and stems of traditional var. were returned to the field.

Intercropped maize always extracted smaller amounts of nutrients than as a sole crop because total biomass and the percent of each nutrient in the tissues, except Mg, was always less in the intercrop than in the monocrop (Table 9.3). In monoculture improved maize var. tended to use more N than traditional var. In monoculture, traditional maize var. take up more P, K and Ca than improved var. although they use them rather inefficiently, at least in favorable environments such as that of CIAT HQ (Table 9.4).

Table 9.3. Nutrient uptake by maize in association with cassava and sole crop; avg of 2 improved and 2 traditional maize var. at CIAT HQ.[1]

	Nutrients (kg/ha)						
Cropping System	Total biomass	N	P	K	Ca	Mg	S
Intercropped	8078 a	117 a	22 a	102 a	21 a	20 a	14 a
Sole crop	10769 b	158 b	32 b	142 b	27 b	27 a	19 b

[1] Data followed by the same letter are not significantly different ($P \leq 0.05$).

Table 9.4. Nutrient uptake by traditional and improved maize var. as sole crops and at 2 planting densities.

		Nutrients (kg/ha)					
Planting Density	Maize Variety	N	P	K	Ca	Mg	S
30,000 pl/ha	Improved	151	27	121	21	21	17
	Local	125	25	116	23	21	15
50,000 pl/ha	Improved	183	33	146	26	31	21
	Local	173	41**	185**	36**	33	23

Total biomass and the amount of commercial production per unit of nutrient uptake was calculated for the cassava and maize monocrop and for their association. Cassava was more efficient than maize in production of total biomass and biomass of roots per unit of nutrient taken up, particularly of N, P, K and S. Maize is more efficient than cassava in the production of stem and leaf biomass per unit of Ca and Mg. The clones were the most efficient users of N for production of both total biomass and grains. Maize and cassava cultivated in association are more efficient in the use of nutrients than the sum of the components when cultivated as sole crops (Table 9.5).

The cassava/maize association with an improved maize var. exports approx. 45% of N, P and K out of the farm system. Cassava and a traditional maize var. export only 35% of these nutrients. Improved maize var. return ca. 50% of N and P to the soil via crop residue vs. 70% for an intercrop with a traditional var. (Table 9.6).

9.1.2 Intercropping cassava varieties with maize.

Two newly released cassava varieties, bred specifically for the Colombian North Coast (CG 1141-1 and CM 3306-4), were tested with maize (V-156), using the same methodology developed for testing improved maize var. with cassava. The local var. Venezolana was used as a check. The experiment (2 blocks) was conducted for 2 yr at 10 contrasting sites (farms). After planting and applying preemergence herbicides, crop management was the farmer's responsibility.

Table 9.5. Production Index (PI)[1] for different nutrients in cassava associated with maize and cassava and maize as sole crops.

		Maize Varieties			
Nutrient	Crops[2]	Clavo	Limeño	H 211	V 258
N	YM	19.8	16.7	17.5	17.6
	Y+M	20.0	19.3	19.2	17.8
K	YM	20.1	16.0	15.8	15.5
	Y+M	20.2	17.3	16.8	16.0
Ca	YM	8.6	7.6	7.3	7.2
	Y+M	9.1	9.0	7.4	8.1
Mg	YM	7.0	6.0	6.2	6.2
	Y+M	8.0	7.6	6.5	7.0
S	YM	2.6	2.0	2.2	2.3
	Y+M	2.6	2.5	2.3	2.3

[1] Amount of commercial product per unit of nutrient taken up.
[2] YM = Cassava and maize intercropped; Y+M = avg value of PI for cassava and maize as sole crops.

Table 9.6. Percent of different nutrients returned to the soil in a cassava/maize intercrop and in maize as sole crop.

Cropping System	Maize Var.	Nutrients (%)				
		N	P	K	Ca	Mg
Intercrop	H 211	54.2	51.2	56.0	90.4	80.8
Sole crop		49.8	52.0	80.2	97.2	77.9
Intercrop	V 258	60.5	53.0	58.5	90.0	80.3
Sole crop		51.1	57.8	80.3	93.9	79.6
Intercrop	Clavo	69.6	63.7	65.2	90.6	9.6
Sole crop		67.3	77.0	92.0	98.5	90.1
Intercrop	Limeño	62.0	56.3	54.9	90.0	80.4
Sole crop		63.3	70.0	91.0	98.6	88.0

Table 9.7 shows that the two improved cassava clones outyielded Venezolana in monoculture (not statistically significant). These on-farm results are similar to those obtained on two experiment stations and on other farms before the release of these varieties. Yields of the cassava clones were reduced by maize intercropping (not statistically significant).

The higher CRI of local var. Venezolana indicates its superior capacity to compete with maize. Despite lower yield in monoculture, Venezolana outyielded CM 3306-4 in association with maize and did not differ significantly from CG 1144-1. In a region where cassava is frequently associated with maize for reasons other than yield itself, Venezolana will probably remain popular.

Maize, the dominant component in the intercrop, had high CRIs, yields not being affected significantly by cassava clones (Table 9.7).

9.1.3 Fertility trials

Given that improved maize varieties export more nutrients from the farm system than local varieties, the restoration of nutrients to the farm is vital for sustaining the cassava-maize production system. In the short term, the use of chemical fertilizers is a possibility in regions where fertilizer use is common. In several interviews, farmers pointed out their willingness to fertilize maize if yields improved significantly. They were dubious about the possible benefits of using fertilizers for cassava.

To initiate studies on the effect of chemical fertilizers applied to maize on the performance of intercropped maize and cassava, a series of on-farm experiments were conducted with selected farmers. A relatively low level of fertilizer (N, P_2O_5 and K_2O) (50-40-25 kg/ha of

Table 9.7. Yields (t/ha) and CRs of 2 recently released cassava var. on the North Coast of Colombia and the local var. Venezolana; avg of 2 cropping seasons and 2 reps on 10 farms.

	Yield		Maize Yield			
Variety	Monocrop	Intercrop	Monocrop	Intercrop	Cassava CR	Maize CR
CG-1141-1	16.6	9.3	1.83	2.17	0.47	2.12
CM-3306-4	14.9	7.5	1.83	2.13	0.43	2.32
Venezolana	13.3	8.4	1.82	2.10	0.54	1.82

N, P_2O_5 and K_2O) was applied to maize ca. 12 DAP. Treatments were arranged in a slit-plot design, 2 reps on 4 farms. Researchers and farmers planted, fertilized and harvested the plots; other activities were the farmers' responsibility.

In association with cassava, fertilized improved maize var. yielded significantly more than fertilized traditional maize var. Fertilized improved maize var. yielded significantly more in intercrop with cassava than nonfertilized improved maize var. Yields of cassava were not affected by the level of fertilization applied to the intercropped maize. [9.4]

Yields of cassava intercropped with traditional maize var. (fertilized or not) were lower than those obtained with improved var. (Table 9.8).

Three farms representing low, medium and high levels of soil fertility were selected to conduct a similar set of experiments in an area where no technical recommendation existed for fertilizing cassava in pure stand or in association with maize. Only recommendations for maize fertilization in monoculture had been tested successfully successfully in farmers' fields. The levels recommended for maize in pure stand were applied to maize (only one improved var. V-156 used) intercropped with cassava to validate this technology. Different levels of fertilizers were applied to rows of the intercropped maize, ranging from 25-100 kg/ha of N; 50-100 kg/ha of P_2O_5 and 0-35 kg/ha of K_2O. Higher levels were used in low-fertility soils than in relatively more fertile soils.

The effect of fertilizer treatment on maize yield, the fertility level of the farm, and the interaction between these 2 factors were statistically significant. Maize responded positively to fertilization whereas cassava RY was not significantly affected (Table 9.9). A cost-benefit analysis demonstrated that the low level of fertilization resulted in the highest marginal net return.

[9.4] Cortes, M.H. 1991. Ibid.

Table 9.8. Effect of fertilization of maize on cassava and maize yield (t/ha) in sole crop and in association in farmers' fields of the North Coast of Colombia.

Treatment	Cassava Yield	Maize Yield
Fertilization	16.18 NS	1.49
No fertilization	16.74	2.57
Cropping patterns		
Sole crop	20.21 a[1]	2.26 a
Association	12.71 b	1.78 b
Maize variety[2]		
V-156		2.36 a
V-109		2.20 a
SV-901		2.07 a
Local or criollo		1.46 b
Maize var. X Cropping system[3]		
Cassava/V156	13.81 a	
Cassava/V-109	13.21 a	
Cassava/SV-901	12.93 a	
Cassava/ Local or criollo	10.91 b	

[1] Amounts followed by the same letter are not significantly different ($p < 0.05$ DMRT).
[2] Means of monocrop and associated maize.
[3] Maize var. are considered as nested in plots where the 2 crops are associated.

Table 9.9. Effect of level of fertilization on yields of cassava and maize in association and marginal return on investment in fertilizers.

Fertilization Level	Yields (t/ha)[1]		Marginal Return
Range (-) of N, P_2O_5, K_2O	Cassava	Maize	
Low (0-50/50/0-15)	12.95 a	3.03 b	5.68
Medium (25-75/75/15-25)	13.12 a	3.58 a	5.50
High (75-100/100/25-35)	13.35 a	3.65 a	3.98
No fertilization	11.55 a	1.89 c	0

[1] Data followed by the same letter are not significantly different ($P \leq 0.05$).

Levels of fertilization frequently recommended for maize monocrop were used in this experiment. Improved maize var. responded better to fertilization than traditional ones. For the soil types common on the North Coast of Colombia, these levels can be applied to intercropped maize given that the amount of N does not affect cassava HI negatively. These levels can be recommended, at least in the short range, to improve maize/cassava yields while other methods to maintain soil fertility are being developed.

The successful replacement of traditional by improved maize var. means not only better maize yields but also better cassava RYs. Results obtained on the North Coast of Colombia, with another set of maize var. in coastal Ecuador, and under more controlled conditions in a more favorable environment at CIAT HQ indicated that if improved maize var. become available to farmers, a rapid switch from traditional to improved var. will probably occur. Profit-oriented farmers will benefit from higher maize yields while either maintaining or improving cassava RY.

9.1.4 Land preparation

Land preparation is one of the most labor- and capital-intensive activities in cassava production. Because of seasonal labor shortages in several regions of Latin America, plowing and harrowing are increasingly done with tractors. The high demand for tractors at planting time increases the cost of this activity and affects the opportune availability of machinery. The negative effects of continuous land preparation with tractors and plowing year after year at the same depth have been extensively reported in the literature.

Although research results are few, reduced tillage for cassava production is frequently practiced by farmers when land is prepared by hand. Although cassava is sometimes planted in very sandy soils, zero tillage is rare among farmers. Few research results on the effect of zero tillage on cassava production have been reported in the available literature. A long-term (3 yr) experiment to study the effect of zero tillage vs. plowing and harrowing on cassava intercropped with maize was conducted with farmer participation on the North Coast of Colombia. After land preparation, maize and cassava were planted following the available technical recommendation for the region. Plowing and harrowing incorporate crop residue, which remains on the soil surface in the zero-tillage system. Application of preemergence herbicides and subsequent manual weeding were done the same way in both treatments. Other cultural practices, except harvesting, were the farmers' responsibility.

In the first year, maize yields from plots where land was prepared mechanically were significantly higher ($P=0.05$) than on zero-tillage plots (Fig. 9.4). After the second and third years, there was no significant difference between the two soil-preparation treatments in terms of maize yield. Maize yields showed an overall tendency to decrease from year 1 to 3 in treatments with mechanical land preparation; they tended to stabilize over time in the zero-tillage treatment.

No significant differences in total cassava fresh RYs were found during the experimental period. In the third year the weight of marketable roots in the zero-tillage treatment was significantly higher than with the conventional soil preparation. Cassava RY and HI tended to decrease with time in mechanically prepared soil. Stabler cassava RYs were associated with zero tillage.

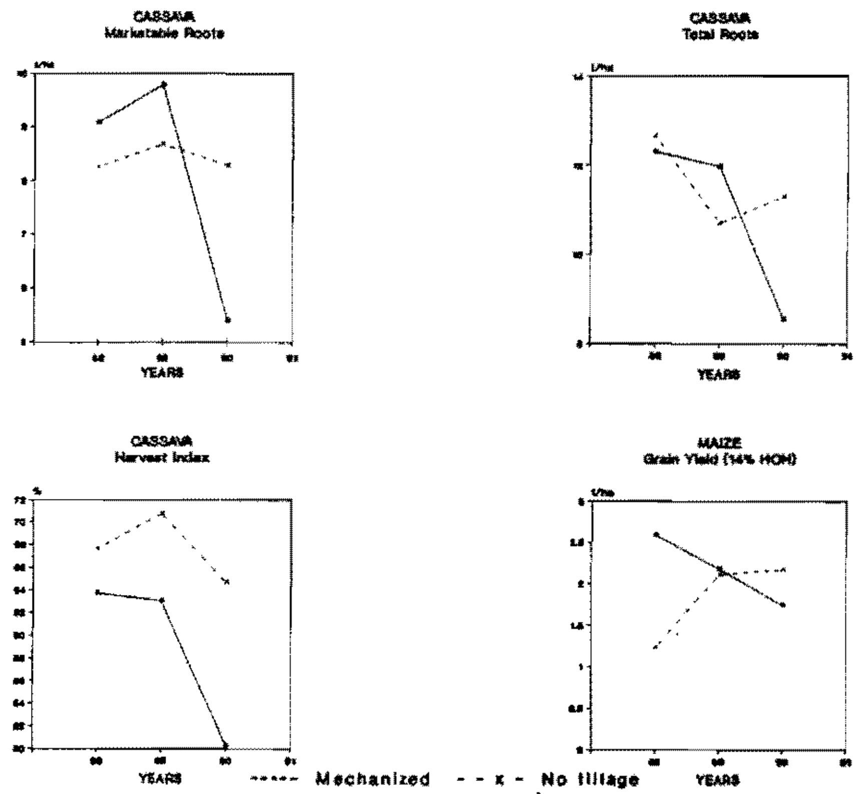

Figure 9.4. Effect of tillage on yields of cassava and maize in association.

No significant differences were found between treatments for soil nutrients. Total K increased significantly over time in both treatments. Contrary to previously reported results, a significant increase in soil pH was found in mechanically prepared plots at the end of the third year. Data on soil physical characteristics are not yet available.

9.2 Intercropping Cassava and Cowpeas

Cassava and cowpeas are intercropped more frequently than cassava and common beans, particularly in regions with a prolonged dry season such as NE Brazil. They are also frequently intercropped in regions with relatively high temperatures during the growing season.

Two spatial arrangements are commonly used for this intercrop: planting cassava and cowpeas in alternate rows and interplanting them in the same row. Although most farmers intercrop in the same row, most published research refers to intercropping in alternate rows. According to farmers, same-row intercropping facilitates weeding of the inter-row spaces, especially when a desiccant weed killer is used to complement hand labor. It is also practiced when weeding and hilling-up are done by animal-drawn implements.

Due to the rapid initial growth of cowpeas and the relatively slow initial growth of cassava, yields of intercropped cowpeas are often similar to those obtained in pure stand. On the contrary, cassava RYs are negatively affected by cowpea competition during crop establishment, particularly if environmental conditions favor the early development of cowpeas.

A medium-sized, branched cassava clone (CMC-40) and a short, branched clone (CM-1918-3) were intercropped in the same row with a single cowpea var. (S 5). Plant density and planting dates (simultaneous planting and cowpeas planted 7 and 14 days after cassava) affected the degree of competition between species. When intercropped in the same row, cowpeas yielded significantly less than when intercropped with the more vigorous cassava CMC-40 (Table 9.10).

Cowpea yields are significantly decreased by competition with cassava when cowpeas are planted 1-2 wk after cassava. More vigorous cassava clones were less affected by cowpea competition. In the case of CMC-40 the increased intraspecific competition due to high cowpea planting densities resulted in reduction of cowpea yield and increased cassava RY (Table 9.11). The influence of cowpea planting densities on cassava RY is not clear; however, the intraspecific competition is noticeable only after the optimum (13.33 pl/m^2 planting density for cowpeas is reached. The CRI was generally higher for cowpeas. Table 9.11 shows an increase in CRI value for CMC-40 and a decrease for cowpeas above the optimum plant density for cowpeas. This was not the case for the less-vigorous CM 1918-3. The CRI is similar for cassava and cowpeas at a planting density of 33,000 pl/ha of cowpeas. In alternate-row experiments cassava was always the dominant species. The CRI is higher for cowpeas associated with the less-vigorous cassava var. The cassava yield component significantly affected by either the relative time

Table 9.10. Effect of cassava var. on yield (t/ha) of cowpeas intercropped in the same row (means of 3 planting dates and 5 cowpea densities).

Cassava Clone	Cassava[1]	Cowpeas[1]
CMC-40 (medium height, branched)	20.23 a	1.54 a
CMC-1918-3 (short, branched)	16.10 a	1.91 b

[1] Data followed by the same letter are not significantly different ($P \leq 0.05$).

Table 9.11. CRI of 2 cassava clones and cowpeas intercropped in the row at different densities and relative planting dates.

Cassava Clone	Cowpeas (pl/m²)	Cassava Yields	Cowpea Yields	CRI Cassava	CRI Cowpeas
CMC-40	3.33	19.309	1.122	1.09	0.91
	6.66	15.121	1.528	0.64	1.56
	9.99	17.096	1.662	0.53	1.89
	13.33	14.908	1.731	0.52	1.92
	16.6	14.105	1.699	0.61	1.64
CM-1918-3	3.33	24.787	1.632	0.58	1.71
	6.66	19.960	1.725	0.44	2.27
	9.99	17.690	1.936	0.44	2.27
	13.33	18.046	2.057	0.36	2.78
	16.66	20.685	2.210	0.32	3.13
	Planting date[1]				
CMC-40	0	18.294	2.158	0.42	2.40
	7	20.020	1.639	0.61	1.64
	14	22.388	848	1.30	0.77
CM-1918-3	0	13.552	2.378	0.28	3.39
	7	15.368	2.025	0.38	2.63
	14	19.135	1.333	0.72	1.39

[1] 0 = simultaneous planting of cassava and cowpeas; 7 and 14 correspond to cowpeas planted 1 and 2 wk after planting cassava, resp.

of planting or planting density of cowpeas was the no. of roots formed during the competition period with cowpeas. This variable correlates closely with cassava RY and could be used to predict cassava RY by sampling cassava plants immediately after harvesting cowpeas.

9.3 Technology Validation with Farmers

9.3.1 Stake production and selection

Good-quality planting material is a key factor for attaining good cassava RY; however, very small stakes or stakes damaged by insects or pathogens are commonly planted by small farmers in some regions. For this reason scientists believe that farmers do not select planting material. Extension programs in many countries train farmers in methods for selecting adequate planting material and frequently distribute printed instructions for doing so. Several field observations have shown, however, that quality of planting material was better than expected in many cassava-producing regions. Furthermore, in surveys conducted in several countries, farmers answered correctly when asked about how to obtain the best planting material from a cassava mother plant.

A 4-yr experiment was carried out to study whether the quality of the planting material used depended on the quality of the available material, the farmer's ability to select it, or some other factor. A subsample of 26 farmers selected from a representative sample of 360 on the North Coast of Colombia planted the experiment using 2 sources of planting material from local var. Venezolana: the stakes that farmers had set apart to be used as "seed" (FS) and stakes from cassava planted by CIAT researchers to be used specifically for planting material (CS). Farmers (F) and CIAT (C) selected material from these two sources so that three treatments (FSxF, FSxC and the check CSxC) were tested on 26 farms (2 reps). Treatment CSxF was not included because the high quality of the planting material produced by CIAT staff made selection by farmers meaningless.

CIAT planting material was specifically selected, planted and given optimal agronomic management, including the recommended plant density, timely weeding, chemical protection when needed, etc. It was generally produced on the same farm where the plots were established. The effect of site and subsequent transport on the quality of the planting material was reduced by producing the stakes close to the planting sites.

A very high effect of years and locality on cassava RY was registered in the 4-yr analysis. In 1987 stakes selected by CIAT from farmers' planting material yielded significantly more cassava than the rest of the treatments. In the other years and in combined statistical analysis, no significant difference between treatments was registered for either total or marketable root wt or HI (Table 9.12).

These results show that farmers in the area studied are familiar with the technology required to produce good-quality reproductive material and know how to select properly both mother plants and planting stakes from them. The use of low-quality planting material may be related to stake availability and to the size of the plots to be planted. The area planted to cassava each year in a given region varies according to price fluctuations. After a favorable year, more land is planted to cassava and shortages in planting material often occur. Faced with shortages, farmers tend to plant all available material instead of leaving uncultivated land.

Table 9.12. Effect on RY (t/ha) of 2 sources of cassava stakes and selection by farmers and researchers before planting; data are avg of 26 farms on the Colombian North Coast over 4 yr.[1]

Source	Selected by	TRY[2]	MRY[2]	Aerial Biomass	HI
Farmer	Farmer	15.1a	11.6a	11.6a	53.3a
Farmer	CIAT	15.4a	11.9a	11.0a	54.7a
CIAT	CIAT	15.3a	11.6a	11.6a	54.0a

[1] Amounts followed by the same letter are not statistically different ($p < 0.05$, DMRT).
[2] TRY = Total wt of fresh roots; MRY = Wt of marketable roots.

National extension programs should address their efforts to ensuring the production of sufficient planting materials in areas where farmers know how to produce quality stakes. The promotion of farmer organizations could contribute to solving availability problems in critical periods.

9.3.2 Chemical Treatment of Stakes

Chemical treatment of stakes before planting is frequently recommended to prevent germination problems. Technical recommendations in many countries include this practice in printed material addressed to farmers or extension agents. In regions with proven high incidence of plant pathogens and certain insect pests, this practice ensures good plant stand and decreases the risk of crop losses (see Cassava Program Highlights, 1990). Most farmers, however, do not treat stakes, citing the cost of the chemicals and the extra labor needed to carry water to the planting site as their reasons for not adopting this technology. On the North Coast of Colombia, chemical treatment of stakes before planting is included in the official technical recommendation to farmers. In personal interviews and surveys, farmers claimed they obtained the same results with either treated or untreated stakes.

An experiment was designed with ICA and the farmers to validate stake-treatment technology. Two sources of stakes from the local var. Venezolana were used: the planting material that farmers had already selected and planting material produced by CIAT researchers in nearby plots. Each lot of stakes was divided in two and one treated according to the recommendations. A split-plot design was used with stake source as the main plot and chemical treatment as subplot. Twelve farmers participated in the experiment (3 reps/farm for 3 yr). Except for stake treatment, planting and harvesting, crop management was the farmers' responsibility.

There was a strong effect of year and location on fresh RY. Stake source did not influence results significantly. Treating stakes did not increase yields significantly (Table 9.13). The avg RY obtained after 3 yr was similar for treated and untreated planting material (15.3 vs. 15.2 ha, resp.). Neither source nor treatment affected yields significantly.

In accordance with these results, it is recommended that national research and extension services validate the possible benefits of technology developed elsewhere with farmers before launching extension campaigns to promote its application.

9.3.3 Pre-production trials

Research to support the development of improved cassava production technology is mainly disciplinary in nature and generally conducted on experiment stations. Subsequent on-farm research is responsible for adapting technology to site-specific conditions and for integrating new technology components into farmer's production systems. Although

Table 9.13. Effect on cassava RY (t/ha) of sources of stake (farmers and CIAT) and chemical treatment of stakes before planting; avg of 10 farms (3 reps/yr) on the Colombian North Coast.

Year	Source	TRY[1]	MRY[1]	Treatment	TRY	MRY
88	CIAT	17.54	13.10	Treated	17.98	13.05
	Farmer	17.48	12.81	Untreated	17.03	12.83
	LSD	1.75	1.30		1.75	1.30
89	CIAT	15.73	12.50	Treated	14.91	11.85
	Farmer	14.82	11.62	Untreated	15.44	12.37
	LSD	1.27	1.22		1.27	1.22
90	CIAT	11.14	8.40	Treated	11.61	9.01
	Farmer	12.28	9.81	Untreated	11.81	9.17
	LSD	1.43	1.23		1.43	1.22

[1] TRY = total wt of fresh roots and MRY = wt of marketable roots, resp.

on-farm research is usually conducted with farmers and seeks their active participation in the management of experiments, a follow-up phase in which technology components are adapted to existing production conditions is still required. Agricultural production systems consist of a yearly sequence of events that begin before the onset of the rainy season and end with postharvest activities. The testing of new technology components that would eventually replace some of the existing production practices should be done in approx. the same sequence so that the production system being tested is a mix of traditional and new production practices. The adoption of any technology component by farmers depends strongly on the interaction between new and existing technology. Use of manual labor, particularly in peak demand periods, is a key factor determining whether a technology component will be adopted by farmers.

On the North Coast of Colombia, several technology components to improve production of cassava and associated crops have been developed by on-farm research teams over the last 8 yr. These components have yet to be fully validated in large plots, under the complete management of farmers, to ascertain their compatibility with current farmer production practices. Selection of these technology components was done 3 yr ago by ICA and CIAT scientists; they were then discussed with a group of farmers to determine if they would be willing to test them on their farms. During the cropping seasons of 1989-90 and 1990-91, 40 and 36 plots were planted, resp. (Table 9.14). Farmers were instructed on how to apply the new technology, but all aspects of crop management were their responsibility.

Table 9.14. Components of improved and traditional technology tested in pre-production trials with cassava and maize in association on the Colombian North Coast.

Item	Improved Technology	Traditional Technology
Soil preparation	NA[1]	Farmers' practices
Seeds		
Maize Cassava	Improved var., selection & treatment[2]	Local var., selection, no treatment
Weed control	Preemergence herbicides	No herbicides
Insect control		
Maize	Lorsban 2.5%[3]	No control
Fertilization		
Maize	40 kg N/ha[4]	No fertilizer

[1] Improved technology not available.
[2] Stakes treated only the first year of trials.
[3] Lorsban = chlorpyrifos; high maize plant density used only during Yr 2 of trials.
[4] Applied only if necessary.

Plots sizes were always larger than 0.7 ha. Two samples (100 m^2) were taken at harvest time to determine crop yields. Nearby plots planted by the same or different farmers were previously selected as checks. One or two 100 m^2 samples were taken from check farmers to assess yields obtained with traditional technology.

In the 1989-90 cropping season, maize yields obtained with the improved technology were similar to those obtained by the farmers. Cassava RYs in this cropping season were equal or above farmers' yields. A major limitation for comparing levels of technology was the difficulty encountered in sampling farmers' fields. In 1990-91 maize and cassava yields obtained with the improved technology were superior to those obtained with traditional technology. Yields in the second cropping season were higher than those of the first year (Fig. 9.5).

Manual labor requirements for the improved technology were similar to those of the traditional technology, both in terms of amount and temporal distribution. Total production costs of improved technology were 8% above what farmers normally spend to produce cassava and maize (Figs. 9.6 & 9.7).

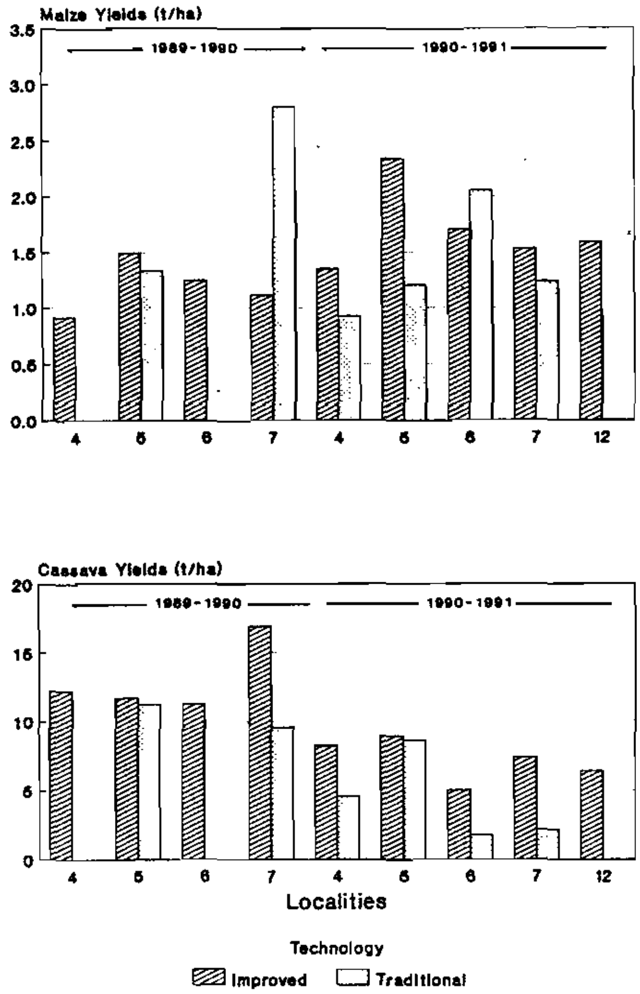

Figure 9.5. Yields of maize and cassava in association with improved and traditional technology on the North Coast of Colombia.

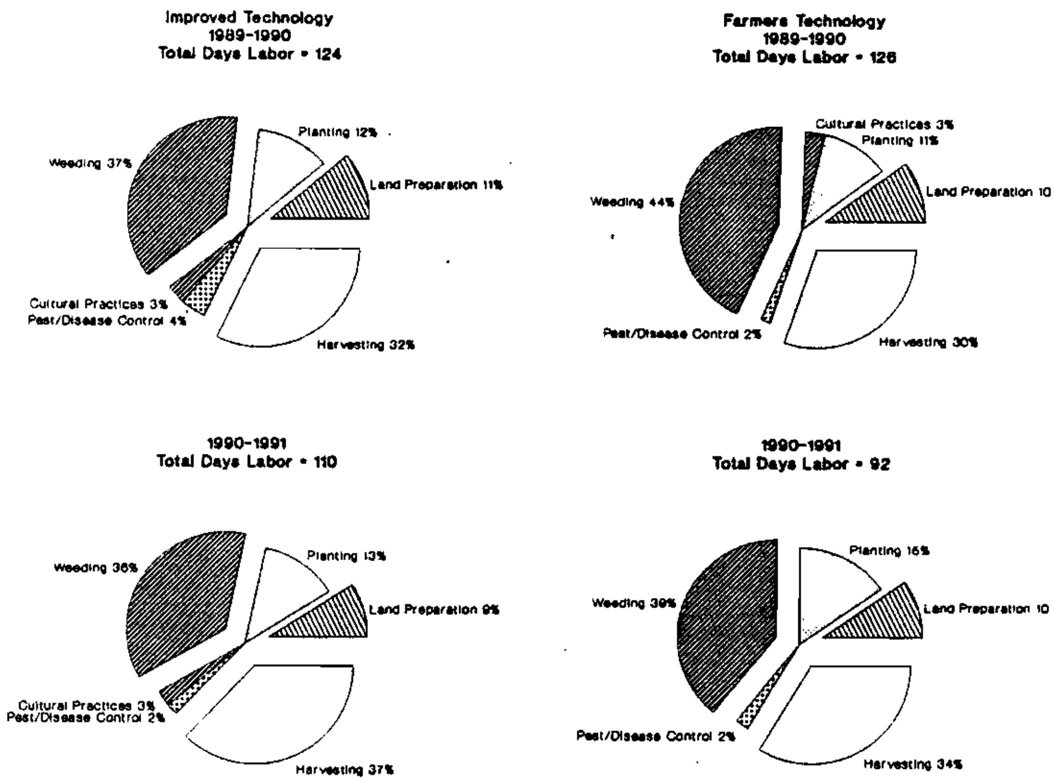

Figure 9.6. Hand labor use for activities in th maize/cassava cropping system.

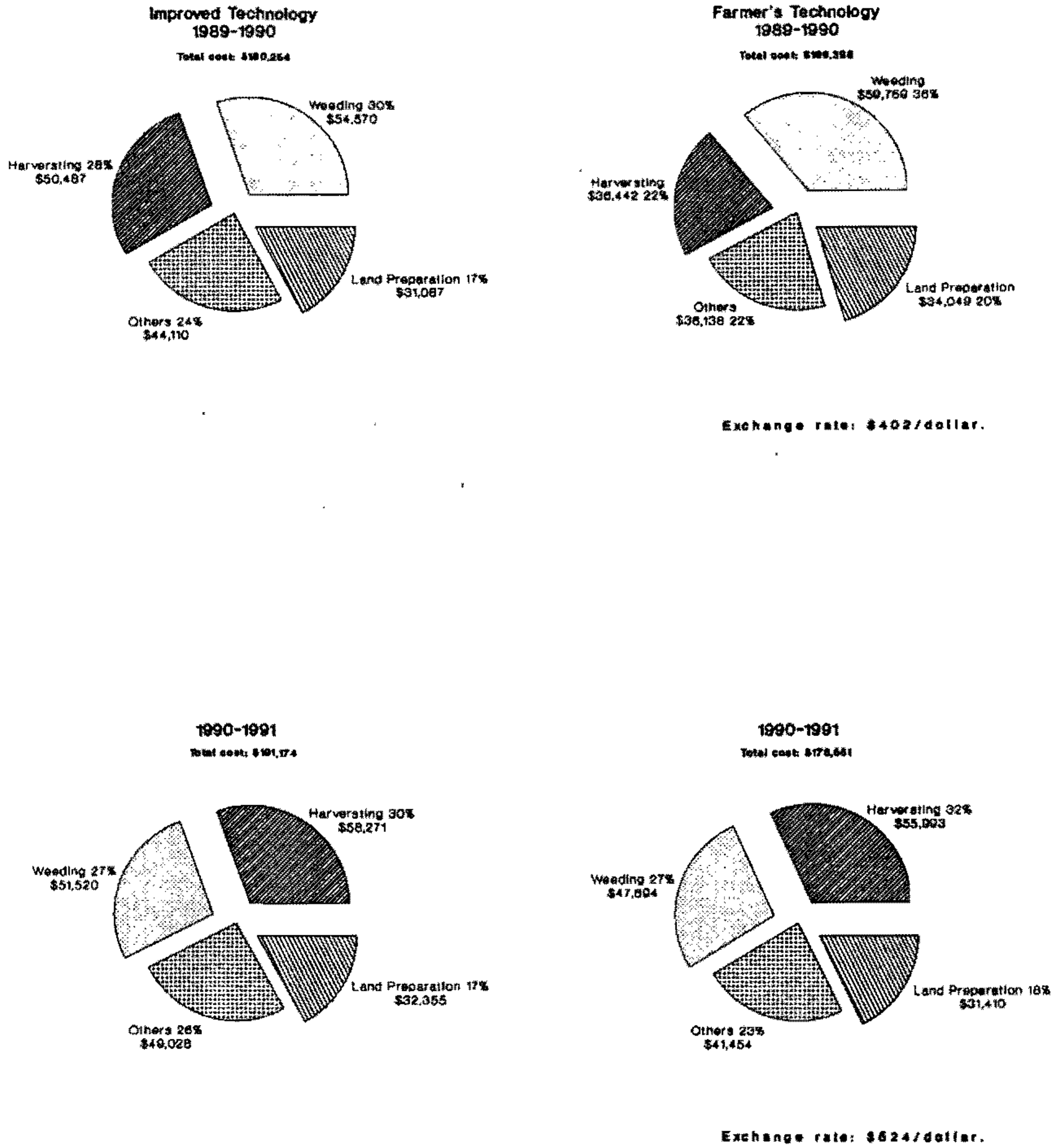

Figure 9.7. Production costs as percent of total cost by activities.

10. PLANT NUTRITION AND SOIL MANAGEMENT

Over the past 5 yr, the Physiology Section has conducted research on nutrition and soil management at both Santander de Quilichao (Cauca) and at Media Luna (Magdalena). Research focused on (1) evaluation of cassava germplasm for adaptation to soils low in P; (2) long-term effects of continuous cassava cultivation on productivity; (3) evaluation of cassava germplasm under moderate levels of applied fertilizer in poor sandy soils; and (4) the effect of plant mulch on cassava productivity and stability on sandy soils. In addition, a collaborative research project to elucidate mechanisms associated with the crop's adaptability to low-P soils was initiated in 1988 with a doctoral student from the Swiss Federal Institute of Technology. Highlights are given here of research findings that shed light on the potential of cassava in poor soils as well as the response of the crop to soil fertility management.

10.1 Screening Germplasm for Adaptation to Low-P Soils (Santander de Quilichao)

In continuation of efforts to characterize cassava germplasm for adaptation to low-P soils, several advanced breeding lines and clones were screened (4 reps) at the Santander de Quilichao station from 1986-90. The accessions were planted (10,000 pl/ha) in plots with low available P (<4 ppm) that had received no P fertilizer for the last 8 yr. Half the plots received 75 kg P/ha annually (8 yr). Adequate levels of N and K were applied at planting to the whole experimental area. P fertilizer in the form of triple superphosphate was banded around the stakes at planting. Tables 10.1 to 10.3 show the RYs of the best adapted clones at 10 mo after planting along with the calculated P adaptation indices. At both levels of P, there were significant differences in RY among genotypes ($P<0.01$). The overall avg RY of all genotypes at low P was significantly lower than the avg RY with adequate P in all seasons. Moreover, yields have been stable at both levels of P over the past few years. These reasonable yields without P application might indicate that native P uptake by cassava was effective. Cassava is known to be highly dependent upon VAM association for P uptake. It is possible therefore that cassava roots were effectively colonized by efficient strains of the fungus.

These highly adapted genotypes (indices >1.5) included 2 CIAT clones that were recently released as new commercial var. (CM 523-7 and CG 2177-2, Tables 10.1 & 10.2) and some traditional clones from Brazil. The remainder of the screened accessions showed either intermediate (indices from 1.49 to 1.0) or low (indices <1.0) levels of adaptation. Taking into consideration that cassava was continuously cultivated in this site for the last 10 yr, the moderate level of productivity maintained without P application suggests that acid soils with low available P but high OM can support sustainable yield. Nevertheless, the significant response to P fertilizer observed in these trials indicates that cassava still benefits from applied fertilizer. Those genotypes highly adapted to low-P soils can be used as genetic resources for breeding new materials.

Table 10.1. RY and low-P adaptation index of 11 clones (out of 77 accessions) best adapted to the low-P soils of Santander de Quilichao, 1986-87 season.

	Fresh RY (t/ha)		
Variety	P_0[1]	P_{75}[1]	Adaptation Index to low P[2]
Panamiña	56.0	57.4	3.13
CM 489-1	37.3	73.5	2.60
CM 507-37	36.2	57.3	1.97
M Ven 321	32.9	62.6	1.96
CM 516-7	26.4	71.3	1.79
CM 523-7[3]	25.2	72.6	1.74
M Bra 226	38.6	45.5	1.67
M Bra 41	37.5	45.9	1.63
CM 305-41	34.9	48.7	1.61
CM 975-5	34.2	48.3	1.57
M Ecu 68	35.6	45.8	1.55
Avg of 77 accessions	26.8	39.3	1.0

[1] P application in kg P/ha

[2] Low - P adaptation index = $\dfrac{\text{Yield } P_0 \times \text{Yield } P_{75}}{\bar{X}\text{ Yield } P_0 \times \bar{X}\text{ Yield } P_{75}}$

[3] Released in 1990 for the Eastern Plains under the name "ICA-Catumare."

Table 10.2. RY and low-P adaptation index of varieties best adapted to the low-P soils of Santander de Quilichao (1987-88 season).

	Fresh RY (t/ha)		
Variety	P_0	P_{75}	Adaptation Index to low P
CG 913-4	43.9	46.4	1.99
CG 2177-2[1]	31.3	52.2	1.59
CG 1370-5	32.1	49.2	1.54
Avg of 33 accessions	27.0	38.0	1.0

[1] Released in 1990 for the Eastern Plains under the name "ICA-Cebucán."

Table 10.3. RY and low-P adaptation index of varieties best adapted to the low-P soils of Santander de Quilichao (1989-90 season).

Varieties	Dry RY (t/ha) P_0	Dry RY (t/ha) P_{75}	Adaptation Index to low P
CG 996-6	13.1	16.9	2.05
CM 305-41	13.9	14.6	1.86
M Bra 383	11.9	16.2	1.78
M Bra 191	10.9	16.9	1.67
Avg of 33 accessions	8.8	12.5	1.0

10.2 Relationships Between Leaf Gas Exchange, Total Biomass, RY and Adaptation to Low-P Soils

Using a portable infrared CO_2 analyzer, leaf gas exchange (CO_2 uptake and H_2O loss) was measured on upper canopy, exposed, fully expanded leaves of the 33 genotypes screened for low-P adaptation during the 1989-90 season. Measurements were conducted 6 times between 3 and 6 mo after planting with a total of 24 leaves measured/genotype/P treatment when incident sunlight was > 1000 μ mol m^{-2}/s in the photosynthetic active range. Gas exchange data were averaged throughout the measurement period and correlated with RY and total biomass at 10 mo after planting. Low-P adaptation index and some other growth parameters were also included in calculating simple correlations. Among this group of genotypes, leaf photosynthesis was significantly correlated with RY, total biomass, top wt, storage root no. and low-P adaptation index (Table 10.4). Mesophyll but not stomatal conductance was also significantly correlated with these yield and growth parameters. These patterns of correlations confirm earlier findings at CIAT that a direct and positive relation exists between single leaf photosynthesis and yield of cassava (CIAT Annual Reports 1988, 1989). Another important finding is the significant positive association between RY and both top wt and storage root no. It appears that when HI is high (in this group of genotypes, HIs were > 0.6), improvement in yield could be achieved by improving the crop's photosynthetic capacity through higher leaf area and higher leaf photosynthetic rate (carbon assimilation source) and by increasing storage root no. (sink strength). Adaptation to low-P soils also appears to be directly related to both the assimilation capacity and storage root no. High assimilation capacity and high sink strength would probably lead to higher P use efficiency (PUE), particularly in soils low in P.

Table 10.4. Correlation coefficients between leaf gas exchange characteristics, RY, biomass and low-P adaptation index of 33 clones, 1989-90 season.[1]

	Leaf Conductance (H2O)	Mesophyll Conductance (CO2)	Dry RY	Top Dry Wt	Total Biomass	Storage Root No.	Low-P Adaptation Index	HI
Leaf photosynthesis	0.81**	0.97 **	0.48 **	0.39 *	0.49 **	0.37 *	0.51 **	0.12 NS
Leaf conductance (H2O)	-	0.69 **	0.29 NS	0.25 NS	0.31 NS	0.11 NS	0.30 NS	0.03 NS
Mesophyll Conductance (CO2)	-	-	0.53 **	0.40 *	0.56 **	0.49 **	0.57 **	0.08 N.S.
Dry RY	-	-	-	0.58 **	0.98 **	0.62 **	0.99 **	0.33 NS
Top Dry Wt	-	-	-	-	0.76 **	0.50 **	0.58 **	0.52 **
Total Biomass	-	-	-	-	-	0.65 **	0.96 **	0.09 NS
Storage Root No.	-	-	-	-	-	-	0.67 **	0.07 NS
Low-P Adaptation index	-	-	-	-	-	-	-	0.31 NS

[1] Mean of the two P levels.
NS = Not significant at 5%
* = Significant at 5%
** = Significant at 1%

10.3 Long-Term Response to NPK Fertilizer in Infertile Acid Soils (Santander de Quilichao)

For the last 8 yr cassava was continuously grown on infertile acid soils at Santander de Quilichao to assess the effect of this permanent cultivation system on cassava productivity and its response to applied fertilizer.

Two cassava clones (M Col 1684 and CM 91-3) were planted annually at the same sites. The fertilizer treatments (4 reps) consisted of 3 levels of NPK (i.e., 0, 50 and 100 kg/ha each of NPK). Each of the three elements was also varied independently at 3 levels of 0, 50, 100 kg/ha while the other two elements were kept constant at 100 kg/ha. Treatments were allocated at random in a complete randomized block design within the site. All fertilizer treatments were applied at planting. Harvest was always conducted at 11 mo after planting. Figure 10.1 illustrates the long-term response of cassava to NPK. It is clear that cassava is highly responsive to K, particularly when the soil is poor in this element; on the other hand, there was little response to N and P. Moreover, in the absence of adequate K levels, no benefit is achieved by applying high levels of N and P. In cassava a large portion of absorbed K (> 60%) is removed with the harvestable roots; whereas significant amounts of absorbed N and P are recycled to the soil through fallen leaves and crop residue. It is known that a crop of cassava can return to the soil from 3 to 6 t of dry leaves during its growth cycle of 10-12 mo (see Chap. 3, sec.1). In addition to the native OM in the soil, these relatively large amounts of crop residue can serve as a source of nutrients.

In conclusion, it can be stated that cassava productivity could be maintained at a reasonable level in acid soils high in OM, provided that moderate levels of K fertilizer are applied to compensate partially for the soil K removed in the harvestable roots. However, when soils are poor in OM or in sandy soils, other nutrients such as N and P would limit productivity.

10.4 Response to NPK Fertilizer in Sandy Soil (Media Luna)

In contrast with the Quilichao soils, the Media Luna soils are sandy with extremely low OM and nutrient contents (CIAT Annual Report, 1988). Yields of cassava in that region declined rapidly in the last few years. Therefore, field trials were initiated two years ago to evaluate yield response to moderate levels of NPK fertilizer. Trials were conducted on a private farm using 13 cassava clones, among which were were local varieties as well as some CIAT advanced clones. Split applications of fertilizer (50-20-43 kg/ha NPK = 330 kg of 15-15-15 compound fertilizer) were made at 30 and 60 DAP.

Table 10.5 shows data of dry RY and biomass production for the 1989-91 seasons. The avg increases for all clones due to fertilizer application were 88%, 140% and 109% for dry RY, top growth and total biomass, resp. This indicates that by continuously growing

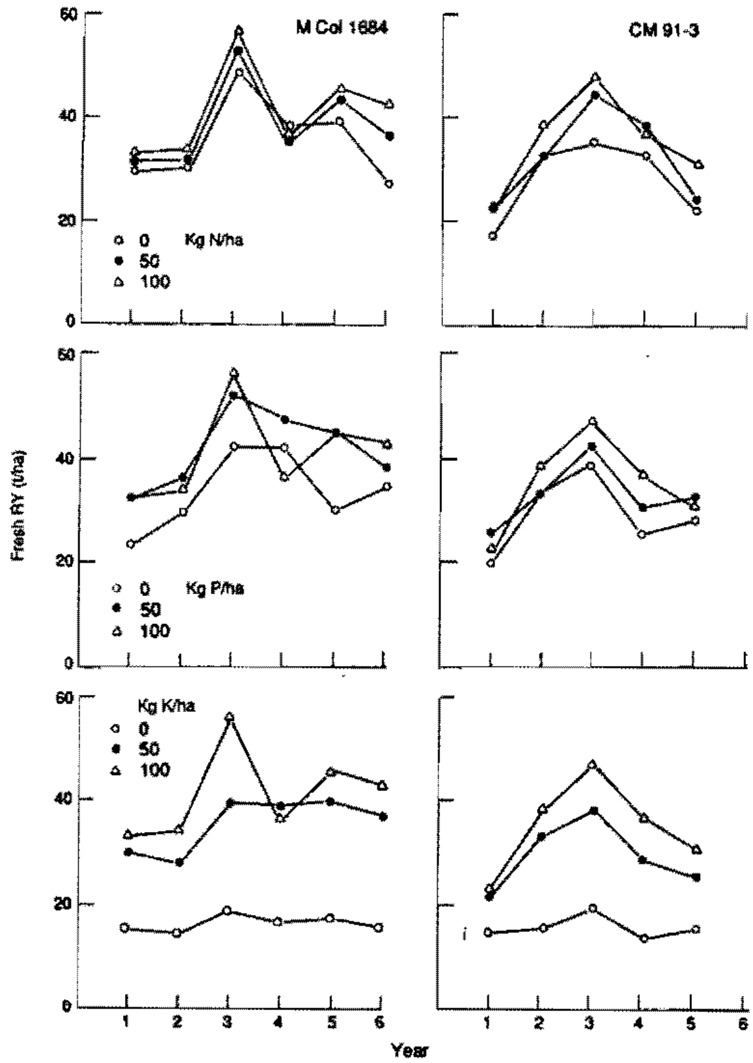

Figure 10.1. Long-term response of cassava to NPK fertilizer in a low-fertility soil at Santander de Quilichao, Cauca.

cassava on this poor sandy soil, productivity will decline and the need to fertilize the soil will become more crucial. Besides the substantial gains in yield, top growth was also greatly enhanced. This is of a paramount importance to cassava growers as sufficient good-quality stakes are essential. The cost of added fertilizer is insignificant compared to the large gains in yield and the ensured planting materials. There is also a possible reduction in weeding costs as fertilizer enhances cassava growth and reduces weed populations.

Table 10.5. Response of cassava to NPK fertilizer in the sandy soil of Media Luna (Magdalena, Colombia); avg of the 1989-91 growing seasons.

	Fertilized			Unfertilized		
Varieties	Roots	Tops	Total	Roots	Tops	Total
	Dry RY (t/ha)					
CG 1220-2	5.9	6.2	12.1	2.3	1.8	4.1
CG 1355-2	8.2	4.3	12.5	5.2	3.0	8.2
CG 1372-5	6.7	6.1	12.8	2.8	2.6	5.4
CG 1411-1	4.6	4.6	9.2	1.9	1.3	3.2
CG 912-8	6.3	5.9	12.2	3.3	2.5	5.8
CM 3320-4	6.3	4.2	10.5	2.7	1.7	4.4
CM 4181-1	7.0	5.0	12.0	3.1	1.9	5.0
CM 507-37	5.0	6.0	11.0	3.3	1.7	5.0
M Bra 191	6.9	5.1	12.0	4.3	3.0	7.3
M Bra 383	5.5	5.4	10.9	3.2	2.3	5.5
M Col 1505[1]	4.4	6.0	10.4	2.7	2.8	5.5
M Col 2215[1]	5.1	4.3	9.4	3.5	2.0	5.5
M Col 2216[1]	5.5	6.2	11.7	2.8	2.6	5.4
Avg	6.0	5.3	11.3	3.2	2.2	5.4
% increase	88	140	109			
LSD 5% var.	0.9	0.8	1.5			
Treatments	0.53	0.7	1.13			

[1] Local varieties.

10.5 Soil Management Systems at Media Luna

A 3-yr trial was conducted on a private farm at Media Luna (Magdalena) during 1988-91 to determine whether cassava productivity could be improved in poor sandy soil with fertilizer and/or plant mulch in combination with the tillage system. In general the soil is poor in OM and in nutrients (P and K ≤ critical levels), illustrating the very low fertility level typical of this cassava-growing area. The local var. M Col 1505 was used as a test material after selecting the planting stakes from a well-fertilized field. The treatments consisted of two tillage systems (i.e., zero tillage and conventional tillage), two fertilizer levels (i.e., no fertilization and 330 kg/ha of the compound fertilizer 15:15:15 in a split application at 30 and 60 DAP). Mulch was applied at a rate of 10-12 t/ha green material (≈ 3-4 t/ha DM) at planting. The source of mulch consisted of weeds, grasses and crop residue. Planting was done after the onset of the rainy season in May; harvesting, 11 mo afterward.

Figure 10.2 illustrates yield responses in the three consecutive seasons. Irrespective of tillage system, there were strong responses to fertilizer and mulch application with cumulative effects during the 3 yr. Mulch greatly enhanced RY without fertilizer application, irrespective of tillage method. The effect of tillage was more apparent in the first year when combined with mulch. In absence of both fertilizer and mulch, RY remained stable at a low level around 8-10 t/ha fresh root. As an avg of all years, RYs were greatly enhanced by either applying mulch or fertilizer (Fig. 10.3), with the greatest response to mulch occurring without fertilizer.

These data indicate that cassava productivity in this poor sandy soil is greatly enhanced by applying either chemical fertilizer or mulch. The latter appears to be beneficial in improving the physicochemical properties of the soil; moreover, it can alleviate water stress in these sandy soils by reducing water evaporation from the surface soil normally exposed to high temp (Fig. 10.4). Reducing evaporation from soil is of a paramount importance as sandy soils are characterized by a low water retention capacity. Another advantage of mulching is the great reduction in HCN content of cassava roots in the absence of fertilizer (Fig. 10.5).

In regions where cassava is normally grown in marginal poor soils coupled with prolonged drought such as NE Brazil and Sub-Saharan Africa, application of mulch, if available, could be beneficial for cassava production. Alternatively, cassava may be grown in rotation with other field crops that yield sufficient residue to be used as mulch. In cases where fallow can be practiced, natural vegetation may be used for mulching. On hillsides, where cassava is grown in degraded lands, mulching would be advantageous to minimize soil erosion as well as improve productivity. It is therefore warranted to evaluate this management system on steep lands combined with other practices effective in controlling soil erosion such as live barriers, which could be used as source for mulch (See Chap. 11).

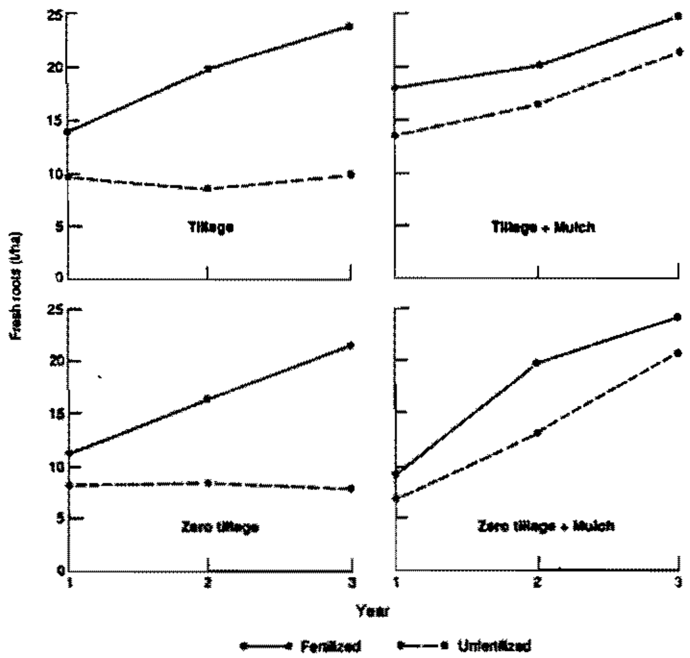

Figure 10.2. Responses of cassava to fertilizer application (330 kg/ha of 15-15-15 NPK), surface mulch and tillage system on sandy soil at Media Luna (Magdalena). Note the cumulative positive effect over years of both mulch and chemical fertilizer.

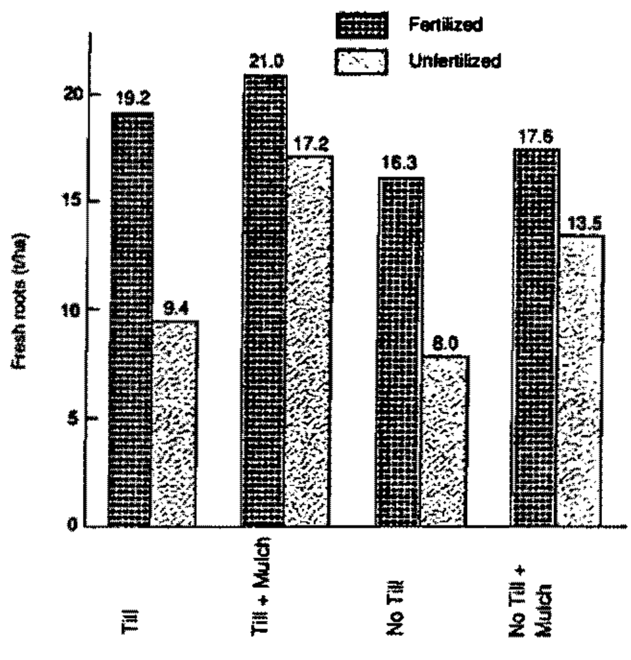

Figure 10.3. Three-year (1988-91) avg response of cassava to chemical fertilizer, mulch and tillage system on the sandy soil at Media Luna (Magdalena).

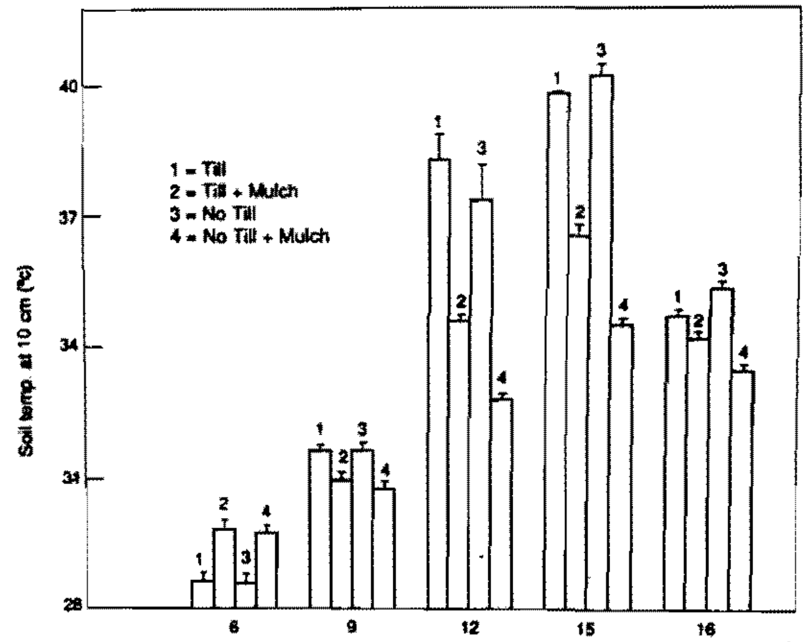

Figure 10.4. Soil temp at Media Luna (Magdalena), as affected by surface mulch and tillage system. Note the large decrease in soil temp under mulch at midday.

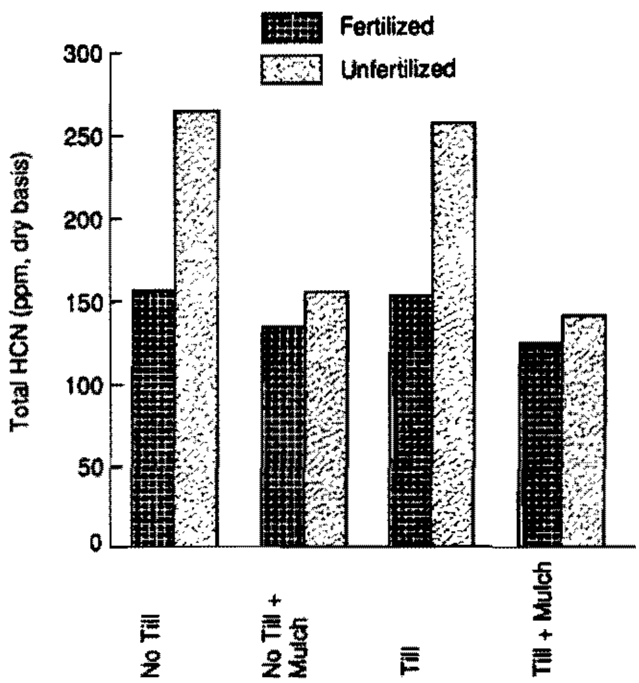

Figure 10.5. Total HCN in cassava roots at 11 mo after planting as affected by chemical fertilizer, mulch and tillage system. Note the large decrease in HCN under mulch in the absence of chemical fertilizer.

10.6 Varietal Differences in Response to P

Trials conducted previously in Santander de Quilichao indicated a wide range of response for adaptation to low P-soils in cassava germplasm (CIAT Annual Reports, 1986-91). Varieties well adapted to low P-soils have good yield at both low and adequate P supply. The objectives of this study were to identify mechanisms involved in varietal response to P and to determine the relative importance of P uptake (P acquisition) vs. internal use. Through a collaborative project with the Swiss Federal Institute of Technology, a 2-yr trial (1988-90) was conducted on a private farm in Santander de Quilichao. The soil-P level at the experimental site was about 2.5 ppm (< the critical level).

The experiment was laid out in a split-plot design with three reps. The following fertilizer treatments were assigned to the main plots: (1) unfertilized; (2) 100-0-100 kg/ha NP; (3) 100-50-100 kg/ha NPK; and (4) 100-100-100 kg/ha NPK. In the subplots, 4 cassava var. were planted (10,000 pl/ha): CM 523-7 released in 1990 as "ICA Catumare," CM 489-1, M Col 1684 and CMC 40. Sequential harvests of 8 protected pl/plot were made every 2 mo. Plants were separated into roots, stakes, stems, young leaves, mature leaves, fallen leaves, petioles, flowers and fruits in order to determine fresh and dry wt and P content. Total P uptake was estimated as the sum of P accumulation in the different plant parts. For fine root density determination, 12 soil samples/plot were taken at the mid-distance between 2 plants. A hand auger (433 cm3) was used to sample within the 0-20 cm soil layer. Rootlets were separated from soil by flotation, and root length was estimated using the grid line method.

10.6.1 Yield response

Figure 10.6 shows dry RY at final harvest for both crop cycles. The two most contrasting clones, M Col 1684 and CM 489-1, maintained different responses; i.e., significant response to P application in CM 489-1 and a lack of significant response in M Col 1684. Under low P, however, these 2 clones had similar RYs in both years.

10.6.2 P uptake

Figure 10.7 illustrates the total P uptake over time as affected by fertilizer levels. All varieties accumulated more P at high P levels (50 and 100 kg P/ha) than the control. Between 2 and 8 mo after planting, P uptake was nearly linear in all clones and P treatments (Fig. 10.8). In all clones, the P uptake rates were higher with higher P supply. At all levels of P supply, the ranking order among clones was CM 523-7 > CM 489-1 > M Col 1684 > CMC 40. The same pattern of ranking was observed with fine root length density (RLD) (Fig. 10.9), suggesting that RLD is of a paramount importance in P uptake. This is further illustrated by Figure 10.10 where P uptake rate was plotted as a function of RLD. At both low and high P supply, uptake rates increased with increased RLD. At a given RLD, all clones absorbed more P at high P supply. It appears therefore that the

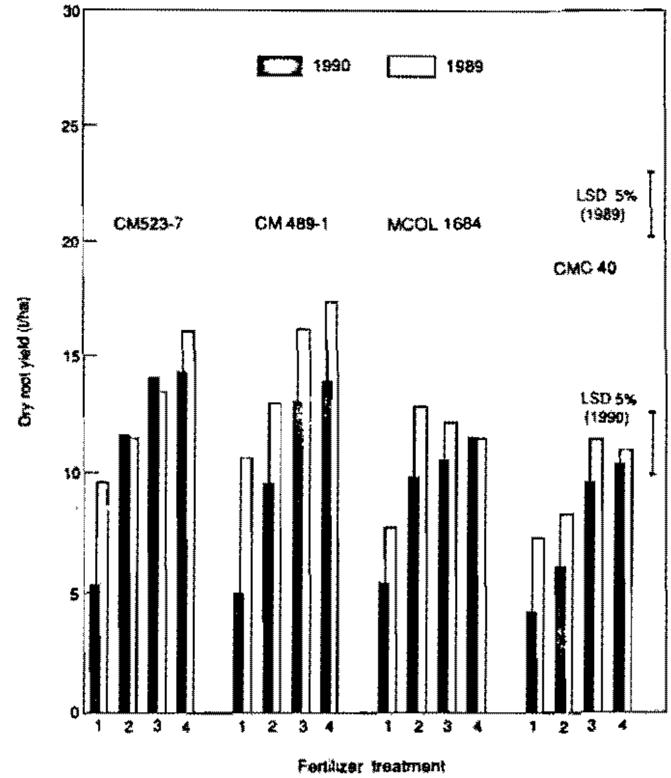

Figure 10.6. Responses of cassava to P fertilizer in low-P soil at Santander de Quilichao. (1) No fertilizer; (2), (3) and (4): zero, 50 and 100 kg/ha P with 100 kg/ha N and K.

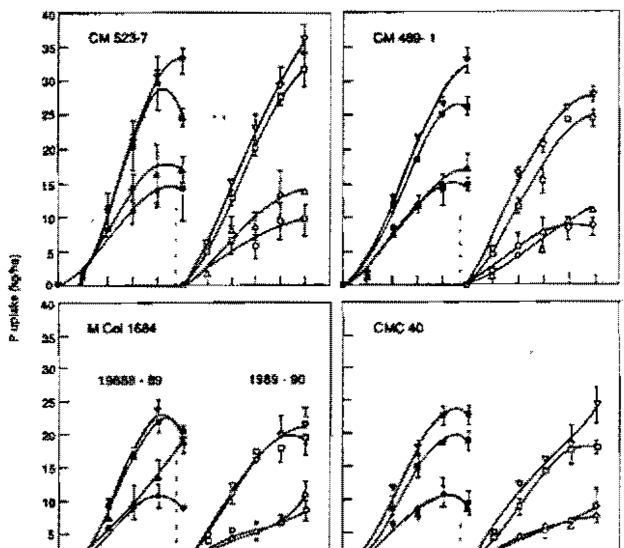

Figure 10.7. Total P uptake at different P fertilizer levels as a function of time after planting. (o,o) No fertilizer; (▲,), (■,), (▼,) 0, 50, 100 kg P/ha with 100 kg/ha N and K.

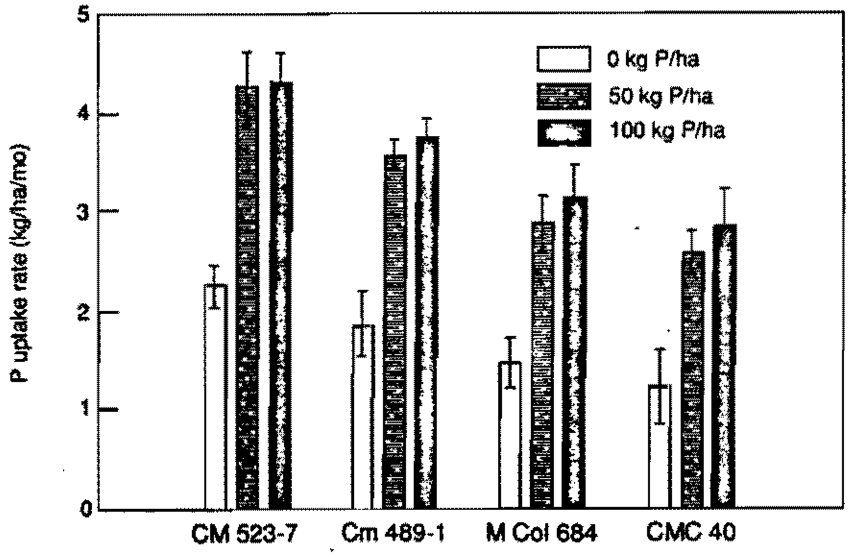

Figure 10.8. P uptake rates (2-yr avg) at different P fertilizer levels.

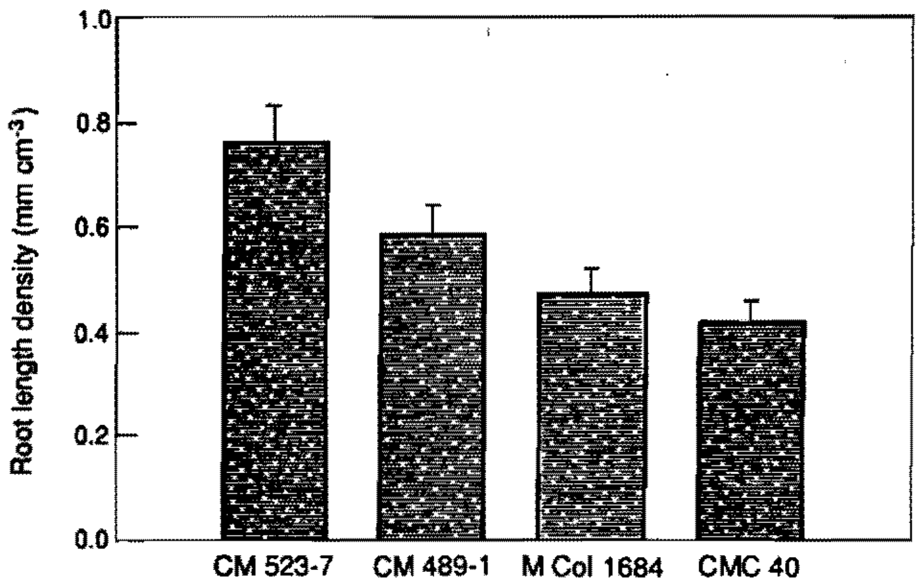

Figure 10.9. Fine RLD of 4 cassava clones (2-yr avg of all P levels). Note the same ranking among clones as with P uptake rates (Fig. 10.8).

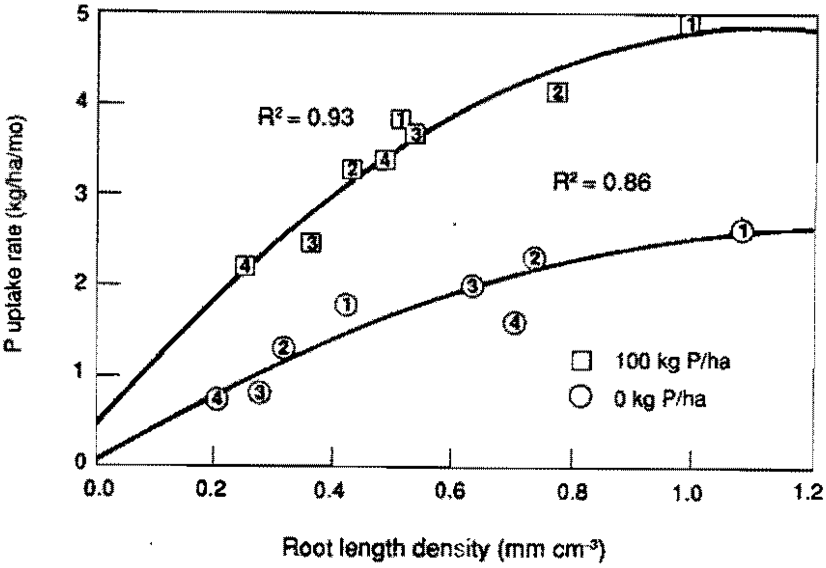

Figure 10.10. P uptake rate as a function of RLD and P supply (2 yr). (1) CM 523-7; (2) CM 489-1; (3) M Col 1684; (4) CMC 40.

lack of RY response to P in clone M Col 1684 was not related to limitations in P acquisition.

10.6.3 Internal use of absorbed P

Figure 10.11 illustrates the relationship between total P uptake (10 mo after planting) total and aerial biomass, and RY. The slopes of the regressions may indicate the PUEs. Clones M Col 1684 and CM 489-1 showed similar efficiency for total biomass production, which was higher than those in CM 523-7 and CMC 40. CM 489-1 showed higher efficiency in root production than in aerial biomass. M Col 1684, on the other hand, favored aerial biomass at the expense of root production. The two other clones showed equal efficiency for storage roots and aerial biomass. This suggests that pattern in DM partitioning between top growth and storage roots is a key factor in PUE. In M Col 1684, HI (storage roots/total biomass) decreased with increases in P uptake (Fig. 10.12). On the other hand, more P was allocated to top growth as P uptake increased. In contrast, CM 489-1, CM 523-7 and CMC 40 were characterized by nearly constant HIs over P

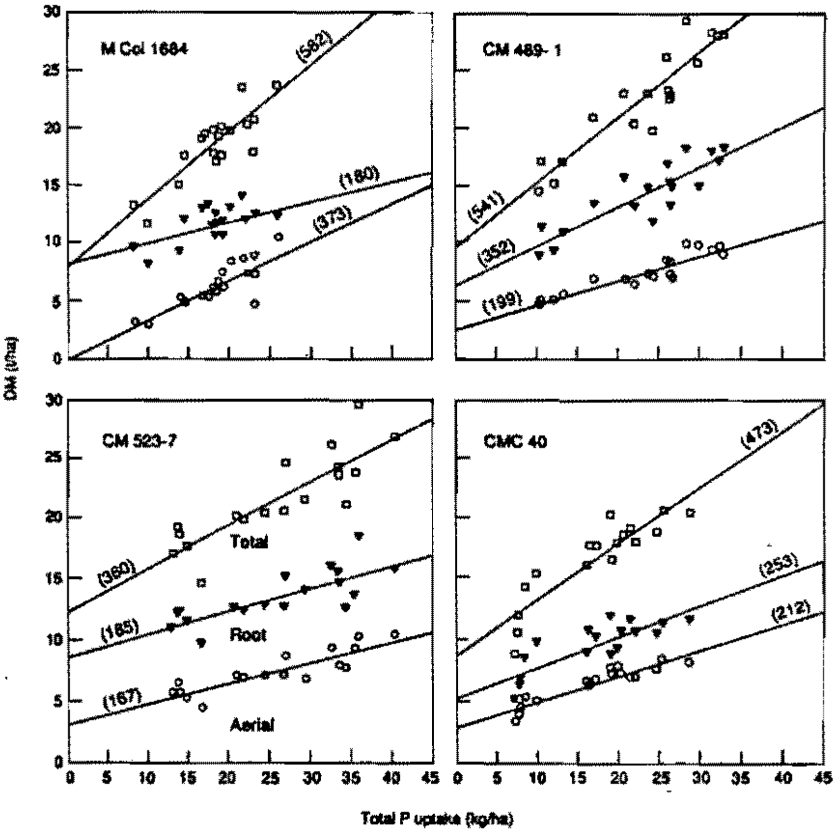

Figure 10.11. Relationships between P uptake and total biomass, RY and aerial biomass at 10 mo after planting (2 yr); slopes of the regression lines are given between brackets (kg DM/kg P uptake).

uptake gradient, as was the proportion of P allocated to top growth. Furthermore, M Col 1684 was observed to form more apices, flowers and fruits than other clones (data not shown). These morphological differences may partially explain differences in PUE among genotypes.

In conclusion it may be stated that genotypic differences in response to P are not related to limitations in P uptake. Internal use of absorbed P and patterns of biomass partitioning are more important. Sink capacity of storage roots and top growth habits of clones appear to be related to varietal response to P.

Adaptation to low P-soils could be enhanced by selecting for high fine RLD, high storage root sink capacity and late-to-medium branching.

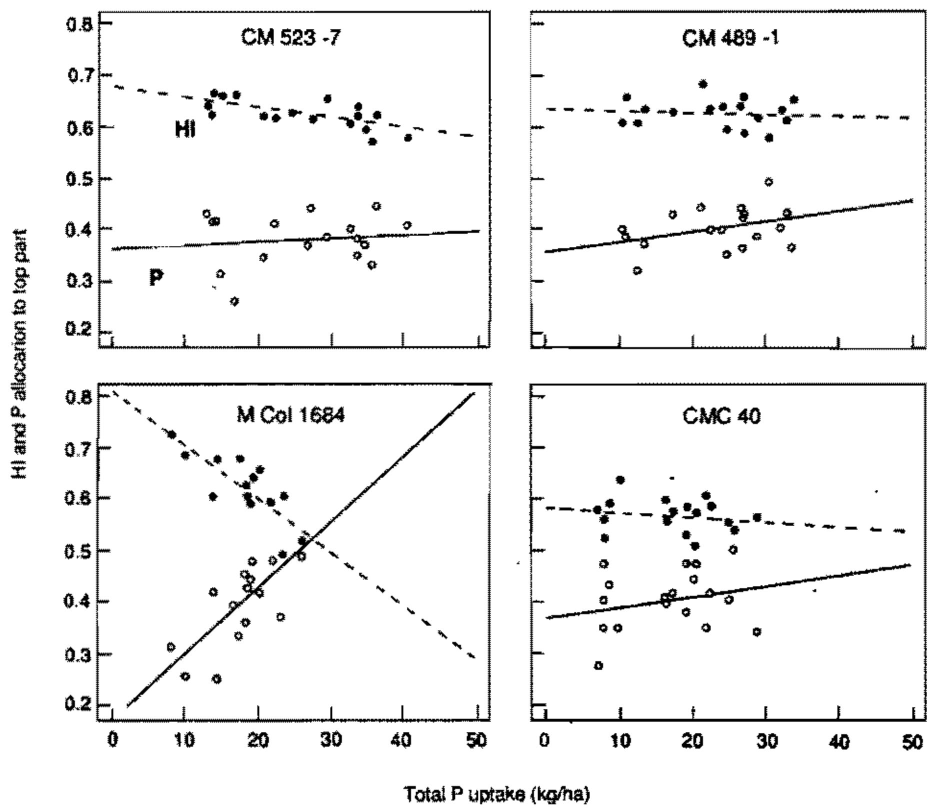

Figure 10.12. Relationships between P uptake and HI (o) and P allocation to top growth (o) at 10 mo after planting (2 yr).

11. SOIL CONSERVATION AND PRODUCTIVITY

Conservation of natural resources is essential to ensure sustainable production and to reduce environmental degradation in agricultural ecosystems. Soil degradation due to erosion and depletion of nutrients in many parts of the tropics has reached an alarming level. The level of soil degradation is further aggravated when resource-poor farmers are forced to grow their crops on marginal steep lands. When stripped of their natural vegetation cover, these steep lands become prone to severe erosion by heavy rainfall. Although cassava is not recommended for growing on hillsides with slopes >10%, a significant portion of cassava production occurs in hillside regions with greater slopes. Since 1979 the Cassava Program has put major emphasis on investigating soil erosion in cassava-based cropping systems, as well as on production management systems effective in reducing soil erosion while maintaining productivity (CIAT Annual Reports, 1982-86). To strengthen this research effort, a collaborative research project was initiated with the U. of Hohenheim, Institute for Plant Production in the Tropics and Subtropics, Germany, in 1986. Two doctoral students and, more recently, a postdoctoral researcher have collaborated with the Physiology Section in executing this project. The project has focused on (a) collecting fundamental data on soil erosion in the Inceptisols to assess long-term effects on soil degradation and (b) evaluating different cultural practices in relation to soil erosion and productivity. The trials were established at 2 sites: The CIAT Experiment Station in Santander de Quilichao (alt. 1000 m) with an avg slope of 10-15%, and a private farm in Mondomo, Cauca (alt. 1450 m) with an avg slope of 15-20%. The soils (Oxic Dystropept and Oxic Humitropept, resp.) are acidic, high in Al saturation (50-85%) and low in nutrients in the thin top soil (15-25 cm).

Based on the results of this on-station research, the project is currently extending its activities to farmers' fields, in close cooperation with local institutions and organizations operating in the northern parts of the state (Cauca). Collaboration with local farmer groups and local institutions will constitute a basic principle of further research done by CIAT's Cassava/Soil Conservation Program in order to:

- Bridge the gap between research and practice
- Assure that on-station field research meets the necessities of local farmers
- Accelerate the application of adequate soil conservation practices on the farmers' fields
- Achieve a more sustainable impact on farm practices able to reduce erosion risks

In this report some findings are presented that indicate the potential of soil erosion on hillsides and the effects of different crop management systems on soil loss and cassava production.

11.1 1987-1989 Trials

11.1.1 Soil losses and cassava productivity

Total annual soil losses as affected by crop management systems are presented in Table 11.1. Monthly cumulative soil losses are shown in Figure 11.1. The overall avg annual soil losses from the bare plots were >100 t/ha, which shows the high erosion potential of these soils. Depending on the amount and intensity of the rainfall (Fig.11.2) soil losses can exceed 300 t/ha/yr (Table 11.1). At both Quilichao and Mondomo, the major portion of soil losses occurred between Oct. to Dec. when rainfall was highest (Figs. 11.1 & 11.2). The impact of highly intensive rainfall is better illustrated by the estimated kinetic energy of rainfall (Fig. 11.3)--the largest amount of rainfall being associated with the highest kinetic energy value. This information has important practical implications for soil conservation on hillsides where cassava often is grown. It is likely that soil losses will be large when planting coincides with intensive rainy periods due to the fact that cassava canopy development is slow during the first 3 mo; through proper management, however, soil losses can be minimized.

Compared with the traditional cassava cultivation on flat lands, growing cassava in contour ridges or with grass barriers has led to much lower soil losses. On the other hand, growing cassava in down-slope ridges or in association with early-maturing grain legumes resulted in much higher soil losses than the traditional practice (Table 11.1). Too much soil disturbance might have occurred during the planting, weeding and harvesting of the legume crop. Although minimum tillage (preparing only holes for cassava stakes) greatly reduced soil erosion, cassava productivity in Quilichao was much reduced (Table 11.2), probably due to competition from the natural weed vegetation and because of soil compaction. Other management practices, however, did not show large variations in productivity. It appears therefore that growing cassava either in contour ridges or in association with live barriers is not only effective in reducing soil losses but also in maintaining cassava productivity. The choice of a specific management practice--particularly with respect to its socioeconomic implications--would probably depend on the farmer's conditions. Nevertheless, the long-term benefits of controlling soil erosion and hence maintaining soil fertility (Table 11.3) should be assessed against the extra costs required for soil conservation measures. It is therefore warranted to evaluate these management technologies in participation with farmers, taking into account their traditional practices in an integrated farming system.

11.1.2 Minimum estimates for runoff

Like soil losses, runoff was measured after erosive rain storms on a regular basis using permanent water collectors. Given the fact that the water collecting system did not always function properly, particularly during intensive rain storms, the runoff volumes measured in these trials should be taken as minimal estimates (Table 11.4); higher volumes of runoff are likely to occur on larger slopes. Nevertheless, these minimum estimates of runoff

Table 11.1. Soil losses during 1987-89 cropping seasons at Quilichao and Mondomo (t dry soil/ha).

	Quilichao			Mondomo		
Treatment	1987/88	1988/89	Mean Quilichao	1987/88	1988/89	Mean Mondomo
Bare Fallow	49	197	123	45	311	178
Cassava/Flat	5	17	11	10	40	25
Cassava/Contour-ridges	4	8.5	6.3	1.4	2.6	2
Cassava/Down-slope ridges	31	68	49.5	34	13	23.5
Cassava/Cowpeas	8	29	18.5	20	47	33.5
Cassava/Grass strips	5	15	10	1.5	3	2.3
Cassava/Min. tillage	2	2	2	3	2.5	2.8

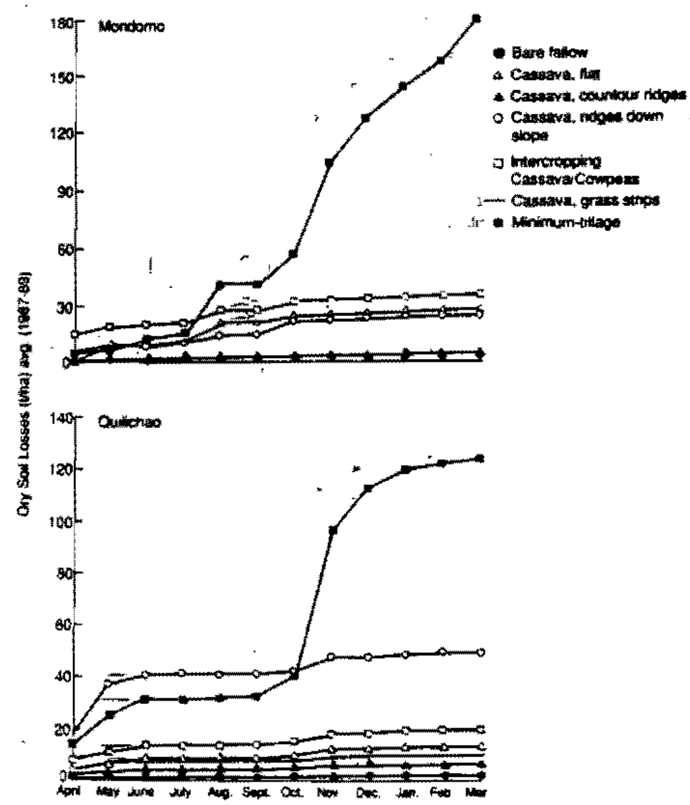

Figure 11.1. Cumulative soil loss at Mondomo and Quilichao as affected by some cassava-based cropping systems (2-yr avg).

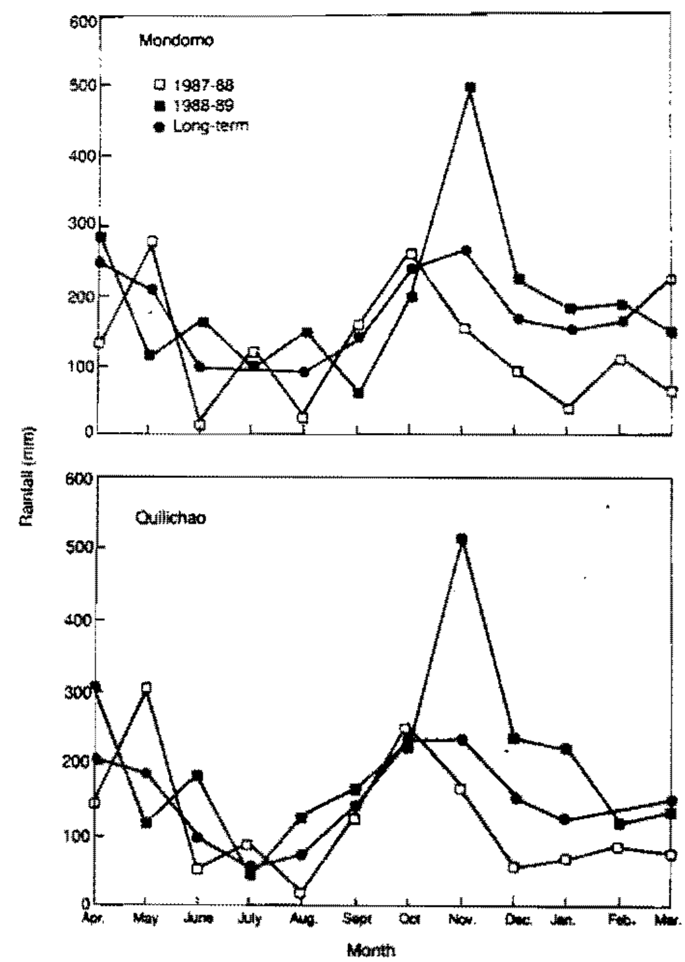

Figure 11.2. Monthly rainfall at Mondomo and Quilichao during the 1987-89 seasons, along with long-term rainfall patterns.

show that growing cassava in down-slope ridges results in larger volumes of runoff as well as soil losses (Table 11.1). The two management practices--i.e., growing cassava in contour ridges or with live barriers--were effective in reducing runoff and consequently soil losses. These findings indicate the importance of crop management systems in conserving both soil and water. Taking into account that cassava is a long-season crop (8-18 mo), conserving water by reducing runoff during the rainy season should reflect favorably on productivity when the crop has to endure long periods (2-3 mo) with sporadic or no rainfall. The combined effect of reducing soil losses and runoff would lead to improved soil water status.

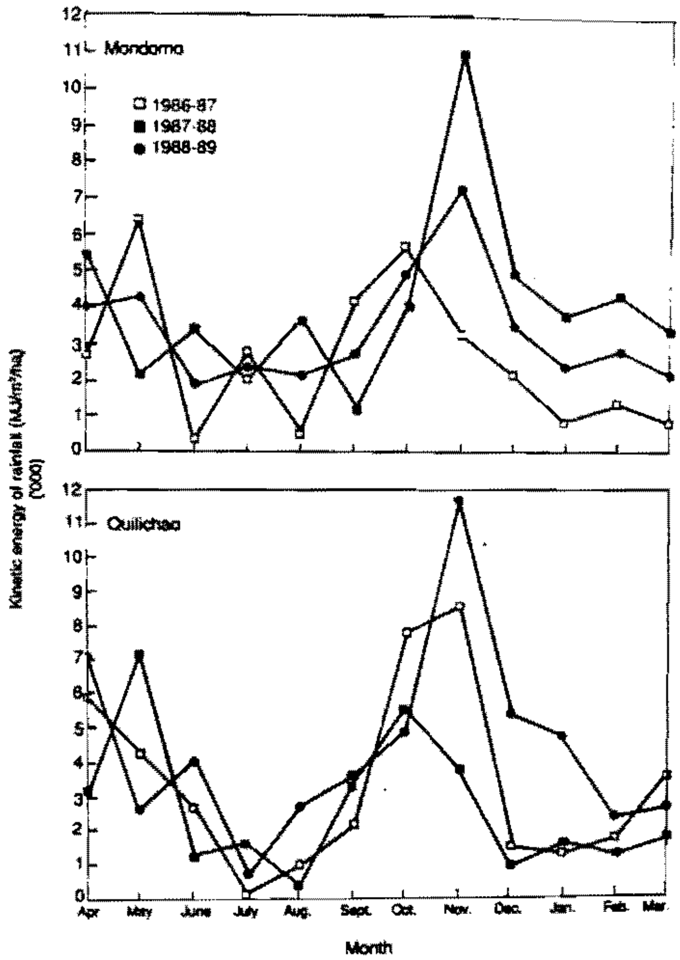

Figure 11.3. Kinetic energy of rainfall at Mondomo and Quilichao, 1986-89.

11.1.3 Prediction of soil losses using the Universal Soil Loss Equation (USLE)

As stated, one of the objectives of this research effort was to collect fundamental information on the characteristics of rainfall, soils and crops in order to test the applicability of the USLE for predicting soil erosion in the Andean regions of the humid tropics. Originally developed for temperate zones, the validity of the USLE needs to be tested in the tropics, where limited information exists. More data on a longer term basis are required before the model's utility can be judged). Short-term results (2 yr) were inconsistent in relation to actual and predicted soil losses. Only in the second year, were there significant correlations between the erosivity indices utilized in the USLE and the

Table 11.2. Cassava fresh RY in erosion trials at Quilichao and Mondomo (t/ha).

Treatment	Quilichao CM 523-7 (3-yr avg)	Mondomo M Col 1522 (1988-89)
Cassava-Flat	31.1	19.7
Cassava-Contour ridges	29.7	15.3
Cassava-Down-slope ridges	27.7	15.4
Cassava-Cowpeas	21.3	16.8
Cassava-Grass strips	27.1	18.2
Cassava-Min. tillage	9.0	15.7
LSD 5%	3.7	2.9

Table 11.3. Annual losses of OM and of some nutrients in eroded soils; avg of two cropping seasons (1987-89) at two sites (± SD).

Treatment	OM (t/ha)	Mg	K	P
		kg/ha		
Bare fallow	9.0 ± 7.5	1.9 ± 0.72	6.2 ± 3.9	0.6 ± 0.4
Cassava-Flat	1.2 ± 0.9	1.2 ± 0.86	1.7 ± 1.6	0.23 ± 0.2
Cassava-Contour ridges	0.24 ± 0.2	0.3 ± 0.2	0.39 ± 0.2	0.06 ± 0.05
Cassava-Down-slope ridges	2.2 ± 1.4	2.7 ± 1.5	3.0 ± 1.6	0.53 ± 0.4
Cassava-Grass barrier	0.4 ± 0.4	0.5 ± 0.5	0.63 ± 0.5	0.1 ± 0.1

Table 11.4. Minimum estimates of runoff at Quilichao and Mondomo, 1987-89 seasons.

Treatment	Quilichao		Mondomo	
	mm	% Rainfall	mm	% Rainfall
Bare fallow	125	6.4	103	5.3
Cassava-Flat	123	6.0	126	5.8
Cassava-Contour ridges	113	5.8	71	3.4
Cassava-Down-slope ridges	201	10.3	152	7.9
Cassava-Grass barriers	110	4.7	140	6.5

actual soil losses at both Quilichao and Mondomo (Table 11.5). However, the differences between the data of the 2 cropping seasons suggest that long-term studies are essential.

11.2 Potential of Forage Legumes as Ground Cover in Relation to Soil Conservation and Cassava Productivity

Permanent ground cover with forage legumes is one of many crop management systems favored for soil conservation and for improving soil fertility in the humid tropics. As cassava farmers rarely apply chemical fertilizers, forage legumes in association with cassava might be viewed as an alternative "biological source" for soil improvement. Two-year field trials were initiated at Santander de Quilichao to evaluate the potential of this system in relation to cassava productivity and soil conservation. The trials were established on a low-fertility site that had been under cassava cultivation for several years. Several forage legume species were solid-sown and cassava stakes were planted in small prepared pits (minimum tillage). One experiment received no chemical fertilizer; the other, 500 kg/ha of 10-20-20 NPK compound fertilizer at planting. Table 11.6 shows data on avg dry RY as affected by the legume association and by surface mulching with plant residue. Mulching by leaving cut weeds on soil surface greatly enhanced RY, particularly in the absence of chemical fertilizer. This confirms similar responses to mulching observed in the poor sandy soils at Media Luna (Magdalena) (See Chap. 10).

Applying mulch to soils low in nutrients seems to be a viable alternative for improving soil fertility and hence productivity. On the other hand, association with forage legumes showed variable effects on cassava productivity. With the more vigorous clone CM 507-37, some legume genera (e.g., *Siratro*, *Zornia* and *Pueraria*) did not significantly reduce cassava yield in absence of fertilizer application, but others (e.g., *Desmodium* and *Arachis*) depressed yield. Yield depressions were more striking in the case of M Col 1684. With applications of chemical fertilizer, all forage legumes depressed yields of cassava (as compared to sole crop) in both var. It seems, therefore, that the success of this cropping system would depend on the degree of competition between the forage legumes and cassava and on the availability of water during the growth cycle.
Growing cassava in association with forage legumes should be further investigated as an alternative system for soil conservation and fertility improvement, taking into account both the short- and long-term consequences.

11.3 Soil Losses and Runoff in Cassava-Legume Association vs. Other Practices

In Quilichao, intercropping with forage legumes resulted in the highest soil losses as compared to other cropping systems (Table 11.7 & Fig. 11.4). In the establishment phase, kudzu (*Pueraria*) lost 74%, centrosema 83% and zornia 91% in the first 60 days of the cropping cycle; once established, only small losses occurred. In Mondomo, shortly after planting, two strong rains caused heavy losses on the standard bare plots, while cassava plots recently plowed by oxen showed no erosion. Until October, a few low-

Table 11.5. Correlation coefficients of various erosivity indices of the USLE and soil losses from bare and tilled soils at Quilichao and Mondomo.

	Indices										
	KE	I_{30}	EI_{30}	EI_{30}max	A	KE_{25}	I_{15}	EI_{15}	I_m	EI_m	AI_m
Quilichao											
1987-88	0.362NS	0.555*	0.486NS	0.491NS	0.348NS	0.412NS	0.530NS	0.485NS	0.452NS	0.436NS	0.422NS
1988-89	0.398*	0.669***	0.750***	0.836***	0.290NS	0.590**	0.561**	0.730***	0.513**	0.712***	0.681***
Mondomo											
1987-88	0.054NS	-0.092NS	-0.052NS	-0.253NS	0.030NS	-0.004NS	0.060NS	-0.019NS	0.411NS	0.172NS	0.182NS
1988-89	0.564**	0.787***	0.802***	0.837***	0.480*	0.745***	0.795***	0.804***	0.786***	0.806***	0.785***

KE = kinetic energy of erosive storms

I_{30} = max. 30-min. intensity of an erosive storm

EI_{30} = product of kinetic energy and I_{30} (rain factor of the USLE)

EI_{30} max = EI_{30} of biggest storm between two sampling days

A = amount of erosive rainfall

KE_{25} = kinetic energy of rain with > 25 mm/h intensity

I_{15} = max. 15-min. intensity of an erosive storm

EI_{15} = product of kinetic energy and I_{15}

I_m = max. 7.5-min. intensity of an erosive storm

EI_m = product of kinetic energy and I_m

AI_m = product of amount of erosive rainfall and I_m

Table 11.6. Cassava dry RY under different cropping systems at Santander de Quilichao, 1987-89 seasons.

Cropping System	Unfertilized CM 507-37	Unfertilized M Col 1684	Fertilized CM 507-37	Fertilized M Col 1684
	Dry RY (t/ha)			
Cassava, weeds removed	7.2	5.8	18.0	10.5
Cassava + mulch (weeds)	11.0	9.1	19.0	13.6
Cassava + zornia	6.9	5.6	15.3	8.3
Cassava + kudzu	8.5	3.2	12.2	4.9
Cassava + centrosema	6.7	2.0	14.2	6.8
Cassava + siratro	8.3	2.3	11.5	6.2
Cassava + desmodium	4.1	2.0	10.7	5.7
Cassava + *Arachis pintoi*	5.2	2.3	12.5	8.1
LSD 5% (Var. X System) Unfertilized = 1.4			LSD 5% (Var. X System) Fertilized = 2.1	

Table 11.7. Annual dry soil losses (t/ha) and runoff (mm) in different cassava cropping systems 1990-91.

Treatments	Quilichao Soil Losses	Quilichao Runoff (10 mo)	Mondomo Soil Losses	Mondomo Runoff (8 mo)
Bare Fallow	142	144	228	123
Cassava-Flat	8.3	48	12.8	60
Cassava-Contour ridges	3.1	44	2.0	37
Cassava-Kudzu (No. 9900)	15.4	43	-	-
Cassava-Zornia (No. 8283)	27.4	80	6.9	78
Cassava-*Centrosema acutifolium* (No. 5568)	12.6	38	2.5	63
Cassava- *Centrosema macrocarpum* (No. 5740)	-	-	5.5	58
Cassava-Elephant grass strips	4.0	50	1.0	49
Cassava-Vetiver grass strips	1.3	45	4.7	53

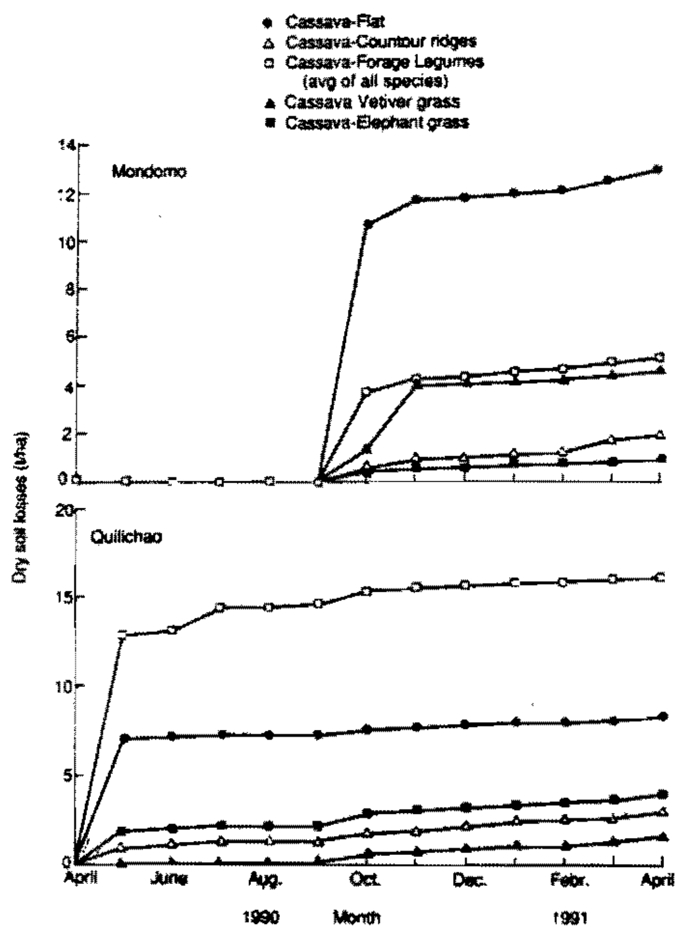

Figure 11.4. Cumulative soil loss during the 1990-91 season at Mondomo and Quilichao as affected by some cassava-based cropping systems.

intensity rains fell, causing small losses only on the bare plots. As in previous years, growing cassava in contour ridges and the use of live barriers have led to the smallest soil losses at both sites. Despite steeper slopes in Mondomo, only cassava-zornia intercropping and flat planting were above the soil loss tolerance limit of 5 t/ha/yr; whereas other cropping systems had soil losses below this limit. The standard bare plots lost 142 t/ha/yr in Quilichao and 228 t/ha/yr in Mondomo (Fig.11.5), which means a loss of 1.4 cm and 2.5 cm of topsoil, resp. On the bare plots, about 11% of rainfall was lost as runoff, the rates of both sites being similar. All cropping systems had low runoff with highest rates in the cassava-zornia system (6-7%), which was accompanied by higher soil losses. This was due to the very poor establishment of zornia (Table 11.8).

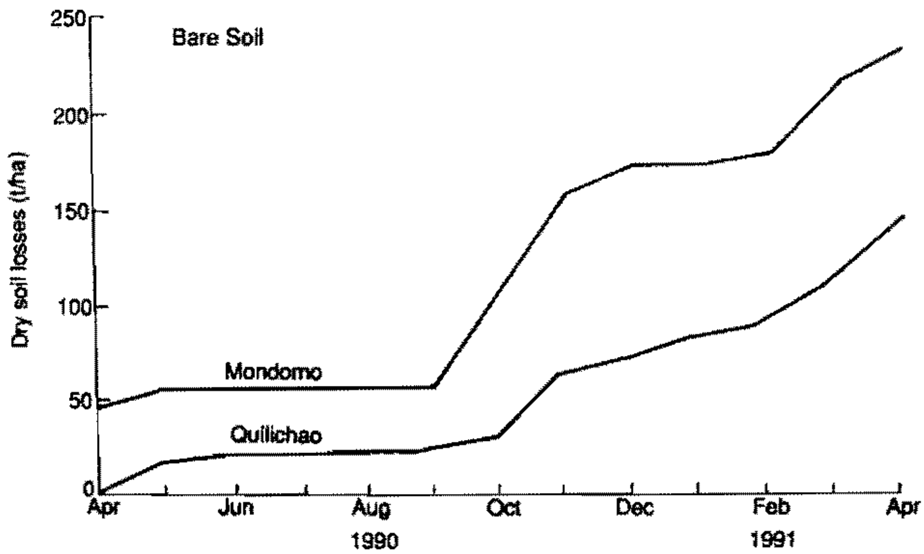

Figure 11.5. Cumulative soil loss from the bare soil during the 1990-91 season at Mondomo and Quilichao.

Table 11.8. Fresh RY of cassava and DM yields of forage legumes (t/ha), 1990-91.

Treatment	Quilichao (11 mo)		Mondomo (8 mo)	
	Cassava CM 507-37	Forage	Cassava CMC 40	Forage
Çassava-Flat	35.7	-	18.3	-
Cassava-Contour ridges	35.6	-	15.4	-
Cassava-Kudzu	20.7	2.9	-	-
Cassava-Zornia	27.2	3.4	17.5	0.1
Cassava-*Centrosema acutifolium*	31.8	3.4	18.2	1.4
Cassava-*Centrosema macrocarpum*	-	-	11.5	2.5
Cassava-Elephant grass (75% area cassava)	23.6	5.3	16.0	9.7
Cassava-Vetiver grass[1] (87.5% area cassava)	28.5	1.1	13.1	1.2

[1] Cassava and Vetiver grass 10 months old, the other treatments 11 months old.

It was difficult to establish the legumes satisfactorily. Heavy rains washed down the seeds even on these moderate slopes, especially the small-seeded zornia. Reseeding was necessary for all legumes, which led to soil compaction (10-15% higher bulk densities than on the other ones) and consequently to higher soil losses at the beginning of the cropping cycle in Quilichao. In Quilichao, kudzu and centrosema required 3 mo to reach 50% soil cover, zornia nearly 2 mo more. In Mondomo, legume development was generally slower; the highest soil cover achieved by zornia was 5%. Disturbance of soil, decreasing soil coverage and further compaction by harvest operations and evaluations have led to somewhat increasing soil losses after cassava harvest in March 1991 in Quilichao and in January 1991 in Mondomo. Long-term data are required to evaluate the cassava-legume system properly in relation to soil conservation and cassava productivity.

11.4 Productivity in Cassava-Legume Association vs. Other Practices

Traditional planting of cassava on plowed flat land and on contour ridges produced the highest yields in Quilichao, confirming earlier results that improvement of soil structure by tillage is essential for good RYs at this site (Table 11.8). On the other hand, intercropping with forage legumes reduced cassava RY in the dry season, probably because of the slow development of associated cassava as compared to sole cropped cassava. Compared with sole cassava on the flat, kudzu depressed cassava yield by 42%, zornia by 24% and *C. acutifolium* by 9%.

Forage legumes and cassava were established simultaneously while live elephant grass barriers were established one year before (1989). The grass covered 25% of the plots. On a hectare basis, 34% fewer roots were harvested than with traditional planting, compensated partly by 5.3 t/ha DM of fodder grass. This resulted in an effective reduction (based on actual cassava area) of RY of 9% due to competition by the grass strips. Cassava with vetiver as barrier was established in 1990 on grassland one month after the other treatments. Production of the legumes used in Quilichao was quite similar. Kudzu and centrosema had to be cut 4 times because of their climbing growth habit, while the bushy zornia was cut twice.

In Mondomo, growing cassava on the flat or in association with *C. acutifolium* produced the highest yields. Growing cassava in association with *C. macrocarpum* produced the lowest RY, suggesting stronger competition by this legume species. The best forage production was obtained with elephant grass, which did not depress cassava production based on actual cropped area.

In mixed farming systems with an animal component, the production of forage in association with cassava for erosion control might be a viable option. Reduction in cassava RY can be compensated by fodder production. In absence of the animal component, other soil erosion control measures such as tree strips for fuel or fruit production might have more potential.

11.5 Soil Properties as Affected by Soil Erosion and Cassava Cropping Practices

Table 11.9 shows changes in some soil chemical properties after 4 yr of consecutive cassava cropping and of clean-tilled fallow compared with the original soil. High soil losses in the bare plots decreased soil contents of available nutrients and of OM accompanied by an increase in Al saturation. K, Mg and Ca contents decreased overproportionally, which is confirmed by a selective loss of K and Mg with sediment (data not shown). Fertilization of cassava restored soil fertility and enriched soil in P, K and Mg. Measurements of aggregate stability--an important parameter in soil structure and its susceptibility to erosion--showed the highest stability in the original soil, followed by cassava in contour ridges > flat planting > bare plot (Fig. 11.6). It decreased with increasing soil loss, time of soil exposure, no. of weedings and tillage operations. In the contour ridges, mixing of top and subsoil during field bed preparation has probably led to an aggregate size distribution similar to the original soil. Proportion of sizes < 0.25 mm, including grains of the most erodible size fractions, is about 18.5% in the 4-yr-old bare plot and in flat planting. In contour ridges and in original soil, the percent of these small-sized grains is much less.

11.6 Conclusions

In conclusion it may be stated that soil losses in the traditional flat planting system of cassava on hillsides are above the tolerance limit. Other practices such as growing cassava in contour ridges or in association with live barriers are more effective in reducing soil loss and in maintaining cassava productivity. In view of CIAT's recent major emphasis on natural resources management and on reducing environmental degradation, soil conservation and fertility maintenance should be integrated into the farming system as a whole, taking into consideration both short- and long-term consequences. The current efforts in the Cassava Program will continue in collaboration with Hohenheim U. and with several national institutions.

Table 11.9. Changes in some chemical properties of surface soil in different cropping systems at Santander de Quilichao, 1987-91.

Year	Treatment	Accum. Soil Loss t/ha	pH	%OM	P ppm	K	Ca	Mg	Al Sat.
						meq/100 g soil			
1987	Original soil	0	4.6	7.3	1.4	0.16	0.85	0.3	75
1991	Bare soil[1]	553	4.0	5.4	1.0	0.07	0.21	0.05	93
1991	Cassava-Flat[2]	34	4.4	7.2	10.8	0.13	1.76	0.73	53
1991	Cassava-Contour[2]	15	4.2	7.4	17.7	0.18	1.69	0.62	57

[1] Unfertilized.
[2] Lime (500 kg/ha) and fertilizer applied.

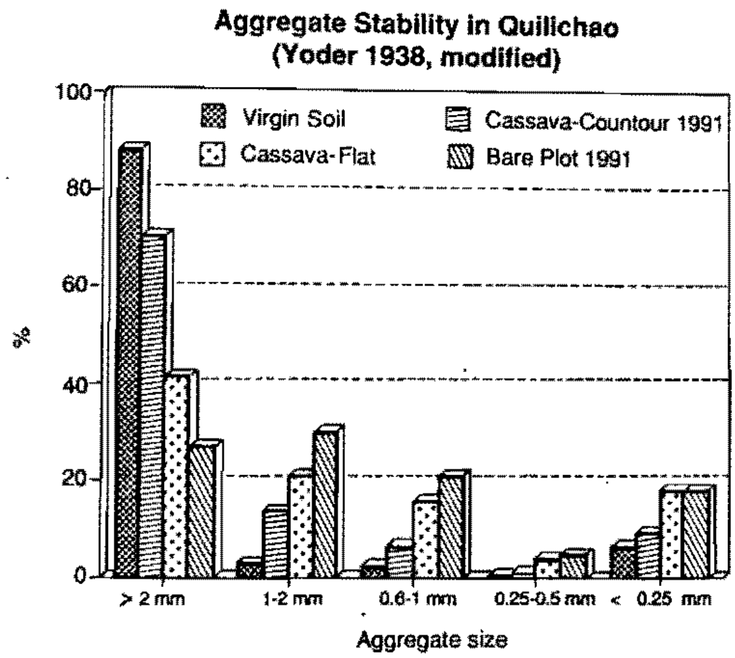

Figure 11.6. Soil-aggregate stability at Quilichao as affected by some cassava cropping practices.

12. PROCESS AND PRODUCT DEVELOPMENT

Research in the area of process and product development over the last decade has made an important contribution to the Cassava Program's demand lead strategy. This research was justified for the following reasons:

- Stagnation of existing cassava markets has reduced the possibility of adoption of improved production technology and of welfare improvement for small farmers.
- New or improved cassava products have high potential for linking farmers to growth markets and provide opportunities for rural income generation.
- There were no alternative institutions conducting research and extension activities in this area, especially in Latin America.
- CIAT has a comparative advantage in linking processing and marketing research with cassava production activities in integrated cassava projects.

12.1 Objective

To create new markets for cassava through the development of novel or improved cassava-based products, with an emphasis on small-scale processes suitable for generating income for small cassava farmers.

12.2 Methodologies

As a direct result of the R&D experiences gained during the 1980s, a methodology for process and product development has evolved. The methodology consists of four stages:

- Identification of product opportunities through idea generation and selection
- Research under controlled conditions to develop the experimental process and product, and to define market potential further
- Pilot-scale testing of process, product and market under real conditions and under the management of small farmer groups
- Commercial expansion and replication of the pilot experience

Collaboration with other research institutes in the research or experimental phase of projects has been a feature of CIAT's approach: national expertise and interest in cassava product development has thus expanded during the decade. The pilot phase is always carried out in Colombia, within the context of integrated cassava projects. The active participation of the Integrated Rural Development Fund (DRI) of the Colombian Ministry of Agriculture has been instrumental in facilitating the coordination of activities with a range of Colombian agencies (e.g., CORFAS, SENA, ICA, INCORA), whose participation is essential to ensure success. The role of the Cassava Program is therefore greatly reduced once the commercial or expansion phase is initiated although the absence of a Colombian institution responsible for research and technical assistance in cassava postharvest utilization activities has been a major limitation.

This chapter will cover the first 3 phases of the product development process. The commercial or expansion phase will be reported in the Colombia country report (Chap. 14), and all pilot and commercial activities in other countries will be reported in their respective chapters.

12.3 Priorities

A wide range of potentially viable cassava-based products can be listed a priori. The selection of priority products for research at CIAT was necessary in order to focus the limited resources available on research with the greatest potential benefits within a reasonable timeframe. Cassava products can be divided into primary or intermediate products (e.g., flour, starch, chips) and derived or secondary products made from the intermediate ones (e.g., high fructose syrups, animal feed concentrates, extruded snack foods). Product development has focused on the former.

The four primary products that were initially identified at CIAT were:

- cassava chips for animal feed
- fresh, conserved cassava
- cassava flour for human consumption
- cassava starch

It was decided not to focus on "farinha," important in Brazil, or on cassava leaves for animal feed. Table 12.1 shows the type information used to decide the research priorities for activities during the 1980s.

Dried cassava for animal feed was an obvious first choice for action, with a simple low-cost technology already developed and tested, and good market potential in Colombia and other Latin American countries. The biggest constraint was the weakness of farmer organizations capable of managing and operating small-scale processing cooperatives in cassava-producing areas.

Cassava flour for human consumption was seen as an attractive proposition, although with a more uncertain demand due to the novelty of the product. An efficient, small-scale process to obtain high-quality cassava flour was needed to be developed. The potential

Table 12.1. Checklist of research priorities in cassava process and product development, as defined early 1980s.

	Dried Cassava (Animal Feed)	Cassava Flour (Human Consumption)	Fresh Conserved Cassava	Cassava Starch (Human/Industry)
Demand situation	+ + +	+ + ?	+ +	?
Raw material supply	+ + +	+ + +	+ +	+ + +
Physical environment (*)	+ + +	+ +	+ + +	-
Organizational factors	+	+	+	+
Existing activity	no	no	no	yes
Consumer/client acceptance	+ + ?	+ ?	?	+
Capital needs	low	medium	low	medium
Labor availability	+ + +	+ + +	+ + +	+ + +
Technology availability	+ + +	+	+	+ + +
Benefit distribution	Farmers + landless laborers	Farmers + landless laborers	Farmers + rural/urban labor	?
Decision	Proceed, pilot project	Research process & market	Research process & market	On hold

Notes: + + +, + +, +, - relative advantage or disadvantage of each product.
? research required to resolve doubts or supply information.
(*) Availability of water; climatic factors, etc.

of fresh conserved cassava to alter radically the prevailing market decline of the fresh product in urban situations had been demonstrated. Consumer acceptability of stored roots was unknown, however; and further technology development was required. The market potential for cassava starch was unknown and dependent upon process improvements aimed at greater efficiency and a higher quality product. Environmental considerations--namely, the requirement for large volumes of water and the pollution hazards generated thereby--also contributed to the decision not to dedicate core funds to this product. In the late 1980s special funding from CEEMAT (CIRAD-France) permitted research to initiate in this area.

12.4 Dried Cassava for Animal Feed

12.4.1 Background

During the 1970s CIAT carried out basic research on cassava drying; and a chipping machine was designed, adapted from a Thai model. In 1980 economic studies demonstrated the feasibility of using dried cassava to replace imported sorghum in Colombia. A pilot plant was constructed under a DRI/CIAT agreement, with funding from the Canadian International Development Agency (CIDA). The plant, which was operated and managed by a small farmer cooperative in Betulia (Sucre), rapidly proved the technical, market, economic and social feasibility of the project. Since 1984 DRI has been coordinating the expansion of the dried cassava industry to a large number of small farmer groups in the Atlantic coast region. CIAT's role was gradually reduced, terminating in 1989 (see Chap. 14 for information on expansion of this agroindustry).

The success of the dried cassava project in the Atlantic coast region of Colombia has in recent years produced feedback on new research activities needed to solve certain problems faced by the farmer groups. Since 1987 the following research activities have been carried out in response to this demand:

12.4.2 Equipment improvement

12.4.2.1 Root chipper. The expansion of the dried cassava industry in Colombia and elsewhere led to a demand for a chipping machine with increased capacity. An improved chipping machine was designed in collaboration with UNIVALLE, Cali and field tested. The cutting surface was improved by replacing the perforated disc with 8 interchangeable blades with a trapezoidal cross-section, mounted on a disc. The interchangeable nature of the blades increased the useful life of the discs, and chip geometry was also more uniform. The new machine was field tested on the Atlantic Coast of Colombia in 4 different drying plants. Over 20 trials, the throughput of the machine varied from 8.2 to 12.3 t/h (mean of 10.0 t/h)--an increase of over 100% compared with the previous model. Other advantages of this new machine include shorter drying times and reduced transport costs because of greater chip uniformity and density when packed. This chipping machine has now become standard on the Atlantic Coast, and the plans have been distributed to several other countries.

12.4.2.2 Pedal-operated chipper. In several regions of Colombia and in other countries, farmers are too disperse to make associative forms of drying feasible. A small-scale chipper was therefore designed for use by individual farmers for farm-level drying of chips. A pedal-operated machine was built and tested, based on a Filipino design. Improvements were made to the seat, pedal and handle positions; disc and blade dimensions were also altered to optimize the use of force employed. The disc (65-cm diameter) has 8 blades arranged radially. Chip dimensions are 60x7x5mm. Two operators taking 10-min turns can chip 400 kg roots/h. The cost of the machine is approx. US$235. The machine has been evaluated by 4 small farmer groups, where it has proved useful not only in facilitating individual drying of small amounts of cassava, but also to groups involved in fresh cassava storage, who need to process small volumes of reject roots. Some groups have adapted small motors to drive it. It is now commercially available in Colombia and can be marketed through coops.

12.4.2.3 Moisture content (MC) determination. Dried cassava chips are acceptable to industrial clients (animal feed companies) once the MC has been reduced to below 14%. Higher values carry risks of microbial contamination and reduced storage times. Lower

MC represents an economic cost to the drying coops, not only because it reduces the total volume sold but also results in longer drying times. It is thus important for coop members to be able to estimate accurately and rapidly the MC of the chips as they are drying to determine when drying can cease. At present subjective measures such as chip appearance and texture are used. A more accurate and objective method was sought; however, it was found that no standard lab method existed against which to calibrate any rapid method. Animal feed companies use oven drying at over 100°C; whereas at CIAT longer drying times at 60°C are used for lab determinations. A study was therefore conducted to identify a standard methodology for MC determinations in order to select a rapid method for potential use by drying coops. Freeze-drying chips at ambient temp gave the most accurate results as regards residual moisture and changes in total carbohydrate contents during drying. Calibration equations were obtained for oven drying at 60 and 70°C against freeze drying. In the second stage of the study, three rapid methods were evaluated against oven drying at 70°C: infrared lamp, distillation with vegetable oil, and a Brabender MC determination oven. Calibration curves were again obtained. Both infrared lamp and oil distillation offered potential at the drying plant level; however, trials with some drying coops using the latter equipment were not successful as the operation was too complex.

In a second study, humidity measurements made using natural and forced-ventilation ovens, infrared lamps and an electric system (Motomco), compared to the standard measurements obtained with a freeze dryer. Linear regression models indicated that the Motomco and Despatch forced-ventilation oven and the natural-convection oven provide reliable humidity measurements; measurements with infrared equipment varied in time due to fluctuations in voltage and amperage.

12.4.2.4 Artificial/mixed drying. The Atlantic Coast of Colombia is characterized by a well-defined drying period of about 20 wk between December and April. Recently, the drying season has been extended as the farmers have learned to manage plants more efficiently and have reduced loading rates. Artificial drying offers an alternative during periods of high rainfall when natural drying is impossible. It is also an option for other regions where a high and evenly distributed rainfall pattern makes natural drying difficult. Although artificial drying incurs additional costs for energy use, it can result in labor savings. Product quality is improved, but the animal feed market offers little or no monetary reward for improved quality. Mixed drying systems are an intermediate option: an initial day of natural drying is followed by artificial drying to reduce MC to the required level. Mixed drying results in lower drying costs than the full artificial drying option and could be used to increase plant drying capacity, by allowing drying at night after a day of natural drying.

An artificial coal-fired drying system was added to a 1500m² natural drying plant to constitute a mixed drying system, which was pilot tested in 1990-91. Results as regards costs and benefits were compared with natural drying (i.e., a 4000m² drying area, equivalent to capacity increase when adding an artificial drying unit). The results (Table

Table 12.2. A comparison of natural and mixed drying of cassava chips at coop drying plants on the Atlantic Coast of Colombia, 1991.

	Drying System		
	Natural	Mixed	Natural
Capacity (t/y)	432	1150	1150
Drying infrastructure	Floor 1500m^2	Floor 1500m^2 + 30m^2 artificial drying chamber	Floor 4000m^2
FFR (%)	56	71	72
Net earnings (%)	14	13	15
Production cost (Col $/t)[1]	72,500	73,239	71,071
Capital investment (Col $)[1]	7,200,000	15,700,000	15,100,000

[1] US$1 = Ps.600.

12.2) were that the financial rate of return (FRR) and capital costs of the mixed and natural drying systems were remarkably similar. The former permits out-of-season drying, with a more regular cash flow and better use of fixed costs.

12.4.3 Milling and mixing

Added value at the rural level can be increased through the cooperative production of balanced feed rations from locally available ingredients, including cassava, and their use to raise livestock (chickens, pigs, etc.) by local farmers. A pilot project involving the construction of a small-scale feed mill, consisting of hammer mill, vertical feed mixer and equipment for measuring and incorporating molasses into the feed ration, was funded by DRI for operation by a farmer coop. Dried cassava was milled and incorporated into feed at levels from 35-55%, depending on the price and availability of other raw materials. Experimental diets were from 9-18% cheaper than locally available commercial feed concentrate. However, feeding trials with chickens, conducted on three farms in the area, showed that feed consumption and final liveweight were less for the cassava-based feed than the commercial one. Feed conversion rates were only 5% lower. One possible reason is the difference in presentation of the two feeds; the commercial feed is a pellet while the experimental cassava-based feed is a meal, a less efficient means of providing nutrients. Further feed trials and semicommercial operation of the pilot plant are envisaged (a DRI-ICA project proposal).

12.4.4 Future research

Continued expansion of the dried cassava industry in Colombia has produced more topics for research. Although animal feed concentrate producers are uniformly concerned about aflatoxin contamination of cassava chips, this has been confirmed in only one case during the last ten years. Poorly dried cassava with MCs in excess of 14% have routinely been analyzed at CIAT for aflatoxin presence and found negative. Studies are required to determine, under controlled conditions, the ambient and chip moisture and temp conditions under which aflatoxin are produced. Observations to date would suggest that cassava chips have an advantage over sorghum and maize in this respect.

The opening of many Latin American economies to world market forces could have implications for the viability of the dried cassava industry based solely on the market for animal feed. Market research to assist diversification efforts is an urgent necessity. This is under way in Ecuador, where diversification into industrial markets is already well advanced (see Chap. 15).

12.5 Fresh Cassava Conservation

12.5.1 Background

The rapid postharvest perishability of the fresh roots results in a poor-quality, inconvenient foodstuff for urban consumers. Large marketing margins due to the risks of commercializing a highly perishable product frequently make cassava more expensive than competing carbohydrate sources in the urban environment.

Research on physiological deterioration of fresh cassava roots, conducted by CIAT and the NRI during the late 1970s, led to the development of a simple storage system based on root curing in polyethylene bags to prevent the onset of physiological deterioration, and a treatment with a thiabendazole-based chemical to prevent secondary microbial deterioration. Thiabendazole is a permitted agent for postharvest use in many fruits and vegetables. Residues in cassava tissues have been analyzed at less than 20% of permitted levels.

The storage system was field tested in several edaphoclimatic regions of Colombia with success, except in high-altitude areas where slower curing resulted in higher storage losses. Consumer testing of the stored root acceptability and farmer trials with the storage technology were initially conducted in Bucaramanga (Santander, Colombia), an area of high cassava consumption and production (see CIAT annual reports 1985-86). As this DRI-CIAT project was expanding to semicommercial operations, the deteriorating public order situation in the cassava-production region (Magdalena Medio) forced the closure of this project; however, DRI was sufficiently convinced of the potential of the storage technology to finance a pilot project on the Atlantic Coast region. Originally, it was thought advisable to keep the fresh cassava projects separate from the dried cassava project; however, the Bucaramanga experience showed that the two products were complementary and could be run in the same area or by the same farmer groups, to their mutual benefit.

12.5.2 Barranquilla pilot project

The Atlantic Coast region has the highest per capita consumption of cassava in Colombia (53.3 kg/yr; national avg 25.5 kg/yr). The dried cassava project had by this date (1987) already produced over 30 small farmer coops and strong support for cassava in rural development agencies. Barranquilla (population 1,000,000) is the largest city in the region.

12.5.2.1 Market and consumer studies. The principal results of a series of wholesaler, retailer and consumer surveys were:

- Small neighborhood shops are the most important retail outlet for fresh cassava. Only one market exists, retailing 12% of total volume. Although supermarkets retail only 9% of total volumes, nearly 50% of the cassava purchased by the upper income stratum is from this outlet. Of the cassava purchased by middle- and low-income consumers, 75% is from small neighborhood shops.

- Fresh cassava is more expensive and of lower quality (i.e., more deteriorated) in small shops than markets.

- Small shopkeepers purchase 20 kg of cassava 5 or 6 times a week. Consumer purchase frequency is higher for low-income strata, but purchase volume is lower.

- Low-income consumers purchase foodstuffs daily due to cash limitations (daily wages). Storage of fresh cassava is not an economic option for them.

- Wholesale preferences for cassava were based on production region or certain varieties. Retailer and consumer preferences were related to visual characteristics (peel and parenchyma color).

Based on these results, two marketing strategies were formulated:

- Cassava in 4-kg sized bags for sale through supermarkets to middle- and high-income consumers.

- Cassava in 12-kg sized bags for sale to small shopkeepers, who will benefit from improved quality, fewer losses, better availability of cassava to clients, and fewer visits to the wholesale market. Low-income consumers who purchase from such neighborhood shops would benefit from quality and less waste, but not from convenience.

12.5.2.2 Consumer panel. 25 middle- and high-income consumers were supplied with a 4-kg bag of recently treated and packed cassava, and asked to evaluate the product after 1 and 2 wk of at-home storage. A fresh root sample of the same var. was also evaluated as a control. Losses of stored cassava were only 2.6% after 2 wk, compared with a postharvest life of 24 h for var. Venezolana under normal conditions. Eating quality of the fresh roots was evaluated as excellent or good by 96%. Roots stored for 2 wk were of comparable quality: 100% good or excellent. Only 9% noticed a sweeter taste of stored roots, which were generally rated as easier to cook and peel than fresh roots. Similar results were obtained with 21 shopkeepers: 95% thought this system would result in increased sales.

A final trial was conducted in a supermarket, where 2-kg bags of treated and packed cassava were placed on sale. All 70 bags were sold in one day. Follow-up interviews showed that 95% of consumers rated eating quality as good or excellent. Mean storage time at home was 4.6 days for 2-kg bags and 6.4 days for some 4-kg bags that were also sold. Optimum bag size was 4 kg, although 2 kg was useful for product introduction.

12.5.2.3 Farmer trials. A region producing high-quality cassava as continuously as possible throughout the year was sought. COOPROMERCAR, a DRI-supported coop of farmers in Repelón (Atlántico), was commercializing tomatoes at a loss, and members also produced cassava for individual sale to traders. The coop is situated in a irrigation district, thus off-season cassava production was possible. Venezolana, the preferred var. in Barranquilla, was widely grown, and eating quality was excellent.

Farmers organized a production team for the fresh cassava storage operations, producing all the bagged cassava used for the consumer testing in Barranquilla. Costs of the packing and treatment process were monitored. Following the end of the consumer-testing period, prices for the supply of bagged cassava were negotiated between a supermarket chain and the coop. The results of the first 2 mo commercialization of over 50 t of cassava are presented in Table 12.3. Although the bagged cassava was more expensive than the normal cassava (Col$60/kg vs. Col$52/kg), this was acceptable to consumers as a higher proportion of the purchased product was consumed and quality was better.

12.5.2.4 Project expansion. In collaboration with DRI, a project was developed with the objective of expanding the volume of cassava in bags marketed in Barranquilla to 4000 t/yr (approx. 10% of the market). To meet this objective, activities were initiated on several fronts:

- Identification of cassava-production regions capable of supplying the Barranquilla market with high-quality fresh cassava. As no one production region produces high-quality cassava 12 mo a year, it is necessary to switch production region at certain times. The best harvest months for each region were identified, and farmer organizations already existing in each region were contacted.

Table 12.3. Results of initial 2 mo of marketing 51 t of cassava in bags by COOPROMERCAR, Repelón, Atlántico Colombia (Aug./Sept. 1987).

	Cost/kg Cassava Col.$[1]
Fixed costs	2.25
Variable costs	
Raw material	26.43
Labor	1.84
Polyethylene bag	2.39
Thiabendazole	0.98
Other	1.69
Transport to Barranquilla	2.83
Total	38.45
Income from sale of cassava	44.44
Less cash flow, working capital cost, depreciation	6.31
Net profit margin	5.66
Total profit on 51 t sold	288.875

[1] Col$ 252 = US$1, Sept. 1987.

- Training of cassava coops in storage technology. To date a total of 15 coops and 2 second-order organizations have been trained. Of these, 11 have used the storage technology commercially.

- Organization of a distribution enterprise in Barranquilla. A second-order federation of the cassava coops in Atlántico, Magdalena and Bolívar (the states closest to Barranquilla) was formed in 1989 (FAGROCOL). Although the Federation's main activity was to commercialize dried cassava, the coops were also interested in using the Federation to set up a distribution enterprise to coordinate sales of fresh cassava in Barranquilla, essentially to act as an intermediary. DRI obtained a space in the new wholesale market in Barranquilla for FAGROCOL, which opened in 1990. DRI and CORFAS provided FAGROCOL with a small amount of working capital to initiate operations. Orders for over 100 t/mo were rapidly obtained from supermarkets and restaurants.

Problems were soon encountered, however:

- Quality control. As the no. of coops treating and packing cassava increased, the variability in quality became marked. This was due to both variations in inherent eating quality of the cassava and in the execution of the treatment and packing operations.

- Lack of public awareness of the advantages of stored cassava

- Shortage of working capital

The Federation decided to take a more active role in the treatment and packing operations, and experiments were conducted to see if delayed treatment was a feasible option. This would allow operations to be carried out at one central location under Federation control, rather than at the level of the individual coops.

12.5.2.5 Modifications to the storage technology based on the pilot experience. Four basic problems were identified:

- Lack of quality control by individual coops. The solution was to:

  - pack cassava into large polypropylene sacks initially (no treatment)
  - transport to central location
  - treat with thiabendazole
  - repack into polyethylene bags of required size

  There were no significant differences between treatment at harvest or after 24 h; delaying treatment 48 h did affect storage success, however.

- Extreme susceptibility of Venezolana to physiological deterioration at certain times of the year (deterioration <12h after harvest). The solution was to prune the aerial part of plant 5-8 days before harvest, which reduced the severity of deterioration without affecting eating quality.

- Secondary deterioration due to bacteria not controlled by thiabendazole. The solution was to include sodium bisulfite in the root treatment, which gave excellent control of bacterial problems.

- Large no.of roots with excessive mechanical damage, unsuitable for storage. The solution was to cut away damaged area, cover exposed surface with calcium carbonate powder (desiccant). The exposed surface dries cleanly; after removal of superficial tissues, the remainder of the parenchyma is of good eating quality

12.5.2.6 Recent Developments. This series of experiments provided a range of technology options suitable for all conditions. FAGROCOL started to use the new methodology in early 1990, using the space at the wholesale market for treatment operations. On arrival, cassava was selected for treatment and storage, based on actual orders; the remainder was sold in the normal fresh market. FAGROCOL soon gained a reputation for selling high-quality cassava, becoming the price setter for all intermediaries. At this time, most of the 35 intermediaries in Barranquilla switched from sisal sacks to polypropylene sacks for the transport of roots from the field. This was a direct result of the project's experiences with polypropylene sacks alone, permitting a longer storage life of var. Venezolana.

During 1990 FAGROCOL supplied supermarkets directly with bagged cassava, and an urban distributor was hired to reach the small shops in lower income barrios. Some sales were also made directly from the warehouse in the wholesale market. Total volumes traded reached 10-12 t/wk. Unfortunately, from October 1990 onward, FAGROCOL was beset by a series of financial problems resulting from losses taken in commercializing and exporting other products (yams, tomatoes, etc.). Since early 1991 they stopped commercializing fresh cassava for lack of funds (DRI did not approve a new cassava-related project for an organization in debt). The organization is currently being liquidated.

Fortunately, the supply of fresh cassava in bags has continued in Barranquilla throughout 1991, as private individuals have set up operations. One individual in Barranquilla is marketing approximately 15 t/wk. In addition COOPROMERCAR is once again commercializing bagged cassava directly to both Barranquilla and Cartagena. Several wholesalers are now supplying untreated cassava in polyethylene bags to small shopkeepers (12 kg cassava/bag), increasing storage life 2-3 days.

12.5.2.7 Future activities. DRI-CIAT activities will terminate early in 1992, given the absence of an organization to execute projects of a cooperative nature, and the recent success of the private sector in taking this technology to a commercial level. The situation will however be monitored to ensure that any further problems are resolved. The effects of the project on the fresh cassava market in Barranquilla will also be evaluated, given that some of the technology components have recently been widely adopted. The lessons learned in this project will be applied to similar projects now under way in Santander (DRI-Colombia) and in Paraguay.

12.6 Cassava Flour for Human Consumption

12.6.1 Background

High-quality cassava flour for human consumption has the potential to be used as a substitute for wheat flour in a no. of food products. Several institutes have researched the formulation of bakery and other foods using cassava flour, and the substitution rates are known in many cases. Many tropical countries import significant volumes of wheat, which could be replaced by cassava if price competitive. This requires a low raw material price and efficient low-cost processing. Industrial-scale processes for obtaining cassava flour have been developed in Brazil and elsewhere, but are little used in practice.

From 1984-86 IDRC funded a project at CIAT in which an efficient, small-scale process for the production of high-quality flour was developed, in collaboration with UNIVALLE. Bread formulated with cassava flour was tested under lab conditions at the Institute of Technological Research (IIT), Bogotá and with bakeries and consumers in Colombia.

Finally, an evaluation of the wheat flour system in Colombia was made to assess the feasibility of a cassava flour industry and to recommend market channels for the product.

The cassava flour process developed at CIAT consists of root reception and selection, washing and removal of the outer bark layer, chipping, artificial fixed-bed drying using a coal or coke fired burner with heat exchanger, followed by premilling to reduce chip size. Premilled chips can be milled successfully in a normal wheat flour mill (90% conversion rate to high-quality flour). The conversion rate from fresh roots to pre-milled chips is approx. 3:1, compared with 2.5:1 for cassava chips for animal feed and 4.5:1 for cassava starch. The efficiency and low cost of this small-scale process result in a highly price-competitive product.

12.6.2 Pilot project

In 1989 IDRC funded a second (pilot) phase of this project with CIAT and DRI as the joint executing agencies. This project, in which UNIVALLE is also collaborating in a research-support capacity, is now in its final year. The cassava-production component of this integrated project, involving the farmer testing of production technology packages, is reported elsewhere (Chap. 9). A discussion of the three main objectives of this second phase follows.

12.6.2.1 <u>Objective 1</u>. To implement, adapt and evaluate, on a pilot scale in a rural context, the technology developed for production of dried cassava chips and flour. After evaluating six sites on the Atlantic Coast according to relevant criteria, Chinú (Córdoba) was chosen. The farmer coop (COOPROALGA) in this cassava-growing area also operates a natural drying plant.

The cassava flour pilot plant was designed by an architectural firm in collaboration with CIAT. It was subsequently scaled down (to an annual capacity of 200 t) to reduce construction costs to US$ 50,000. A UNIVALLE-led team worked on improving the root-washing machine, coupling of washing/chipping machines, and chipping machine. Design criteria emphasized reliability, efficiency and security.

The original plant personnel, including a plant chief, production chief, three workers and a watchman, were selected by the farmer coop's administration. Personnel changes have occurred; new personnel receive in-service training conducted by CIAT. The current plant chief is also the community leader.

Because of intervillage rivalries, the plant was denied a stable water supply; therefore, COOPROALGA had to build its own well and pipeline at a cost of US$9,000. As the root-washing step was initially impossible, the plant produced chips for animal feed in 1990. Once water supply limitations were overcome, the plant initiated production of cassava chips for human consumption in January 1991, producing 30 t in the first semester. This was sent to a Medellín wheat mill for milling. The target extraction rate, already achieved, is 90% of first-grade cassava flour plus the two by-products, second-grade cassava (6%) and peel (3%). About 1% is lost in the milling and screening processes. Chemical analyses of the different flours have been obtained.

During the first months of plant operation, chip quality of all lots was closely monitored. Table 12.4 presents representative results. Samples have been slightly above the 50 ppm limit for total HCN, but this has not been seen as important by industrial clients. Starch, fiber and ash contents are all satisfactory. Microbial counts have not consistently met standards, however--the major concern of potential industrial clients.

The conversion rate of fresh cassava to premilled chips has averaged 2.7. With an extraction rate of 90% to obtain high-grade flour, the fresh root-to-flour conversion rate is 3.3. Pilot plant operation as of Aug. 1991 points to the following three main challenges: (a) to obtain a continuous supply of freshly harvested, high-grade roots, (b) to lower drying costs through improved burner and heat exchanger design, and (c) to produce chips that are microbiologically acceptable to the food industry.

To meet the first challenge, a network of cassava wholesalers is being established in several regions to supply freshly harvested, high-grade roots during the period from June to Nov. Neighboring farmers can supply roots from Dec. to May. This network will also

Table 12.4. Chemical composition and microbial quality of 2 samples of cassava produced by the pilot plant, compared with Colombian standards.

	ICONTEC Standard	Sample 1	Sample 2
Chemical Composition			
MC (%)	12 (max)	5	5
Starch (%)	62 (min)	89	87
Ash (%)	2 (max)	1.4	1.5
Fiber (%)	2,5 (max)	1.4	2.0
Total HCN (ppm)	50 (max)	36	61
Aflatoxins	0 (max)	0	0
Microbial contents			
Aerobic mesophilous bacteria	200,000 (max)	6,300	627,200
Coliform bacteria	100 (max)	0	1,200
E. coli	0 (max)	0	0
Salmonella	0 (max)	0	0
Fungi and yeasts	100 (max)	0	100

Note: ICONTEC, Colombian Standards Institute; standard set for cassava flour for human consumption.

help meet challenge (c). Challenge (b) can be confronted by building the burner with brick instead of iron and by modifying chamber dimensions. The burner and heat exchanger should also be protected from cool night winds. Improvement of microbiological quality is mainly sought by washing the cassava roots with sodium hypochlorite-treated water for 5 min. In addition, the period between cassava harvest and processing is minimized to avoid deterioration.

12.6.2.2 Objective 2. To identify and research cassava flour markets and promote the use of cassava flour in these markets. A market study was conducted at 3 geographic levels: locally (Chinú area of influence), regionally (Atlantic Coast) and nationally (Medellín and Cali). More than 200 small, medium and large food processing companies representing multiple food categories were surveyed and given cassava flour samples to enable flour substitution trials. A second survey obtained feedback on substitution trial results and intent to purchase. This study identified food segments where cassava flour utilization has potential. To estimate volume potential, this information was complemented with secondary information on wheat imports, and experts were interviewed in firms participating in key food categories. The main conclusions were as follows:

- A conservative estimate of market demand in the medium term (5-10 yr) for cassava flour as a substitute of other flours or starches in the food industry is 22,000 t/yr. This estimate assumes low substitution and adoption rates in the bread-making segment, by far the largest one in the food industry. The main food categories where use of cassava flour is most feasible are: processed meats, sweet cookies, pasta and soup noodles, cakes, spice bases, bread-making, meat pies, porridge mixes, soup mixes, soft sweets, ice-cream cones, breading and sauces. In some of these categories, cassava flour exhibits functional advantages over competing flours given its high water-absorption capacity, binding potential, crispness-enhancement characteristics, etc.

- The main raw material to be substituted would be wheat flour, as well as corn flour and sweet cassava starch. Consequently, the recommended market-penetration price for cassava flour could be equivalent to 80-90% of the price for wheat flour in Medellín, currently at Col$230/kg (US$0.38). This price is acceptable to major clients. Of the two largest cities nearest Chinú (Medellín and Barranquilla), the former exhibits a greater and more concentrated demand and has been selected as the site of initial market penetration.

Initial promotion of cassava flour was conducted in the context of the national market study and consisted of personal contact with the interviewer, a promotional pamphlet and a sample. Subsequent promotional activities have concentrated on the target market, Medellín. Twelve large- and medium-sized firms representing key food categories, most of which had expressed a positive buying intention after the substitution trials, have been visited twice, and 50- to 200-kg samples have been provided for further trials.

A cassava flour distribution system in Medellín is being established with the participation of TECNAS, a processed-meat consultant, and Harinera Antioqueña, the wheat mill. The former is focusing on the processed-meat markets, while the latter will concentrate on other markets such as cookies, cakes and bread-making. By-products will be sold to the animal feed industry. Negotiations with these two distributors involved decisions on buying and selling prices, scope of responsibilities, and costs of services provided. TECNAS has proposed to purchase the first-grade cassava flour and resell it, while the mill would charge for milling and distribution, without purchasing the product. The financial model of the cassava flour pilot plant has been very useful in negotiations.

A brand name for cassava flour, YUKARIBE, is being registered nationally in the flour category. This name will appear on the 50-kg polypropylene bag, which is larger and denser than the ones used for packaging wheat flour.

In general, it can be concluded that food-processing companies tend to be quite conservative when adopting new raw materials. The microbiological quality of the flour is important to potential clients in Medellín; this has been the major limitation to proceeding with commercial sales.

In the area of product development, formulations using cassava flour were developed for a typical sweet ("manjarblanco") and porridge ("coladas"). Manjarblanco can be prepared, maintaining good organoleptical quality, substituting 25 to 100% of the standard rice flour with cassava flour. In coladas, other flours were substituted successfully with cassava flour at 5 to 20% levels. Preparations presented 24-h stability; consistency was softer and texture slightly granular.

12.6.2.3 Objective 3. To estimate feasibility of establishing a cassava flour agroindustry and make recommendations, if warranted, on implementation on a national basis. A feasibility study should consider technical, financial, marketing, social and organizational aspects. Given that most of these aspects have been discussed already, financial aspects will be discussed here. Financial models of the pilot plant were developed to analyze the impact of multiple variables on financial profitability (as measured by the FRR) and annual cash flow. The basic model includes investment costs, variable and fixed costs, sales price and a cash flow estimate for 8 yr.

It was demonstrated that (a) selling cassava flour is more profitable than selling cassava chips; (b) the most profitable milling alternative is in-plant roller milling (FRR >50%), followed by subcontracting milling externally in a wheat mill and by in-plant hammer milling; and (c) financial profitability is highly sensitive to plant capacity and capacity utilization, root price and fresh root-to-dry chip conversion factor.

The financial model was very helpful in negotiating cassava flour prices with potential distributors and clients. The model indicated, for example, that it is more profitable to sell to TECNAS than to sell through the wheat mill, under current conditions.

It must be noted that the government's current free-market policy in Colombia may affect the project negatively if the real price of wheat decreases greatly; a minor price reduction can be absorbed easily by reducing profitability margins. In the case of an unanticipated, radical price reduction of wheat, alternative industrial markets can be pursued.

12.6.3 Support research

12.6.3.1 Small-scale mill development. Although the pilot plant is currently producing only premilled chips, the provision of a small-scale milling capacity, which would permit the in-plant production of flour, would increase the FRR by 10%. Trials with existing small hammer mills resulted in conversion rates of chips to high-quality flour of only 65%. Research is currently under way to evaluate several alternative systems for small-scale milling, and to design and test a prototype mill based on the best option. Eleven different combinations of mills, screens and different sized meshes were tested. For each system, the content of fiber, ash, HCN and extraction rate were taken. The best option was found to be a system consisting of (a) roller mill, with the cylinders set to different speeds (420 and 230 rpm); and (b) two screens in series, with 2.38mm- and 2.50mm-diameter mesh. This has given extraction rates of 90% in initial trials, with fiber and ash contents of 1.5 and 1.3%, resp. A prototype mill incorporating these features will be evaluated in the pilot plant during 1992.

12.6.3.2 Flour storage studies. To study stability of cassava chips during storage, batches were stored in government warehouses in three cities exhibiting different climatic conditions. Samples were analyzed monthly to determine microbiological and physicochemical quality. Results indicate little variation with time regarding the latter aspect. Yeast and mold populations were within norms; aflatoxins and pathogenic bacteria were not found. In addition, initial aerobic bacteria counts were high but decreased to acceptable levels after 20 days.

12.6.4 Future plans

A third phase of this joint CIAT/DRI project has been submitted to IDRC for funding. If approved, activities over the next 3 yr will focus on:

- Expansion of pilot plant capacity to commercial level
- Evaluation of in-plant milling system and local marketing of cassava flour
- Identification of sites for replicate plants in Colombia
- Continued market promotion of cassava flour
- Training of national institutions in the technical and other aspects of cassava flour processing

- Redesign of the plant and equipment to reduce costs

- Dissemination of project results outside Colombia

The World Food Program of the United Nations has offered financing for new cassava flour plants in Colombia, based on the project progress to date.

A similar project is currently under way in Indonesia, where the national agricultural research program (CRIFC) has been developing small-scale cassava flour processing equipment, which is now being pilot tested. At the same time, private sector food companies have been initiating their own cassava flour production for manufacturing a range of cookies and cakes for the national market and export. The Cassava Program is collaborating with CRIFC in evaluating flour quality (analytical methods) and in exchanging information on processing equipment.

12.7 Cassava Starch

12.7.1 Background

Native and modified starches are important raw materials for many industrial products; e.g., in food processing, paper manufacturing, textile, adhesive and oil drilling industries. As a glucose polymer, starch is also a raw material for producing many derived products in sugar chemistry (glucose, fructose, maltodextrins, mannitol, etc.), each of them with specific properties and specific uses in food, chemical or pharmaceutical industries.

Although cassava is one of the best sources of starch (ca. 85% of root parenchyma DM), it represents only 4% of the starch used by industry. Annual production of cassava starch for industrial uses is about 800,000 t, mainly in Brazil (for the national market) and Thailand (for export to Japan and the EC).

Many small-scale cassava starch industries exist in tropical countries where the product has specific uses in traditional food industries corresponding to a specific market niche; e.g., "krupuk" in Indonesia, sago in India, "pandebono" in Colombia, "biscoicho" in Brazil and "chipa" in Paraguay. In Colombia and Brazil, "sour" starch is produced, a naturally fermented starch whose specific functional properties are irreplaceable in the manufacture of traditional cheese breads. This small-scale industry has a high socioeconomic importance in specific regions of these countries; nevertheless, the sector presents many problems in terms of production, processing and commercialization, which limit its development. In order to research and develop new technologies for this industry, a collaborative project between CIAT-CEEMAT/CIRAD on "Production and utilization of cassava starch" was initiated in 1989.

A technical diagnosis of the traditional process in Colombian cassava extraction plants ("rallanderías"), which process from 1 to 5 t of fresh roots daily, was carried out to determine the main problems of this industry. These were identified as:

- Low process efficiency with starch losses of 25%
- Large variation in product quality, with no objective parameters for quality evaluation of sour starch being available
- Lack of knowledge of the effect of the raw material on starch quality and extraction yields

The following priority areas of research were established in agreement with producers and users of starch:

- Standardization of analytical assays
- Characterization of sour starch
- Equipment technology improvement
- Study of the influences of raw material and the process on product quality
- Study of the mechanisms involved in natural fermentation (for sour starch production)

These topics have been developed in collaboration with Colombian institutions: IIT, The Consulting and Development Service for Coops and Small Enterprises (SEDECOM), UNIVALLE (Food Section, Chemistry Department, Dept. of Mechanical Engineering) and the U. Autónoma del Occidente (Depts. of Mechanical and Industrial Engineering) in Cali.

Some national agencies are supporting this project in Colombia, Ecuador and Paraguay by providing technical assistance for cassava production, commercialization and farmers and starch producer organization in order to transfer the first results of research (see respective country reports).

12.7.2 Improvement of the sour starch extraction process

The traditional sour starch extraction process includes the following steps:

- Washing and peeling the roots to remove adhering soil and peel
- Grating the roots to destroy cell walls and release starch granules
- Extracting the starch under running water and screening the pulp to separate the starch granules from other components (mainly fibrous residue called "afrecho")
- Separating the solid starch from the starch milk by decanting into tanks and running off the supernatant after a one-day decanting period (the yellowish upper layer of sedimented starch ("mancha"), which contains proteins and some impurities, is removed before a new sedimentation or the transfer of starch to fermentation tanks at the end of the wk)
- Natural fermenting of sedimented starch in tanks for 20 to 30 days
- Solar drying of wet starch to 12-14% for long-term storage

In a first stage, equipment technology design was based on the same principles as the existing equipment, keeping costs to a minimum. The improved equipment is now being evaluated with the producers in some pilot rallanderías. In a second stage, the possibility of scale reduction of equipment using advanced technology is been studied. This will involve using a grater with water, vacuum filter and separation to offer a new small-scale technology (5-10 t fresh roots/day) with the possibility of continuous operation.

12.7.2.1 Washing/peeling. The presence of external peel affects end product color and increases the quantity of mancha. The traditional washer is a rotating drum (diameter 0.80m, length 1 m). The following modifications have been made:

- addition of 2 or 4 abrasive rollers
- distribution of washing water from the central axle
- direct power transmission by a reduction motor

The peeling rapidly reaches 90%, which increases machine capacity to 1 t/h.

12.7.2.2 Extraction. The low efficiency of the process is due to poor release of starch granules during grating and limited extraction of starch (an avg 18% of the starch is left in the afrecho).

- Inefficient sieving, may result in a too high fiber content in the final product.

- Extractor capacity (200-250 kg/h) is less than other steps in the process, which creates bottlenecks and decreases productivity.

The traditional grater is made of a wooden drum covered with a perforated iron sheet. The extractor is a rotating drum equipped with internal paddles and a cloth fixed around the drum is used as a sieve.

The following improvements were made:

- Grater: cutting blades fixed on a plastic drum with a high rotation velocity. To reduce costs a wooden drum has been built and will be tested this year.

- Extractor: a traditional cylindrical water extractor was equipped with 4 mechanized mixing screws to improve contact between water and the cassava mash, and an external metallic sieve (60 mesh).

- Sifter: a vibratory sifter with 2 sieves (80 & 120 mesh) was tested. Initial results have shown ca. 20% improvement in the starch extraction rate, reflected in a decrease in the starch content of the afrecho. Additional modifications will further improve this.

12.7.2.3 Starch separation. The natural decantation of starch milk in settling tanks takes 24 h. This is long enough to permit the development of microorganisms and induce chemical changes in the starch. To avoid removal of starch every day, successive sedimentations are carried out during one week. The natural fermentation which thus occurs modifies drastically the functional properties of native starch; in these conditions the final product does not meet industrial specifications for sweet (nonfermented) starch.

During starch separation, 20% of the starch is lost with the removal of the supernatant. The improved system consists of sedimentation in settling channels (100-120 m long, 40-50 cm wide, with a 0.5% slope, as used in India and Brazil). This system has significantly reduced starch losses, increasing recovery from 57% to 69%. This system also permits classifying starch by purity and granule size. Settling tanks and channels have similar capital costs (US$1000). Starch producers have seen the advantages of this improved system, and it has been already adopted by many producers in Colombia. Demonstration plants with this system are now operating in both Ecuador and Paraguay.

12.7.3 Improvement of starch quality

The main quality parameter that sour starch users (small-scale bakeries or large companies) are searching for is "expansion power" during baking; however, no quality test with a scientific basis exists for this parameter. Empirical tests are used; e.g., acid taste or the color of a flame in presence of starch dust. The first priority was to establish a simple method for evaluating sour starch quality, to correlate quality with some sour starch properties, and to explain the mechanisms involved in producing expansion power.

The other, more objective criterion is the microbiological quality of sour starch: *Coliform* bacteria are sometimes found, mainly because of contamination of the extraction water or of the starch during drying by animals. This can be controlled by the adoption of basic hygiene measures.

12.7.3.1 Baking test. The "expansion power" of sour starch is defined as "the ability of a fermented starch to increase the vol. of a dough containing that starch and submitted to a process of baking." The simplest parameter to measure this is the specific volume of the breads after baking; nevertheless, this expansion power depends not only on starch quality but also on the cheese used (presents many fluctuations in quality), the product formulation, the dough texture and consistency, the shape of the breads and the baking conditions. For setting up a reproducible and sensitive baking test, several assays using good- and poor-quality starch samples were carried out under different baking conditions and formulations of cheese, fat, salt and yeast. The following protocol gave the best differentiation between good and bad starch quality, with good reproducibility:

- Manual preparation of a dough made of sour starch (1 part), commercial white ("campesino") cheese (1 part) and cold water (0.5 parts) at ambient temp
- Baking of 6-8 small round breads (15 g) at 450°F for 7 min in a domestic electric oven

- Determination of the avg specific vol. of the cheese breads by the seed displacement method

This test can be used at the level of the lab to determine the influences of raw material or process steps, as well as in the extraction plants as an element of process-quality control and for product price negotiations.

12.7.3.2 Evaluation of different sour starches. To give a quality scale related to specific vol., 35 samples were collected and ranked in 3 classes by clustering the values of the specific vol. determined by the baking test (Table 12.5).

Between specific vol. and starch characterization parameters (biochemical, physical and functional properties), the following significant correlations ($p < 0.05$) were found: total organic acids, lactic (+) and acetic (-) acids, color (brightness), swelling power at 90°C, water absorption at 40 and 500 BU, viscoamylogram characteristics.

The physicochemical parameters and starch functional properties vary greatly from one plant to an another and between fermentations at the same plant. Some factors such as ambient conditions, the variety, water quality and traditional knowledge may be involved in this variability of the natural fermentation. The fermentation step is the key to obtaining good-quality sour starch.

12.7.3.3 Baking power property of sour starch. The studies carried out on the natural fermentation of cassava starch and the modifications of its functional and physicochemical properties that occur during this step have shown:

- A dominant lactic microflora with amylolitic activity
- Production of organic acids, mainly lactic acid and CO_2
- Attack of starch granules by amylolitic enzymes (at end of fermentation, some granules are pitted and porous
- Drastic modification of the functional properties of the starch (decrease in max. viscosity during heating, no gelling tendency during cooling)

Table 12.5. Classes of sour starch clusters[1] .

Class	Quality Starch	Mean Specific Vol. (SD)
1	Good	4.89 ml/g (0.05) a, b
2	Fair	4.21 ml/g (0.170 a, c
3	Bad	3.38 ml/g (0.15) b, c

[1] Values with the same letter represent a significant difference, $p < 0.05$.

It is possible that during baking, organic acids and gases produced during the fermentation and absorbed by the starch granules are volatilized. Partial gelatinization of the starch gives a viscoelastic structure to the dough, which is able to confine the discharged gases. The baking power may therefore consist in a competition between the gaseous expansion and the viscoelastic properties of the amylaceous network; however, other hypotheses can be presented. Molecules may be formed that associate with the starch to produce the adequate viscoelastic structure; e.g.:

- Formation of an amylose-complex during baking

- Production of polysaccharides such as pentosan and dextran (whose beneficial effects are well known in bread-making) by bacteria (*Leuconostoc mesenteroides*), which have been isolated during fermentation; a significant increase of sugars during fermentation also occurs.

- Production of phenolic compounds esterified with these polysaccharides; a complex could occur during solar drying by an oxidative reaction catalyzed by UV rays. This hypothesis would explain the fact that solar drying is indispensable for obtaining good-quality sour starch according to all the sour starch producers.

Based on these different hypotheses, research is now focused on the following points:

- Influence of solar drying on sour starch expansion power
- Presence of amylose complexes, polysaccharide, phenolic compounds and changes in their concentration during fermentation
- Isolation of the microorganisms involved in modifying the physicochemical and functional properties of starch (amylolitic lactic bacteria) and the production of polysaccharides (*L. mesenteroides*)
- Identification of the isolated microorganisms, and metabolic and enzyme system studies

12.7.4 Varietal suitability

According to the starch producers in Colombia, there are large differences between the 2 main cassava var. as regards extraction yields and sour starch quality. M Col 8 (Blanquita, long cycle) yields better but the quality is worse; the contrary is true for M Col 1522 (Algodona, short cycle).

12.7.4.1 Varietal influences on extraction yields and starch quality. Five var. were processed in a rallandería (Table 12.6). The harvest period plays an important role in extraction yields, mainly for var. susceptible to root rots (CMC-40, M Col 8). M Col 8 and CM 523-7 gave the best-quality starch. Other trials have been undertaken this year to evaluate the suitability of var. for sour starch production.

Table 12.6. Extraction yields and sour starch quality for 5 cassava var.

Variety	Age (mo)	Extraction Yield (%)	Specific Vol. (ml/g)	Quality
CMC 40	10	24.4	3.9	Bad
CMC 40	12	16.8	4.0	Bad
M Col 8	10	21.8	4.4	Fair
M Col 8	12	17.8	4.2	Fair
M Col 1684	12	17.9	3.8	Bad
CM 523-7	12	18.3	5.2	Good
M Col 1522	16	20.4	5.6	Good

12.7.4.2. Sour starch quality variation among varieties. To understand the variations in quality, the functional properties of sour starches from different var. were determined. Viscoamylograms (Fig. 12.1) showed differences among the starch paste of different qualities/var.

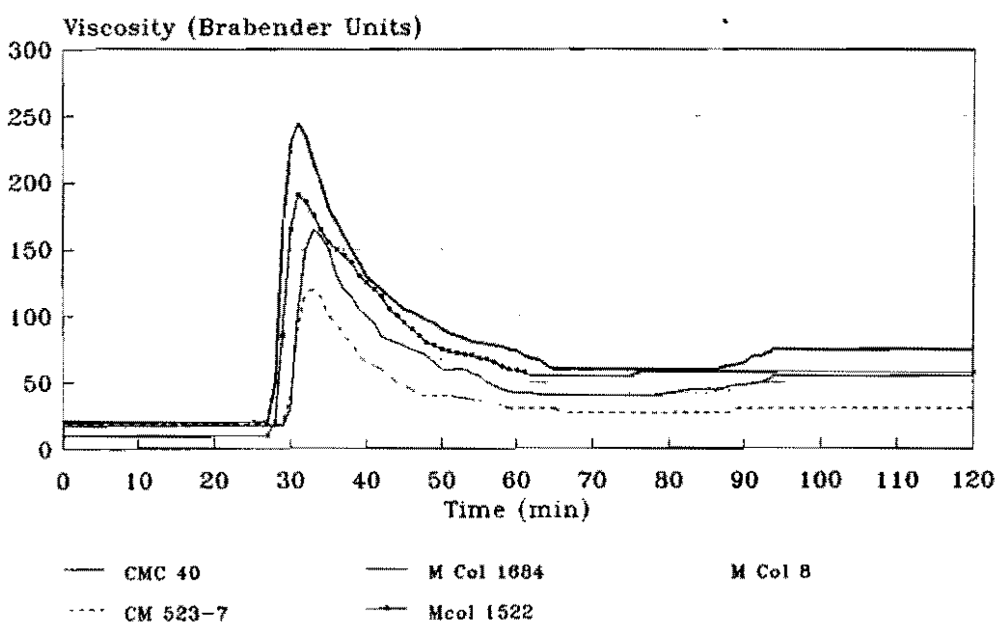

Figure 12.1. Viscoamylograms of sour starches extracted from different cassava var.

- The values of max. viscosity and viscosity after 20 min at 90°C decreased as sour starch quality declined.

- The gelatinization index is lower and near zero for good-quality starches.

This confirms the importance of functional properties in the creation of the viscoelastic network during baking. As mentioned before on the characterization of native starches (4.4.1), varieties must play an important role in explaining the differences in the behavior of fermented starches. A study of the structure and the degree of polymerization of starches during fermentation will provide more information on the changes in starch properties and on the mechanisms of attack of starch granules by microorganisms.

12.8 Future Activities

Of the four priority products researched up to 1991, only two will remain active beyond 1992: cassava flour and starch. Activities in dried cassava and fresh cassava conservation will continue only as required in support of integrated projects involving these products. No new research will be undertaken in these areas. Research on cassava flour will continue through 1994, when the Colombian project will be reaching a conclusion. Research on cassava starch will continue as an important element of ongoing CIAT-CEEMAT collaboration.

No new research will be initiated on other cassava products at CIAT, given the increased emphasis being placed on quality issues. Nevertheless, a great deal of research remains to be done. The Cassava Program will actively encourage and support process and product development research by other institutions in the developing and developed world. A research network is in formation, and a special project to obtain financing for other institutions to carry out this research is being written with a no. of collaborators. Emphasis will be on developing derived products from flour and starch, for food and other industries. Brazilian institutions will be encouraged to undertake product development research on farinha, especially on the potential for improving markets through a better quality product. A vacuum remains with regard to realizing the potential of cassava leaves as animal or human food, which CIAT is unable to fill at present.

REGIONAL COLLABORATION

13. REGIONAL COLLABORATION IN LATIN AMERICA

Although only 22% of cassava is produced in Latin America, the continent of origin of the crop, it is still a major food crop with a per capita production of 74 kg in 1986-88, 75% of which is produced in Brazil. Cassava production declined throughout the 1970s and early 1980s as a result of several factors, notably the growth of wheat flour subsidies, which caused a decline in consumption of farinha (a toasted cassava flour) in Brazil; and the declining consumption of fresh cassava in rapidly urbanizing populations. There are now signs that this trend has been halted. Table 13.1 shows the production data for cassava in Latin America from 1987 to date. If the preliminary data for 1990 are confirmed, cassava production in Brazil, Colombia and Latin America will be at its highest since 1986, 1981 and 1972, resp.

The traditional utilization of cassava in Latin America has been dominated by the production of farinha in Brazil, which accounts for 50% of the cassava produced in Brazil and 40% of the total for the Americas. Fresh cassava for human consumption accounts for approx. 25% of production; animal feed, also from the fresh root, accounting for another 20%. Starch and other industrial uses total only 5% of production, while about 10% is wasted (Fig. 13.1). The small amount of cassava dried for animal feed does not yet account for a significant percent of the total utilization of the crop in Latin America although it is now locally important in several regions.

13.1 Modes of Collaboration

The Program operates two distinct modes of collaboration with Latin American countries. The first is the more traditional approach of interacting with national research programs, with the aim of strengthening these important but often underfunded institutions. Most countries now have cassava research programs, partly as a result of CIAT efforts over many years; however, these programs remain small and of relatively low status within their organizations. Nevertheless, there are many dedicated professionals with years of experience in cassava research and extension. Collaboration with such personnel consists in (a) training courses and workshops on specific themes at CIAT and in-country; (b) joint research projects, particularly in areas where for ecological reasons it is not possible to conduct the research in Colombia; and (c) applied and adaptive research aimed at the cassava-production regions in each country. In the area of cassava utilization and product development, national programs do not have and are not developing a research capacity. Research collaboration in this area has therefore been mainly with universities and food technology institutes. Several national research and extension programs are now undertaking adaptive research and extension activities in the area of utilization.

Table 13.1. Cassava production in Latin America ('000s t).

	1970	1980	1987	1988	1989	1990
Latin America	34,735	29,940	30,590	29,109	30,843	33,700
Brazil	29,464	23,466	23,464	21,612	23,247	25,400
Colombia	1,200	2,150	1,260	1,280	1,509	1,939
Paraguay	1,580	2,031	3,468	3,890	4,000	4,000
World	97,597	124,707	136,801	141,109	147,500	150,000

Source: FAO production data (1990, preliminary), except Colombia (Ministry of Agriculture).

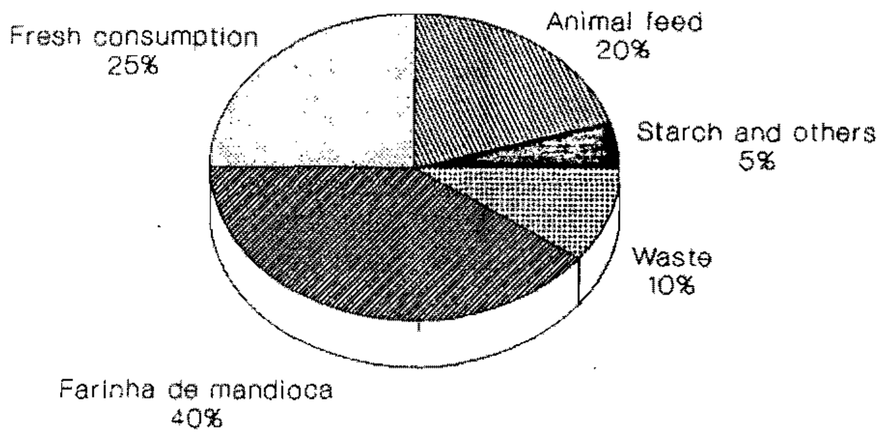

Figure 13.1. Cassava utilization in Latin America

The second methodology used by the Program is that of collaborating with a variety of national and local institutions in integrated cassava production, processing and marketing projects. These projects have been designed to enable improvements in cassava production, processing and marketing to be a vehicle for rural development in specific regions of priority countries. Through the development of better markets for cassava-based products (novel or improved) and with the involvement of farmers in organizations dedicated to processing fresh cassava, significant income and welfare improvements can be generated. As these projects require actions in areas as diverse as organisation of farmer groups, credit provision, institutional strengthening, etc., in addition to the technical aspects of cassava production and processing, coordination with a wide variety of collaborating institutions is necessary.

Four stages have been identified for integrated cassava projects:

- Macro planning (at the national level): identification of an appropriate production region, product to be marketed, etc.

- Micro planning (at the regional level): characterization of cassava production, processing, marketing in the selected region; identification of sites for pilot activities, etc.

- Pilot stage: participatory testing of all project components in real world situations, including production, processing and marketing aspects, plus the institutional, organizational and credit actions required to obtain success.

- Replication, expansion or commercial stage, in which the technologies and other aspects tested in the previous stage are expanded and consolidated at a commercial level.

13.1.1 Country priorities

Over the past 5 yr the Program has focused its attention on 4 countries: Brazil, Paraguay, Colombia and Ecuador. Together these 4 countries account for over 90% of the cassava produced in Latin America.

As the largest cassava-producing country, Brazil is an obvious priority for the Program. The size of the country is such, however, that several distinct cassava-production regions can be identified: from the semiarid NE region to the subtropical South. The NE region has been given the highest priority, both by CIAT and by Brazil itself, which located the National Cassava Research Program CNPMF in a state in this region. The NE produces 50% of the cassava in Brazil and has the largest concentration of rural poverty on the continent. Secondary priority has been given to the southern subtropical region.
Paraguay, which produces 4 million t of cassava yearly, has the highest per capita consumption on the continent (> 100 kg/capita/yr, even in urban areas). It is the most widely cultivated crop in the country, found on over 200,000 of the country's 250,000 farms.

Colombia produces over 1.9 million t of cassava per year, mainly for fresh consumption. As the host country for CIAT and the site of pilot testing of many of the Program's utilization and production technologies, it is in a good position to benefit from these activities. Economic studies have also demonstrated the potential for increasing cassava production and utilization in Colombia. The Atlantic Coast, which is the major cassava-producing region in Colombia, is among the poorest regions of the country.

Although Ecuador is a minor producer of cassava (150,000 t/yr), it is a major crop in the Manabí region. The feed requirements of the growing shrimp industry in this coastal region provided a ready market for the small-scale rural industrialization of the crop.

Contacts have also been maintained with Panama, Cuba, Costa Rica and Mexico through training and occasional technical visits. Argentina, Bolivia, Venezuela and Nicaragua are countries with an increasing interest in cassava development, and contact is expected to increase in the future.

13.2 Training and Networks

13.2.1 Training

Table 13.2 gives a breakdown of training events by type and by country. In the early 1980s the training emphasis of the Cassava Program was placed on cassava production and utilization courses held at CIAT. By 1987 the emphasis had changed to participating in courses held in the countries. Since 1988 annual courses have been held in Colombia, organized by DRI and PNR, resulting in a large body of trained professionals in all institutions involved in integrated projects in Colombia. Similar in-country courses in Brazil, Ecuador and Paraguay have all supported the growth of integrated projects in these countries. Courses of a more specialized nature have also been stressed; e.g., diagnostic skills, experimental design and analysis, HCN analysis methodology and integrated pest control. Since 1990 training in integrated project formulation, implementation and evaluation has also been important. Other events (seminars, workshops, etc.) have been held at CIAT and in-country on topics such as cassava starch, integrated project methodologies and the cassava-maize association. An annual cassava research seminar has been a feature of the integrated project in Ecuador.

Table 13.2. Courses, workshops seminars and meeting held in Latin America, by country, 1987-91.

Type of Event	Colombia[1]	Brazil	Paraguay	Ecuador	Cuba	Peru	Mexico	Others[2]
Course	6	6	4	3	4	2	1	3
Workshop	2	2	2	1	0	0	0	1
Seminar	0	2	0	2	0	0	1	0
Meeting	2	1	1	1	0	0	0	0

[1] Includes events at CIAT.
[2] Panama, Nicaragua, Guatemala, Bolivia.

Now that an adequate corps of trained professionals exists, future priorities will be focused on forming 3 regional training teams: Southern Cone, NE Brazil, and Central America, Mexico and the Caribbean countries.

13.2.2 Networks

Many of the activities inherent in international collaboration can best be carried out through networks of interested parties. In 1988 the Program organized a meeting at the request of several countries to found a cassava network for Latin America. Unfortunately this exercise was premature in that the human and financial resources required to operate such a network adequately did not exist. Since then, however, several smaller networks have evolved, focused on specific research or development topics, with more limited objectives.

13.2.2.1 Pan-American Cassava Breeders' Network. The Cassava Breeding Network is described in Chap. 2, Sect. 2.2.2.

13.2.2.2 Southern Cone. A meeting was held in Paraguay in Oct. 1990 to discuss the possibility of collaboration among Argentina, Paraguay and the southern Brazilian states of Rio Grande do Sul, Santa Catarina and Paraná. These cover one relatively homogenous subtropical cassava-production area with many similar production and utilization problems, which are frequently different from those of other regions of the continent. CIAT HQ cannot carry out research of relevance to the subtopics. At the initial meeting, the current status of cassava production and utilization and the areas of R&D of interest to each party were presented. A further meeting in Rio Grande do Sul in May 1991 helped define these ideas in concrete proposals for forming a network with several components: germplasm, production, processing and utilization, socioeconomics and technology transfer. Funding for the germplasm component, based at Itajai, Santa Catarina, Brazil, exists within an IFAD financed project. Also, within the technology transfer component, a project to form a subregional team for training technology intermediaries has just got under way with financing from the Interamerican Development Bank (IBD). For the other components, some specific topics of interest to the group of countries were agreed upon, and a further meeting is planned for 1992.

13.2.2.3 Integrated projects. Integrated projects exist in Brazil (Ceará), Colombia, Ecuador and Paraguay, with incipient projects in Panama, Bolivia, Argentina and other states of Brazil, (including Rio Grande do Sul, Bahia, Paraiba and Pernambuco). Informal contacts between projects have been occurring for a no. of years; but as a result of a course on integrated projects held at CIAT in 1990, it was decided to continue contacts on a more regular basis in the future. At that event, participants gained immensely from the experiences, both positive and negative, of other countries. A study visit to the Colombian integrated project was highly successful in opening up issues for discussion and in giving the participants an appreciation of technological advances relevant for other areas. A second workshop was held in Portoviejo, Ecuador in July 1991, at which the project advances during the previous year were discussed and 2 special issues dealt with: farmer organization and monitoring, evaluation and impact of projects. One feature of this event was the leading role of FUNDAGRO--the Ecuadorian agricultural development institution supporting the project there--in organizing and funding the meeting. The Ceará project funded the participation of extension agents and farmer leaders. In this way the Integrated Projects Network has already developed certain financial independence. A further meeting in 1992 was tentatively arranged to take place in Ceará.

13.2.2.4 Utilization research. Given that research in processing and utilization of cassava falls outside the mandate of many national programs in Latin America, the Cassava Program has attempted to build links with research institutions of a diverse nature in Latin America. Strong links have now been established with UNIVALLE (Cali, Colombia) and with the State U. of Sao Paulo (Brazil). UNIVALLE has been a collaborator of the Cassava Program in product development of cassava flour and starch since the early 1980s. The Botucatú campus of the State U. of Sao Paulo has been active in encouraging cassava utilization research at a wide number of Brazilian universities and research institutes. A working group now exists to coordinate research on cassava utilization in Brazil. Other universities in Ecuador, Colombia, Argentina and Costa Rica have more limited interests. In the developed world, CEEMAT/CIRAD of France and NRI of the UK are both carrying out and supporting research on cassava utilization focused on Latin America and Africa. These institutions have close contacts with CIAT. An informal network of institutions interested in research on cassava starch has existed since an international workshop on this subject was held in Santa Catarina, Brazil in 1989. A second workshop was held at CIAT in 1991, with the participation of starch producers and industrial users as well as researchers. This grouping of interested parties is the basis upon which a research network with a broader scope can be built.

The new CIAT strategic plan envisages a reduction in the Cassava Program's product development activities. A significant potential for product development research still remains, especially as regards the development of secondary or derived products from starch and flour. It is the Program's intention to ensure that the necessary research is undertaken by other institutions, through the financing of special projects where necessary, so that the demand lead progress already achieved with cassava during the 1980s can continue beyond the year 2000. CIAT will continue an active role in the interface between production and processing (i.e., raw material quality) and in determining research priorities based on market potential.

13.3 Country Reports

Chap. 14-17 describe in detail the progress made in Colombia, Ecuador, Brazil and Paraguay, countries on which the Program has focused its collaboration for the past five years. The situation in Panama, Mexico, Cuba and Costa Rica is briefly described below.

13.3.1 Panama

Cassava is of great economic importance for small farmers and rural-urban consumers in Panama. Several typical Panamenian dishes are based on cassava. As most of the population is concentrated around the capital, both the poultry and swine industries have increased significantly in recent years, resulting in a demand for balanced feed rations.

The national R&D institution (IDIAP) has dedicated significant effort to cassava, despite political problems. As a result of development and promotion activities undertaken in collaboration with the CIAT Cassava Program, cassava now plays an important role as a component of feed concentrates for poultry and swine; and demand is on the increase. In addition the private sector has become more interested in developing the crop for agroindustrial purposes.

Technical assistance provided by the Program has concentrated on supporting the integrated development of the crop. This requires simultaneous work on production, transformation and commercialization. Initially, IDIAP and CIAT economists conducted a macroeconomic study on the potential of cassava in the country, as well as that of other carbohydrate-producing crops. This study demonstrated the importance of fresh cassava in the human diet and identified the potential for using cassava in rations for poultry and swine. Subsequent regional analyses indicated that production was concentrated in Ocu (Herrera), leading to the selection of this region for R&D activities.

The principal production systems were characterized, and problems/opportunities for improving production were identified. Possible sites for locating a natural drying plant to be operated by farmers on a pilot basis were also identified; and from these "Los LLanos de Ocu," a farm run by a farmer coop, was selected.

An in-depth study of potential markets was initiated. Possible buyers of dry cassava chips within the feed industry were identified, and studies on raw material production costs were undertaken on the basis of real production figures and theoretical purchase prices for the product. Simultaneously, studies were conducted on the physical characteristics of production. One of the principal problems identified on traditional farms was the low fertility of the soils and a high incidence of weeds. Yields of roots and of planting material were low; leading to serious problems of availability of planting material.

Based on these findings, it was concluded that the potential demand for cassava was much greater than what farmers could produce, given their current level of technology and access to land. Industrialists' lack of knowledge of cassava as a raw material was identified as a limiting factor for marketing. In addition, the distance from production centers to urban centers and feed industries was a critical problem for marketing fresh cassava and dried chips, given the relatively high cost of transportation in Panama.

Despite relatively low commercialization margins, the pilot plant "Los Llanos" began operating successfully and was imitated by other small farmer associations as well as private investors. Today there are 7 drying patios in the region. The local feed industry is purchasing chips despite the problems that have affected the country's entire economic sector.

The existence of a new market for cassava has stimulated production, and the farmers are demanding improved technology. Technical recommendations on planting density, stake selection, fertilization and weed control have increased production considerably. Progress has been made on the use of minimum tillage to prevent surface erosion of easily saturated soils. Technical recommendations are also available for intercropping cassava with maize and cowpeas, without an adverse effect on yield.

The introduction of improved varieties has been successful. The local variety "Brasileña," introduced many years ago, shows symptoms of systemic pathogens. "Dayana," introduced by CIAT in 1984, is one of the best yielding varieties in the country (20 t/ha avg vs. 15 t for the local check). With technical assistance from CIAT, a complete germplasm testing scheme has been established, together with the rapid multiplication of that germplasm based on tissue culture.

Training technical personnel has been a constant concern of the project. In the last five years, more than 20 technicians from the state and private industry have been trained in CIAT courses. At the local level, IDIAP and MIDA have trained many small-scale farmers in production, operation of the drying plants and commercialization of the dry chips.

The challenge for the future lies in coordinating the public and private sectors so that they complement each other in production, transformation and commercialization of cassava.

13.3.2 Mexico

Despite being one of the supposed centers of origin of cassava, production of the crop in Mexico is minimal (ca. 3000 ha). In the 1970s, however, at a time when Mexico was importing increasing volumes of feed grains, a great potential for cassava was envisaged as a partial substitute for these imports. Accordingly, a national cassava research program was created within the National Institute for Agricultural Research (INIA, now INIFAP) in 1977, based in Huimanguillo, Tabasco. The aim was to develop cassava production, processing and utilization technology for commercial-scale production on the acid, infertile soils of the savannas around Huimanguillo. A young and highly motivated team of scientists was formed; and by 1980 it was considered that sufficient progress on variety selection and related production technology had been made to initiate an ambitious plan for promoting cassava production among the farmers of the region.

After a rapid initial expansion in cassava production from 100 ha in 1981-82 to a level of 2404 ha in the 1984-85 cycle, the area under cassava has slowly diminished; and today the crop has been virtually abandoned, both by farmers and by official state organizations. INIFAP's national cassava program has been virtually disbanded. This situation, which contrasts sharply with that occurring in other countries, has merited an analysis of the technical, economic and institutional factors that led to the demise of a program that held such promise 10 yr ago.

Among the principal reasons identified as affecting the program's future were:

- An overinvolvement of and control by state agencies of aspects relating to cassava production and processing. Production and processing input and output decisions, market outlet and marketing strategy definition and profit distribution decisions were all in the exclusive domain of program officials. Participation of farmers in decision-making processes was almost totally absent, resulting in a rapid loss of commitment and motivation.

- Cassava production and profitability were lower than expected, principally because of untimely delivery of state-controlled inputs and services.

- Too great an emphasis was placed on production--both in research and in promotion activities--and not enough on processing alternatives and market identification and development. Links among and integration of these components were almost totally lacking.

The model for cassava development in Huimanguillo was quite different from that being adopted at the same time in other Latin American countries, such as Colombia, Panama and Ecuador. Two factors stand out: (a) the very high level of state intervention and investment, and (b) the absence of mechanisms for validating and adapting both production and processing technology prior to promoting it among a large number of farmers.

13.3.3 Cuba

CIAT's relationship with Cuba has been quite different as the Cuban R&D institutions are stronger than those of the other Caribbean countries. Consumption of root crops, especially cassava, is a tradition in Cuba. Close relationships have been maintained with the national program, but efforts have concentrated on training technical personnel and broadening the germplasm base. Cuba is an active participant in the Pan-American Germplasm Network, organized in the last few years.

Previous annual reports have described the so-called "Colombian" system for producing cassava, employed in Cuba for many years. This system is a mixture of Cuban technology and technology developed at CIAT. As a result the country has become self-sufficient in cassava, and a good part of the production is being processed for domestic consumption.

13.3.4 Costa Rica

In Costa Rica the consumption of cassava is relatively low. Together with the Dominican Republic, Costa Rica dominates the export market of cassava for the US and Europe. The country exports more than 30,000 t/yr of cassava to the US. The roots are either treated with paraffin wax and exported fresh; or peeled, sliced, packed into polythene bags and frozen. There is strong government support for infrastructure, working capital and marketing contacts.

The dependence on a single var. (Valencia) means a high degree of risk for exporters. The CIAT Cassava Program is collaborating with the National Cassava Commission on identifying and characterizing Costa Rican germplasm, which was mostly introduced from CIAT, in order to increase its diversity. Personnel have also been trained at CIAT HQ.

Future cooperation will focus on designing research to identify environmental and varietal factors that affect the quality of the fresh roots. Ex-ante economic analyses do not indicate the feasibility of transforming fresh cassava into dry chips as the cassava-producing zones are located in areas with high rainfall.

14. COLOMBIA

Being located in Colombia, the CIAT Cassava Program has naturally had a very special relationship with national institutions, different from that formed with institutions in other Latin American and Asian countries. The diverse cassava production and utilization situations in Colombia have provided the ideal ground for testing and adapting both production/processing technologies and participatory R&D methodologies. The practical work carried out in Colombia has served the Program in its endeavors in other countries by providing a learning experience for Program staff and visiting research and extension personnel from other countries. In this respect, the Program acknowledges with gratitude the excellent collaboration that it receives from its Colombian counterparts in a wide range of institutions.

14.1 DRI/CIAT Integrated Project, Atlantic Coast of Colombia

14.1.1 Background

Colombia was the first country in which an integrated cassava production, processing and marketing project was initiated. The project now has a history of 10 yr in the Atlantic Coast region of Colombia. The role of the Cassava Program has evolved significantly since the early 1980s. The Colombian institution most closely involved in the project has been DRI, the Integrated Rural Development Fund of the Ministry of Agriculture. CIAT has maintained a series of agreements with DRI since 1981, through which all the project-related activities of the Program have been financed. DRI is the overall coordinating institution for project activities although numerous other institutions are involved, for example:

- CORFAS: provision of credit, technical assistance in accounting and processing
- FINANCIACOOP: credit provision and supervision
- ICA: cassava production, research and extension
- INCORA: land reform
- SENA: coop formation and consolidation, some technical assistance in processing

In addition DRI supported the formation of a second-order organization in 1986, grouping the coops and associations of small farmers into one National Association of Cassava Producers and Processors, ANPPY.

From 1987 to 1991, the Cassava Program collaborated with DRI and the other institutions and farmer organizations in the following activities:

14.1.2 Marketing

Until 1989 technical assistance was provided to ANPPY for dried cassava commercialization. Following the withdrawal of CIAT technical assistance in 1989, ANPPY has been essentially self-supporting in this area.

Surveys of fresh cassava consumption and marketing were carried out in Cali, Medellín and Bogotá in collaboration with CORFAS. These provided information on consumption habits (purchase frequency and amount, varietal preferences) and market information (market share by retail outlet, margins) of relevance to the possible future expansion of the fresh cassava storage technology to other Colombian cities after the Barranquilla pilot experience. These studies, combined with those conducted previously in Bucaramanga and Barranquilla, provide a complete picture of fresh cassava marketing and consumption in the principal urban centers of Colombia.

14.1.3 Processing

Most of the CIAT activities carried out within the framework of the DRI/CIAT agreement have been at the pilot level (see Chap. 12 on product and process development). These include improvement to chipping machine design, animal feed ration formulation and testing at farm level, fresh cassava storage and cassava flour for human consumption. As these activities formed an integral part of the DRI-coordinated actions in this project, they received considerable institutional support. Technical assistance to the farmer groups in processing and commercializing dried cassava was initially a CIAT activity; but this was gradually handed over to national institutions. CIAT ceased to perform this function in 1989; however, it was not straightforward to find a suitable institution to take over this role. The marketing of dried cassava chips has been assumed by ANPPY, which organizes the price and volume negotiations with the animal feed companies on behalf of the farmer groups affiliated to it. As this now involves contacts with over 15 companies in at least 5 cities in Colombia and the dispatch of cassava from over 50 drying plants, the operation has become exceedingly complex. Problems still occur with regard to chip quality (poor drying). Technical assistance has been devolved to CORFAS, as the agency with the closest and most frequent contacts with the drying coops; however, this has not been entirely satisfactory as CORFAS is essentially a credit provision and supervision agency with a limited number of technical staff. In addition, recent problems with the national system for distributing credit lines for small-scale agriculture have resulted in the reduced presence of CORFAS in the project region. Creative approaches to solving the problem of technical assistance to farmer groups in the project are urgently required.

During the 2 yr in which CIAT was involved in technical assistance to the cassava drying plants, 7 new plants were constructed, and many others expanded the area of drying floor. In total 41 coops, as well as ANPPY, received assistance. The presence of DRI-funded CIAT personnel in close contact with the drying plants provided an excellent opportunity for firsthand knowledge of any remaining problems, which served as feedback for research at CIAT. In this way, the need for an improved cassava chipper was identified, and the improved model was tested with the farmer groups themselves for firsthand reactions.

14.1.4 Production

The integrated project on the Atlantic Coast initiated with a strong emphasis on processing and marketing given that the declining and unstable demand for fresh cassava was the immediate constraint facing small farmers. By the late 1980s, however, this had led to increased interest in improved production technology by the small farmer beneficiaries of the project. Whereas processing technology can be relatively straightforward to introduce and support within a project context, the development and diffusion of improved production technology requires a longer timeframe. With this in mind, during the mid 1980s ICA gave increased emphasis to cassava production research in the project region, through the formation of a working group of researchers who jointly planned, executed and analyzed research results, together with CIAT. This Group of Cassava and Associated Crop Researchers (GRUYA) has proved an excellent forum for discussing research methodologies and for obtaining results with relevance to the whole region, as similar experiments can be carried out by a no. of researchers over a wide area. One result of this has been the increasing emphasis on participatory research with farmers, especially for varietal development (see Germplasm Improvement, Chap. 2). Similarly, the widespread use of PPPs--planted and managed in collaboration with farmers--to test promising technology recommendations, has resulted in a no. of significant findings (see Cropping Systems, Chap. 9).

In the states of Sucre and Córdoba, cassava production has increased dramatically in the last few years. As most cassava is still produced by the small farm sector with limited land available for crop rotation or fallow, increasing pressure is being placed on the natural resource base of the region. The GRUYA group is placing more emphasis on soil fertility maintenance and other aspects of sustainable productions systems.

14.1.5 Farmer organization

In 1986 DRI supported the formation of ANPPY, the second-order organization of farmer groups involved in the cassava integrated project. Initially, ANPPY's major function was to organize the commercialization of dried cassava produced by the first-order groups in the different end markets. It has been very successful in this activity, holding periodic price negotiations with individual companies and obtaining favorable results for the farmers. ANPPY is financed through a 1% levy on sales. Given the concentration of farmer groups in the states of Sucre and Córdoba, however, coops in other states were not so well attended. Thus in 1989, several coops from the states of Atlántico, Magdalena, and Bolívar formed a separate second-order organization, FAGROCOL, in order to commercialize their dried cassava, which was usually sold in a different terminal market from that of the remaining ANPPY coops. FAGROCOL also contained coops organized around the production and commercialization of other crops (yams, maize, tomatoes, etc.), as well as being the executing agency of the fresh cassava storage project in Barranquilla until 1990.

During 1989 the first cassava drying plants were constructed by private individuals--all in Sucre and Córdoba. In 1990 ANPPY received the first two affiliates from this private sector. By July 1991 the no. of private-sector affiliates of ANPPY had increased to 31, compared with 34 coops and associations. The rapid and dynamic growth of privately operated and owned cassava drying plants, while amply demonstrating the economic profitability of cassava processing under increasingly free market conditions, has been a source of considerable tension within the project itself. Collaboration between the private and coop sectors is advantageous in terms of price negotiations with the animal feed companies and for producer lobbying at a political level, regionally and nationally. Private-sector plants have rapidly improved process efficiency, and the coop plants can learn from these experiences; however, there is tension related to the distribution of benefits, with the coop sector favoring a high raw material price (small farmer benefits) and the private plants a lower price in order to maximize margins (processor benefits). As a result of this tension, a no. of coops, especially newly formed ones, have left ANPPY to form a separate organization for commercializing dried cassava (ASOCOSTA); and institutional support to ANPPY has declined. Despite these problems, the no. of drying plants and their production has continued to expand at the same rate as in 1990.

The Cassava Program has collaborated with both ANPPY and FAGROCOL in the development of the cassava flour and fresh cassava pilot projects, resp. (see Chap. 12).

14.1.6 Institutional aspects

Close collaboration between CIAT and DRI has been a salient feature of the project, both in the Atlantic Coast region and at the national level (Bogotá). In each state DRI coordinates technical assistance teams composed of representatives of each collaborating institution. CORFAS and SENA have been the most active members of these teams, with functions of credit provision, supervision and technical assistance in processing, and in coop formation, organization and accounting, resp. Technical assistance teams have worked well in the principal project areas of Sucre, Córdoba and Atlantico, but have been less active in other states where fewer plants exist. Some regional institutions (e.g., FIDES, a Sucre development foundation) have recently become involved. ICA has taken on an increasingly important role now that demand for improved production technology, the release of a new variety in 1991, and the success of the GRUYA group in carrying out farmer participatory research have all combined to make cassava production a high-priority issue.

14.1.7 Monitoring and evaluation (M&E)

Initially CIAT carried out the project M&E in collaboration with DRI. In 1989 DRI and CORFAS became solely responsible. The dynamic nature of the growth of the cassava drying industry since then has not been fully captured by the M&E system currently in operation as CORFAS monitors the performance only of the plants to which it provides credit. Delays in publishing the results have reduced their usefulness. In effect, the drying of cassava for animal feed has passed from being a project to being an autonomously expanding agroindustry. The project M&E system has thus proved inadequate to cope with this expansion. In addition the spontaneous growth of dried cassava plants outside the project region has also failed to be captured.

Monitoring information is currently available to CIAT from the following sources:

- CORFAS: coop plants receiving credit
- ANPPY: affiliated plants--coops and private
- Animal feed companies: volumes purchased nationally
- Processing equipment manufacturers: purchasers of equipment

The lack of an integrated M&E system is not only disadvantageous to the development of the industry itself; but it also makes the assessment of project impact--both within and beyond the project boundaries--difficult to carry out. This will be one of the priority areas to coordinate actions with all interested parties in the coming years.

14.2 PNR/CIAT Collaborative Project

The National Rehabilitation Program (PNR), which is a special rural development program operating out of the Ministry of the Presidency in Colombia, has as its responsibility those areas of the country that for diverse reasons are suffering from public unrest. These are among the poorest, most isolated and least developed regions of the country. As such, cassava is an important or potentially important crop in many of these areas, where poor market access is a common feature.

Following the success of the DRI/CIAT collaboration in developing a cassava drying agroindustry on the Atlantic Coast, the PNR proposed a similar agreement to expand dried cassava production to other regions of the country. Unfortunately the absence of a Colombian institution able to provide technical assistance in cassava processing meant that CIAT was the only alternative. Accordingly, it was agreed that the PNR would finance technical assistance by CIAT in 4 regions of Colombia for 2 yr. At the end of this period, responsibilities would be handed over to national institution(s).

The areas for expanding the dried cassava industry were agreed between CIAT and PNR, with the active participation of DRI, which also has national coverage, although with an emphasis on small-scale farmers. The states agreed upon were:

- North and South Santander
- Cesar
- Sucre and Córdoba (in areas not covered by DRI)
- Meta

The activities and achievements in each region are detailed below. Despite the fact that all activities were to be related to the expansion of dried cassava for animal feed, in effect potential for the fresh cassava storage technology and the need for improved varieties and planting material have resulted in the broadening of project actions in all regions to include other aspects of processing and production.

14.2.1 Cesar

Cassava production in Cesar fell from 121,000 t in 1980 to only 56,000 t in 1987. It then increased again, reaching 127,000 t in 1990. The decrease in production during the early 1980s was due mainly to market problems. In contrast to other areas of the Atlantic Coast region, land for cassava production is not a limiting factor: activities in the PNR/CIAT project were therefore focused on the potential of drying cassava for animal feed to provide a secure market for cassava and hence encourage production increases. Four drying plants had been built and operated by farmer groups within the framework of the DRI project from 1984-88; however, these were operating at low levels of capacity for lack of institutional support, poor coop organization and financial problems resulting from poor administration and late arrival of credit.

14.2.1.1 Technical team. The team is coordinated by PNR; members include ICA, SENA, CECORA, Caja Agraria (the rural agrarian bank, which also provides extension services through EDO units). INCORA has been an intermittent member. CECORA left the team in 1991; since then there has been no institution responsible for technical assistance in marketing of dried cassava.

14.2.1.2 Processing. Initially there was a shortage of funding for the construction of drying plants in Cesar; but a project was finally approved in 1990, and one additional plant initiated operations in 1991. The plant is operated by a coop of 200 members (COOTRADECO), which has several years' successful experience commercializing maize. Lack of institutional assistance in this area is not a limitation. Technical support has been given to the existing coops, and some reactivation was possible although the lack of financing for working capital has been a limitation. Interestingly, while the institutional financing for working capital has been a limitation. Interestingly, while the institutional sector of Cesar has been relatively weak, drying of cassava chips has been spontaneously expanding through the activities of individual small-scale farmers, who have constructed small drying areas and purchased manual chippers. COOTRADECO has been purchasing dried chips from these farmers and selling them, together with their own production, to animal feed companies in Bogotá. Projects for constructing 4 more drying plants with existing coops are under consideration by PNR.

Experiments were also carried out with the fresh cassava storage technology, using cassava harvested from the Sierra Nevada region of the state. Storage times of 3 wk were obtained. A test market was carried out in Valledupar, in which 14 t of bagged cassava were sold in supermarkets. The project has not progressed further for lack of working capital for the coop.

14.2.1.3 Production. When the PNR/CIAT agreement started, no cassava-related activities or research was being conducted by ICA-Cesar. Two years later, cassava has been recognized as one of the strategic crops in the state, and all the ICA stations (CRECEDs) and Caja Agraría EDOs have trials in progress. Trials have involved the testing of 10-15 var., including local and CIAT germplasm, using the participatory research methodology. Several promising materials have been identified as a result of these farmer-managed and evaluated trials.

14.2.1.4 Courses and other events. A course on cassava production, processing and marketing was held in Valledupar in March 1991, with the participation of personnel (30) from institutions in all regions of the PNR project. Field days have been held with farmers and institutions on 4 occasions.

14.2.2 Sucre and Córdoba

Although Sucre and Córdoba are the 2 states in which the DRI cassava project has had the greatest concentration of activities, there remain areas (not covered by DRI) where drying plants have not been built even though cassava is an important crop. As the PNR program has different objectives and priorities, it was possible to expand project coverage. Cassava production in Sucre and Córdoba has been increasing significantly, reaching 170,000 and 189,000 t in 1990, resp; however, these production increases have occurred in areas where drying plants exist or where access to the fresh market is good--not those in which the PNR operates.

14.2.2.1 Technical team. The initial strength of the technical teams in Sucre and Córdoba was recently weakened by the departure of the institution responsible for technical assistance and training in marketing (CECORA). In addition to providing support to existing coops, the technical teams have been active in promoting the formation of new coops and associations.

14.2.2.2 Processing. During the 2-yr period of the agreement between CIAT and PNR, 4 drying plants were built using PNR finance. Five additional groups have been legally constituted, and projects for constructing plants prepared. Other groups are in the process of formation. The 4 drying plants have been operating at a 75% avg level of capacity. These plants are located in the least developed parts of the 2 states, including areas with significant guerrilla activity. The success of the project in bringing a viable economic alternative to these forgotten regions of the country cannot be underestimated. The location of drying plants in these isolated communities has also resulted in a greater presence of government institutions than previously.

14.2.2.3 Production. Given that the ICA/GRUYA group is active in these states, no specific activities were carried out in the PNR project on cassava production. A project has been prepared for financing seed multiplication plots for the PNR regions of the states.

14.2.2.4 Courses and other events. Personnel from Sucre and Córdoba attended the courses organized in Meta and Cesar in 1990 and 1991, resp. Many events were held with farmer groups related to the promotion and formation of coops.

14.2.3 North and South Santander

These 2 states contain several important cassava-production regions: 186,000 and 90,000 t in South and North Santander, resp. When the project started in June 1989, cassava drying plants already existed in the Magdalena Medio region of South Santander, a PNR area. However the farmer coops operating these plants had suffered from consistently deficient technical assistance in almost all aspects of cassava production, processing and marketing, as well as in coop formation and management. In South Santander, a farmer group was experimenting with conservation of fresh cassava in bags using the CIAT-developed technology, marketing the roots in Bogotá. In North Santander, small farm production of cassava chips by hand chipping and drying on any available surface, had already been initiated spontaneously. Intermediaries were purchasing these small volumes of chips from individual farmers and selling them in Bucaramanga.

14.2.3.1 South Santander

- Consolidation of technical teams. There were two technical teams in the state: one coordinated by PNR for the Magdalena Medio region and the other by DRI for the region of Socorro. The former comprised the following institutions: INCORA (land reform), SENA (coop organization), ICA (cassava production), Agriculture Secretariat of the state, DRI, FONDISER (a regional NGO). Technical assistance in commercialization was and still is lacking. This has been a serious constraint to project expansion. The PNR/CIAT convenio provided technical assistance in cassava processing.. The DRI-coordinated team for the Socorro region was similarly constituted, but with the addition of CORFAS for technical assistance in commercialization. The technical teams meet every 4-6 wk, with joint sessions every 2 mo.

- Processing. Technical assistance was provided to 3 coops, each with 500m² of drying floor. An additional group, awaiting the approval of a project to finance construction of a drying plant, has already processed cassava manually. In Socorro, assistance was provided to a coop originally promoted by DRI, SENA and ICA, in which the main activity is conserving fresh cassava for the Bogotá market. This group is marketing approx. 3-4 t/wk, year-round. Cassava is selected into three quality grades: the highest quality is treated and packed for the Bogotá market using the CIAT technology, Grade B is sold on the local fresh market, and Grade C (noncommercial) is chipped and dried for animal feed use. The total cost including transport, finance charges and administration is Col$119/kg cassava, while the price received from the supermarket clients in Bogotá is Col$150/kg (US$1 = Col.Ps.600). Even at the low level of vol. traded in Bogotá, this coop has been able to make substantial profits in one year of operations. Two recent problems are the appearance of the Cyrtomenus bug (which affects root quality) and the lack of knowledge of the product and its management by the clients in Bogotá.

- Production. In collaboration with ICA, varietal trials with CMC 40 and CMC 76 were planted in the Magdalena Medio region. With the support of a no. of PNR technicians, 16 plots (0.25 ha each) were planted throughout the Magdalena Medio region using local var. and improved production technology (soil preparation, stake treatment and selection, weed control). These plots are the initial phase of a PNR project that will finance the planting of 92 plots with farmer collaboration.

- Courses and other events. A course on cassava production and processing for 29 technicians of the state was held in June 1990. Talks and lectures were given to students at local universities, and informative leaflets on cassava processing were produced.

14.2.3.2 North Santander

- Technical team. When the project started, there was no team although one drying plant had recently been built by a coop with funds from a regional development corporation, CORPONOR. The technical team is constituted by the PNR, DRI, ICA, the state Secretariat of Development and CORPONOR. CECORA (responsible for commercialization) and SENA (coop organization) have been intermittent members. Meetings are held every 2 mo.

- Processing. In addition to the plant financed by CORPONOR, 5 small (200m²) plants have been financed, 3 of which are currently under construction. Farms are disperse, which hinders associative forms of drying. Many small farmers dry hand-chipped cassava as a backyard activity, selling to local intermediaries. The idea behind the small plants is to facilitate some associative drying and also to permit the coops to take an active role in assembling dried cassava from small farmers and marketing this in Bucaramanga or Cúcuta (project awaiting approval). Trials of the fresh cassava conservation technology were also carried out with ICA using local varieties. Storage times of 4 wk were obtained with good eating quality.

- Production. In collaboration with ICA, 7 CIAT hybrids and 2 local control var. were planted in Oct. 1990. In addition plots of 2 local and 4 CIAT var. were planted for seed multiplication. Four demonstration plots (0.25 ha each, containing 3 local var. and 1 CIAT hybrid) were planted in the vicinity of drying plants in collaboration with the State Secretariat of Development. Four more plots were planted in 1991.

- Courses and other events. A one-day course on cassava production and processing was held in Cúcuta in Feb. 1991, with 33 participants from 6 institutions.

14.2.4 Meta

The area devoted to cassava production in Meta fell from 20,000 to 4,000 ha from 1980-89. This was due to the fall in demand in Bogotá, the principal market for fresh cassava, where other production regions of the country have increased their market share; however, demand for dried cassava chips in the animal feed industry in Bogotá was estimated at 20,000 t in 1990. In order to supply this market, actions were required not only in the area of cassava processing but also in production.

- Technical team. Upon the initiation of the project in 1989, a technical team was constituted under the coordination of the PNR. Member institutions are ICA, the State Secretariat of Agriculture, CECORA and INCORA.

14.2.4.2 Processing. In 1989 a coop was formed to dry cassava for animal feed at Alto Casibare. Financed by PNR-Meta, operations began in Oct. 1990. The Piedmont area of Meta is characterized by high, well-distributed rainfall; thus the plant was designed to include artificial drying as an option for processing when conditions for natural drying were unsatisfactory. This plant was built in an area where little cassava is cultivated, but where farmers have good land availability to increase production. Thus, although the process has operated efficiently, there has been insufficient supply of fresh cassava to permit continuous operation; however, now that farmers have a secure local market for their fresh cassava, production should increase. A further mixed natural/artificial drying plant was approved and built with PNR funding at Cerritos in early 1991.

Trials of the cassava conservation technology were carried out together with ICA. The varieties tested included the two recently released by ICA. The bags of cassava were evaluated by housewives in Villavicencio, the main city in Meta. Results were excellent even after 30 days' storage.

- Production. Once the lack of cassava production to supply the drying plants was identified as a major constraint, considerable emphasis was placed on establishing seed multiplication plots. The scarcity of stakes was a major factor limiting expansion of production. Multiplication plots were established at 7 sites, including ICA experiment stations, the U. de los LLanos, the State Secretariat of Agriculture field station and in farmers' fields. Over 100,000 stakes were planted (25,000 in 1989 and the rest in 1990) for distribution to members of the coops and other farmers in the region, as well as for use by ICA and other institutions to increase further their supply of planting material. Stakes of the 2 recently released var. (Catumare and Cebucán) were in particular demand.

- Courses and other events. A course on cassava production, processing and marketing was organized in Granada (April 1990) with the participation of 31 representatives of different institutions and members of coops, not only from Meta but also from other regions of the PNR/CIAT project. This course was repeated in June 1990 in Arauca, where COAGROARAUCA was responsible for organizing the event. A third course was held in Villavicencio in July 1990, in collaboration with the U. de los LLanos and DRI. These events have served not only to improve the participants' technical knowledge, but also to assist in the formulation of projects for constructing and operating cassava processing plants by coop groups.

14.2.5 Future

The initial project with PNR terminated in May 1991. Although the original idea was to transfer CIAT's responsibilities to other institutions at that time, this was possible in only one of the 4 regions: Santander, where FONDISER, an NGO whose objective is the agroindustrial development of the region, was identified. An agreement between PNR and FONDISER is now operational, and the area of activities has been expanded to include adjacent regions of other states.

In the Atlantic Coast region and Meta, no national institution could be identified; thus it was agreed to continue CIAT activities on the Atlantic Coast for 6 mo more (Dec. 1991), att which time it is hoped that PNR will contract ANNPY to take over this responsibility. In Meta the PNR-funded CIAT assistant left at the end of the original 2 yr, and it was decided not to replace him. Activities have therefore ceased in this state; but if a national executing agency can be identified, activities will be renewed.

14.3 Cauca Starch Project

In 1990 an integrated cassava project was begun in the state of Cauca. This project is organized and financed by Colombian national institutions and NGOs. Cauca has a production of approx. 30,000 t of cassava, 95% of which is used as raw material for the small-scale production of starch, both sweet and fermented, sour starch. Over 170 family owned starch plants exist, providing direct and indirect employment for 5000 families in rural areas. This is the third most important economic activity of the state, after sugarcane and coffee production and processing, with a large percentage of the benefits accruing to the small farm sector of the population.

Project objectives are to improve (a) the sustainability of cassava production through better management of natural resources; (b) the efficiency and quality of the starch produced from cassava, hence expanding food and industrial markets; and (c) the marketing system for cassava starch so that farmers and processors obtain a larger percent of the margin.

14.3.1 Production

These activities are led by the Cauca Valley Corporation (CVC), a body responsible for the conservation of natural resources in the Cauca River watershed. The Cassava Program is participating with the development of erosion control and soil fertility management technologies, for testing at the farm level. CIAT germplasm is also being tested in this area, and varieties suitable for starch extraction are being identified.

14.3.2 Processing

The Cassava Program is closely involved in the process improvement component of this project, which is led by a local NGO, SEDECOM. The improved equipment developed in the CEEMAT/CIRAD collaborative project with CIAT is being tested in two pilot plants (a coop and a private plant). The basic research being conducted on sour starch by CEEMAT will also feed into this project.

14.3.3 Marketing

This component is led by FINANCIACOOP, an institution that provides credit and business advice to coops. A coop has been formed to link the small-family based starch producers into one marketing organization, thereby reducing their dependance on intermediaries. The coop has also been able to improve and standardize quality of the final product.

14.4 Other Regions of Colombia

Cassava drying plants are in operation in several other states of Colombia. In Cauca, a United Nations Coca Substitution project has financed the construction of 4 drying coops. After a slow start these are now operating at a high level of capacity. CIAT was involved in site selection and periodic technical assistance to this project. The drying plants are also used to produce dried plantain for sale as animal feed. In the Urabá region of Antioquia, two drying plants are in operation and more are under construction. One pilot plant for artificial drying is under evaluation in this region, supported by a local NGO. Further coop and private drying plants are in operation in Caquetá, Arauca and Antioquia.

Although the Cassava Program has played a minor role in these regions of the country, many of these plants are using CIAT-designed equipment, now available commercially in Colombia.

14.5 Impact

The adoption of production and processing technologies by farmers in Colombia is detailed in Chap. 25.

15. ECUADOR INTEGRATED CASSAVA PROJECT

The Ecuador Integrated Cassava Project, initiated in 1985, was conceived as both a social and technical experiment. Cassava chipping and solar drying technology from Thailand had been tested and proven successful on the Atlantic Coast of Colombia in a collaborative effort by CIAT and Colombia's integrated rural development office (DRI); however, the institutional costs were quite high. The challenge for CIAT was to replicate the technological success of the Colombian experience successfully, but at a lower institutional cost. This required different institutional and organizational arrangements, emphasizing new actors: farmer organizations and national program staff in the field, from extensionists to farmer-promoters.[15.1]

While some might consider the transfer of the cassava processing technology from Colombia to Ecuador as "merely extension, not research," quite the opposite is true, being decidedly experimental. The basic technology transferred was the same as that used in Colombia; but the method of transfer and the new social and institutional environment were radically different. Once transferred across the border, a process of change and adaptation began that continues today. The initial technology has evolved into new activities in response to new demands from farmer/processors and cassava product users. This in turn requires researchers to address new issues such as product quality, marketing alternatives, greater efficiency and new processing technology and equipment. This report summarizes the changes in the social, organizational and institutional context embracing the processing technology in Manabí Province, highlights ongoing research activities and results, and lays out possible pathways for the future. The project has expanded to create a second site in Esmeraldas Province, but this report focuses on the activities in Manabí.

15.1 Cassava in Ecuador

National level statistics on cassava production in Ecuador vary considerably. Estimates of total area of cassava range from 26,000 to 40,000 ha [15.2]. Estimates for Manabí range from 5,500 to 14,000 ha. The remainder is grown in the Amazonian region, the southern province of Loja, the humid coastal province of Esmeraldas, and in scattered areas of various provinces within the humid lowland western region flanking the Ecuadorian Andean cordillera. Yields average 10 t/ha.

[15.1] Romanoff, S. 1991. The bottom line or how farmer-promoters reduced the cost of organizing producers in an integrated rural development project. Culture and Agriculture, Spring/Summer, 41:1-6.

[15.2] Ministerio de Agricultura (MAG), Depto. de Programación, Portoviejo, Manabí, Ecuador, 1990. Instituto Nacional de Estadística y Censos, Encuesta de Superficie y Producción por Muestreo de Areas, Resultados de 1990, Tomo 1.

During the decade of the 1970s, there was close collaboration between CIAT and the National Institute for Agricultural Research (INIAP) on testing cassava varieties and agronomic practices. Most of this work focused on the humid western zone and operated from the INIAP experiment station at Pichilingue. In 1981, however, a study indicated that without the integration of cassava production, processing and marketing, there would be little incentive for farmers to adopt technology to increase production and less chance for developing alternative uses for cassava.[15.3] The report also recommended that cassava chipping technology could be a viable alternative in light of a rapidly growing livestock sector (swine and chickens) and insufficient energy sources. The conditions for increasing cassava production were not economically favorable, however, until 1985.[15.4] This set the stage for launching the cassava integrated project in Manabí.

15.2 Principles of the Ecuador Integrated Cassava Project

As the project has evolved, three guiding principles have emerged, becoming the "culture" of project participants and the criteria for good collaboration among participants:

- The transfer of technology--be it social or technical--is more rapid, effective and efficient when users are directly involved and responsible.

- A farmer organization is the most effective intermediary agent between the large no. of farmer participants and the institutions designed to serve development interests and objectives. The organization can be an efficient channel for project services, credit and information dissemination; and it can serve as the most equitable manager of resources, postharvest processing, marketing and distribution of benefits.[15.5] As such, the resources, activities and funds destined to strengthen the farmer organization should be channeled directly through the organization because the learning and experience of managing these will contribute to the growth, maturity, wisdom and ultimate sustainability of the farmer organization.

- There is a need to establish and maintain good interinstitutional communication and collaboration. The farmer organization--not merely a recipient of the benefits of the project but an active participant--should be part of the institutional group supporting the project. The idea is that as a result of the project, the farmer organization becomes an equal partner in the institutional setting, able to operate its services and activities in collaboration with other development institutions, but not dependent upon them.

[15.3] Cock, J.H. et al. 1981. La yuca en el Ecuador: Recomendaciones para el desarrollo y ejecución de un proyecto de producción, secamiento y comercialización.

[15.4] CIAT. 1988. Cassava Program Annual Report 1985. CIAT Working Document No. 38:7-11.

[15.5] Romanoff, 1991, op. cit.

15.3 The Cassava Integrated Project in Manabí Province

As the result of several visits to Ecuador in 1985, Manabí Province was identified as an appropriate place to test processing technology because it had cassava smallholder production in excess of current demand, marketing problems, a high small-farmer population where family members often migrate in search of off-farm income, and dry weather for solar drying. In addition, key individuals in research and extension institutions promised necessary support for the experiment.[15.6]

From the start, farmer processors have been key teachers, technology transfer agents, promoters and leaders of the project. CIAT's role has been to guide and foster this process by providing time, space and access for the farmer-to-farmer transfer to take place. Institutional development professionals including CIAT staff have become partners and collaborators with farmers in transfer and testing activities.

The first farmer-to-farmer contacts were between Colombian farmer/processors and potential farmer/processors in Manabí. The former taught the latter how to dry cassava; farmers from Manabí then visited Colombia to see the technology in action (the "technical" technology) and to learn how to organize and manage the processing plants (the "social" technology). A farmer leader and a mason from Colombia worked in Manabí on the design and building of plants at the beginning of the project. Manabí farmers from Bijahual and Jaboncillo, who were members of preexisting farmer organizations, carried out their own experiments to see if the technology worked and could be profitable. When convinced by their own actions, they set about forming other groups of farmers to test the technology and join them in marketing the resulting product. Members of the initial two groups were joined by others from subsequent groups, forming a committee to market dried cassava, with assistance from MAG-Guayaquil and CIAT.

The first farmer groups became legal farmer associations (APPYs), and the early marketing committee grew into a union of producer/processor associations, UAPPY. As the needs of the APPYs has grown, the services provided by UAPPY have increased. Today the functions and responsibilities of UAPPY include:

- administrating and managing loans and donations
- providing processing credit to the APPYs
- commercialization
- product milling, finishing and transformation
- product quality control
- accounting
- transportation

15.6 For a complete description of the early steps to form farmer groups and establish the interinstitutional base of the Ecuador Integrated Cassava Project, see CIAT, 1988, op cit., pp. 7-9.

- training
- forming new APPYs
- communication among members
- R&D of new products, processes, markets

Many of these activities or services could have been channeled through existing public institutions; however, lodging them within UAPPY and training UAPPY leaders to manage them has strengthened the organization. The organizational structure of UAPPY as of October 1991 is depicted in Figure 15.1.

The administrator, who plays the key management role, has a fifth-grade education, similar to most of the APPY presidents. The people occupying the positions under the administrator have a very different educational profile. The training coordinator has an Agr. Eng. degree from the U. Técnica de Manabí (UTM) and is a former president of his APPY. The office manager, who is currently the president of her mixed APPY, is completing a degree in Economics at the UTM. The special projects manager is an APPY member and a mechanical engineer. Most UAPPY paratechnicians have completed high school.

The strategic use of qualified and trained people from within the organization to carry out specialized tasks is one way in which UAPPY optimizes its heterogeneous human resources and maintains a certain independence from supporting institutions. This enables UAPPY to collaborate with development institutions, to negotiate on a more equal footing with other institutions, and to obtain the services and support its members require.

From the beginning, the MAG, INIAP and CIAT have collaborated closely in the project. In 1987, when FUNDAGRO, an Ecuadorian private foundation for agricultural development, took over the support of cassava research, extension and eduction through a USAID-funded project, the FUNDAGRO cassava program coordinator was assigned to coordinate the interinstitutional committee. A key element is that UAPPY is a member of the committee on equal footing with all other institutional members, having an equal "voice and vote" with other representatives in defining problems, designating priorities and assigning resources. The committee served initially as a device for communicating activities in order to stimulate participation and reduce overlapping efforts. In 1990 the committee took on the responsibility for evaluating project activities internally and planning for the coming year. With the second round of annual project planning by the committee under way, results to date indicate that research, extension and education activities are more in line with farmer problems, there is a greater degree of interinstitutional collaboration within activities, and there is a better allocation of project financial resources to priority problems than there was when activities were planned by individual institutions.

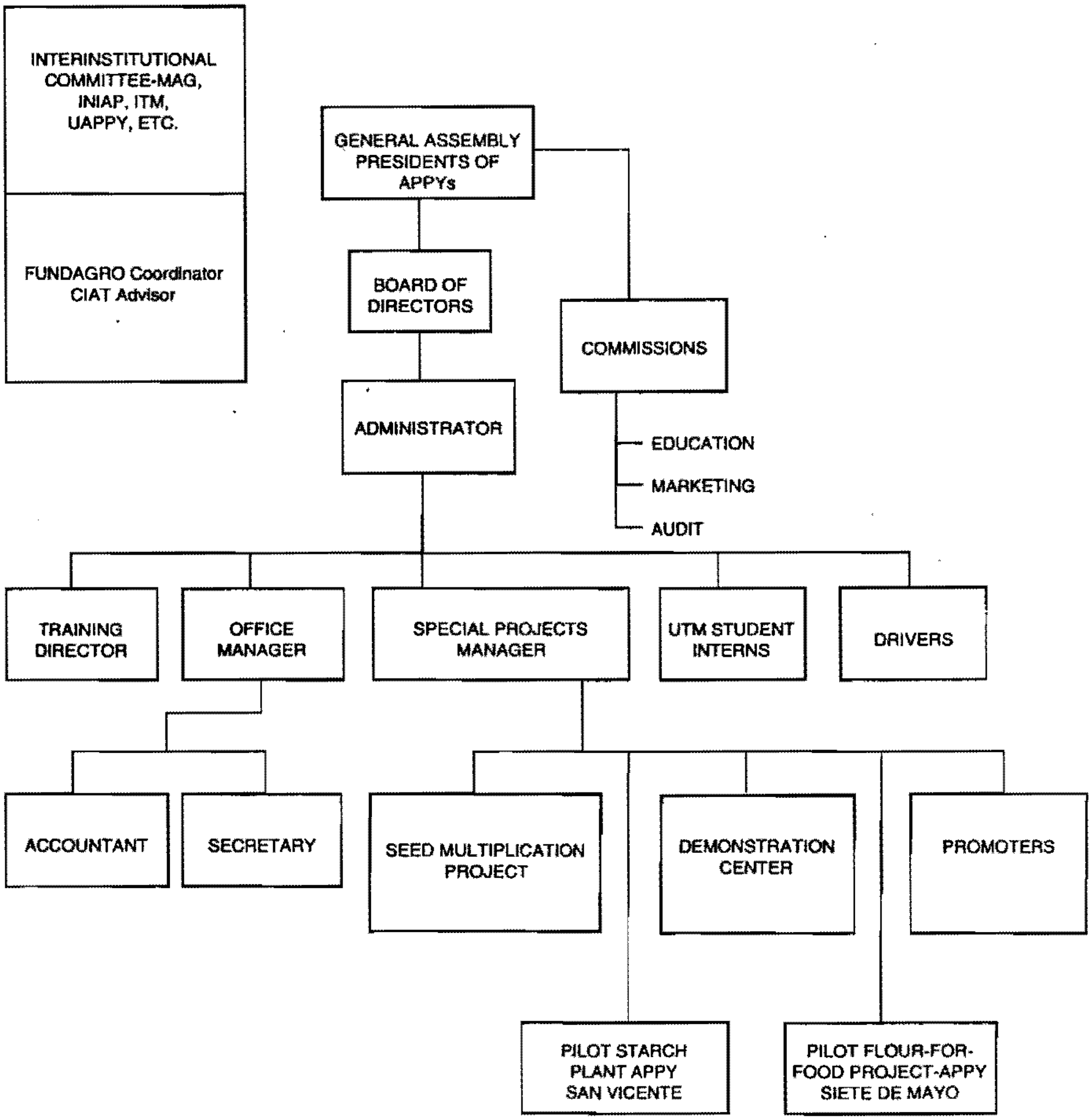

Figure 15.1. Organizational structure of UAPPY, Nov. 1991.

15.4 Growth and Evolution of UAPPY Production and Marketing

Table 15.1 summarizes the growth and development of UAPPY as a whole. The 6 yr can be divided into three stages: experimental (1985-87), commercial (1988-89) and expansion-diversification (1990-91).

From 1985 to 1988, the no. of cassava processing associations grew rapidly from 2 to 16. While establishing new groups was based on the farmer-to-farmer principle and assisted by both the MAG and INIAP, growth was fueled by a strong market demand and reasonable funding for construction and credit. When CIAT first introduced the cassava drying technology, it was assumed that the market would be the same as that in Colombia--the balanced feeds industry for poultry and livestock. During the first year, the cassava chips were sold to these same industries. Then, serendipitously, it was discovered that cassava flour was an ideal substitute for chemical agglutinants for the feed pellets used by the Ecuadorian shrimp industry. Although cassava comprises only 2-14% of each pellet, the scale of shrimp production and feed demand is such that the demand for cassava flour is over 8,000 t/yr. The price paid by the feed industries for cassava flour given its agglutinant characteristics was better than that paid for its nutritional quality by the poultry and livestock feed industries. The latter sets the price for dried cassava at 80-85% of the price for maize. Given the fluctuations in the price for maize and the prevalence of subsidized imports of both maize and sorghum, which tend to lower the price periodically, the shrimp feed market was far more appealing and encouraged the expansion of the processing associations.

Funding for creating the APPYs came initially from donations from USAID (PL-480 funds) and from various embassies. These funds had few strings attached and little or no interest rates. By 1988 donor funds for construction were becoming scarce, and PL-480 funds donated to the UAPPY now had to be used for credit to the member associations at near to commercial rates of interest. Combined with rapidly increasing inflation, it became much more difficult for UAPPY to obtain funds to create new APPYs, which had to assume from the onset much larger debts and interest rates than the earliest APPYs. By the end of 1988, UAPPY stopped promoting formation of new APPYs as they could not guarantee that construction funds would be available. Groups that wanted to join had to come up with their own funds and begin operating with only the bare minimum of infrastructure.

The basic infrastructure included a simple masonry storage shed, a 600 m^2 cement drying patio, a motor-operated cassava chipper, and various implements for handling and collecting the chips. Many APPYs start processing right away, purchasing only the chipper and motor (made locally by two entities). They use existing shelters for storage and in lieu of a cement patio, construct wooden and chicken wire trays (1 x 2 m), which are placed on bamboo stands, tilted to take advantage of drying breezes. APPYs were initially constructed on 0.5 to 1 ha of flat land. UAPPY now advises new groups to secure a minimum of 1 ha to start as it has been found that a minimum of 1000 m^2 of

Table 15.1. Total cassava processed by UAPPY-Manabí, 1985-91 (t).

Year[1]	Total no. of APPYs	Cassava Flour: Whole Industrial	Cassava Flour: White Industrial	Cassava Flour: Refined Whole Industrial	Cassava Flour: Refined White Food	Cassava Flour: Afrecho	Fresh Treated Cassava	Cassava Starch: Industrial	Cassava Starch: Food	Cassava Starch: Bagasse	Cassava Starch: Purchased Industrial	Cassava Starch: Purchased Food
1985-86	2	50										
1986-87	4	79					19					
1987-88	10	353					28		4			
1988-89	16	1012							5			
1989-90[2]	16[3]	365	564.5		33			43.5	2.5			
1990-91	18[3]	288	982	200	6	52		119	1.5	48.8	69	3.5

[1] The UAPPY-Manabí economic year runs from July 1 to June 30.
[2] This was the first year records were disaggregated by type of flour.
[3] Includes production from the UAPPY Centro Demostrativo.

drying patio is required to reach efficiency and economy; moreover, APPYs with land to spare can consider expansions and alternative processing technology in the future.

APPYs buy fresh cassava from their members and other producers. They chip the fresh roots, dry them, sack the chips and sell them to UAPPY. The UAPPY general assembly, composed of the presidents of the APPYs, sets the price for the chips. Some APPYs produce under this price and thereby make an additional profit over that they receive after UAPPY markets the chips. Others have higher costs of processing and lose money on chips, profiting only from the final UAPPY sale.

UAPPY has experienced a strong pattern of product diversification that is unlike any of the organizations involved in other CIAT-linked integrated projects. In 1987, two of the APPYs experimented with preparing, packaging and selling fresh treated cassava for the fresh consumption export market. Although this activity expanded the following year, it was discontinued for two reasons: First of all, it was very risky. UAPPY was responsible for the product all the way to the shipping docks. While the channels from the APPYs to the docks were handled smoothly, there were often delays once the material arrived at the docks. The buyers would reject material after it stayed too long at the docks, resulting in losses for UAPPY. Secondly, to be successful in fresh export production, UAPPY needed a year-round source of good-quality roots. Manabí Province, with its distinct wet-dry seasons, is not an ideal climate for producing quality roots year-round. With both marketing and production constraints, the activity was dropped. Unfortunately, no other group within Ecuador's more humid zones--where the majority of the fresh cassava for human consumption is produced--has tried the technology.

In 1987-88 UAPPY added two new APPYs composed solely of women who produced starch rather than dried chips (see Sect. 15.5). This represented an important expansion into the market of quality starch for human consumption, which was sold to various stores and individual food processing users. In 1989 UAPPY successfully sold industrial-quality starch to a large Guayaquil cardboard factory as a substitute for maize starch used to make glue for corrugated boxes. A 1989 study[15.7] estimated the demand for industrial-quality starch by this industry to be about 3,500 t/yr. Given the potential demand and the less-demanding processing for industrial-quality starch, there was a decrease in production of starch for human consumption. In fact the factory demanded more starch than UAPPY could produce. So as not to lose this market, UAPPY contracted to purchase starch from private starch producers in the area. While this move was strategically correct from a marketing perspective, it placed UAPPY in the position of being a middleman--a role that it was not intended to have.

The shrimp feed industry, unlike other livestock feed industries, demanded cassava flour, not chips; thus UAPPY had to develop milling capacity and management as well. The

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15.7 CENDES. 1989. La industrialización de la yuca.

UAPPY, in close collaboration with a local NGO metalworking training and research facility - FACE - developed portable hammer mills to grind cassava chips into flour. An APPY member to be in charge of the mill operation and maintenance. This sparked the idea of developing a UAPPY Demonstration Center, where new technology could be designed and tested, and UAPPY members could learn and experiment with the technology through training and demonstration events. With PL-480 funds, land was purchased 17 km from Portoviejo (UAPPY HQ), and a structure for housing the processing equipment was begun in 1987. Although PL-480 decided not to finance the termination of the structure, it was eventually completed with other USAID monies through the FUNDAGRO-supported cassava program. UAPPY shifted the milling task from the APPYs to the Center and also used the structure as a temporary warehouse and depot to assemble freight loads for Guayaquil, Quito and elsewhere. The Center also has a drying patio and standard chipping and starch-making equipment. Although its production is not large, the Center does produce regular quantities to offset some of its operating costs.

In 1988 several of the shrimp feed factories complained that the cassava flour made of whole unpeeled roots contained too much ash (due to the peel) and requested a peeled product. UAPPY complied, at a higher price for the peeled product, and began selling both whole and white (peeled root) industrial cassava flour, depending on the clients' needs. Initially, APPY members resisted peeling not only because of the additional labor involved but also because many people had no skill in peeling outside of the traditional areas where cassava starch is produced from peeled roots. This activity soon became a valuable source of additional income for both member and nonmember families who could earn as much as a month's minimum wage in two weeks time peeling cassava in the late afternoons and evenings at the local APPY. In the 1990-91 processing year, UAPPY generated more than S/.15,000,000 (US$16,000) in wages paid to peel cassava. Most of these wages were paid to poor women, children and the elderly who had no other source of income during this period of the year. The importance of the income generated for poor households has made it difficult to consider introducing machinery to mechanize peeling.

Despite these early moves toward diversification, the bulk of the UAPPY product was still destined to one single market--the shrimp industry--until 1989, when two things happened to change this. First of all, 1988-89 had been a very profitable year so UAPPY and APPYs had money available to expand their facilities in order to increase production significantly. With an assured promise of a large new secure revolving fund for operating credit from PL-480, both UAPPY and the APPYs invested their profits in expanding their drying capacity. As the drying season approached, however, the funds were not released despite constant pressure from UAPPY and the FUNDAGRO coordinator. With no other recourse available to them, some APPYs borrowed money from private lenders at rates up to 120%/year; others bought and processed cassava on credit from members; the rest simply could not process. Then, UAPPY received another blow: the shrimp industry slumped. Competition from Asian producers and a shortage of larvae to stock ponds caused a cutback in production and a simultaneous halt to cassava purchases. UAPPY's response was to tighten their administrative belt by releasing half the staff, halving the salaries of the remaining staff, canceling all nonessential training courses and social gatherings, and putting the UAPPY vehicle in a garage. They then launched an all-out campaign to sell cassava flour to other industries. When the PL-480 funds were finally released at the close of the processing season, they were used to pay back loans. UAPPY managed to find new buyers and the shrimp industry came alive again; by April 1990 all the stored production had been sold. The economic balance for the year was poor, but a valuable lesson had been learned.[15.8] UAPPY, in coordination with its committee of supporting institutions, set as its first priority, diversification of the markets for its existing products and expansion of its production base to include new products. Two examples of this policy are already in place.

In 1990 UAPPY began refining the whole-root cassava flour by passing it through a mechanical vibrating sifter (developed again in collaboration with FACE) to yield a flour of the same granular size as wheat. This was sold to a factory that uses it as the filler for the resins used to make plywood. Currently the three largest plywood factories purchase refined whole cassava flour from UAPPY as a substitute for 20-42% of the wheat. Bran, the by-product from sifting, is sold as a source of fiber to the livestock feed industries in the highlands. UAPPY uses the same mechanical sifter to produce a white flour for human consumption (noodles). While the total amount of flour sold for human consumption is small, UAPPY is currently testing better processing methods in order to expand production.

Table 15.2 summarizes the types of markets UAPPY is currently dealing with, the products sold to each market, and the changes in the amounts sold to these markets between 1989-91. UAPPY has decreased its dependency on the shrimp market by 30%. Table 15.3 summarizes the total volume of production by product and the total sales for 1990-91. UAPPY total sales for this year were US$352,610.

Figure 15.2 shows the avg income earned by UAPPY members and nonmembers over this same period. Income to members is the sum of fresh cassava sales to the APPY, wages earned working at the APPY, money earned from peeling, and member shares of profits from sales. For nonmembers, income is mostly from sales of fresh cassava and peeling; however, a few APPYs employ some nonmembers as wage laborers. At one APPY, Miguelillo, all manual labor in processing is done by hired nonmember labor. Income decreased in 1989-90 due to the aforementioned problems. The further decline for 1990-91 is due to increasing costs, inflation and failure of prices for cassava products

[15.8] Although UAPPY vowed that this would never happen again, a very similar situation has developed this year with a promised grant from the Central Bank through FODERUMA to be used for operating credit and construction. Because of bureaucratic delays and demands, the money will likely arrive in March 1992, 8 mo late and too late to be used in this processing season.

Table 15.2. Market shares of annual processed cassava production for 1989-90 and 1990-91.

	UAPPY Products	Total Tons Sold 89-90	Total Tons Sold 90-91	Percent of Total Amount Sold 89-90	Percent of Total Amount Sold 90-91
Shrimp feeds	White and whole industrial flour Industrial starch	974.4	1,207.2	96.0	69.3
Cardboard boxes	Industrial starch		209.1		12.0
Plywood factories	Refined whole industrial flour		226.5		13.0
Traditional cassava starch bread	Food starch	20.3	5.2	2.0	0.3
Pastas and noodles	Refined white food flour		6.9		0.4
Cattle and swine feeds	Starch bagasse and flour bran	20.3	87.1	2.0	5.0
	Total	1,015.0	1,740.0	100.0	100.0

Table 15.3. Total volume of production by product and value of sales, July 1990-June 1991.

Product	Total Volume 1990-91 (t)	Prices 1990-91[1] Sucres/t	Prices 1990-91[1] Dollars/t[2]	Total Sales
White industrial flour	982	172,546	192	188,544
Refined white human consumption flour	6	231,000	256	1,536
Whole industrial flour	286	148,016	165	47,190
Refined whole industrial flour	200	198,704	221	44,200
Industrial starch[2]	188	288,728	321	60,348
Food starch	5	461,620	512	2,560
Bagasse	49	96,250	107	5,222
Bran	52	52,030	58	3,016
Total	1,768			352,610

[1] US$1 = 900 Sucres, avg exchange rate during year.
[2] Includes 68.81 t of industrial starch purchased from private processors.

(especially those sold to the shrimp industry) to keep up with rising production costs. Nevertheless, averages such as these mask a great deal of difference among the APPYs.

15.5 Differences Among APPYs: Results of Monitoring Studies

From the beginning of the project, the economists of INIAP's Planning Unit at the Portoviejo Experiment Station have conducted economic monitoring studies of the APPYs. They also conducted a survey of the cassava-maize production system as part of a baseline effort and a dynamic analysis of the changes in the system due to the

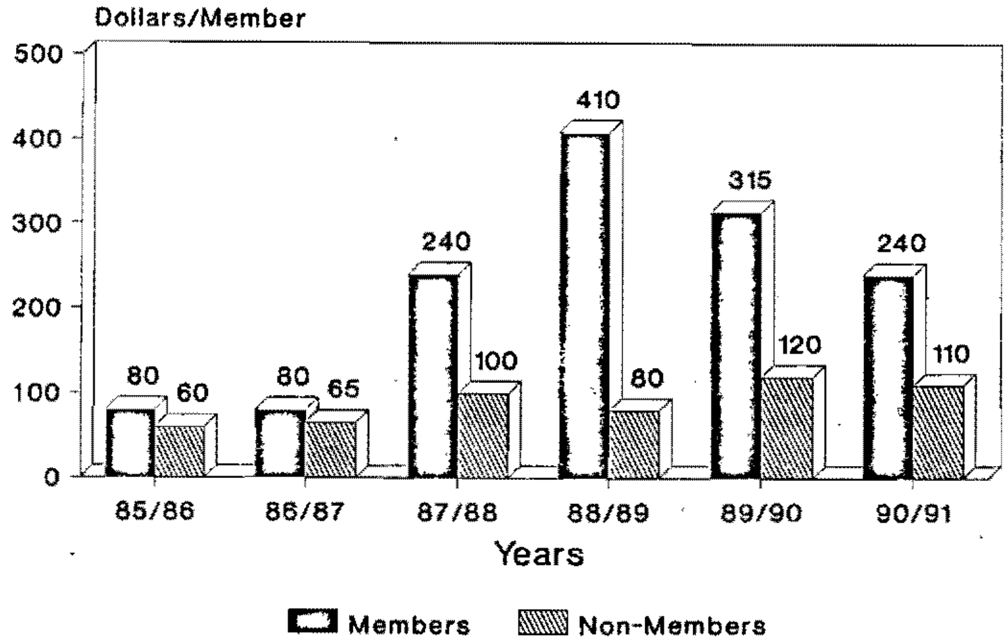


Figure 15.2. Income earned by farmers from the Cassava Project.

introduction of the processing technology. Until this past year, both activities were funded by IDRC. CIAT participated in the design and implementation of these activities. During the lapse between in-country advisors, the quality and continuity of CIAT support for the monitoring activities diminished, and the ongoing production systems survey was delayed. In 1990, the survey was completed and the data processed at CIAT with the support of the Biometrics Unit. The data were returned to INIAP and copied to FUNDAGRO in early 1991. Preliminary reports were completed on earlier versions of the data set, but a final report is still pending. Observations from the production systems study and their implications for agronomy research are included in Section 15.7.1.3 and 15.8.

Monitoring data is collected fairly regularly at each APPY by treasurer/managers. Production data (variety, origin, quantity, distance) on the cassava processed are collected on the sales slips for APPY purchases. Processing data is recorded by the treasurer/manager on forms provided by UAPPY. UTM student interns with UAPPY assist managers in recording the information correctly. The UAPPY accountant holds short courses on how to record financial data and regularly reviews balance sheets and account books. An economist employed with INIAP (formerly on IDRC funds and now supported by the FUNDAGRO project) collects and analyzes the economic data each year; and with the help of the INIAP senior economist, presents this to INIAP for the annual station report and for the annual cassava seminar. To date, none have been directly submitted to UAPPY.

Although the financial data from the APPYs and the UAPPY is carefully monitored and used in decision-making, much less use is made of the other data collected in the monitoring or survey activities. Several CIAT-sponsored surveys exist as unanalyzed data sets. Until this year the monitoring data was handwritten and cumbersome to analyze. Most analysis has been done in aggregate averages, providing little information to make management changes in the APPYs. As of 1990, the monitoring data is disaggregated according to agro-ecological zones within the project area; and this has increased its relevance. A major collaborative effort between FUNDAGRO's Quito office and CIAT this year has been to enter all the monitoring data from previous years (1985-89) into a data base; results from 1990-91 are currently being entered. The objective is to be able to make analytical comparisons among groups of APPYs, individual APPYs over time and to identify APPY management problems and possible solutions. Setting up a more agile, responsive, easily analyzable monitoring system is still a necessity and a priority for next year.

Despite these problems, it is still possible to identify differences among the APPYs and to begin to identify what makes some APPYs more successful than others. UAPPY has dedicated substantial time to discussing problems among APPYs this year and is conducting in-depth visits to each APPY to deal with the individual problems identified and to improve APPY-UAPPY communication. The starting point for this analysis is the annual UAPPY evaluation which takes place at the end of the UAPPY production year (July). This is an opportunity for questioning annual results, policies and differences in results among APPYs. After this year's evaluation, UAPPY administrators, elected officers, FUNDAGRO, CIAT advisors and selected APPY presidents met to discuss the results, problems and the plan of visits to the APPYs.

In terms of APPY infrastructure (maturity, membership, and production), maturity is an important variable because older APPYs received funding for construction and early operations at low or no interest levels. Later APPYs carry a much larger burden of interest and have not been able to expand. Size of drying space is the key limiting factor as a result of funding potential. The more space, normally the more production; however, where management is poor (e.g., APPY Maconta), a large drying patio may not be used optimally and production will be substantially lower than in APPYs of much smaller size. On the other hand, small APPYs with good management and max. use of limited drying space (e.g., Siete de Mayo) can achieve significant production.

One strategy to maximize processing capacity is to develop both flour and starch processing capability. Thus far, only two APPYs, Bijahual and Miguelillo, have done this. Each employed its own profits to build and purchase equipment for starch processing. Lack of water and credit for construction have prevented other APPYs from following their example.

Roughly 30% of the UAPPY members are women, concentrated in 4 all-women APPYs. Those women who belong to mixed groups tend to be wives and daughters of men who are members, or single women who already played leadership roles in their communities. Elected officers of the mixed APPYs are often women. The women's groups tend to be composed of women who have not been leaders; in fact, most had never worked for wage income outside the home before. Two of the women's groups are very new. Cascabel just formed this year; and although they bought land for their plant, they decided to plant crops on their parcel and use the money from the sales this year to begin the construction. The Las Piedras group formed in 1989 and joined UAPPY in 1991. They were assisted by a US Peace Corps volunteer, who secured them a grant of US$5,000 (half the cost of a starch processing plant). They processed a small amount at the end of the year to test their equipment. This year they are processing more and are receiving regular in-service training in managing an APPY from a promotor/manager of a nearby APPY (Tablones) and training in starch processing technology from a woman member of San Vicente, one of the original women's starch processing groups.

San Vicente and San Miguel have had hard times economically. Both APPYs were organized prior to the cassava project, around income-generating projects for women, but based on unmarketable products and too small an infrastructure for too many women. Joining UAPPY and processing starch brought them, for the first time, income that they controlled within the household. This in turn increased their independence and "voice" within their households and the rural community. However, the small size of their plants and the small drying area limited them in the past to making quality starch for human consumption, a higher value, more labor-intensive product. When UAPPY moved into the industrial starch market, the women's APPYs followed suit, especially San Vicente. Although easier to produce, it earned less income and the profits to be shared annually among members decreased drastically. Dissatisfaction at watching the growth of the other APPYs caused San Vicente to nearly disintegrate in 1990 while San Miguel stagnated. San Vicente--after a long process of internal problem-solving with help from UAPPY--bought a new piece of land, sold their old starch plant, and are now embarked on a major project to test and adapt a prototype starch plant designed to produce better quality more efficiently. San Miguel has decided to take a similar route and has recently bought a new piece of land to build a larger plant (see Sect. 15.7.2.5).

Location of the APPYs is also related to their processing capability. The 18 APPYs are located in the central portion of the Province, which is divided into two major ecological zones: one with rainfall averaging > 1000 mm annually; the other, 500-1000 mm. Ten APPYs are within the drier zone; 5 are well within the wetter zone; and 3 (Tablones, El

Algodon and Las Piedras) are located on the transition line, but as their area tends to be well watered, they are grouped in the higher rainfall zone. Those APPYs in the wetter zone have a longer rainy season and fewer total no. of sunny days and thus a shorter drying period. But because of the rain, they have more abundant cassava, better quality fresh material and lower prices so their production costs are lower. In the drier zone, the APPYs have the conditions for processing (sunlight), but no cassava is available for lack of rainfall. Because of greater competition for fresh cassava given their proximity to many private starch processors, production costs are higher.

APPYs also differ in their empresarial nature. A few view themselves as a business venture, and the bottom line is max. processing for profits. Others are more cooperative in style, operating more for the welfare of their members and demanding a level of individual contribution in terms of kind or labor.

One of the suppositions underlying the concept of the integrated cassava projects was that the processing activity would encourage members to plant more cassava. In, Manabí, however, this does not seem to be the case. More cassava in the region is being processed, but the production increases at each plant are not a result of increasing amounts of roots supplied by members. Most members have very little land and cannot increase the area under cassava and still produce other foodstuffs for on-farm consumption and the market. As processing plants increase in number and size and demand more fresh cassava, members cannot respond, so an increasing amount of the fresh cassava processed is sold to the plant by nonmembers. For APPYs in the drier zone, purchasing cassava from wetter regions is a viable strategy, rather than a negative indicator. Examined from this perspective, the impact of UAPPY in central Manabí has been the creation of 18 new local purchasing sites for cassava, where virtually no market existed. The beneficiaries of the project are far more than UAPPY members.

UAPPY's role in the future will be to concentrate on identifying new markets, new products and even new crops to process. Staying ahead of the market and being responsive to shifts in demands will be the key to long-term viability for UAPPY and the cassava program as a whole. Training and research in the project today reflect the recognition of these needs.

15.6 Training

Within the project training is carried out at several levels: international courses and seminars, training courses within participating institutions for staff and members, and courses given by one institution for another. Rather than listing all of the training events at each level, some examples from each will demonstrate how training is organized and how it benefits the project.

In the past, participation in international training courses and seminars for researchers was primarily by INIAP researchers though on two early occasions, MAG officials participated in CIAT cassava activities. In 1990, when the interinstitutional committee of the cassava project took on responsibility for planning project activities, it recommended that funds for training of researchers be extended to university faculty and students conducting thesis research within the program, and to members of UAPPY. This decision recognized that INIAP was not and could not be the only entity conducting research in support of the project. University students conduct thesis research with UAPPY. UAPPY members regularly conduct adaptive research on processing and production technology for cassava as well as other crops in the production system. International training is now used as a mechanism for promoting integration among these institutions and to develop new research activities. Two examples demonstrate this change.

In September 1990, the project sent an INIAP agronomist, a UTM thesis student and the UAPPY training coordinator to the CIAT cassava seed course. Upon their return, they designed a cassava seed multiplication project that was funded and implemented in 1991. In February 1991 the UAPPY special projects manager and 4 other members were sent to CIAT for a month to receive individualized training in new processing technology for starch and flour. Three of the four are now working with the special projects manager as UAPPY paratechnicians, testing new processing technology under Manabí and UAPPY conditions. The fourth person is working as a promotor for a new women's APPY.

UAPPY has always played a key role in training its members. Training courses on a variety of technical, organizational and management topics have been held at UAPPY HQ with appropriate APPY representatives attending. The assumption was that the representative participating in the course at HQ would inform/train those members who were not participants. Last year, APPY presidents complained that they were not able to communicate the "learnings" from the training courses to their members because they lacked training skills themselves. They requested either to have training in how to train or to carry the training program out to the larger UAPPY membership. The training coordinator sent out a questionnaire to all APPYs to find out whether they wanted their own training courses and what kind of training was desired. They wanted training courses at the APPYs in addition to specific technical training courses normally organized centrally. This demand shaped the planning for the 1991 training program. Additional funds were solicited from FUNDAGRO to expand the number of courses given. Four themes were selected for the year. The director identified MAG extension staff as trainers for the courses, and together they programmed 4 short courses for each of the 18 APPYs over the year. UAPPY solicited support from the MAG's World Bank-supported extension project, PROTECA, for vehicles to transport the trainers to the courses. Although PROTECA promised support, they rarely came through; and UAPPY usually supplied the transportation. UAPPY controlled all funds for the training program, including the per diems for the MAG trainers. If the trainers canceled courses or cut back on the no. of days, then UAPPY reduced the per diem accordingly.

The UAPPY training program has been quite successful thus far. APPYs have kept attendance high, often with self-imposed fines for missing courses. To date, 80% of the program is complete. FUNDAGRO funds have covered 76% of the training costs and UAPPY/APPY funds (a percent of sales goes into an education fund) have covered the rest. Evaluations show that 30% of the UAPPY members are now capable of leading and managing their APPYs, and 45% of the APPYs are capable of functioning alone without direct UAPPY supervision. A mixed training plan of APPY and UAPPY-level courses will likely be implemented in 1992.

With respect to institutional training, INIAP normally runs a cassava production course each year for extension agents and participants from other institutions. The INIAP Tropical Roots and Tubers Program also holds field days and farmer demonstrations or competitions for UAPPY cassava farmers in conjunction with its on-farm variety and production trials. This year, due to scheduling difficulties, INIAP decided to postpone its production course. The UTM had wanted to include faculty members in the course and appealed to the FUNDAGRO coordinator for help in running the course at the UTM. The coordinator agreed to the course but proposed that UAPPY organize it, and the UTM agreed. With leadership provided by the UAPPY seed project agronomist and collaboration from the seed project paratechnician, a UTM student working on artificial drying technology, the UAPPY administrator, project manager and selected farmers, the course was given to a group of 16 UTM faculty. The outcome was very positive and may set the stage for future training by UAPPY for others.

15.7 Integrated Cassava Project Research: 1990-91 Highlights

As a result of the interinstitutional committee's recognition that research can and should be done by institutions in addition to INIAP, FUNDAGRO approved for the 1991 cassava program work plan several research activities under UAPPY management. Although most of these deal with processing problems, research in other areas such as seed multiplication and marketing is also managed by UAPPY. Some of the advantages of conducting research within the UAPPY vs. a ministerial context is greater flexibility to shift directions in response to preliminary results and a less bureaucratic financial system, both of which are crucial to adaptive research activities.

Research on cassava in Ecuador can be divided into production and postharvest categories. The majority of the production research is conducted by INIAP at its experiment stations in Portoviejo and Santo Domingo, and in farmers' fields in Manabí and Esmeraldas. Postharvest research is concentrated in Manabí.

15.7.1 Production Research

15.7.1.1 Varietal testing. Since the early 1970s, INIAP has been testing cassava materials from CIAT and others collected nationally. A collection of the national materials is maintained at Portoviejo, but a complete characterization and elimination of duplicates remains to be done. Evaluation of local cassava varieties in Esmeraldas and Santo Domingo is ongoing. INIAP will release a new variety in 1992 called "Portoviejo 650," which is M Col 2215, widely grown in Venezuela and Colombia. After its initial introduction to Ecuador in 1987, it was submitted to several years of multilocational testing before release. Although it does not always outperform other local varieties in yield in all ecological conditions, in drier regions it yields better than others and has a higher DM content. A recent harvesting and processing test at 8 mo showed a DM of nearly 40% and processing conversion rates at nearly 2.5:1. This feature alone makes it quite desirable for UAPPY farmers. UAPPY's urgent demand for new varieties with higher DM content, improved drought tolerance and earliness has stimulated the cassava project to support UAPPY in developing a seed multiplication activity.

15.7.1.2 UAPPY Seed Multiplication Project. A recently graduated Agr. Eng. who had done his thesis research on rapid multiplication techniques with UAPPY is in charge of the seed multiplication project. He is backstopped by an INIAP agronomist and assisted by a UAPPY paratechnician who attended a 6-wk small farmer seed course at CIAT. The objective is to create a seed multiplication capacity within the UAPPY to ensure the supply of good-quality planting material to UAPPY members and to earn money from the sale of materials to nonmembers. At present UAPPY has 3 seed multiplication lots (3500 plants) for Portoviejo 650: two in Bijahual and one in Jaboncillo. With these, UAPPY hopes to have 75,000 plants at the end of the year in order to plant 8-10 ha of the new variety by mid-1992. Material from these will be used to plant about 90 ha of the new variety in 1993.

15.7.1.3 Agronomy and production systems. Most of the agronomy research has been directed toward spacing, planting density, stake treatment and storage, and preemergent weed control. Nearly all of the station and on-farm agronomy trials have been done in monoculture, despite the fact that more than 70% of the cassava in Manabí is grown in mixed cropping, primarily in association with maize. Cassava is also grown in association with at least 10 other crops, including peanuts, cotton and cowpeas. Work by INIAP soil scientists has examined fertilizer-soil relationships under maize-cassava systems; an agronomy thesis examined yields under different spacing arrangements in maize-cassava production systems. Little work has been done on other intercrops with cassava nor has explicit attention been given to the impact of cassava cultivation on hillsides where the majority of the Manabí cassava is grown.

During the past and present production seasons, UAPPY leaders have argued for INIAP production research to be directed to mixed cropping, hillside systems and agronomic measures to conserve soil moisture. Some UAPPY members are conducting their own field trials on several of these concerns. UAPPY is also requesting recommendations on the management of the new var. Portoviejo 650 under the prevailing mixed crop system as the architecture of the new variety (short and bushy) is quite different from the traditional varieties (tall with little branching). UAPPY pressure during planning meetings last year resulted in INIAP agronomy maize-cassava trials this year with the new variety. In addition, an MS degree student in agronomy from the U. of Florida plans to conduct maize-cassava trials during 1992 in collaboration with INIAP and the UAPPY. A UTM student will conduct theses research on the response of Portoviejo 650 to K fertilizer, and another UTM student (son of an APPY member) intends to conduct thesis research on cassava-peanut systems under irrigation.

15.7.1.4 Pests and diseases. Conventional wisdom concerning cassava cultivation in Manabí maintains that cassava suffers little from pest problems and that aside from preemergence herbicides, few chemicals are used on the crop. However, changing cultivation patterns, increasing cultivation in dry zones, and new varieties may change this. INIAP is conducting research this year on biological control of mites and cultural controls for Phyllophaga. A multidisciplinary survey of cassava pests and diseases is being conducted in all cassava-growing regions of Ecuador to provide the diagnostic information to guide future research in this area.

15.7.2 Postharvest research

15.7.2.1 Fresh cassava handling. Little attention has been given to this area. An economics thesis[15.9] on the marketing of fresh cassava to Guayaquil concluded that there was a 20% loss due to deterioration during commercialization. Despite this, cassava is considered as an indispensable foodstuff for 81% of the lower income population surveyed. Annual per capita consumption of cassava by this group is 34 kg, and frequency of consumption is 2.9 times/wk. The majority of the fresh cassava comes to Guayaquil from La Mana area, near Quevedo. The study recommended that INIAP initiate production research in the zone as it is the most important fresh cassava production area. INIAP has not yet followed up on this recommendation; however, it is conducting trials this year on the use of perforated plastic bags and chemicals for preserving fresh cassava for marketing.

15.7.2.2 Livestock feed. Given the potential importance of dried cassava as a livestock feed, it is surprising that so little research has been done on this topic. In 1990 INIAP proposed four experiments with dairy cattle and swine to determine the feasibility of feeding cassava silage or dried cassava in mixed rations, but none of the trials was implemented. Some preliminary work has been done on cassava feed for highland dairy cattle at the INIAP Sta. Catalina station.

The U. Politécnica in Guayaquil was contracted by FUNDAGRO in 1989 to study the use and quality of shrimp feed pellets made with varying percentages of cassava flour. Results were inconclusive as apparently some of the data were mixed up and resulting values were not at all probable. Some of the balanced feed factories that use cassava flour in their shrimp feed pellets claim to have conducted research on the quality of pellets made with cassava; however, these results are not readily available.

[15.9] Mosquera Larrea, Aníbal H. 1989. Características de la comercialización de yuca fresca en la ciudad de Guayaquil. Economics thesis, U. Central del Ecuador, Facultad de Ciencias Económicas, Escuela de Economía.

15.7.2.3 Demonstration center. The UAPPY demonstration center is a prime site for conducting postharvest and processing research. Given the absence of any other institution with processing research capability on cassava, the center should play a key role in the research program for the future. It is also an ideal location for linking farmers and professional researchers in collaborative problem-solving research.

Current research activities include the evaluation of an artificial dryer for cassava chips at different temp and capacities; the testing and modification of starch processing equipment introduced from Colombia; the design of an artificial starch dryer; construction and testing of a centrifugal flour sifter; and construction of a stainless steel cassava chipper with a receptacle for producing quality flour for human consumption.

15.7.2.4 Flour processing. In addition to the work at the demonstration center, INIAP is currently conducting an experiment to determine the technical, economic and nutritional feasibility of producing flour using the grater commonly used to grind cassava roots to extract starch. Traditional starch processors often use the grater in this way when prices for starch are too low or when there is intermittent rainfall and starch drying is not possible. Positive results could reduce the cost of processing flour and provide alternative markets for traditional producers.

UAPPY is running a pilot project in the APPY Siete de Mayo to test improvements in the processing of flour for human consumption. The new cassava chipper will be tested at the APPY, along with different management techniques designed to improve quality and reduce contamination.

15.7.2.5 Starch processing. Specific attention to starch processing increased in 1990 as a result of the demand for industrial cassava starch from the cardboard box industries. A CEEMAT-CIAT starch specialist provided critical technical assistance to UAPPY and made recommendations for areas in traditional starch-making technology that needed research or modifications. A survey of nearly the entire universe of traditional cassava starch producers (208) was completed in 1990. It was found that two processing technologies exist: one is completely manual; the other, semimechanized. Producers process from 50 kg to 2 t of starch/wk depending on the size of the plant, no. and size of sedimentation tanks, and drying space. About 3,500 t of starch, including both industrial and food consumption qualities, are produced yearly. The processing activities generate a total of 2500 daily jobs during the approx. 6 mo of annual processing. There is no technical assistance directed toward this industry so the majority of the processors rely on their own resources to finance their operations, informal sector credit, or financing by intermediaries.

The survey also revealed serious problems with contamination of starch that is intended for human consumption, adulteration by intermediaries of industrial quality starch, and a total lack of technology for handling waste water from the plants. The survey data are being used by two UTM economics students doing a thesis project with UAPPY on the economics of starch production in Ecuador.

As mentioned earlier, UAPPY has built a pilot starch processing plant on the new site for the San Vicente women's APPY with funding from FUNDAGRO. The plant is nearly complete and trial processing runs have produced starch products superior to what is currently produced by private processors or UAPPY. The plant will enter full production in mid-Nov. A UAPPY paratechnician is training the women to operate the plant and is monitoring the assessment of its operational and economic efficiency. The design of the plant retains the manual labor of the women members, but has made the labor more efficient and less tiresome. Rather than lifting buckets of water to wash the cassava mass, a plumbing system delivers it directly to each washer. A water filter removes sand from the water supply. A pre-washing tank cleans the roots more completely and with less effort. If the plant is successful, UAPPY plans to modify other APPY starch plants and experiment with lower cost construction materials.

In addition to substantial market represented by the cardboard box industry, there is also a strong interest in starch from Latinreco, the research division for Nestle in Latin America, which operates near Quito. Latinreco researchers are collaborating with UAPPY in characterizing the quality of the UAPPY products and for the past 6 mo have been running trials in their pilot processing plant using UAPPY starch. Results thus far have been quite good and they plan to increase their experimentation in hopes of creating commercial products using UAPPY starch. Entry into the Nestle market would open other important doors to commercial food processors and expand the demand for UAPPY starch.

15.7.2.6 Marketing. The search for new markets for UAPPY products and understanding the demand characteristics for potential new markets has been a priority for UAPPY since 1989; however, the UAPPY commercialization committees have pursued new markets in a rather ad hoc fashion. While they have achieved success in some areas, a more organized approach to marketing will likely increase the chance of successful market entry. Based on a market study of cassava food consumption flour in Colombia, the cassava project embarked on the design of a similar study for Ecuador. The study involves a broad range of institutions and has brought new ones into more direct involvement with the project, such as Latinreco and the U. Politécnica in Quito. Different from the Colombia study, the survey will examine the potential markets for 9 UAPPY flour, starch and by-products, cutting across all potential industrial and cottage-industry sectors. An inventory of all potential users has been made, and a selection for the survey in 5 locations is complete. Due to delays, the first survey will be initiated in 1992.

In addition to the new products survey, a Dutch MS student--in collaboration with FUNDAGRO, CIAT and UAPPY--is doing his thesis research on the macroeconomic issues and future for cassava products, particularly the market potential offered by the plywood and resins industries.

15.7.2.7 Characterization of UAPPY products and by-products. In conjunction with the new markets survey, the cassava project is characterizing all the flours, starches and by-products of the UAPPY according to variety used and date of harvest. Samples of 3 varieties (2 traditional and M Col 2215) at 4 harvest dates (8, 10, 12 and 18 mo) are being analyzed for their nutritional, functional and microbiological quality. Results will be used to provide information to potential users and to identify needs for improvements in quality. Analyses are being done at the U. Politécnica of Quito, Latinreco and CIAT. UAPPY also had the help of a food technology student from L'Ecole Superieure D'Agronomie Tropicale, Montpellier, France in organizing and defining the methodology for the study, as well as handling the first set of analyses.

15.8 Future Directions

It seems clear that the future for UAPPY will be directed to further expanding its markets, improving the quality of its products, and exploring other agroindustrial avenues. The results of UAPPY's efforts to understand and define the parameters of the national market for cassava products will also determine whether the program should expand further into new areas and create new UAPPYs.

Production research for the future should concentrate on varieties suitable for dry zones, mixed cropping on hillsides, with high DM suitable for processing. UAPPY should enhance the demand for higher DM varieties by implementing variable pricing for fresh cassava according to DM content at the APPYs. Research should also direct attention to the longer range sustainability of cassava cultivation on dry, fragile hillsides and should begin to study technologies that will conserve the natural resources that support cassava production. Research should also move into other cassava-growing areas. Diagnostic surveys to determine production problems and opportunities should be conducted in the other zones, especially in Esmeraldas.

Processing research should focus on product quality, methods of quality control and market demand. In addition, there is a critical need to address the contamination produced by waste water from starch processing and design systems to eliminate waste before the water returns to the streams and river systems. UAPPY should consider other kinds of processing technology compatible with their existing organizational structure and physical infrastructure. UAPPY is already considering a proposal to develop a maize starch extraction plant within the demonstration center as a way of industrializing the other major cash crop of the UAPPY farmers and take advantage of the drying space when cassava is not being processed.

The UAPPY experience has validated the three principles that guided the project from the start. It is evident that the project is now fully embraced by the participants, who becoming more and more in control of the decisions that guide the activities of the program. It is likely that FUNDAGRO funding will decrease as the initial project goals have been met. The challenge for UAPPY and its collaborating institutions will be to carry the effort into its fully commercial and diversified future.

Huffstutlar[15.10] warned that the third wave of farmers would be different from those of the first and second waves. The fact that larger, industrial interests are now inquiring about how they might "create a UAPPY" to supply them with cassava products for various industrial purposes should not then be surprising. The next stage of the cassava project in Ecuador should be well worth watching and deserving of continued CIAT involvement.

[15.10] Huffstutlar, S. 1989. UAPPY evaluation and recommendations. Costa Rica: Agricultural Cooperative Development International.

16. BRAZIL

Brazil is the world's second largest producer of cassava (nearly 16% of the world total) and the largest cassava producer in Latin America, accounting for nearly 75% of the total production in the region.[16.1]

The CIAT Cassava Program's relationships with national research and extension services in Brazil have been channeled through the Brazilian Agricultural Research Institute (EMBRAPA), the Brazilian Institute of Technical Assistance and Rural Extension (EMBRATER), and the National Center for Research on Cassava and Fruits (CNPMF). CNPMF, in turn, implements its working strategy through the National Research Program for Cassava (PNP-Mandioca), which provides financial and technical support to research and extension agencies at the state level.

This fruitful collaboration has resulted in a number of projects. Collaboration at the disciplinary level (breeding, pathology, entomology, utilization, etc.) has been reported elsewhere; this chapter focuses on the significant activities that have been undertaken within the framework of the Ceará Integrated Cassava Development Project.

16.1 Activities Leading up to Project Execution

16.1.1 1987

Responding to a request from CNPMF, the CIAT Cassava Program organized a workshop in November 1987 for a group of 21 researchers and extension personnel from various states of NE Brazil, including six members of the CNPMF cassava team. The objectives of this workshop were threefold:

- Update the knowledge of the participants in relation to advances made by the CIAT Cassava Program in the last years.
- Evaluate their current activities in the light of this new knowledge.
- Exercise a critical analysis of the national research program in cassava (PNP-Mandioca) with the aim of integrating research and extension activities and the overall development of the cassava crop in the region.

The participants made a diagnosis of the situation of cassava in Brazil, particularly in the NE. The potential for establishing Cassava Integrated Development Projects was

[16.1] FAO. Perspectivas alimentarias, Marzo 1990.

identified as one of the principal alternatives for overcoming the limitations faced for expanding the crop in the region.

The workshop also included, for the first time in the history of Cassava Program training events, a group of 5 policymakers from key institutions in the region. This group attended the final part of the meeting, participating actively in the evaluation of the diagnosis and the discussion about future work plans.

16.1.2 1988

CNPMF underwent serious administrative problems, and its participation was practically frozen. Given the excellent results obtained in the 1987 workshop, CIAT was able to cooperate directly with state agencies across Brazil, especially in the NE.

The state of Ceará with 6 participants in the workshop (2 policymakers and 4 technicians) formed the Ceará Cassava Committee (CCC), responsible for coordinating all activities related to the crop in the state. The CCC collaborated closely with CIAT in developing a project proposal submitted to the W.K. Kellogg Foundation (KF), requesting financial support for implementing an Integrated Cassava Development Project in the state.

One of the CCC's main achievements during 1988 was the installation of 8 cassava drying plants with funds from various sources, among which the CIAT Cassava Program collaborated with US$ 20,000. The Program also cooperated with state agencies in carrying out cassava training events in Porto Alegre, Rio Grande do Sul (EMATER-RS), Fortaleza, Ceará (EMATERCE), and Recife, Pernambuco (IPA).

16.1.3 1989

Based on the positive results of its first training experience with policymakers, the Cassava Program decided to organize a study tour for a group of high-level authorities from 4 states of NE Brazil (Ceará, Pernambuco, Paraiba and Bahia), including the Secretary of Agriculture and the Presidents of the agricultural research and rural extension agencies. Representatives from EMBRAPA, funding agencies at national and regional levels, and farmer organizations were also invited. These 4 states plant 612,637 ha of cassava (1987), accounting for 36% of the total area planted in Brazil and 51% of the total area planted in the NE.[16.2] The study-tour included visits to ongoing Integrated Cassava Development Projects in Ecuador and Colombia, as well as to CIAT HQ. The foundations were laid for subsequent and successful developments in the history of the Cassava Program's collaboration with the overall development of the crop at regional and national levels in Brazil.

16.2 Fundacão Instituto Brasileiro de Geografia e Estatistica (IBGE), Anuario Estatistico do Brasil, 1989.

In May 1989, after considerable planning and negotiations, the proposal for the Ceará Integrated Cassava Development Project was finally approved by the KF, and the 3-yr project got under way.

16.2 The Ceará Integrated Cassava Development Project

The process of developing alternative markets for cassava producers requires key institutional interventions aimed at overcoming the inherent limitations caused by the lack of diversification in cassava markets. The CIAT Cassava Program has been involved in implementing this type of institutional interventions (Integrated Cassava Development Projects) in key target cassava-producing areas of Latin America during the last 10 yr. The Ceará Integrated Cassava Development Project is aimed at establishing the production of dry cassava chips for animal feed as a viable agroindustry among small farmers across the main cassava-production areas of the state.

16.3 Progress Toward Outcomes

16.3.1 Development of the pilot project

Project implementation has been strongly influenced and benefitted by prior activities carried out by agricultural research and extension agencies in the state in relation to small-scale cassava farming and processing. The experience accumulated over these past years has served as a foundation for the project and its organizational infrastructure.

At the onset of the project, there were already 12 cassava drying plants organized (1986-89); but they were not functioning successfully. These groups were reactivated and another 47 farmer groups established, for total of 59 dry cassava agroindustries operating in 1991. The selection process for new groups includes a formal request by the community. Then the Regional Cassava Committees (RCCs) evaluate the new group's potential for dry cassava processing activities. Baseline data on rural communities with potential to join the project are maintained at the central level; and depending upon the availability of funding, the processing facilities are then established. During 1989 a total of 11 new groups were organized; in 1990, 18; and in 1991 another 18 new drying plants were established (Table 16.1).

16.3.2 Identification of local institutional support and financial resources

The incipient state-level CCC, created in 1988, gained general recognition as the coordinating body for all the activities related to the promotion and development of the cassava crop in the state of Ceará. During these 2 yr, the CCC has sought to decentralize all project activities through the formation of the RCCs in the principal areas of project influence. To date, the 5 RCCs established have been accepted by the two main counterpart agencies--EMATERCE and EPACE--as part of the prevailing institutional

Table 16.1. Dry cassava agroindustries established in Ceará, 1986-91.

Region	86-87	88-89	89-90	90-91	91-92	Total	Financial Sources[1]
Ubajara	1	2	1	2	1	7	1(2);2(3); 3(2);
Sobral	1	2	3	3	4	13	1(5);2(5); 3(3);5(1);
Itapipoca	1	3	2	5	6	17	1(8);2(7); 4(1);6(1);
Cariri	1		2	3	2	8	1(4);2(1); 3(1);7(2);
Limoeiro		1	3			4	1(1);2(3);
Crateus				1	1	2	2(2);
Fortaleza					3	3	1(3);
Russas				4		4	2(1);7(3);
Baturite					1	1	1(1);
Total	4	8	11	18	18	59	1(24);2(22); 3(6);4(5); 5(2)

[1] 1 = IBRD; 2 = PAPP; 3 = BNB; 4 = SIC; 5 = Other.

landscape, thereby facilitating the performance of project personnel in their activities as advisors to the farmer groups.

Linkages between the CCC and the Secretariat of Agriculture (SEARA) and Land Reform have been strengthened significantly during this period; and it is expected that by the end of the project, the CCC will be functioning as a technical body annexed to SEARA. Some of the programs in which the CCC is receiving direct support from SEARA are as follows:

- Funding (US$ 15,000) of a special project--conducted jointly by CNPMF, CIAT and CCC--aimed at controlling a severe outbreak of witches-broom disease.

- Funding (US$20,000) of specific requests from farmer groups to install dry cassava agroindustries in several cassava farming communities.

- A project (US$50,000) presented to the NE Bank of Brazil (BNB), has been approved; and in coordination with SEARA, 50 dry cassava agroindustries will receive financing to purchase oxen-pulled wagons for transporting cassava roots to the drying plants. This credit line is of special significance as this is the first time that a loan-type credit program based on price variations of dry cassava chips has been accepted by the funding agency. The functioning of the credit program will be carefully monitored and evaluated as it could become the basis for formulating future credit programs for investment, operation and production.

- EMATERCE and EPACE created a revolving fund (US$10,000/yr) out of the resources allocated to them by the project, which during the first 2 yr has been used as working capital for the dry cassava agroindustries: 23 farmer groups in 1990 and 49 in 1991. It is expected that by the end of the project, the administration of this revolving fund will be directly assumed by the farmer groups through some form of second-order organization representing all the cassava farmers participating in the project.

- The installation of dry cassava agroindustries is being carried out with active participation of the main local executing agency, EMATERCE, which maintains direct relations with local, national and international programs that are potential sources of financial support. Thus far the project has been functioning within its goals using these type of grant-type financial resources (Table 16.2).

16.3.3 Production technology

One of the more important components within the strategy of Cassava Integrated Development Projects is production technology . The Ceará Project uses a methodology that includes two components: pre-production trials and seed production plots.

- Pre-production trials. Aimed at increasing farmer adoption of improved cassava production technology, these trials are being installed in the vicinity of the drying plants to allow maximum participation of farmer groups. The planning, establishment and evaluation of these trials involve active participation of technicians from the two main counterparting agencies, EPACE and EMATERCE.

Table 16.2. Estimated financial support of Brazilian development programs to the Ceará Cassava Project, 1986-91.

Period	No. Farmer Groups	Total Value US$	Sources of Funding [1] (%)
1986-87	4	16,025	1
1988-89	8	24,425	1;2;3;5
1989-90	11	46,715	1;2;3
1990-91	18	158,082	1;2;4
1991-91	18	101,801	1;2;5;4
Total	59	347,048	1(36.8%);2(49.3%) 3(6.9%);4(5.5%); 5(1.5%)

[1] 1 = IBRD, 2 = PAPP, 3 = BNB, 4 = SIC, 5 = Others.

In 1990 a total of 15 pre-production plots (PPPs) were installed and harvested after 15 mo. Results show that productivity levels in the state can be increased significantly through improved production technology. Avg RY was 22.4 t/ha, 59% more than avg RYs obtained in farmers' plots (Table 16.3). In 1991 the no. of PPP was increased to 44, covering the main areas of project influence.

- Seed production plots. Initial results have not been as promising as expected because the farmers have placed more importance on the seed plots as a source of roots for the drying plants than as a source of planting material, preferring to get low-quality seed from other sources and leaving the seed plots unpruned at planting time. Additional factors affecting the success of this activity have been the farmers' lack of experience in the practice of pruning plants to obtain planting material and the fact that the period between planting and harvesting represents a lag period of at at least 6 mo, making the storing of stakes for planting material unfeasible.

  Most of the 15 cassava seed plots planted in 1990 were harvested at 15 mo, thus becoming another source of benefits for the farmers as the roots obtained from these plots were donated to the drying plants. In 1991 the no. of cassava seed plots installed was increased to 41, covering the principal cassava-producing areas in the state.

Table 16.3. Avg yields of PPP[1] in Ceará, 1990-91.

Region	Community	Fresh RY (t/ha) PPP	Fresh RY (t/ha) FF[2]	Variety
Cariri	Serra Santana	36.70	22.30	Joao Grande
Itapipoca	Solidao	30.25	22.30	Fragosa
Sobral	Folha Larga	12.70	11.90	Guarani
Limoeiro	Aracati	17.20	7.60	Fragosa
Ubajara	Jua dos Vieiras	15.38	6.47	Cruvela Rasteira
Avg		22.44	14.11	

[1] Planting density of 10,000 pl/ha, plot area 2,500m².
[2] FF = Farmers' fields

16.3.4 Processing technology.

A very important factor in implementing cassava-based rural development projects is the farmers' adaptation to the new processing technology, where they are supposed to function as suppliers of raw material to markets that present specific characteristics of demand, quantity, quality and frequency.

Experiences in similar projects in Colombia and Ecuador indicate that this adoption and adaptation process requires an adjustment period of 2 to 3 yr before the groups are able to administer their processing units efficiently. To assess this, a parameter called "Processing Efficiency" was used, which compares the real annual output of the drying plants with a theoretical output estimated according to climatic and management factors. These two factors combined determine the efficiency and the level of profitability with which the farmer groups operate their enterprises. In the case of Ceará, it was assumed that for a 6-mo period (Aug.-Dec.), the climatic conditions are suitable for solar drying of cassava chips and that a loading rate of 10 kg/m^2 takes 2 days to reach desired MC levels (10-13% wet basis). Management factors include the no. of times that the drying plant operates during the year and the amount of chips processed each time.

Table 16.4 compares the processing efficiency of 10 agroindustries that operated in 1989-90. It can be observed that during the second processing season the total annual output of these plants increased by 191% and that the avg level of Processing Efficiency was 58.8% as compared with the first year (20.2%). In general it can be concluded that after 2 to 3 yr of operation, the efficiency levels of the drying plants must be between 60-70% to be profitable.

16.3.5 Commercialization

- Marketing channels. Different from what had been expected, the product is not being sold to large-scale consumers such as the animal feed industries as was the case in Colombia and Ecuador. In the case of Ceará, 70% of the total production in 1989 was purchased by low- to medium-scale consumers (< 10 t/yr) and 30% was sold to consumers with purchases over 10 t/yr (only 5% of the total no. of consumers). In 1990 there were some changes, with the large-vol. consumers purchasing a significant 62% of total production but they continued to represent only 5% of the total population (Fig. 16.1).

- Dry cassava and cassava flour prices, 1990-91. It has been estimated that there are more than 14,000 cassava flour processing units ("casas de farinha") operated under communal-type arrangements and located throughout the rural areas of the state. These farinha agroindustries process an estimated 200,000 t/yr. The commercialization system within which these farmer groups operate usually forces them to sell at low prices. Factors such as the poor quality of the farinha, the small

Table 16.4. Efficiency of processing of cassava drying plants Ceará Project, 1989-90.

Farmer Groups	Drying Area (m^2)	Annual Output t/yr Theor.[1]	Actual 1989	Actual 1990	Efficiency of Processing[2] 1989	1990
Poco dos Cavalos	600	360	108.3	269.3	30.1	74.8
Jua dos Vieiras	600	360	96.9	238.8	26.9	66.3
Lagoa Grande	434	260	120.0	311.5	46.1	119.8
Folha Larga	700	420	92.6	248.9	22.0	59.2
Solidao	450	270	118.0	232.2	43.7	86.0
Dourado	700	420	3.9	132.3	1.0	31.5
Lagoa do Mato	700	420	47.5	166.5	11.3	39.6
Cachoeira do Boi Morto	380	228	17.3	102.2	7.6	44.8
Barreiro	600	360	41.9	108.3	11.6	30.1
Serra Santana	400	240	5.0	86.4	2.1	36.0
Total		3,338	651.4	1,896.0		
Average					20.2	58.8
Increment (%)			191		191	

[1] Estimated according to the following assumption: loading rate of 10 kg/m^2, 2 lots/wk, 20 wk/yr.
[2] Processing Efficiency calculated as the relationship between actual and theoretical annual output.

scale of operation, and the rudimentary type of infrastructure utilized prevent the farmers from obtaining better incomes from this processing activity.

The KF-funded project offers a solution to this situation by creating a marketing alternative for the cassava farmers through the production of dry cassava chips for animal feed, where the farmers can get better prices and increase their net incomes. For the last 2 yr the CCC, in collaboration with the RCCs, has been monitoring the evolution of prices for cassava products and by-products in the areas of project influence; and it has been proved that during the processing period (July to Dec.), the production of dry cassava chips has been a more profitable activity for the farmer groups than processing the roots in the form of farinha. In 1990 the production of dry cassava chips gave the farmers a net profit of Cr$ 10.14 for every kg produced vs. a net loss of Cr$ -10.29 for farinha. In 1991 data for the first month of processing are showing the same tendency, with the dry cassava giving the farmers a net profit of Cr$ 4.17 vs. a net loss of Cr$ -8.33 for each kg of farinha produced (Fig. 16.2).

16.3.6 Organization

- Institutions. The CCC is now fully established as coordinating body for statewide project activities, and the 5 RCCs formed in the main areas of project influence are playing an important role in the decentralization of the planning and execution of activities that the CCC has been promoting. The RCCs are gradually assuming

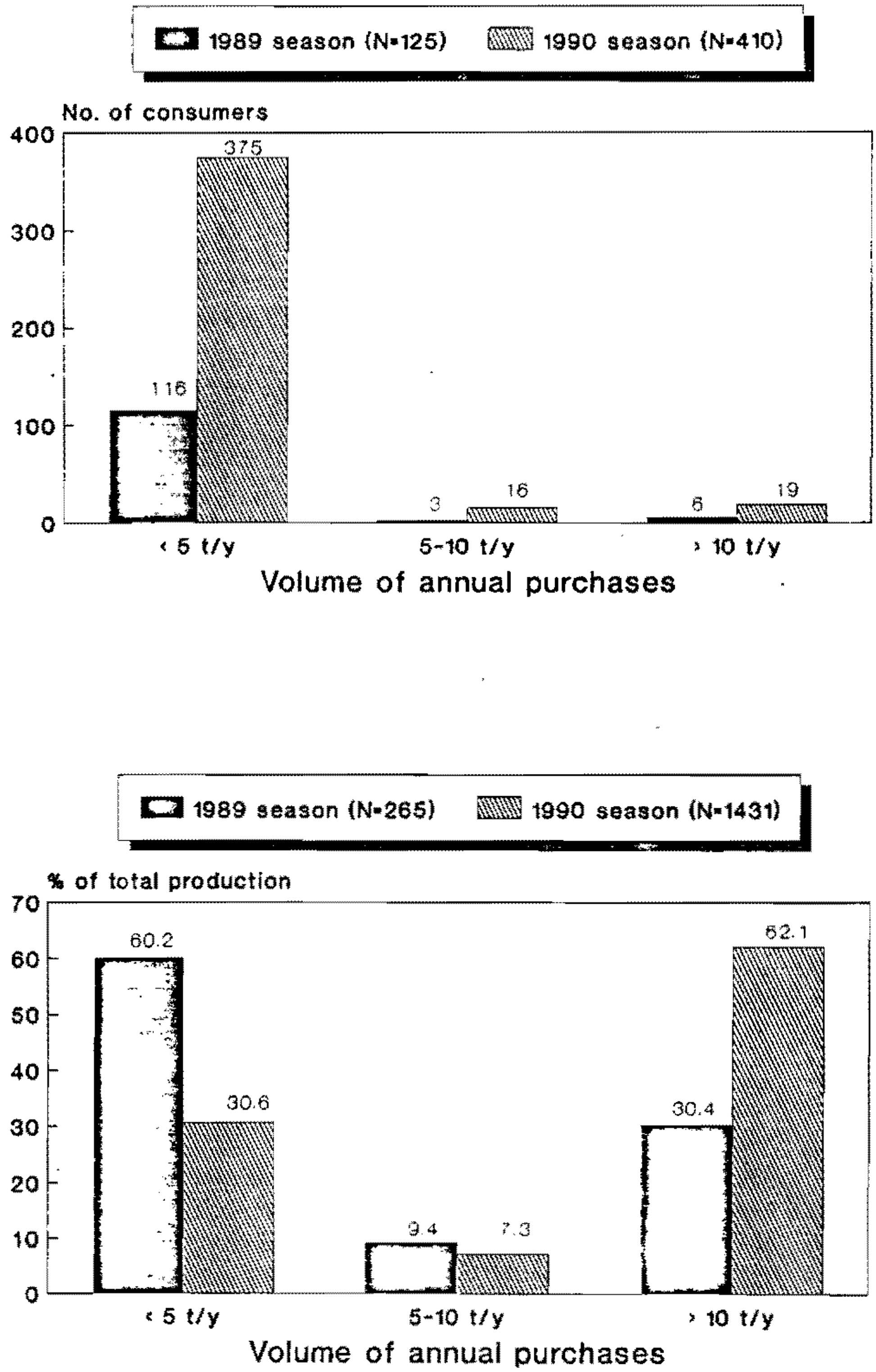


Figure 16.1 Dry cassava commercialization channels in Ceará.

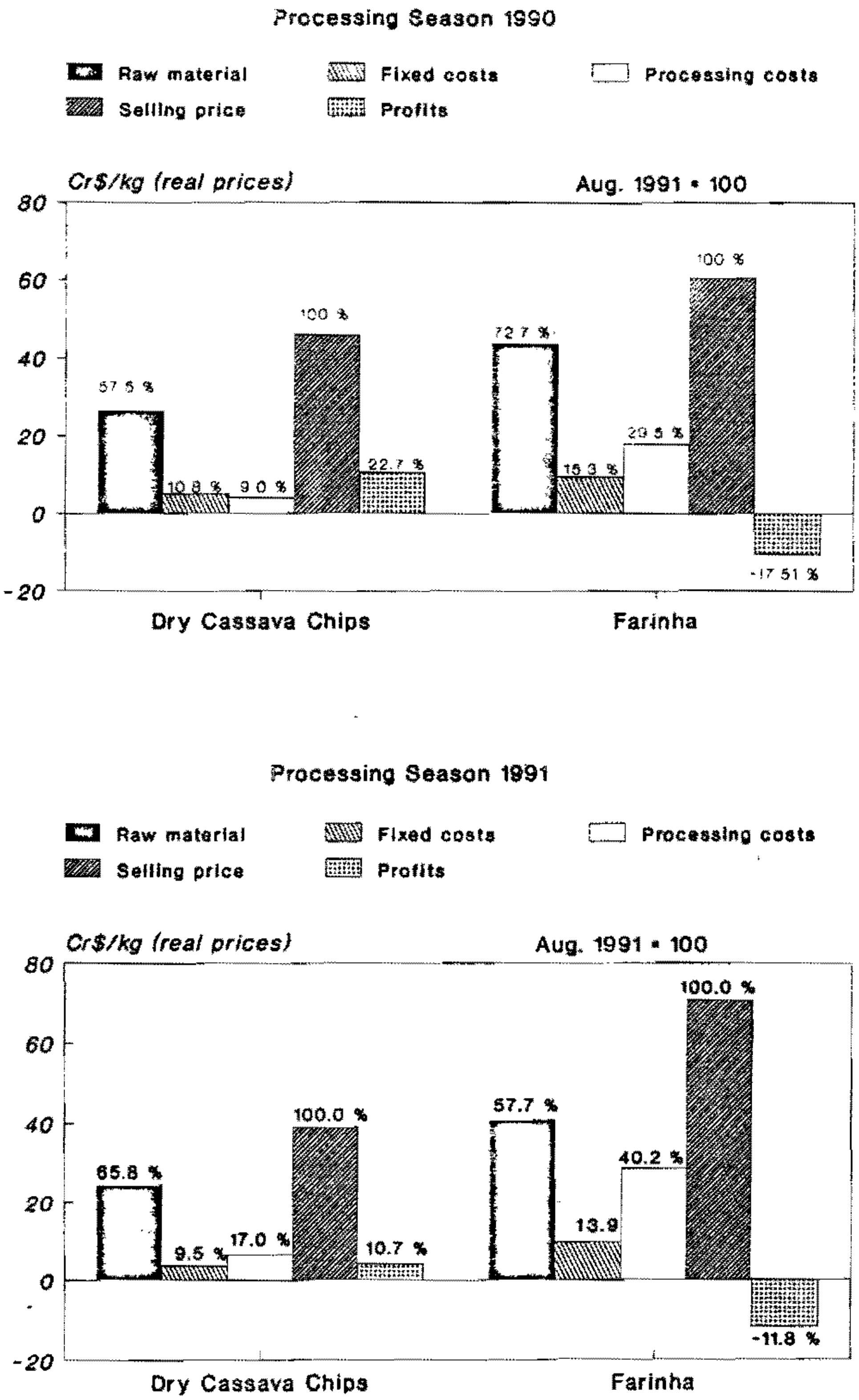


Figura 16.2 Profitability of dry cassava and farinha in Ceará.

responsibility for coordinating regional-level activities in areas such as selecting and organizing new farmer groups, training, technical assistance and identifying new sources of funding for expanding the project to other areas. The CCC offers logistical support to the RCCs and maintains overall coordination of the project at the state level. The incorporation of these committees into the prevailing institutional landscape and their acceptance by their two main counterparts--EMATERCE and EPACE--as valid and functional organizational forms is an important achievement and has facilitated the performance of project personnel in their activities as advisors to the farmer groups.

- Farmer groups. The organization of farmer groups for installing and operating the cassava-based agroindustries has been a very important activity. Defining the type of organizational structure that is most appropiate for small farmer groups is not an easy task, especially in the case of the Ceará project, where the majority of the groups were initially based on larger communal-type farmer organizations (casas de farinha). The CCC and the RCCs are making serious efforts to support already established groups (20-30 socially homogeneous families) in order to capitalize on the degree of social cohesion which they had attained. Initial efforts are based on the specific task of processing dry cassava for animal feeding, which demand sophisticated new skills of management and organization that may be beyond the groups' current capacity.

To date, the project has been able to achieve a reasonable degree of success in establishing small farmer cassava-based agroindustries. In addition to reactivating the initial 12 groups in 1989, 47 new groups were organized in 1990, for a total of 59 farmer groups.

It is expected that by the end of the project (Mar. 1991), there will be 80 groups in all.

There are 3 fundamental elements critical to this process of expanding the social basis upon which the KF-funded project has been built:

- The farmer groups are being formed on the basis of a collective action utilizing a single investment. The function of the group is to gain access to a grant-type of financial resource for a specific purpose decided upon by the group--in this case the installation of a dry cassava processing agroindustry.

- Membership of the group is initially decided upon among the potentially interested members, and all future decisions on new membership have to be agreed by all members.

- The role of the CCC and the RCCs has been crucial in the task of approaching different goverment agencies and development programs on behalf of the farmer groups to obtain grants. At the same time, both these committees have access to KF project funds for assisting and supporting farmer activities.

One of the principal project strategies in the area of farmer organization is the creation of second-order groups at regional and state levels in order to improve the participation and the bargaining power of the farmers in planning and implementing the project. Efforts are being made to stimulate the formation of this type of organizational structures in the main areas of project influence.

16.3.7 Training

The project's training strategy includes four types of activities (Table 16.5): courses, seminars, field trips and special days. The training courses are being conducted at state and regional levels, with the RCCs assuming greater responsibility for their implementation, especially in the case of the courses held at the regional level. The seminars are aimed at encouraging and facilitating farmer participation in the planning and evaluation of project activities at both state and regional levels. The field trips allow beginning farmer groups to become familiar with the principal technical, administrative and organizational aspects needed to operate the cassava-based agroindustries efficiently. The special days are held for purposes of promotion and divulgation of information. Some of the farmers act as trainers, not only allowing significant cost reduction but also stimulating farmer participation in project activities.

16.3.8 M&E

The M&E system of the Ceará project is aimed at tracking progress toward achieving specific project activities. Technicians and farmer-managers of the dry cassava agroindustries are now more familiarized with the methodologies and the forms being used to collect and process information on day-to-day project activities. Additionally, the exchange of information among farmers, technicians, RCCs, counterpart agencies and the CCC, as well as the feedback of the processed information to the technicians and its delivery to the farmer groups, has reached the point where results are being used to guide planning and evaluation activities.

Areas in which the M&E system is currently providing information are as follows:

- Land tenure. Currently there are 59 farmer groups participating in the project for a total of 1380 direct beneficiaries. The land tenure system under which these farmers operate their holdings include 3 forms distributed as follows: owners (59%), sharecroppers (13.8%) and renters (27.2%).

- Age of the participants. Most of the farmers participating in the project are between the ages of 30 to 60 (70%), 17.4% are younger than 30, and only 12.6% are over 60.

- Production. A central assumption to test the success of the project in relation to cassava production is that the opening of an alternative, more profitable outlet for cassava will motivate the farmers to expand their cassava plantings. Monitoring is

Table 16.5. Training events for the period 1989-90.

	1989			1990			1991		
	No. of	Trainees[1]		No. of	Trainees		No. of	Trainees	
Training Events	Events	T	F	Events	T	F	Events	T	F
I. Courses									
A. State Level									
Production	1	38		2	30		1	24	
Organization of farmer groups	1	30		1	20		1	30	
Processing				1	15				
Diagnostic skills							1	24	
B. Regional Level									
Processing				5	21	48	8	20	56
II. Seminars									
A. State Level									
Planning	1	26	16						
Evaluation	1	14	17	1	22	33			
Organization	1	35							
B. Regional Level									
Planning				5	47	54	6	60	119
Evaluation				5	25	35			
III. Field Trips	15	30	123	11	12	82	7	12	36
			120	1	15	120			
IV. Special Days	2	15							
V. Others									
Course for Technicians from Paraiba & Pernambuco									
Study tour to Ecuador & Colombia				1	20		1	6	4
Total	22	188	276	33	227	370	25	176	215

[1] T = Technicians, F = Farmers.
Total no. of training events = 80
Technicians = 591
Farmers = 861

being done for two parameters: the size of the cassava plots and the relationship between cassava plot size and the farmers' land tenure system.

In relation to plot size, the information available shows that the cassava areas have remained fairly constant, with near 80% of the farmers involved in the project over the last 3 yr planting no more than 2 ha. Farmers planting larger cassava plots (> 5.0 ha) do not represent > 5% of the total group.

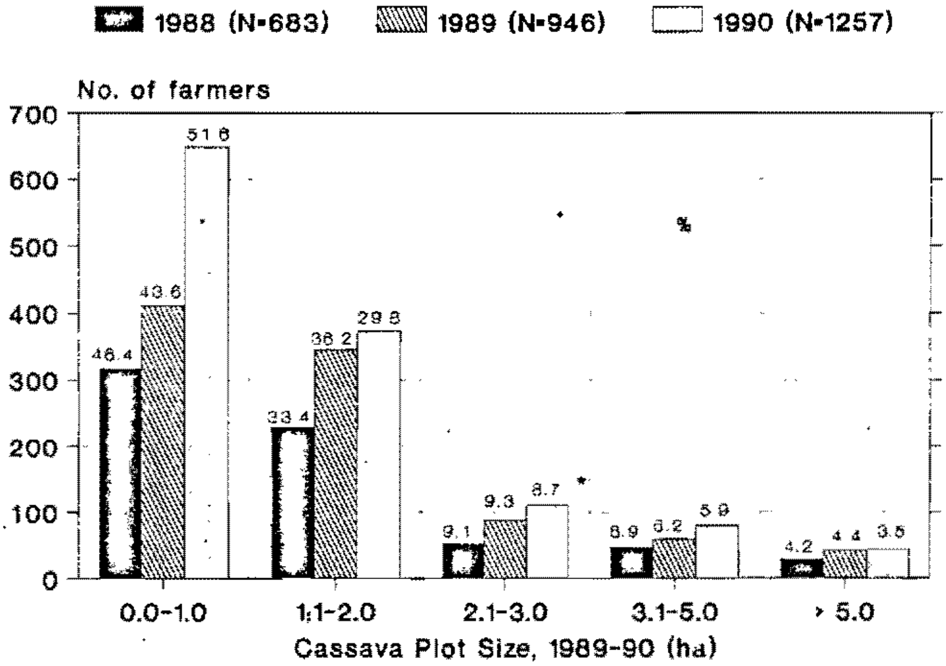


Figure 16.3. Size of cassava plots, 1988-90.

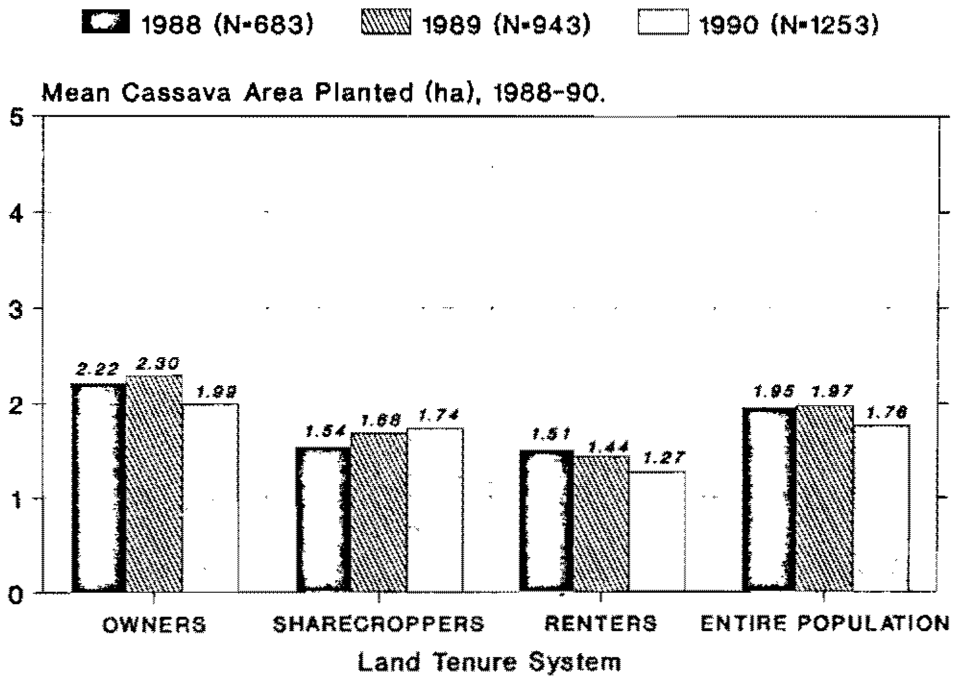


Figure 16.4 Cassava plot size vs. land tenure, 1988-90.

Information collected on the relationship between cassava plot size and the farmers' land tenure system (Figs. 16.3-16.4) indicates that the smallholders have generallly been planting larger cassava areas than sharecroppers and renters. The avg size of cassava plantings for the entire population in 1990 was 10% smaller than in 1988, which could have been caused by a significant decline in avg cassva plantings by the sharecroppers who now plant cassava plots 15% smaller than 2 yr ago. Monitoring of these factors will continue to assess changes that could be related to project impact.

16.3.9 Results of the processing season, 1989-91

- Sales. The first year of the project, 53% of the roots processed were coming from nonmembers and 47% from the farmer groups. In 1990 the vol. of roots sold to the dry cassava agroindustries represented only 28.6% of the total vol., nonmembers selling 71.4%. After the first 2 mo of processing in 1991, it was found that members had sold 53.1% of the total vol. of roots processed by the agroindustries. Of the total population of members, 46% sold roots to the drying plants in 1989; 33.6% in 1990; and 29.6% only 2 mo into the processing season of 1991 (Table 16.6). This situation needs to be monitored and analyzed carefully as it could become a limiting factor in overall group performance.

- Total annual incomes, 1989-91. The total annual benefits received by the members include cassava sales, processing wages and the sharing among members of annual profits. Distribution of the total annual incomes according to the size of the cassava plots planted indicates than the greatest part of the benefits go to the farmers with fewest resources. In 1989, 78.2% of the total annual incomes went to farmers with < 2 ha cassava; in 1990, 77.9%. Data for the first 2 mo of 1991 indicate that only 30.3% of the total annual incomes was gained by those farmers who had > 2 ha planted in 1990. Comparing total annual incomes during 1989-91, it can be concluded that the benefits generated by the project thus far have increased considerably and that the main beneficiaries continue to be farmers with fewer resources (Fig. 16.5).

Table 16.6. Cassava sales, 1989-91.

Item	1989	1990	1991[1]
No. of farmer groups processing dry cassava	12	33	36
No. of members	211	856	840
% members selling roots	40.3	33.6	29.6
% members earning processing wages	15.1	12.0	10.7
Total vol (t) of cassava roots processed	265	3,802	1,461
% sold by members	53	29	53
% sold by nonmembers	47	71	47

[1] Only 2 mo of processing season.

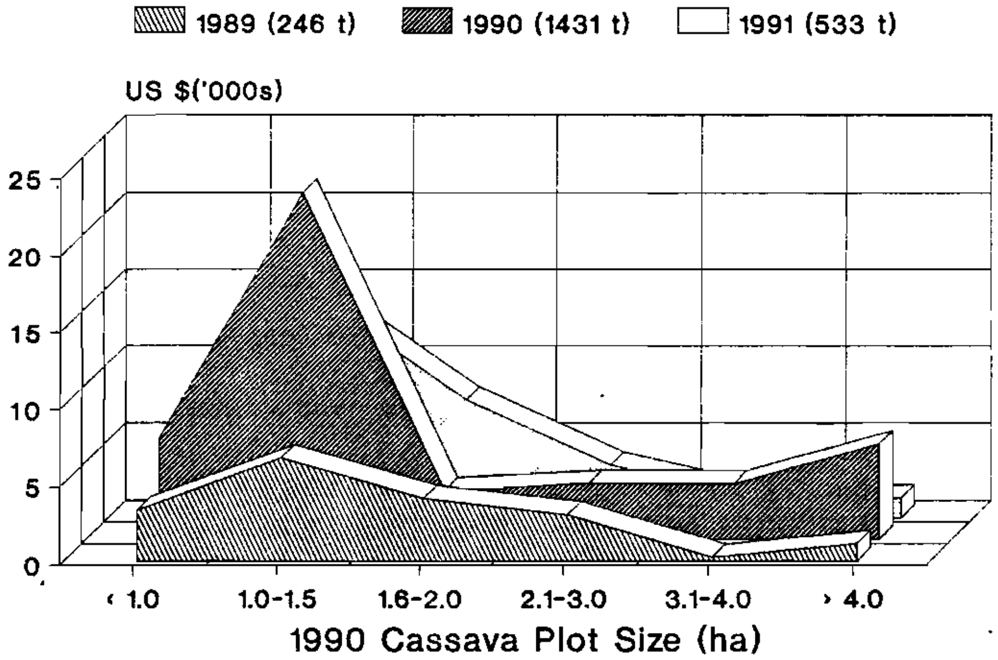


Figure. 16.5. Total annual incomes, 1989-91.

16.3.10 Future Plans

The Ceará Integrated Cassava Project ends in March 1992. By that time, the project is expected to have accomplished its main objectives in relation to agroindustrial development, institutional building and improved welfare for its beneficiaries. SEARA has set up a working group that is formulating a proposal for a second phase of this project, which will be presented to the KF. The proposal includes a continued support role for the CIAT Cassava Program although it is expected to decline over time.

At the same time, EMBRAPA (HQ) and the CNPMF have been working on the formulation of a project to expand the successful experience of the Ceará project to other states in NE Brazil. To date, this initiative has not defined clearly the role that CIAT will play in this process, but demand for increased assistance in the planning and organization of the projects is likely.

17. PARAGUAY

Paraguay is the largest per capita producer of fresh cassava roots in the world. The most important producer of fresh cassava is located in the periphery of the capital Asunción. Soil degradation in this area has pushed production towards Caaguazú, some 300 km away. This area now supplies cassava for most of the country. The native forest recently cleared in Caaguazú opened up new land for agriculture. Cassava production like most other crops depends largely on the natural fertility of the soils; however, soil fertility is rapidly declining in Caaguazú and crop productivity will probably decrease soon if new improved technology is not applied.

Most available technology to improve cassava production has been developed for tropical conditions. The subtropics have received relatively less attention from research. Consequently, developing better technology for the specific environmental conditions of Paraguay implies relatively more technology adaptation activities in addition to strategic research.

Research institutions in Paraguay are relatively weak and staffed mainly with young, inexperienced, but highly motivated professionals. The Agricultural and Cattle Extension Service (SEAG) is probably the most active institution, with offices and personnel stationed throughout the country. CIAT coordinates activities mainly with SEAG although support for the research branch of the Ministry of Agriculture is also provided. IDRC-Canada funds most of the activities in Paraguay. The French Technical Mission also provides support, mainly for postharvest activities.

The Cassava Project in Paraguay, like many others in Latin America, simultaneously considers improvement of production, utilization and marketing of the product although initially more attention has been dedicated to solving production problems. Project activities are concentrated in the states of Paraguarí and Caaguazú although multilocation tests are frequently conducted throughout the country.

Contrary to Caaguazú, recently open to agriculture, Paraguarí has been intensively cultivated for many years due to its proximity to Asunción. Climatic conditions and general soil characteristics are very similar for the two localities; however, avg soil OM and P content are significantly higher in Caaguazú.

17.1 Production

A rapid initial survey in the 2 Project areas complemented the already existing information about cassava in the country. At the same time, an agroecological study was conducted, native varieties collected, and the most commonly cultivated varieties characterized agronomically. Sugarcane, cotton and cassava are the most important crop components of the typical farm in Caaguazú. Cassava is cultivated on more than 90% of the farms;

actual plot size for the different crops depends on market conditions and they are rotated on a 2- to 3-yr basis.

A survey of more than 300 farmers revealed the great importance of cassava as an on-farm animal feed, mainly for poultry and swine that are consumed locally. Approx. 50% of the cassava production is sold for fresh consumption or transformed into starch; the rest is consumed on farm (humans and animals). Large farms tend to consume proportionally more cassava for animal production and at the same time include more cattle in the animal subsystem of the farm.

Manual labor in cassava is intensive, particularly for land preparation and weeding. Harvest date depends mainly upon the type of variety planted and market conditions.The most interesting feature of cassava production in the subtropics is managing the crop to cope with low temp during the growing season. At the onset of the low-temp period, farmers cut the cassava stems at ground level and store them as planting material. As soon as the temp rises again, maize is planted in the interrows of the cassava stubs and the two crops develop simultaneously. Farmers developed this technology by trial and error. Planting new cassava fields also takes place as soon as the temp rises again; and both old and new plants coexist on the same farm. If prices for roots are low, the cassava remains in the field. On one farm it is possible to find 1-, 2- and 3-yr-old cassava fields.

Farmers use oxen-driven implements for land preparation and the first weeding of cassava and other crops. Farmers identified the following as important production constraints: the sporadic incidence, but high severity of CBB, storage of planting material, weed control, marketing and declining soil fertility. Scientists identified soil erosion and germplasm diversity as important production topics affecting the sustainability of the system.

The Ministry of Agriculture presently keeps a germplasm collection with > 150 accessions. CIAT provides technical assistant to characterize this collection, which is duplicated in the country and kept in vitro. Most of the Paraguayan accessions are now part of CIAT's germplasm bank in Colombia. An agronomic collection including the most commonly cultivated varieties as well as other promising material is continuously tested across different localities.

In terms of fresh root production, significant differences exist among the cassava var. adapted to the ecological conditions of Paraguarí. At both project sites, var. Meza-I and Tacuara say-yu performed best. At Caaguazú these 2 var. have continuously outperformed most other var. tested (Table 17.1). There are differences between the two localities not only in yields but also in terms of aerial biomass production and harvesting time.

Table 17.1. Avg yield of marketable roots (t/ha) of different cassava var. tested in Paraguarí and Caaguazú.

	Locality			
	Paraguarí		Caaguazú	
Variety	1989	1990	1989	1990
Tapoyo a moroti	22.2	18.4	28.7	-[1]
Poi	15.6	22.8	23.7	-
Coronel	23.7	24.7	26.3	-
Pyta-i	16.5	20.5	19.5	-
Caballero-i	16.9	19.8	20.9	21.8
Cano-i	20.5	20.0	25.5	28.0
Canó	22.5	24.8	17.3	-
Tacuara say-yu	27.9	35.1	27.6	25.9
Meza-í	28.5	36.9	29.2	33.2
Pomberi	20.9	25.3	23.4	22.0

[1] Not tested that yr.

The var. Meza-í, which consistently outyielded other var. in Caaguazú, also has good DM and starch content. It is not highly resistant to CBB but performs acceptably well under field conditions and high incidence of the pathogen. This var. is now cultivated by several farmers but still needs more diffusion in areas where it could coexist with other var.

Earliness is a characteristic that most farmers consider of vital importance in the selection of an improved cassava var. Table 17.2 summarizes earliness of Meza-í and other var. commonly cultivated in the country.

Table 17.2. Total root fresh wt (t/ha) of 5 cassava var. harvested at 3 different dates.

	Cassava Varieties				
Mo after Planting	Meza-í	Tacuara say-yu	Caballero	Cano-i	Pomberi
6	27	22	25	26	23
9	34	36	25	28	30
15	54	33	38	49	32

Storage of planting material under low temp occurs only in the subtropics. Farmers frequently report losses in both quantity and quality of planting material stored more than 3 mo, the length of time stakes have to remain stored before the temp rises again and planting can be done. Traditional storage technology consists in cutting, leaving the freshly cut stems in the open for 3-5 days, piling them horizontally and covering them with plant debris. A set of experiments conducted with farmers provided information on the effect of vertical and horizontal storage of stems. Vertical storage resulted in significantly less wt loss (Table 17.3). Vertical positioning for storage is now being recommended to farmers by the SEAG.

The slow initial growth of cassava keeps soil unprotected until the canopy closes. Several basic strategies to cope with this problem have been suggested: (a) intercropping cassava with species that grow more rapidly; (b) increasing cassava planting density; (c) speeding up the growth of cassava with fertilizers; and (d) planting early-maturing, more vigorous var. Intercropping and fertilization trials are being conducted with farmers in Caaguazú and Paraguarí to assess their economic viability and test their possible advantage in reducing soil erosion.

The most common practice of associating cassava with other annual crops is the simultaneous planting of the 2 species. At both project sites, however, the first weeding of the interrow spaces using an ox-driven hoe takes place when cassava is still relatively small. Consequently, the crop that is planted in alternate rows with cassava can only be planted immediately after this first weeding. This delayed planting increases the competition with cassava and has a negative effect on the yield of the intercrop.

Simultaneous planting of cassava and cowpeas in alternate rows results in better yields; however, alternate row planting can be practiced in Paraguay only by farmers who cultivate very small plots, where weeding is mainly done by hand. Experimentally, one and 2 rows of cowpeas planted in the interrows of cassava did not result in significant differences in yields between these 2 spatial patterns. Cassava RYs were not affected by cowpeas although cowpea yields were reduced more than 50% due to competition with cassava (Table 17.4). In other environments and cropping patterns, cowpea yields are reduced by no more than 20% when intercropped with cassava.

Table 17.3. Wt loss (%) after storing cassava planting material for different periods; avg of 2 var.

Position for Storage	Weight Loss After[1]		
	5 Days	90 Days	100 Days
Vertical	5 a	26 a	31 a
Horizontal	5 a	19 b	25 b

[1] Percents followed by the same letter are not statistically different ($P \leq 0.05$).

Table 17.4. Yields of cassava (avg of 3 var.) intercropped with cowpeas in two spatial arrangements and sole crop).

Spatial Arrangement	Cassava (t/ha)	Cowpeas (t/ha)	LER
1 row of cowpeas	17	0.46	1.3
2 rows of cowpeas	15	0.45	1.2
Sole crop	16	1.7	1.0

Maize has been traditionally intercropped with cassava in Paraguay. Farmers intercrop these species in different spatial patterns, depending on their relative prices in the market. Intercropping maize with cassava in Paraguay is also affected by the fact that maize planting has to be delayed until after the first weeding of cassava.

Different cassava var. were intercropped with maize var. Suwan-8047 and also planted in monocrop as a check. In the intercrop most of the cassava var. performed similarly in terms of fresh RY, particularly marketable roots; in monocrop, however, performance was significantly different. Cassava var. Cano performed equally well in sole crop and in association; whereas other var. such as Rai yielded significantly more in sole crop. Maize intercropped in alternate rows performed significantly better than maize intercropped in the row (Table 17.5).

The performance of the cassava/maize intercrop depends, among other factors, on the types of var. that are used. Short-stature new maize var. usually compete less with cassava than traditional tall var. The majority of the newly released maize var. are short types with high HIs that perform better at high plant densities, both in monocrop and in association with cassava. Among the most important maize var. released recently in Paraguay is Suwan-8047. As density of this var. increases from 7000 to 28,000 pl/ha, RYs of cassava var. Pita-i tend to decrease (Fig. 17.1). Cassava reduced its yield by 60% when intercropped with maize at high plant densities. The relationship of these two well-

Table 17.5. Yields of cassava (avg 3 var.) intercropped with maize (var. Suwam-8027) in alternate rows and in the same row.[1]

	Cassava		Maize
Cropping Pattern	Total Roots	Marketable Roots	
Maize/cassava, alternate rows	13.6 a	9.7 a	2.7 a
Maize/cassava, same row	13.6 a	10.1 a	1.9 b
Sole crop	20.4 b	15.4 b	3.0 a

[1] Yields followed by the same letter are not statistically different ($P \leq 0.05$).

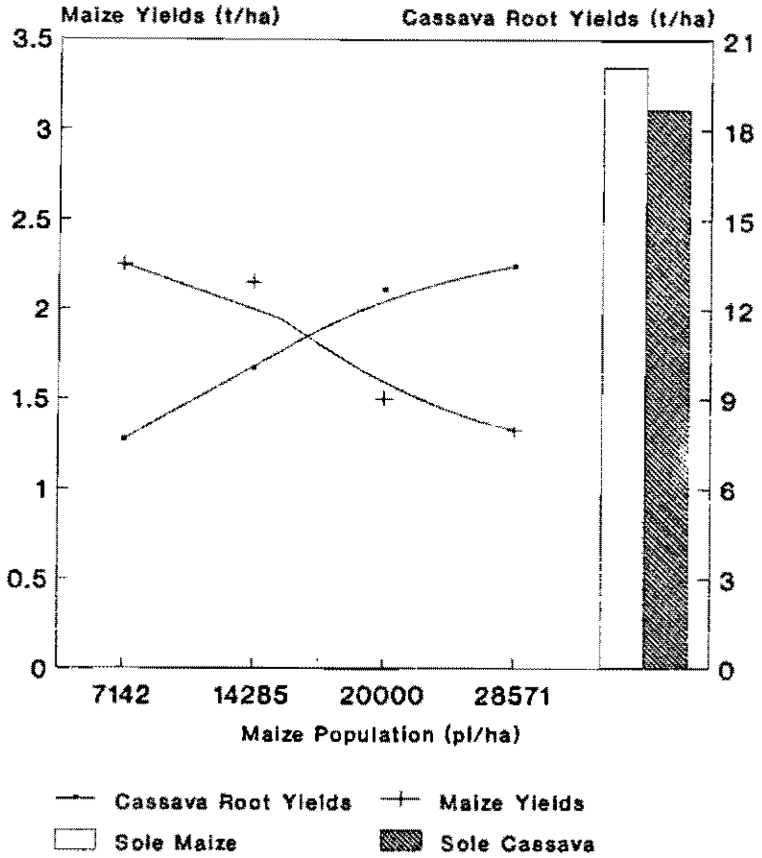


Figure 17.1. Yields of cassava intercropped with maize plants at different densities.

adapted cassava and maize var. provides a valuable tool for predicting cassava RY at different maize planting densities. Intercropping maize and cassava in the same row permits the simultaneous planting of the 2 species and also weeding the interrows with the oxen-driven hoe. Cassava var. recommended for both intercropping and monocrop are now available for both project areas.

A set of experiments aimed at reducing soil erosion by increasing cassava population in Paraguarí indicated that the arrangement in actual use by farmers (1 x 1.2 m) is the only economically feasible alternative and probably the only one acceptable to farmers. Higher plant densities resulted in an excess of small noncommercial types of roots with no industrial use as of yet.

Organic fertilizers are used by some farmers due to the local availability of manure, but their use is not yet widespread. Amounts ranging from 5 to 40 t/ha of manure applied before planting and combined or not with chemical fertilizers have been tested in Paraguarí. Twenty t/ha of manure has resulted in better yields and handling possibilities for farmers. The use of chemical fertilizers for cassava production, combined or not with the use of manure, increases production costs beyond the avg farmer's economic possibilities. Nevertheless, the use of chemical fertilizers is one of the few possibilities for increasing cassava production in Paraguarí, at least in the short term. Similar to other areas of the world, land preparation, weed control and harvesting in the subtropics are cultural practices that demand high inputs in terms of labor. Paraguayan farmers use preemergence herbicides only for cotton production, given the favorable prices for the product. The most commonly available preemergence herbicide is Codal-400 (alachlor and prometryn). This herbicide is selective also for cassava; and given its availability to farmers, it was tested for cassava monocrop production. In preliminary tests 5 lt/ha plus one hand weeding 60 DAP resulted the most effective for weed control and high cassava RY. Production costs were too high given cassava prices. In another set of experiments Codal-400 applied in bands only to the sites where cassava stakes were planted reduced doses and costs by 50% with good control of weeds. The use of this pre-emergence herbicide should be complemented with at least one hand weeding to obtain good yields.

Both the total and the localized application of Codal-400 increased yields by 17 to 40% in comparison with the check that was only hand weeded (Table 17.6).

The development of technological components to improve cassava production in Caaguazú and Paraguarí has led to the formulation of 2 complete technical recommendations for farmers, consisting of a mix of improved components as well as traditional technology that is constantly being evaluated in farmers' fields. The recommendation for Paraguarí includes improved component for var. (Meza-I); better selection of stakes before planting; planting stakes of approx. 20 cm; the use of 20 t/ha of manure before planting plus band application of 300 kg/ha of 12-12-17-2 (NPK and Mg). The rest of the technology (land preparation, weed and pest control) remains exactly as the farmer's traditional practices. For Caaguazú the complete package consists

Table 17.6. Effect of preemergence herbicide applied at two doses and hand weeding on cassava RY.[1]

Treatments	Total Roots	Marketable Roots
Total coverage with herbicide	26.3 a	23.1 a
Band application of herbicide	22.7 b	17.1 b
Hand weeding	23.3 b	17.3 b

[1] Yields followed by the same letter are not statistically different ($P \leq 0.05$).

of the same components, except for the use of fertilizers (not recommended). It doesinclude, however, the application of Codal-400 plus hand weeding for weed control. The rest of the technology remains similar to the farmer's.

17.2. Postharvest Activities

17.2.1 Starch production

Cassava starch has been produced in Paraguay for many years. It is mainly used to make a traditional bread known as "chipa" (78% of total starch production), as well as for other industrial purposes. A diagnostic survey of starch producers was carried out to identify areas where product and process improvement could be beneficial. The majority of starch factories are located nearby Mauricio Troche (Caaguazú). More than 80% of the starch factories are small, usually managed by a single owner and using traditional technology largely based on family labor. The rest of the industries are either partially or totally mechanized. Total annual starch production of the area is only 5,000 t. The whole industry consumes a daily amount of fresh roots that varies from 1 and 5 t/day depending on the season. During the rainy season starch production is minimal, primarily because of drying problems. The avg efficiency of starch production in Caaguazú is only about 59%, compared with other countries--notably Colombia, which has efficiency values of more than 80%.

Several problems affect quality and quantity of starch production. Most of the factories are located close to natural sources of water required for peeling and washing the roots. The water used for the industrial process is later returned to its natural sources or just emptied near the factory, creating a serious contamination problem. The low quality of the water results in poor starch quality, affecting both large and small factories. Chemical analyses have demonstrated high Fe content and microbial contamination by *E. coli* in most of the water samples taken from representative factories.

More than 50% of the small factory owners are also cassava producers. The rest of the factories purchase raw material from farmers in the area. There is a well-defined market preference for some cassava var. for starch production. Among the var. usually harvested 15 mo after planting, var. Cano is preferred for its high starch content. Chara is preferred among the early-maturing var. (Table 17.7). Interviews with farmers and starch factory owners revealed a significant difference between starch content of most varieties during summer (hot) and winter (cool) months, being higher during the latter.

Besides water quality, slow sifting and sedimentation are technical problems that contribute significantly to the low efficiency in most of the factories surveyed. Natural drying of the starch is also a slow process that takes place in the open and consequently results in contamination and frequent oxidation of the end product.

Table 17.7. Preference of starch factory owners for different cassava var. as raw material.

Variety	Preference (%)	Harvesting After
Canó	31.7	15 mo
T. jovi	7.3	15
Conché	4.9	15
Chara guazú	2.4	15
Chara-i	22.2	9
Caballero-i	9.8	9
Cano-i	7.3	9
Pyta-i	7.3	9
Togué-i	4.9	9
Toledo	2.4	9

With respect to managerial problems, lack of capital for infrastructure improvement and sufficient operational funds are among the most important. The constant need of cash to cover the cost of labor, raw material and other operational costs, forces the owner to sell the product even in periods of low prices. Poor record-keeping capacity and lack of short- and long-term production plans are also important problems.

Raw material costs account for approx. 70% of the total production costs of cassava starch; labor, 14%; and drying 5%. These costs are very similar for small cottage-type and large, more mechanized starch factories. The difference between these two types of factories lies in their transformation efficiency and profitability, which are higher in the latter.

The majority of small factories sell starch to intermediaries while larger factories obtain better prices by dealing directly with the end user. Unlike other countries, by-products of starch factories are seldom used for animal production or other purposes.

A pilot (demonstration) plant will be built in the near future by a coop, using the improved small-scale technology developed in Colombia: grating with a system of cutting blades, starch refining using a vibratory sifter, separation by sedimentation in settling channels, and solar drying the final product.

17.2.2 Fresh root conservation

The technology to keep chemically treated fresh cassava roots in plastic bags for long periods to facilitate commercialization, was developed by CIAT. This technology is in stage of either testing, adaptation or adoption in different countries. Ex-ante analyses in

Asunción and Caaguazú assessed the feasibility of this technology for marketing cassava roots. Several successful experimental trials were conducted with the participation of farmers, transporters and merchants.

At the producer level most of the experimental activities were developed at Juan Manuel Frutos (Caaguazú). Trained farmers carried out the harvesting, selection of roots, application of Mertect (thiabendazole), packing, weighing and transport of the treated roots to the Asunción market in small trucks. Treated roots (approx. 30 t) were sold directly from trucks, in small- and medium-sized shops, and in supermarkets. Potential shoppers were stratified by avg family income for acceptability studies. Most consumers informed that after a one-wk storage period, treated roots had the same quality as fresh cassava. Slight deterioration occurred in treated roots after 2 wk. Consumers from all income strata reported that quality of the treated roots was either good or very good. Restaurant customers did not report significant differences between the stored and fresh product.

Close coordination between teams of packers and distributors of treated roots is recommended. Transporting and distributing no more than 12 t/day in 5-kg plastic bags seems most convenient. In the near future, it is hoped to expand this project component to a semicommercial level.

17.2.3 Commercialization

The commercialization studies in Paraguay began with an initial survey to identify the origin (farmers); most common form of transport; wholesalers; distributors; stores and supermarkets; and finally different types of consumers of fresh cassava. An estimate of the no. of persons involved in the different stages of the commercialization process was used to stratify the population and carry out an in-depth survey of a representative sample.

The Municipal Market (DAMA), located in the heart of Asunción, is the place where most of the fresh cassava arrives from the production regions and from where distribution begins. There are three different types of cassava dealers: (a) the truck owner who purchases cassava at farm gate and transports it to the DAMA (nearly 75% of the cassava sold in Paraguay); (b) the truck owner who only transports cassava; and (c) the farmer who also owns a truck and transports his product (14% of the total cassava that reaches the DAMA). As Caaguazú is 300 km away from Asunción, cost of transport is the highest item in the total cost of commercializing cassava. The farmer who transports and sells his product directly profits more than the rest of the dealers. From DAMA 63% of the cassava roots are distributed to supermarkets and small retail stores; the rest goes to State-run mobile markets that sell cassava and other products in different parts of the city. Approx. 26% of the cassava that wholesalers' purchase deteriorates before further distribution, but only 13% of the roots deteriorates at the retail stores. This provides a strong justification for the fresh root conservation component of this project.

During the high-temp period (Dec. to Feb.), the total vol. of cassava passing through the DAMA decreases significantly, more being sold in the relatively cooler period (April-Sept.). From approx. Oct. to Feb., sweet potatoes compete with cassava, both in the DAMA market and in consumer preferences.

17.2.3 Dried cassava for animal feed

A pilot natural drying plant has been built near Coronel Oviedo as a collaborative venture between the SEAG cassava project and a farmer coop. This will test the technical feasibility of drying cassava chips naturally in Paraguay, where the subtropical, seasonal climate presents different problems from those of the tropics. The coop will use the cassava to produce its own balanced feed rations.

18. SEED SUPPLY SYSTEMS

Improved seeds constitute the biological input through which biogenetic innovations are incorporated into agricultural production systems. A lack of adequate seed supply systems (SSS) prevents farmers from benefiting from efficient seed-embodied technologies. Consequently, R&D activities on SSSs has become strategic in modern agriculture.

Organized SSSs have shown multiple beneficial effects by accelerating the flow of improved varieties from the research to adoption phase, expanding the magnitude of adoption, and prolonging the productive life of varieties. More specifically, improved seeds benefit the farmer through higher yield, production stability, lower costs, prevention of disease spread, reduced use of toxic agrochemicals, etc., all of which are associated with the judicious use of quality seeds of improved varieties. However, when superior clones are released and recommended, only a few make it to farmers' fields.

The development of SSSs, especially under atomized and risky market conditions, has been under-researched. There is a general lack of a knowledge base for organizing SSSs under small farmer market conditions. Given this growing concern, CIAT initiated a R&D thrust in 1988 focusing on seed systems. This activity is carried out by the Seed Unit as a multi-institutional effort under the leadership of ICA and CIAT. Colombia has become an ideal country for this type of research given the achievements in market expansion for cassava end products, the release of superior varieties, and the interest of ICA's Seed Division and a host of other local organizations in cassava seed supply. The objective of this thrust is to develop a working model(s) in Colombia. It is expected that the experience accrued, including socio-organizational and production technologies, will enable CIAT to understand the constraints limiting the development of SSSs and to gain a knowledge base that can be transferred to other countries through CIAT's wide range of international activities.

18.1 Problem Definition

It has already been widely documented that in Colombia cassava is produced by the small farm sector (see Chap. 14). This sector is becoming integrated into the market through cassava drying coops, which creates a need for improved seeds. The drying coops have been successful, to the point where they are expanding spontaneously. In addition to ICA, CIAT, DRI and CORFAS, there is a good tradition of participation of a host of local organizations in cassava R&D. These factors, coupled with the growing interest in new cassava varieties, create a favorable environment for developing a cassava SSS. Differences in market, farmer organizations and agroecological conditions must be taken into account when developing an SSS. Excellent sites for studying alternative SSSs include the North Coast, the Piedmont, the Coffee Belt and northern Cauca State, which differ in both market and agroecological conditions.

At the same time, the cassava plant has other specific characteristics that have implications for the SSS:

18.1.1 The market

Cassava growers have limited resources. Traditionally, the source of seeds are the stakes saved by the farmer; e.g., a survey on the North Coast showed that farmers leave a portion of the lot to be harvested before next planting or keep the branches to assure availability of planting materials. They become interested in seeds from outside sources, mainly when changing varieties or when their own planting material is inadequate. These conditions make it nearly impossible to estimate the real demand and plan ahead of time the quantities of seeds to be produced. At the other end of the spectrum, farmers in Quindío (Coffee Belt), have a tradition of buying and selling stakes. Among these contrasting situations, a gradient of market conditions exist, which clearly indicate the need of relevant SSSs.

Genotype-agroclimatic interactions have imposed a need for specific varieties for given regions. These conditions are reflected in small markets scattered in different regions/communities throughout the country. This implies that a few large seed enterprises supplying genotypes to large and uniform markets is unlikely in the foreseeable future. A logical alternative would be to develop SSSs closer to the farmers, in the communities where seeds of specific varieties are needed. Furthermore, this alternative has the potential for strengthening genetic diversity.

18.1.2 The product

Biologically, cassava is a slow, low-vol. seed producer. It takes from 9-12 mo to obtain good root yield and mature stakes. At the end of this prolonged period, each plant will have produced only 5-10 stakes. This contrasts sharply with the multiplication rates found in true-seeded crops.

The seeds (stakes) are bulky, heavy, high in water content, and perishable, thereby posing innumerable economic, technical and logistical problems in seed management. Thus the SSS cannot depend on storage for long periods or transportation over long distances. This again points in the direction of local seed production.

Another important product feature is genotype replicability as the crop is propagated through clones. This means that once a variety is acquired, the farmer would not need to buy seeds of that same variety. Although this can not be generalized for all market situations, there is a clear indication that replacement of planting materials will depend on availability of seeds of new varieties.

18.1.3 Institutional panorama

In the best of cases, the cassava SSSs receive support from research through germplasm development. Basic seed supply, quality assurance services, credit and marketing technologies are scarce. In most countries, institutions have not yet focused on the development of cassava SSSs--in great contrast with the institutional support systems developed around hybrids for maize, rice, sorghum, and others with more advanced SSSs.

Vis-à-vis the limitations, some strengths exist. There is an expanding market for cassava, which encourages the search for improved seeds as an input capable of increasing yield and product quality. Varieties with these features have recently been released for key regions of the country. The ICA Seed Division has created a new section that focuses on developing SSSs for unaddressed markets. It is anticipated that this organization will capitalize on local organization to bring about the institutional support for cassava SSSs. Coops and private organizations are emerging in an autonomous fashion for the purpose of producing, processing and marketing cassava products. These conditions are creating an overall favorable environment for developing a cassava SSSs.

The conditions of the market, the biological nature of the commodity, and the institutional conditions clearly point to the need of alternative schemes rather than one monolithic approach across the land. The system, including its socio-organization and production technologies, needs to be conducive to the initiation of a seed supply process. Furthermore, the overall national system and the specific local cases will need to respond to the conditions of the market, the crop and the agroecological conditions where it operates.

18.2 Activities

The focus has been on developing pilot seed multiplication units with the active participation of private farmers and cooperative organizations. To support this objective, the following specific areas were addressed: training, basic seed supply, seed production methods, and norms and standards for quality control.

18.2.1 Training

The first course ever in cassava seed production (1988) was sponsored by ICA, with CIAT playing a supportive role. There were 14 participants from ICA's Seed Division and CRECED regions, as well as representatives of private seed enterprise (MAIZENA and PROACOL). These professionals have become key promoters in seed production in their specific regions. The insights gained from the first experiences in Sahagún, Córdoba (CRECED-Sinú) and PROACOL, for example, were presented to 29 participants in the second course in 1990.

18.2.2 Basic Seed Supply

Pure and healthy basic seed of improved varieties is of catalytic importance for developing an organized seed multiplication and distribution system. As ICA had not initiated this activity, the CIAT Seed Unit undertook basic seed production with the purpose of being a role model, on the understanding that this would be strictly to support the evolution of the system on a temporary basis. ICA has now begun organizing this function in Villavicencio (Meta) and in El Carmen de Bolívar.

18.2.3 Seed production methodologies

There are two basic methods of cassava propagation: One is based on lab and greenhouse techniques, where rapid increase and freedom from diseases are the main objectives; the other is the traditional method of propagation by stakes. The latter method was chosen as the most likely to set up the process in motion; in vitro methods, when commercially viable, would be useful to perfect the system in the future.

The rationale for beginning with stakes is that this technology already exists in cassava production systems so there is enough improved technology that can be used right away. Moreover, the simplicity of the method would make it possible for local institutions and farmers to participate in the process. Most component technologies were available at CIAT, which were rapidly assembled in a stepwise fashion at the Seed Unit. The improved-stake selection method is based on good agronomy, selection of mature branches of healthy and high-yielding plants at harvest, and cutting and treating prior to utilization. To expedite the process on a more commercial scale, technology innovations in cutting, treatment and packaging were incorporated. Currently, there is a prototype at CIAT, where this process can be demonstrated.

18.2.4 Norms and standards

An organized SSS requires norms and standards to ensure the quality of seeds being marketed. In Latin America, with the exception of Cuba, there has been no experience in developing these standards, much less in implementing them. Nevertheless, based on the experience of the Cassava Program staff and seed scientists from ICA and CIAT, a draft proposal entitled "Minimum specific requirements for production of certified and selected cassava stakes" was prepared for eventual submission to the Ministry of Agriculture. As the ICA Seed Division considers cassava seed supply a nascent activity, it has opted not to implement these measures. Recently, enterprises such as COAGROARAUCA and ASOQUINDIA--anticipating potential external markets--have requested certification of their seeds; thus there appears to be a need for implementing certification on a selective basis.

18.3 Challenges for the Future

The process has been set in motion, but a great deal awaits further actions. The objectively verifiable outputs of this R&D thrust are that important functions such as basic seed supply and commercial seed supply--the two missing links of the chain at the outset--are evolving. As a result increasing amounts of seeds of traditional and improved germplasm are becoming available.

18.3.1 Basic seed supply

Basic seed supply, which has been the key for the massive utilization of varieties in other crops, is by no means a solidly instituted function. CIAT assumed this function because it was the key barrier that had to be overcome to set the process in motion (Table 18.1); however this needs to be strengthened by ICA in Villavicencio (Piedmont) and Carmen de Bolívar. Furthermore, good coordination between variety release and basic seed production is needed to prevent situations where a new variety is released (e.g., ICA-Costeña), but there is no seed available for the farmers. To have a greater multiplying effect and impact, basic seed may also need to be directed purposefully to committed seed multipliers.

Table 18.1. Availability of basic cassava seed at CIAT HQ, August 1991.

Clone/Variety	No. of Stakes[1]	Harvest Date
Traditional varieties		
Chiroza	10,000	April 92
Venezolana	15,000	April 92
Regional Amarilla	4,000	Sept. 91
Released varieties		
P11	110,000	April 92
P12	100,000	April 92
P13	40,000	April 92
ICA-Catumare	150,000	April 92
ICA-Costeña	50,000	April 92
Pre-released clones		
a. For the North Coast		
CM 3306-4	50,000	Sept. 91
CM 3555-6	40,000	Sept. 91
CM 3306-4	100,000	April 92
b. For Eastern Plains		
CG 165-7	6,000	Sept. 91
CM 2166-6	20,000	Sept. 91
TOTAL	595,000	

[1] Estimate of stakes to be harvested.

18.3.2 Commercial seed production

The central challenge has been and will be for some time in the future how to institute commercial seed production in specialized organizations. Training, basic seed supply and production technologies have all centered around this objective.

Many organizations have participated in commercial seed production (Table 18.2). The participating organizations include cassava drying coops, individual private entrepreneurial farmers and large private enterprises. In some cases the seeds are for internal consumption of the organization such in the case of integral coops. In other cases (e.g., COAGROARAUCA and ASOQUINDIA) the seeds are finding internal use as well as surrounding markets.

Experience has shown that entry into commercial seed production has been dynamic although there are a no. of cases of enterprises moving out of cassava seed production. Although a trial period is logical before producing seed on a permanent basis, this "entry-exit" phenomenon needs careful analysis, for expansion of the system will depend upon the institutionalization of cassava seed supply in suppliers with the knowledge and skills to assure availability of quality stakes at a low cost. This will require continuity and specialization.

The rapid entry of new ventures can be traced back to the growing interest in new varieties. Availability of foundation seeds supplied by CIAT and ICA, accompanied by training on seed production technologies, has been the key for materializing that interest in concrete actions. It should be noted that insufficient quantities of basic seed has been a limiting factor which has resulted in reduction of area planted for seed production in many cases.

The abandoning of cassava seed production activities has been frequent as well. The major factor mentioned by those who have stopped this activity has been the high risk due to price fluctuations for the roots, which has had a negative effect on the demand for stakes. When analyzing the cases, a trend can be found: Those more directly interested in cassava roots and end products seem to stay in the business. This had been anticipated from the market analysis, and the results tend to confirm this hypothesis. This suggests a possibility that seed supply can be "piggy backed" onto those organizations that have a more direct interest in cassava production.

It is almost impossible to predict accurately which organizations will endure in seed production. Some groups may engage in this activity with a one-time objective--as a mechanism to obtain basic seed of new varieties. Others may have some comparative advantages and new business opportunities so they can produce seeds in a continuous fashion. Thus participation of a wide range of organizations in commercial seed production seems to be necessary step in the induction phases.

Table 18.2. Organizations that have or are currently participating in commercial production of cassava seeds in Colombia, 1991.

Organization	Sites	Varieties	Area (ha)	Observations
North Coast				
AGROESTACION	Sucre	ICA-Catumare	0.5	Discontinued, unstable market
COAGRO-ALBANIA	Sucre	Venezolana	1.0	Discontinued, unstable market
MAIZENA-INYUCAL	Barranquilla	VenezolanaP-12	2.0	Discontinued, unstable market
APROSOCORRO	El Socorro, Sucre	Venezolana, Costeña	10.0	Discontinued, change of plans
COPROALGA	Algarrobo, Córdoba	Venezolana, P-12, Costeña	1.0	In operation[1]
COPROTUCHIN	Tuchín, Córdoba	Costeña	0.3	Scarce basic seed caused reduction in area planted
COPROSAN	San Andrés, Córdoba	Costeña	0.3	Scarce basic seed caused reduction in area planted
ICA/DRI	Sucre	Venezolana	19.0	Promoting production in 19 organizations
Piedmont				
COAGROARAUCA	Tame, Arauca	Catumare, Cebucán	15.0	In expansion
COAGROCASIBARE	Casibare, Meta	Catumare	2.0	In operation, CIAT-PNR Agreement
Cauca				
FUNDAEC	Santander	P-11, P-13	2.0	NGO promoting seed production among farmers, in expansion
CETEC	Santander	ICA-Catumare	0.5	In expansion
Caldas				
ASOQUINDIA	Armenia, Quindío	Chiroza	5.0	Association of Agronomists, in expansion
Others				
PROACOL	Palmira, Valle	P-11, P-12, P-13	3.0	Discontinued, unstable market
Alvaro Aya	Palmira, Valle	P-11	1.0	Discontinued, unstable market
Jaime Sardi	Jamundí, Valle	P-11, P-13, ICA-Catumare	10.0	Discontinued, unstable market
Semillas del Tolima	Ibagué	P-11, P-12, P-13	3.0	Discontinued, unstable market
Ramiro Restrepo	Honda, Tolima	P-12	6.0	Discontinued, unstable market

[1] Because of difficulties in the coop, one of the members decided to continue on his own.

In terms of organization the evolving system can be visualized as a network of institutions carrying out complementary activities, which enable the flow of seed-embodied technologies from the research phase to farmers' fields (Fig. 18.1). The SSS includes farmers who need improved cassava seeds for planting their fields; specialized groups or individuals who produce the seeds; and specialized research centers who in turn produce basic seed for the seed producers. Experience is showing that local seed multipliers (central links) can have a range of organizational structures.

Flow of improved cassava seeds through local seed multipliers

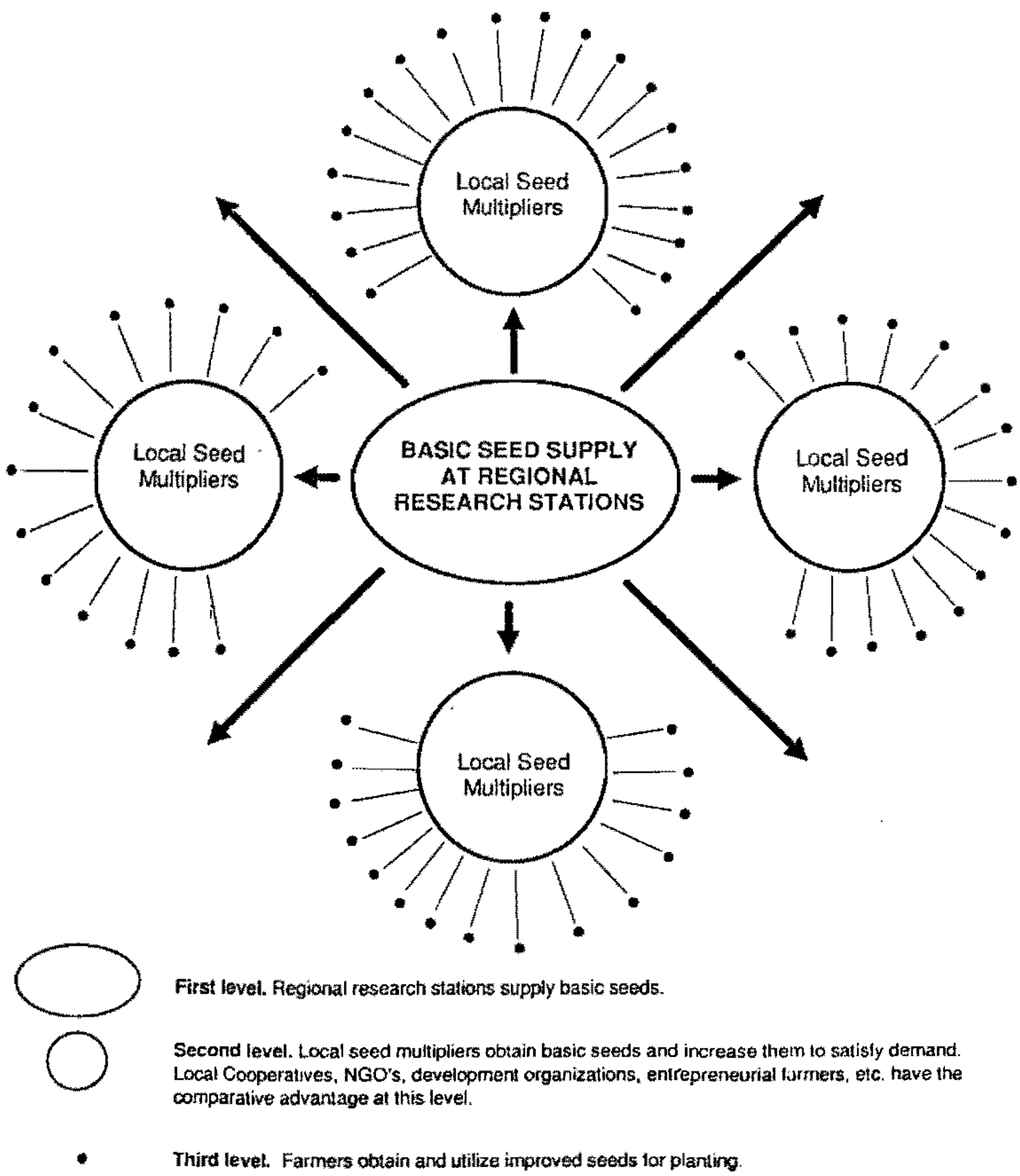


Figure 18.1. Flow of improved cassava seeds through local seed multipliers.

18.3.3 Emerging lessons

Based on these results, some principles for the further development of the Colombian system(s) and for others interested in cassava SSSs can be identified.

- The varietal release process--if not accompanied by organized, well-coordinated basic seed supply--will not be effective. In the best of cases, it is solely an institutional protocol, unsupported by concrete seed multiplication and distribution strategies and thus with very little impact at the farmer level. This principle has been identified in many emerging SSSs including cassava.

- Basic seed programs are essential for supporting the development of organized seed production/distribution activities. Healthy seeds of authentic varieties need to be made available on a timely basis and in sufficient quantities to have an impact. Although this activity is evolving, it is not optimum given the growing demand. Greater commitment on the part of local institutions and more effective distribution policies will be needed.

- Elimination of serious barriers facilitates the entry of a host of organizations to seed production/distribution activities. Barriers in commercial seed production center around access to basic seeds, production technologies and rigidities regarding official norms and procedures for participating in seed production and marketing.

In the future there will be a need to focus on developing basic seed programs in key locations of the country and expanding the no. of commercial seed producers, capitalizing on organizations that have special interest in cassava production such as the drying coops. It is expected that the supportive activities will be carried out by local institutions with active leadership from ICA's Seed Division. The CIAT Seed Unit in turn will focus on developing prototypes in each of the following agroecoregions: North Coast, Piedmont, Cauca and Caldas. These prototypes will need to incorporate production of seeds of other important crops for their region such as maize on the North Coast and beans in Caldas. The prototypes will be closely monitored and information on the initial situation, the evolution process and the resulting impact will be documented. Results of these experiences and evolving organizational and production technologies will be used in future international cassava seed courses and other events.

19. REGIONAL COLLABORATION IN ASIA

During the period between 1966-68 and 1989, cassava production in Asia increased from 21 to 51 million t (Table 19.1), now representing 38% of the total world production as compared with 41% for Africa and 21% for Latin America. Thailand, Indonesia, India, China and Vietnam are the major cassava producers in Asia. Production in Thailand, Indonesia and China is increasing,[19.1] while in India it is decreasing. Yields have increased in Indonesia, India and China; but have remained largely unchanged in Thailand and Vietnam. In most Asian countries the future for cassava appears bright: There is a tendency to shift from cassava used for direct human consumption to its use for industrial processing and animal feed. Technologies for more efficient DM production per area per unit of time and better processing techniques as well as sustainable production systems are much in demand.

19.1 Objective and Priority Setting

The objective of the CIAT Asian Regional Cassava Program is to collaborate with national programs to strengthen their research capacity and produce effective cassava production and utilization technology in order to contribute to the socioeconomic betterment of both cassava producers and consumers and to improve the management of natural resources. Developing viable technologies by working together is the driving force in this research network with national programs.

The framework for setting priorities for CIAT's collaboration with Asian national research programs was provided by (a) the analysis of the results of the Asian Cassava Demand Studies and (b) an international workshop on "Cassava in Asia: Its Potential and Research Development Needs" held in Thailand in 1984. The principal conclusions arrived at by the

Table 19.1. Cassava production in Asia ('00s t), 1966-89.

Country	1966-68	1976-78	1987-89
China	1,535	2,506	3,267
India	3,976	6,234	5,092
Indonesia	11,112	12,527	15,469
Philippines	499	1,549	1,826
Thailand	2,188	12,809	21,774
Vietnam	994	2,661	2,803
Other	678	1,163	1,136
Asia	20,982	39,449	51,367

[19.1] According to Chinese national statistics, cassava production is increasing dramatically.

demand studies were that growth markets exist for cassava in Asia and that productivity-increasing and cost-reducing technology could accelerate the diversification of markets. Priorities set at a regional level were therefore focused on germplasm improvement and soil fertility maintenance and erosion control, which were seen as pivotal elements in ensuring highly productive cassava-based cropping systems. It was also acknowledged that there existed a wealth of postharvest processing and utilization technologies, information about which should be made more widely available at the regional level. Based on this analysis, the Cassava Program posted two of its most experienced scientists to Bangkok, Thailand: A breeder took up office in 1983, followed by a soil scientist/agronomist in 1986.

19.2 Areas of Collaboration

CIAT's collaboration, through its two outposted scientists, has centered on (a) the generation and distribution of breeding materials as a means of broadening the genetic variability in cassava, and (b) agronomy research aimed at developing sustainable cassava production systems. Support for activities in the areas of socioeconomic research and postharvest processing and utilization are provided by CIAT HQ. Training of personnel, the execution of joint projects through research contracts, and the formation of a regional cassava research network for exchanging information have been the principal mechanisms used for improving the national programs' research capacity.

19.2.1 Generation and distribution of breeding materials

A joint Thai-CIAT cassava breeding program was established at Rayong Field Crops Research Center (RFCRC), Dept. of Agriculture, Thailand, which has the dual function of selecting new varieties for Thailand and generating breeding materials for other national cassava breeding programs in Asia. The CIAT cassava breeder helps these other programs conduct adaptive selections from CIAT HQ and Thai-CIAT materials for their own conditions. The Thai-CIAT cassava breeding program at RFCRC is now one of the largest in the world, being comparable in scope and efficiency to those at CIAT HQ and IITA-Nigeria. Progress in the area of varietal improvement is presented in Chap. 20.

19.2.2 Agronomic research towards sustainable production systems

Soil fertility maintenance and erosion control are seen as two vital aspects related to sustaining the income-generating capacity of cassava-production systems. The CIAT Asian Cassava Program promotes research on these aspects in several countries, providing limited funding in the form of research contracts. Those studies will provide underlying principles on which policy alternatives for better natural resource management can be based.

In those countries such as Vietnam, China, Myanmar and Sri Lanka, where no significant cassava agronomy research had previously been conducted, cultural practice experiments are under way. These will provide the basis from which to proceed to developing more effective cassava-based cropping systems in the future. Advances in research on soil conservation and fertility management are presented in Chap. 21.

19.2.3 Socioeconomic research

19.2.3.1 Baseline production and utilization surveys. Despite the obvious importance of cassava and the potential of a significant research contribution, basic information is deficient in many countries. Vietnam is a good example. Upon a request from the Vietnamese Govt. and with support from the CIAT HQ Economics Section, comprehensive cassava production, utilization and marketing surveying activities have been started on a nationwide scale in Vietnam. The objective is to use these primary data to identify and analyze problems and opportunities, which will serve in establishing national program research areas, priorities and strategies.

19.2.3.2 Adoption and impact studies. Studies to assess more precisely the socioeconomic effects of collaborative work and to obtain feedback information for fine-tuning of the Regional Program's research strategy are being undertaken in Thailand and Indonesia. In collaboration with national research and extension scientists, the CIAT HQ Economics Section assists in identifying adoption areas, developing appropriate surveys and analyzing the results.

19.2.4 Postharvest processing and utilization

Over the past 3 yr the CIAT HQ Utilization Section has been assessing the needs for regional collaboration in the area of postharvest processing and utilization. To this end three specific activities have been undertaken:

- Visits in 1988 to the 5 principal Asian cassava-producing countries to obtain firsthand knowledge of (a) production, processing, marketing and utilization patterns, and (b) ongoing research in these areas.

- Inclusion of the postharvest area in the III Asian Cassava Research Workshop held in Malang, Indonesia, in Oct. 1990. Country representatives presented overviews of the current situation with respect to processing, marketing and utilization, as well as research priorities in these areas.

- Holding of a joint workshop with CIP on "Processing, marketing and utilization of root and tuber crops" in collaboration with the Philippine Root Crop Research and Training Centre (PRCRTC), Visayas in April 1991. This workshop focused on methodological aspects related to the generation, transfer and adoption of postharvest technologies using Asian and other experiences as case studies from which to draw recommendations and conclusions.

19.2.5 Training of national program personnel

Short courses and in-service specialization training at CIAT HQ and degree study at Asian universities are the 3 formal mechanisms for strengthening national research capabilities through human resource development. Intensive 5-wk courses at CIAT HQ on research, production and utilization are held every 3-4 yr; while in-service training may take place at any time according to the needs of the national programs and the availability of funds. From 1987-91, 27 Asians participated in the short course held in 1989; 13 received in-service specialization and 5 higher degree training. Apart from formal training, the joint planning and execution of in-country research experiments is one of the most efficient means of improving national research capacity.

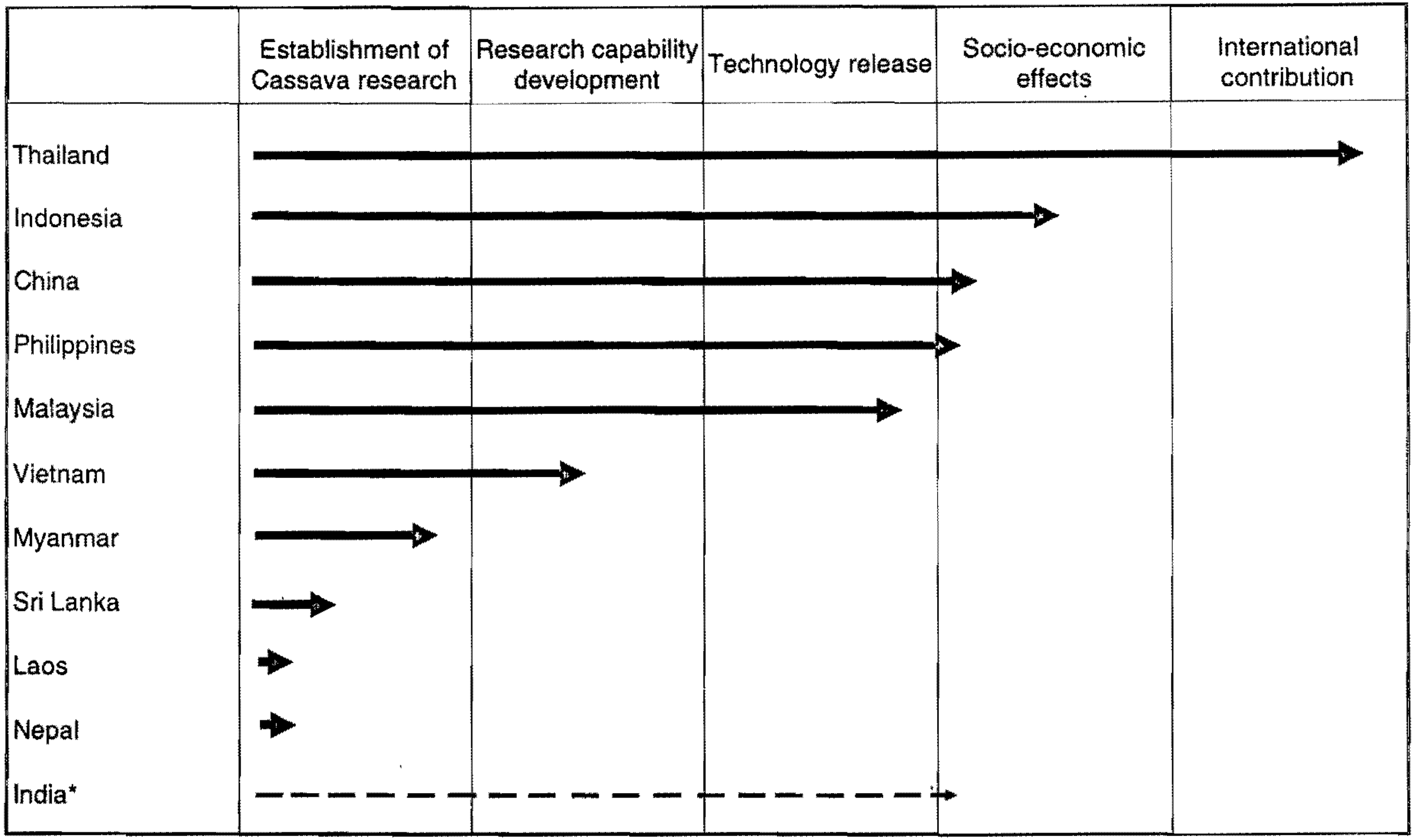
19.2.6 Networking

Through workshops, training activities and research contracts, virtually all the Asian cassava-growing countries participate in what is now known as the Asian Cassava Research Network. The Asian Cassava Research Workshop, held every 3 yr, is a particularly efficient and well-appreciated mechanism for improving network communication. An Asian Cassava Research Advisory Committee has been formed as a channel through which national programs can communicate their needs and make recommendations with respect to regional research activities. It has become evident that the driving force for sustaining intercountry communications is the opportunity to share relevant and applicable knowledge and technology.

19.3 Achievements and Future Emphasis

19.3.1 Establishment and strengthening of cassava research systems

There is enormous disparity in the progress made through CIAT's collaboration with national cassava research programs in Asia, depending on the basic strength of the research institutions, the importance of cassava and the general socioeconomic situation of the country (Fig. 19.1). Compared to the situation 8 yr ago, incipient cassava programs in Thailand, Indonesia, China and the Philippines have evolved into comprehensive research programs; while new cassava research programs have been established in Malaysia, Vietnam and Myanmar. Cassava research has also started in Sri Lanka, Laos and Nepal. To the ongoing cassava research program in India, CIAT has offered training, germplasm materials and communication opportunities. Significant improvement in research competence has taken place in Thailand, Indonesia, China and Malaysia. CIAT involvement has also enhanced interinstitutional cooperation within countries, particularly in China, Vietnam and Indonesia. Horizontal collaboration among countries is being provided by Thailand through the contribution of its best cassava breeding materials to other Asian countries; CIAT acts as an intermediary in this process with the authorization of the Thai Dept. of Agriculture. Economic conditions in Vietnam and China are very favorable for cassava development. Prime attention will be paid to



* Development of Indian cassava research took place largely independent of CIAT collaboration.

Figure 19.1. Development of national cassava research programs in Asia in relation to CIAT collaboration.

these two countries in future years with respect to strengthening their institutional capacity for research on the crop.

19.3.2 Research

19.3.2.1 Breeding. Newly recommended varieties have been released to producers in Thailand, Indonesia, Philippines, China and Malaysia. Significant adoption of varieties released in earlier years has been achieved in Thailand and Indonesia and, to a lesser extent, in China and the Philippines. In the future additional attention will be given to breeding for low HCN and good eating quality, combined with high yield potential and stress tolerance, in an effort to provide dual-purpose cassava for both direct human consumption and industrial use.

19.3.2.2 Agronomy/soil conservation. Concern about the sustainability of cassava production has been generated as a result of the network research on soil conservation. The task ahead is to transfer recommended agronomic practices to production fields by encouraging links between national research, extension and rural development institutions. Agronomic research will in turn be guided more toward the understanding of basic principles and a better definition of strategies for natural resource management.

19.3.2.3 Subtropics. Currently available improved cassava production technology has been developed mainly for the lowland tropics. The adaptability of this technology to subtropical areas such as southern China and northern Vietnam will be evaluated in the coming years.

19.3.2.4 Socioeconomics. Cassava production and utilization surveys and adoption and impact studies will be extended to China and the Philippines. In addition, a collaborative project on the assessment of root and tuber crop markets in Asia and the Pacific, in collaboration with the Economic and Social Commission for Asia and the Pacific (ESCAP-CGPRT Centre, Indonesia) and CIP, has been developed, for which donors are currently being identified.

Beginning 1992, a collaborative study between the Cassava Economics Section, CGPRT and the CRIFC-India will start to analyze current cassava flour processing "models" and future potential for cassava flour for human consumption in Indonesia.

19.3.2.5 Utilization and quality. Close contact has been established with research teams working on cassava flour projects in Indonesia; similar work will be carried out in the Philippines. Emphasis will be on facilitating horizontal contacts between flour projects in Latin America and Asia. CIAT's experience in market-driven research for product development in Latin American is also relevant. Contacts will be expanded with Indonesia, Thailand and other countries to maximize methodological standardization for important root-quality factors.

19.4 Lessons Learnt

Based on the Program's experience with national programs in Asia, the following elements are key for successful collaboration:

- The existence of a favorable socioeconomic environment and technically motivated core staff in national programs
- Provision of viable technology as the basis of institutional strengthening and network formation
- Posting of experienced staff in a respected institution in a country where the commodity is of economic importance
- Research contracts to enhance operational efficiency, but not to support the national program research structure (which creates dependency)

20. GERMPLASM IMPROVEMENT IN ASIA

20.1 Generation of Breeding Materials

20.1.1 Effects of early breeding work at CIAT HQ

The most important task in the first 10 yr (1970s) of the cassava breeding section at HQ (Colombia) was to collect and evaluate a broad spectrum of germplasm, select good cross parents and generate advanced breeding populations to be used by the national program breeders. Many of the current cassava breeder materials in Asia are based on the cross parents originating from this basic breeding work at CIAT HQ. In retrospect, the following 3 factors appear to characterize effectively the current breeder materials in Asia:

- The original breeding population was formed on the basis of world germplasm variation rather than starting from a ready-made population of selected varieties. This helped maintain broad genetic variability even in the present breeders' populations at an advanced selection stage.

- Great progress was made in upgrading the HI of the whole breeding population; hence any breeder population today is endowed with a significantly higher HI than unselected populations.

- A major selection site was set up in Carimagua (E. Plains of Colombia), a location with a harsh growing environment for cassava. This led to a solid genetic basis for resistance to many diseases and pests and tolerance to acid, low-fertility soils.

20.1.2 Progress of Thai-CIAT breeding program

CIAT involvement in Asian cassava varietal improvement was greatly strengthened with the establishment of a joint Thai-CIAT cassava breeding program at the RFCRC, Field Crop Research Institute, Dept. of Agriculture, Thailand in 1983. Later, the cassava research program at Kasetsart U. (KU) also joined this cooperative program. The Thai-CIAT cassava breeding program has dual functions of selecting new varieties for Thailand and generating breeding materials for other national cassava breeding programs in Asia (Fig. 20.1). The CIAT breeder has the additional function of helping breeders in other Asian countries conduct adaptive selections for their own conditions.

The Thai cassava breeding program started forming its breeding population, using local germplasm during the 1970s and gradually incorporating an increasing number of locally selected CIAT HQ clones as cross parents during the 1980s.

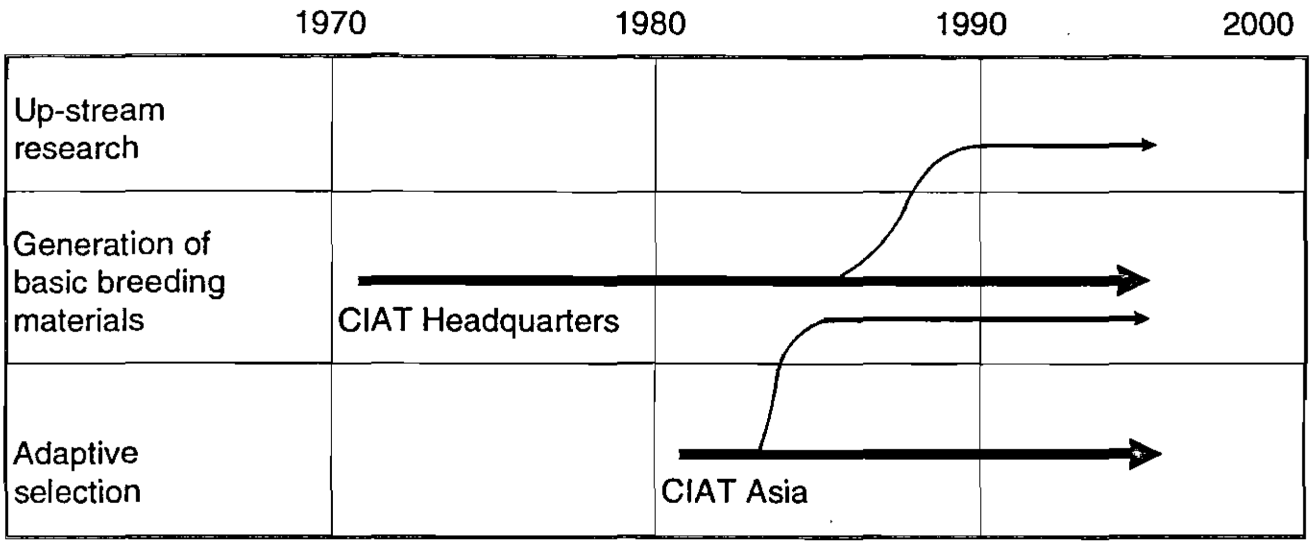


Figure 20.1. Cassava genetic improvement by CIAT.

There was a significant improvement in yielding ability of the breeding population (mean of all regional trial entries, which were then used as the frequent cross parents in hybridizations) during the 1980s (Fig. 20.2). A significant portion of the improvement in DM yield was attributable to the improved fresh RY, but there was also steady improvement in root DM content (Fig. 20.3). HI remained nearly unchanged, but total biomass increased significantly (Fig. 20.4). This is in sharp contrast to the yield improvement during the first 10 yr at CIAT HQ, where improvement in HI was the primary factor for yield improvement. This may be because the yield improvement opportunity through improved HI had been largely achieved at CIAT HQ.

The breeding materials for Thailand as well as for other Asian national programs are formed on the basis of this progress. The present breeding materials generated by the Thai-CIAT program contain well-balanced genes for improved yield components; i.e., high biomass, HI and root DM content.

20.1.3 Comparison of CIAT HQ and Thai-CIAT breeding materials

For most Asian cassava breeding programs, the sexual seed materials provided by CIAT HQ and Thai-CIAT are the major source of their adaptive selection for recommendable varieties. The populations from these two sources were compared at Rayong, Thailand (semiarid lowland tropics) and Lampung, Indonesia (humid lowland tropics). At

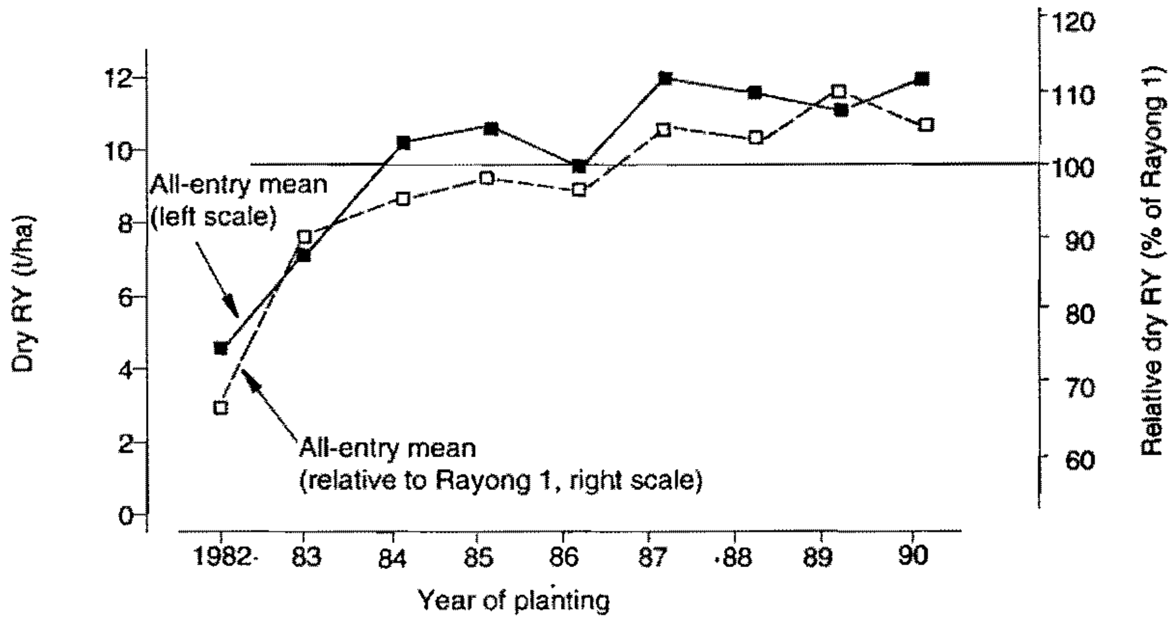


Figure 20.2. **Change in mean dry RY of yield trial entries in Thailand; all-entry mean is the mean of all regional trial entries (8-10 clones) at all the regional trial sites (6-8 locations).**

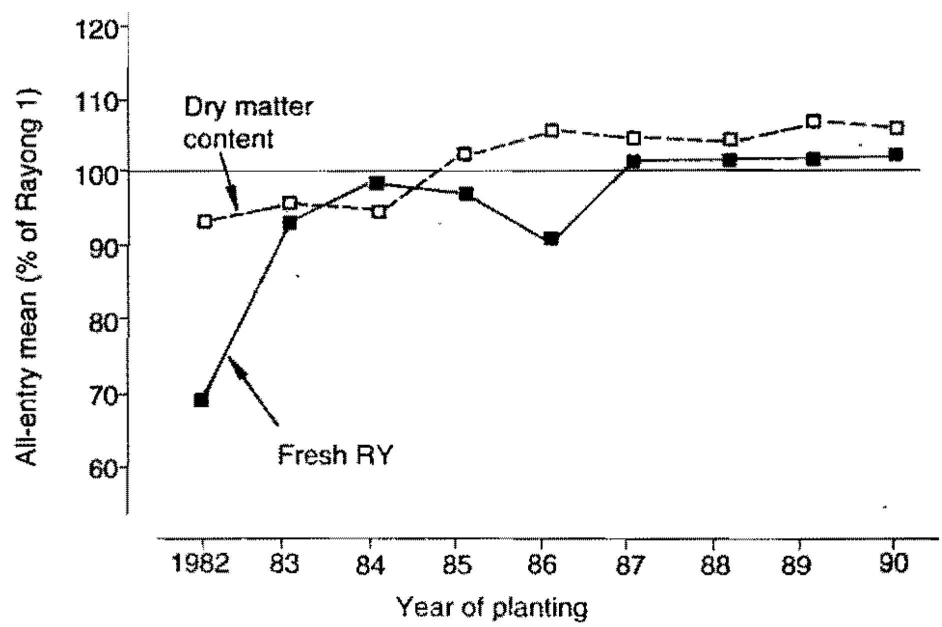


Figure 20.3. **Change in mean fresh RY and DM content of yield trial entries (all-entry mean) in Thailand.**

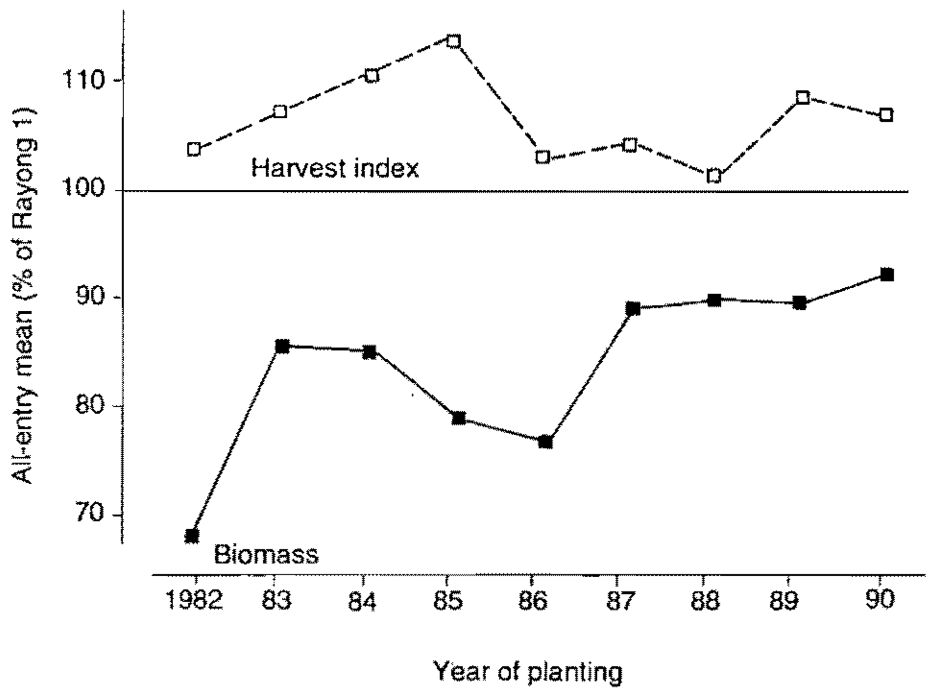


Figure 20.4. Change in mean HI and biomass of yield trial entries (all-entry mean) in Thailand.

Rayong, the Thai-CIAT population was far superior to the CIAT HQ population for all yield traits; but the difference was not conclusive at Lampung (Table 20.1). The result at Rayong was somewhat predictable because the Thai-CIAT population came from cross parents selected at Rayong (local varieties and clones of CIAT HQ origin). This suggests that the Thai-CIAT breeding population has added adaptation to drier climates and that for immediate varietal selection for the semiarid lowland tropics of Asia, Thai-CIAT materials may offer a better chance, while both are a good source for expanding the germplasm horizon. This shows once again the basics of germplasm variation; i.e., germplasm from the center of origin and diversification offers abundant genetic variation, but the germplasm of each location contains genes for local adaptation in a much higher frequency.

20.2 Distribution of Breeding Materials to Asian Programs

A large number of clones are produced and distributed annually to national programs. These materials offer not only genes for general high-yielding capacity but also genes for adaptability and tolerance to many adverse factors--biotic and abiotic--as a result of

Table 20.1. Comparison between CIAT HQ and Thai-CIAT populations in yield characters at Rayong, Thailand and Lampung, Indonesia.[1]

Character	Rayong, Thailand		Lampung, Indonesia	
	CIAT HQ Population	Thai-CIAT Population (% of CIAT HQ)	CIAT HQ Population	Thai-CIAT Population (% of CIAT HQ)
Dry RY	100	138**	100	87*
Fresh RY	100	132**	100	86*
Total plant wt	100	119**	100	87*
HI	100	111**	100	99
Root DM content	100	104**	100	101
Plant type rating	100	119**	100	121**
Germination/survival of planting stakes	100	160**		

[1] Data from a single-row trial at Rayong 1987 (No. entries: 755 CIAT HQ clones and 1228 Thai-CIAT clones) and a replicated yield trial at Lampung 1988 (No. entries: 30 CIAT HQ clones and 41 Thai-CIAT clones), except for germination/survival data which came from 1989 replicated yield trial.

repeated evaluations in harsh environments such as Carimagua (Colombia) or Rayong (Thailand).

Distribution of breeding materials to Asian programs was as follows:

- Sexual seeds from CIAT HQ. A total of 274,196 sexual seeds from some 5,400 crosses have been sent to 9 countries since 1975 (Table 20.2). This is still a major source of breeding material for many national programs in Asia.

- Sexual seeds from the Thai-CIAT program. A total of 47,224 sexual seeds from some 960 crosses have been sent to 11 countries since 1985 (Table 20.3). The importance of this source is gaining significance in many national programs.

- Advanced clones from CIAT HQ. Some 186 clones have been transferred to 5 countries since 1975. This was an important source of varietal selection in the early years.

- Advanced clones from the Thai-CIAT program. Some 215 clones have been transferred to 11 countries since 1988 (Table 20.4). This is a highly significant source for immediate varietal selection by young national programs, such as Vietnam.

20.3 Varietal Selection

20.3.1 Thailand

The Thai-CIAT cassava breeding program may be the largest national cassava breeding program (see Chap. 19). From 1984-93, 7 clones with different adaptive niches have been or will be released. The earlier varieties tended to be adapted more to the relatively fertile soils of better-off farmers. Vigorous efforts are being made to select new varieties adapted to less-fertile soils of smaller farmers.

20.3.2 Indonesia

Selection for high yield and starch content from local, CIAT HQ and Thai-CIAT materials has been highly successful (Table 20.5). Promising results in drought tolerance and broad adaptability are also emerging.

20.3.3 China

Some promising selections have been made from the CIAT HQ materials; yet, the best selection appears to come from crosses between local clones and locally selected CIAT clones (Table 20.6). Selection from Thai-CIAT populations has also begun.

Table 20.2. Cassava F_1 sexual seeds from CIAT HQ distributed to Asian programs.

Country	1975	1977	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Total
Thailand	900	6170	7720	3050	1400	7450	7900	8000	9300	8000	11800	14200	9400	14121	9583	118994
Indonesia	900		700				4600		3050	4950		8600		6000	4219	33019
China						2300	6100		3500	1800	2100	4400	8399	7400	5511	41510
Vietnam							1900						4250	7700	3750	17600
Philippines	900		950		5100	4700	5500	2350	5000			3850	2386		4079	34815
Malaysia	900	1500		2050	1250	4050				200		1490			2918	14358
India	900		850				1050	7900								10700
Sri Lanka									1500							1500
Taiwan	500					1200										1700
Total	5000	7670	10220	5100	7750	19700	27050	18250	22350	14950	13900	32540	24435	35221	30060	274196

Table 20.3. Cassava sexual seeds from the Thai-CIAT program distributed to Asian national programs and to CIAT HQ.

Country	No. of Seeds						Total
	1985	1986	1987	1989	1990	1991	
Indonesia	2950		3130	2621	2840	1139	14952
China				1960	3250	741	6612
Vietnam				3334	2750	1435	6135
Philippines				1400	2300	520	5154
Malaysia				1350	1100		2500
India					1350		2700
Laos							
Myanmar					950		950
Sri Lanka					750		750
Israel					750		750
CIAT HQ		1300	2860		2561		6721
Total	2950	1300	5990	14548	18601	3835	47224

Table 20.4. Cassava clones transferred from the Thai-CIAT Program to Asian national programs and CIAT HQ.

Country	No. of Seeds					
	1986	1987	1988	1989	1990	1991
Indonesia			3			10
China					13	10
Vietnam				13	13	10
Philippines			3		13	10
Malaysia			3		13	10
India					13	10
Laos				4	13	
Myanmar					13	
Sri Lanka					13	10
Israel					13	
Nepal						2
CIAT HQ	117	8			13	13

20.3.4 Vietnam

As Vietnam is in the process of switching from varieties for fresh consumption to industrial varieties, higher yielding, stress-tolerant varieties are much in demand. Clonal introductions from the Thai-CIAT program have been highly successful, and virtually all the Thai-CIAT clones have been outyielding the traditional varieties in South Vietnam (Table 20.7). The best Thai clones are being tested on farms in many locations, and it is likely that several clones will be released shortly.

Table 20.5. Result of varietal trials in Indonesia.[1]

Clone	Origin		Dry RY (t/ha)	Root DM Content (%)	HI
	Hybridization	Initial Selection			
CM 4049-2 UJ	CIAT HQ	Indonesia	20.4	38.2	.65
CM 4031-10 UJ	CIAT HQ	Indonesia	19.5	39.0	.62
Rayong 60	Thailand	Thai-CIAT	17.5	37.5	.66
B 6-3	Indonesia	Indonesia	17.3	37.1	.63
Adira 4	Indonesia	Indonesia	16.9	36.6	.57
B 16-3	Indonesia	Indonesia	16.2	36.6	.60
Rayong 3	CIAT HQ	Thailand	15.5	37.7	.73
OMR 28-19-3 UJ	Thai-CIAT	Indonesia	15.2	36.7	.64
OMR 28-65-7 UJ	Thai-CIAT	Indonesia	15.0	35.7	.57
OMR 28-82-4 UJ	Thai-CIAT	Indonesia	13.5	35.3	.61
BR 18-1	Indonesia	Indonesia	10.9	39.5	.62
Kretek	Indonesian traditional		9.3	33.3	.45

[1] Means of 3 replicated yield trials at UJF, Lampung, Sumatra, 1990-91.

Table 20.6. Results of varietal trial in China.[1]

Clone	Origin		Dry RY (t/ha)	Root DM Content (%)
	Hybridization	Initial Selection		
SC 8729	China	China	12.5	36.5
SM 582-5	CIAT HQ	China	11.4	35.3
South China 205	Chinese traditional	China	10.5	32.9
SC 8758	China	China	10.3	32.2
SC 8741	China	China	10.3	30.0
SM 481-1	CIAT HQ	China	10.0	39.5
SC 8775	China	China	9.8	32.5
SC 8774	China	China	9.1	35.1
SC 8752	China	China	8.7	31.9
SC 8769	China	China	8.0	31.6
SC 8702	China	China	6.3	26.4
SC 8701	China	China	6.2	30.6

[1] Means of a replicated yield trial at SCATC, Hainan, 1990-91.

The information presented in Table 20.7 illustrates many years of network efforts involving many facets as follows:

Germplasm origin: Thailand, Malaysia, Vietnam, Colombia, Brazil, Mexico, Venezuela, Puerto Rico and the Virgin Islands

Hybridization sites: CIAT HQ; Thai-CIAT at Rayong and Sriracha

Table 20.7. Result of varietal trials in South Vietnam.[1]

Clone	Origin		Dry RY (t/ha)	Root DM Content (%)
	Hybridization	Initial Selection		
Kasetsart 50	Thai-CIAT	Thailand	11.3	38.9
MKUC 28-71-66	Thai-CIAT	Thailand	10.5	38.5
Rayong 60	Thailand	Thai-CIAT	10.4	38.2
CM 4231-32	CIAT HQ	Thai-CIAT	9.0	36.9
CM 5262-27	CIAT HQ	Thai-CIAT	8.8	37.0
CM 6125-125	CIAT HQ	Thai-CIAT	8.8	34.2
Rayong 1	Thai traditional		8.4	37.6
CM 6125-117	CIAT HQ	Thai-CIAT	8.2	38.0
CM 5257-33	CIAT HQ	Thai-CIAT	8.1	38.3
HL-24	Vietnamese traditional		7.8	35.7
CM 4785-29	CIAT HQ	Thai-CIAT	7.6	37.7
MKUC 28-71-67	Thai-CIAT	Thailand	7.5	38.1
Rayong 3	CIAT HQ	Thailand	7.4	39.0
CM 5604-21	CIAT HQ	Thai-CIAT	7.4	36.3
HL-20	Vietnamese traditional		7.0	36.5
Hanatee	Thai traditional		7.0	37.1
CM 6125-129	CIAT HQ	Thai-CIAT	6.8	35.9
HL-23	Vietnamese traditional		5.0	36.4

[1] Means of 2 replicated yield trials at Hung Loc Research Center, South Vietnam, 1989-91.

Selection sites: Palmira, Carimagua and North Coast in Colombia; Rayong and Sriracha in Thailand; Hung Loc in Vietnam

Institutions: CIAT HQ; Thai-CIAT Program, Dept. of Agriculture and KU, Thailand; IAS, Vietnam

20.3.5 Malaysia

Steady progress has been made in all steps of breeding, and some good selections have been made for adaptation to peat soils and early harvestability from seed introductions from CIAT HQ.

20.3.6 Philippines

Some selections were made from the CIAT HQ clonal introduction and released as commercial varieties. Selection from CIAT HQ and Thai-CIAT seed introductions is under way.

20.4 Varietal Release

To date a total of 12 var. from CIAT HQ clonal introductions, local crosses of local germplasm, CIAT HQ seed introductions, and local crosses between CIAT clones and local parents have been officially released in 5 countries (Table 20.8). Selections from Thai-CIAT crosses and Thai-CIAT clonal introductions will become more important in the future.

20.5 Socioeconomic Effects

Rayong 3 in Thailand and Adira 4 in Indonesia are reportedly planted on more than 50,000 ha, each generating an economic effect of millions, of US dollars. VC2 and M Col 1684 (not officially released yet) in the Philippines and Nanzi 188 in China are planted on smaller hectarages. The initial adopters of these varieties were primarily advanced farmers (Thailand) and commercial plantations (Indonesia and Philippines). Efforts are being made to spread these varieties to smaller farmers. Adaptability to the conditions of poor farmers is now being added to varieties.

20.6 Future Emphasis

20.6.1 Quality characters

Given the success of selecting for higher yield and adaptability, selection emphasis is gradually shifting to higher root DM content in Thailand, Indonesia and Malaysia. Selection for specific starch quality will have to be considered soon in Thailand. Demand

Table 20.8. Cassava var. released in collaboration with CIAT in Asia.

Category/Name	Country	Year of Release	Main Feature
Selected CIAT clones			
VC 1	Philippines	1986	High yield
Nanzi 188	China	1987	High yield
VC 2	Philippines	1988	Dual purpose
Selection from local cross of local germplasm			
Adira 4	Indonesia		High starch yield
Selection from CIAT cross			
Rayong 3	Thailand	1984	High starch content
Rayong 2	Thailand	1985	Snack foods
Perintis	Malaysia	1988	Adapted to peat soils
VC 3	Philippines	1990	Dual purpose
Selection from local cross between CIAT and local parents			
Rayong 60	Thailand	1987	Early harvestability
Sriracha 1	Thailand	1991	High starch content
Rayong 90	Thailand	1991	High starch content
Kasetsart 50	Thailand	1992	High starch yield

[1] Means of 2 replicated yield trials at Hung Loc Research Center, South Vietnam, 1989-91.

for dual-purpose varieties (for fresh human consumption and industrial processing) is still strong in many parts of Asia. To this end, a combination of low HCN and good eating quality with the high yield potential and stress tolerance of industrial varieties should be sought.

20.6.2 Yield and adaptability

Further improvement in yield capacity appears possible and will continue to be a priority. More emphasis will be given to yielding ability under less-favorable environments through enhanced biomass, better germinating ability under irregular rainfall, and better stake storability. The earlier CIAT HQ breeding materials were known for their generally poor plant type, and some improvement has been made in the Thai-CIAT materials. Selection for better plant type acceptable to Asian growers will continue.

20.6.3 Subtropics

Currently available technology has been developed mainly in the lowland tropics and has not been fully evaluated for adaptability to subtropical areas such as southern China and northern Vietnam. It is important to assess which technical components are valid and available, and which remain to be generated locally.

20.7 Lessons learnt

From our experience in Asia the following lessons have been learnt:

- Cassava germplasm developed at CIAT offers broad genetic variability while indigenous germplasm contains a higher frequency of genes for local adaptation; the use of both germplasm sources in breeding programs is the key to cassava genetic improvement in the region.
- The use of physiological indicators as a selection aid provides the opportunity for improving crop adaptation and yield potential.
- Selection under high stress environments secures broader adaptability within any given set of environmental constraints.
- Gene pool development must take into consideration the quality requirements for actual and potential end use of the crop.
- Cassava genetic improvement, although operationally simple, is a long term endeavor, success at the field level requires a continuity of input from experienced and dedicated scientists both at the national and international level.
- The CGIAR approach to crop genetic improvement, based on a world germplasm collection and the distribution of advanced breeding materials to national programs, is as valid for cassava as for other crops that are grown under more favorable socio-economic conditions.

21. SOIL CONSERVATION AND FERTILITY MAINTENANCE RESEARCH IN ASIA

21.1 Cassava Soils and their Major Constraints in Asia

In Asia cassava is most intensively grown in NE and SE Thailand; Java and the southern part of Sumatra in Indonesia; and Kerala State, India (Fig. 21.1). It is also widely grown in SE China, throughout much of Vietnam and on the southern islands of the Philippines. By overlaying the cassava production map on the FAO World Soil Map for Asia, it is possible to estimate the hectarage of cassava grown on each type of soil. Of the 4.3 million ha of cassava in Asia, about 55% is found on Ultisols, 18% on Inceptisols, 11% on Alfisols, 9% on Entisols, and 7% on Vertisols, Mollisols, Oxisols and Histosols combined. Thus it can be seen that cassava is grown predominantly on Ultisols in almost every country in Asia, except in Indonesia, where it is also extensively grown on Entisols, Inceptisols and Alfisols.

Ultisols are usually found in upland areas with an undulating or mountainous topography and with humid or subhumid climates. Even in subhumid climates rainfall intensity can be very high during certain months of the year. The steep topography and high-intensity rainfall make these soils quite susceptible to erosion. The light-textured soils with low levels of OM are particularly susceptible, even on rather gentle slopes. Most Ultisols are well drained, but are acid and low in fertility. They respond to organic or chemical fertilizer; but when cassava farmers do not have the money to buy these inputs, continuous production can result in nutrient exhaustion and rapid soil degradation. Table 21.1 shows the major soil and climatic constraints in the various countries and regions. Low soil fertility and nutrient exhaustion are of particular concern in Vietnam, Thailand, Indonesia, China and in Kerala State, India; while soil erosion is a major problem in China (Hainan Island, Guandong and Guangxi provinces), Thailand, Vietnam and Indonesia.

During the second Regional Workshop on Cassava in Asia, held in Thailand in 1987, agronomists and soil scientists from 6 of the 7 countries represented indicated that research on soil erosion control and fertility maintenance was of highest priority. During the third Workshop, held in Indonesia in 1990, most countries still considered these the main topics of concern. Since the establishment of the CIAT Cassava Agronomy Program in Asia in late 1986, an increasing number of projects on erosion control and soil fertility maintenance have been set up by national cassava researchers in collaboration with CIAT. Through frequent visits, training, distribution of literature and the organization of workshops, CIAT contributed to the formation of a network of cassava agronomists and soil scientists, who together defined the research priorities and set out to develop practical solutions to the major problems. This report describes the most important results obtained during the past 5 yr (with emphasis on 1990-91) and then draws

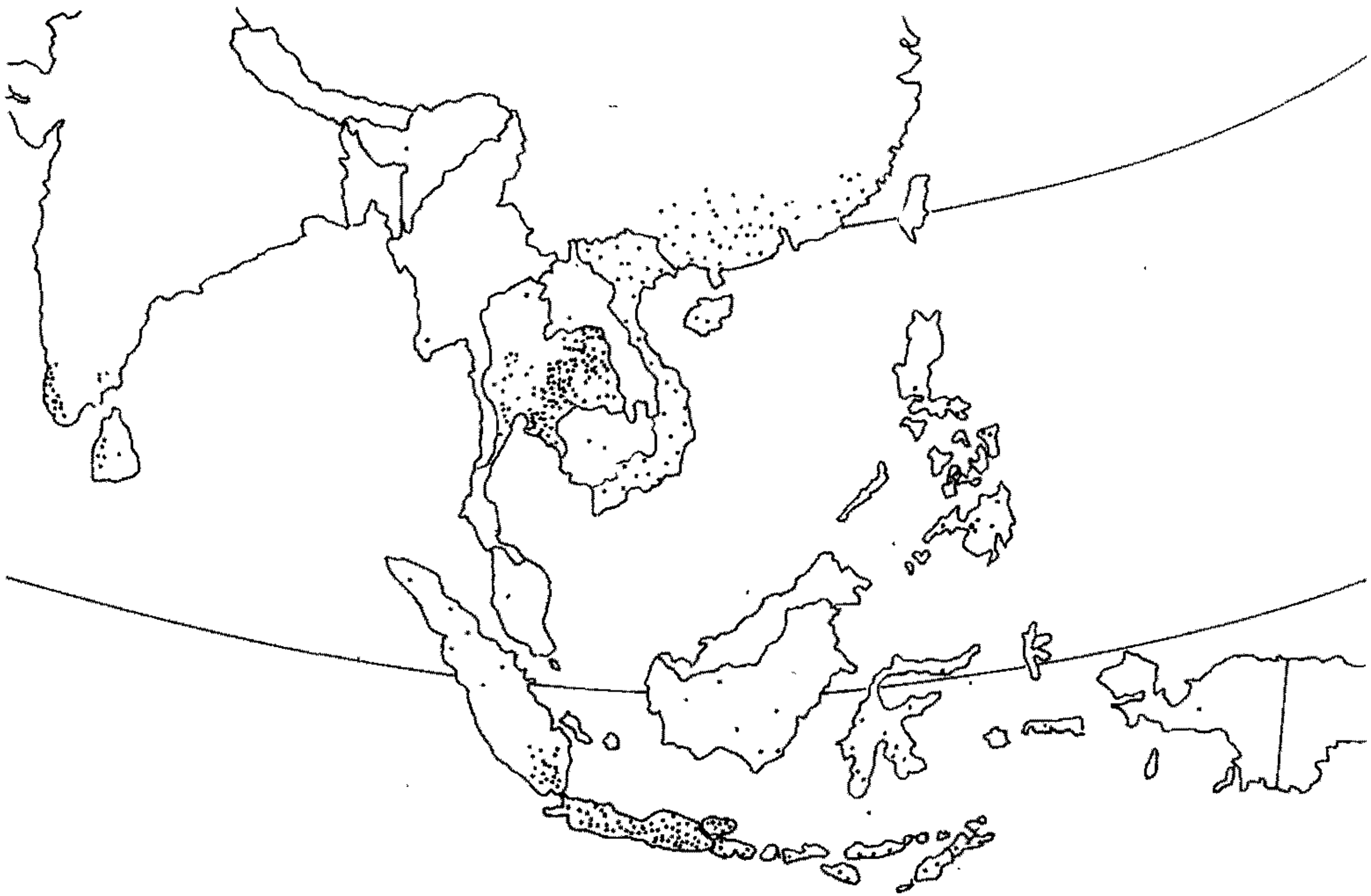


Figure 21.1 Cassava-production zones in Asia in 1989, each dot represents 10,000 ha of cassava.

Table 21.1. Soil and climatic constraints in the cassava-growing regions of Asia.

Country/Region	Soil Constraints: Fertility	Soil Constraints: Susceptibility to Erosion	Climatic Constraints: Rainfall	Climatic Constraints: Temp
Thailand - SE	Low	Very high	Irregular	-
NE	Very low	High	Low-irregular	-
Indonesia- Java	Low-medium	High	Low-medium	-
Sumatra	Very low	High	Medium-high	-
India - Kerala	Low	High	Medium	-
Tamil Nadu	Medium-high	Low	Very low	-
China - Guangdong/ Guangxi	Low	High	Medium	Cold winter
Hainan	Medium	Extremely high	Medium	Cool winter
Vietnam - North	Very low	Very high	Medium	Cold winter
South	Low	Medium	Medium	-
Malaysia - Mineral soils	Medium	Medium	High	-
Peat soils	Medium	Low	High	-
Philippines - Leyte	Medium	High	Medium-high	-
Bohol	Low	Medium	Low	-
Sri Lanka- Central	Low-medium	Medium	Medium-high	-
East	Medium-high	Low	Low	-

some general conclusions from these results with an indication on the future steps required to reach the objective of developing efficient soil and crop management practices for sustainable cassava production in Asia.

21.2 Erosion Control

The Thai Land Development Dept. has estimated that 33% of the total land area is moderately to severely eroded; most of this land is located in the cassava-growing areas in the SE and NE. On Hainan Island of China, several years of erosion control trials indicated max. soil losses of 100-200 t/ha/yr; similarly high levels of erosion were determined for bare fallow plots in Malang, Indonesia. As can be seen, erosion is indeed a serious problem in Asia, not only because it results in a large loss of topsoil, reducing soil productivity, but also because the sediment load of the rivers may cause flooding in the lower-lying areas and silting-up of hydroelectric and irrigation reservoirs.

Cassava is often considered to be a crop that causes severe erosion, but recent research has shown that this depends mainly on the way the crop is managed. For that reason, simple trials to determine the effect of agronomic practices on cassava yield and erosion were set up at 8 different sites in 5 countries. Various soil or crop management treatments were established on plots located on a uniform slope. Below each plot a contour channel (40 cm deep x 40 cm wide) was dug and covered with plastic sheeting. Little holes made in the plastic allowed runoff water to seep away into the soil; eroded sediment collected in these channels was weighed once a month. After determining the MC of sediment samples, the amount of dry soil loss due to erosion was calculated.

Figure 21.2 shows the effect of various crop management and tillage practices on cumulative soil loss due to erosion on Hainan Island, China. Similar to last year (Cassava Program Annual Report, 1990), highest soil losses (193 t dry soil/ha in 8 mo) on a 25% slope occurred in those plots that received intensive land preparation (2 plowings + 2 diskings) without contour ridging. As the intensity of land preparation decreased, erosion losses also decreased; zero tillage caused the least erosion. In an adjacent trial on a 15% slope, highest levels of erosion were observed when cassava was grown without fertilizers; the least when cassava was grown on contour ridges or intercropped with peanuts (Tables 21.2 & 21.3). Planting cassava in a vertical position on contour ridges, with fertilizer, or intercropped with peanuts produced the highest yields with relatively low levels of erosion. In the tillage trial (Table 21.3), complete tillage followed by contour ridging produced the highest yield and a relatively low level of erosion, while zero tillage resulted in the lowest level of erosion, reducing yield only slightly.

Figure 21.3 shows the soil losses due to erosion in selected treatments of a trial conducted on a 5% slope in Lampung Province of Indonesia. When grown in monoculture, cassava caused more erosion than peanuts, rice or maize; while cassava planted in a square (1.0 x 1.0 m) arrangement caused less erosion than when a wider row spacing was used. Various intercropping systems with cassava, rice, maize, peanuts and mung beans caused slightly less erosion than monocropped cassava. Figure 21.4 shows the avg effect of cassava planting arrangement on total crop value and erosion in both monocropped and intercropped cassava. Intercropping resulted in a slightly higher total crop value than monocropping, while cassava plant spacing had no significant effect on the intercropped system. In monocropped cassava, however, the square planting arrangement produced a slightly higher gross income than the wide- or double-row systems. Similarly, in intercropped cassava, planting arrangement had no significant effect on erosion losses; but in monocropped cassava, the square planting arrangement caused much less erosion than the wide- or double-row arrangements. Based on these 3 yr of data, it can be concluded that planting arrangement did not significantly affect the gross income or erosion in intercropped cassava, but that the square planting arrangement produced more income and much less erosion than the wider row spacings in monocropped cassava.

Erosion control trials were also conducted in E. Java in collaboration with Brawijaya U. in Malang, looking mainly at the effect of contour ridging and live barriers on erosion and yield in a cassava-maize intercropping system (Table 21.4). Contour ridging consistently

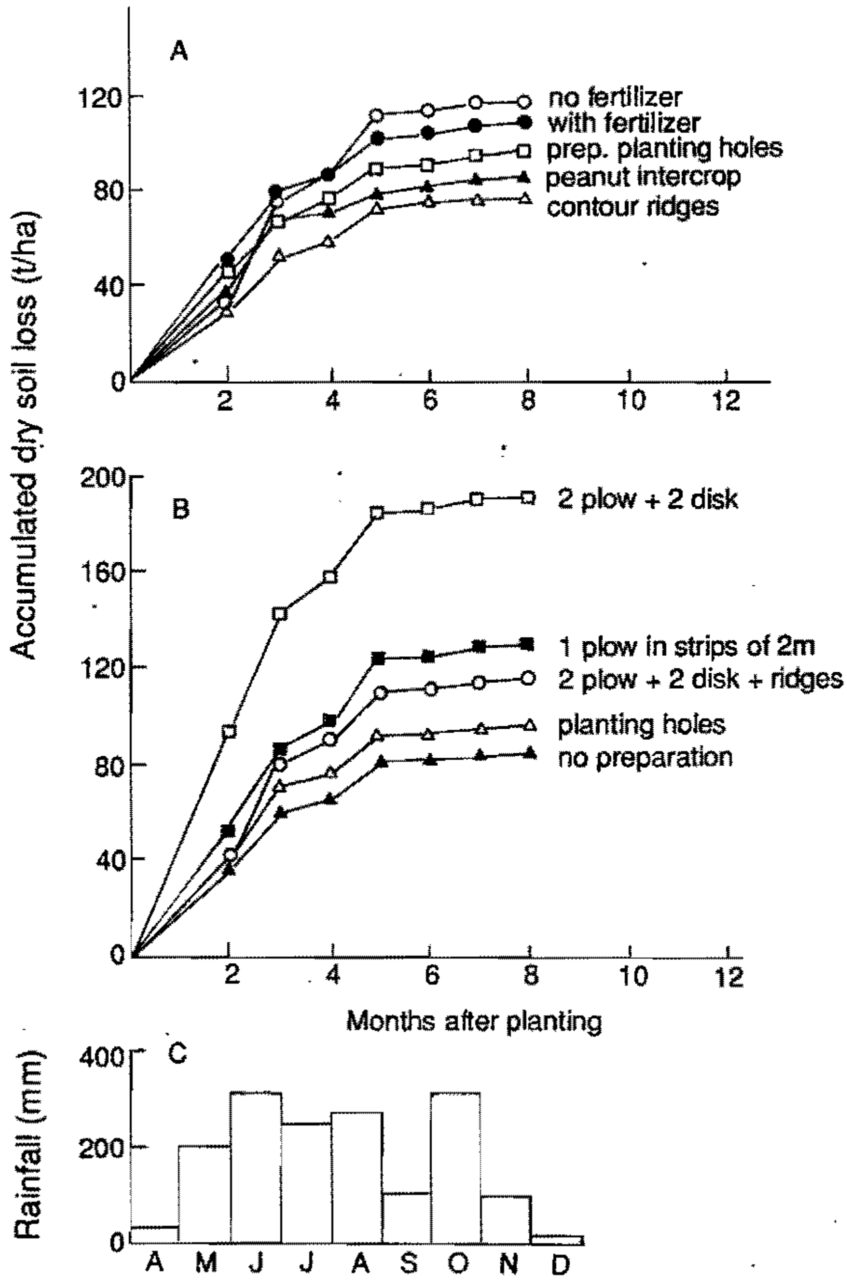


Figure 21.2. Effect of various cultural practices (A) and land preparation methods (B) on accumulated dry soil loss due to erosion on a 15 and 25% slope, respectively, at SCATC, Hainan, China in 1990. Rainfall distribution is shown in C.

Table 21.2. Effect of various cultural practices on dry soil loss (t/ha) due to erosion and on fresh RY (t/ha) of cassava planted on 15% slope at SCATC, Hainan, China in 1990 (2nd year).

Treatments	Soil Loss	RY
No ridge, no fert., horizontal planting, 1.0x0.8 m	119.5 a	25.3 b
No ridge, with fert., horizontal planting, 1.0x0.8 m	110.7 a	33.5 a
No ridge, with fert., horizontal planting, 0.8x0.8 m	118.6 a	32.2 a
No ridge, with fert., vertical planting, 0.8x0.8 m	106.6 a	27.8 b
Contour ridge, with fert., vertical planting, 0.8x0.8 m	77.8 a	31.8 a
Planting holes, with fert., vertical planting 0.8x0.8 m	98.3 a	33.0 a
No ridge, with fert., vertical, 9 rows cassava + 1 row *B. decumbens*.	106.6 a	30.0 ab
No ridge, with fert., vertical, 9 rows cassava + 1 row *S. guianens*.	100.4 a	29.2 ab
No ridge, with fert., vertical, intercropped with peanuts	87.1 a	32.7 a
LSD (0.05)		4.90

Table 21.3. Effect of various methods of land preparation on dry soil loss (t/ha) due to erosion and on fresh RY (t/ha) of cassava planted on 25% slope at SCATC, Hainan, China in 1990 (2nd year).

Treatments	Soil Loss	RY
2 oxen plowing + 2 disking + ridging	117 b	34.6 a
2 oxen plowing + 2 disking, no ridging	193 a	29.6 ab
1 oxen plowing, no ridging	105 b	30.5 ab
4-m wide plowed strip alternated with 1-m strip without preparation	196 a	30.5 ab
2-m wide plowed strip alternated with 0.5 m-strip without preparation	131 ab	28.5 b
Preparation of planting holes with hoe	97 b	27.6 b
No preparation	88 b	29.4 ab
LSD (0.05)	65.35	5.83

reduced erosion compared with no-ridging, and live barriers of elephant and setaria grass were more effective in reducing runoff and erosion than a barrier of peanuts or hedgerows of *Leucaena leucocephala* or *Gliricidia sepium*. Cassava and maize yields were highest in the presence of elephant grass barriers. Unlike most other trials with grass barrier strips, there was little competition between cassava and the elephant grass and no significant reduction in cassava RY; moreover, farmers can cut the elephant grass to feed their cattle, making this a highly attractive management practice.

In Thailand a total of 9 erosion control trials were conducted at 3 locations for 3-4 yr in collaboration with the Dept. of Agriculture and KU. Table 21.5 shows the effect of various crop and soil management treatments on erosion and yield at Sriracha Station. Contour ridging and fertilizer application consistently resulted in high yields and low levels of erosion. Intercropping with grain legumes such as peanuts was very

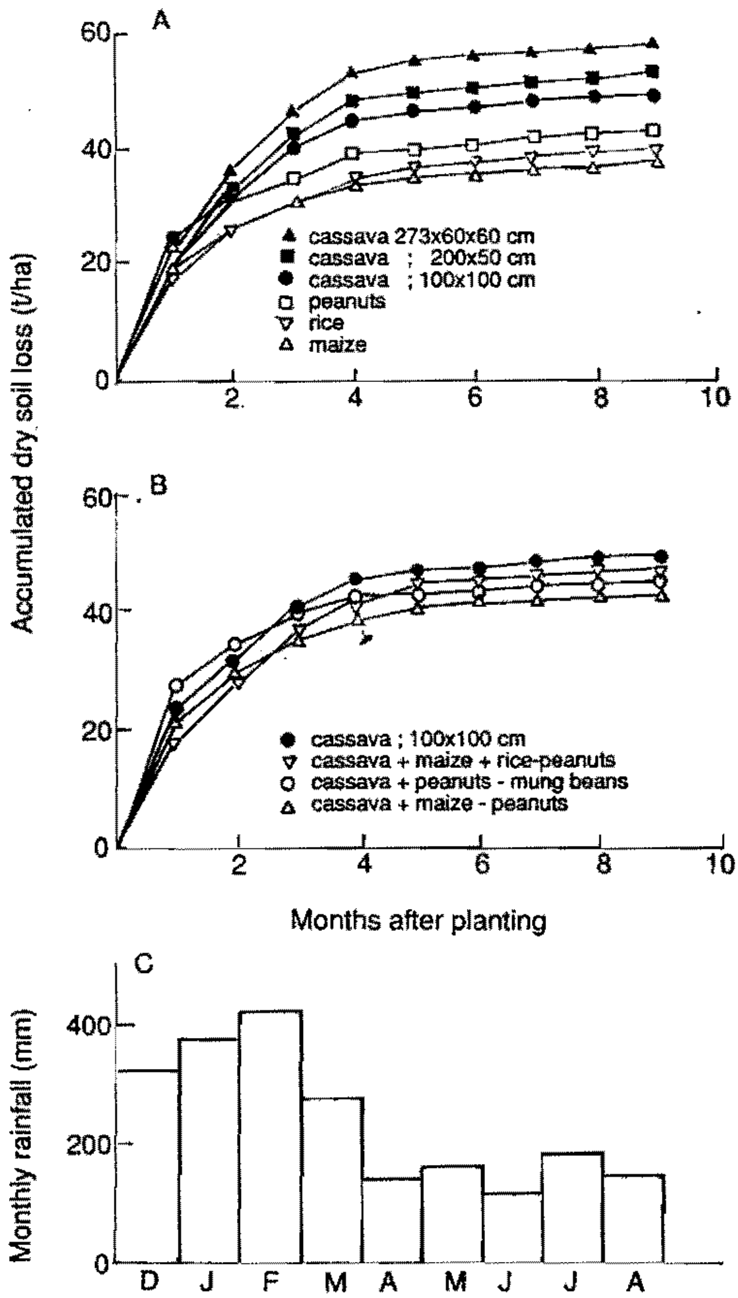


Figure 21.3. Accumulated dry soil loss by erosion in various monocrop (A) and intercropping (B) systems during a 9-mo cropping cycle on 5% slope in Tamanbogo, Lampung, Indonesia in 1989/90. Rainfall distribution is shown in C.

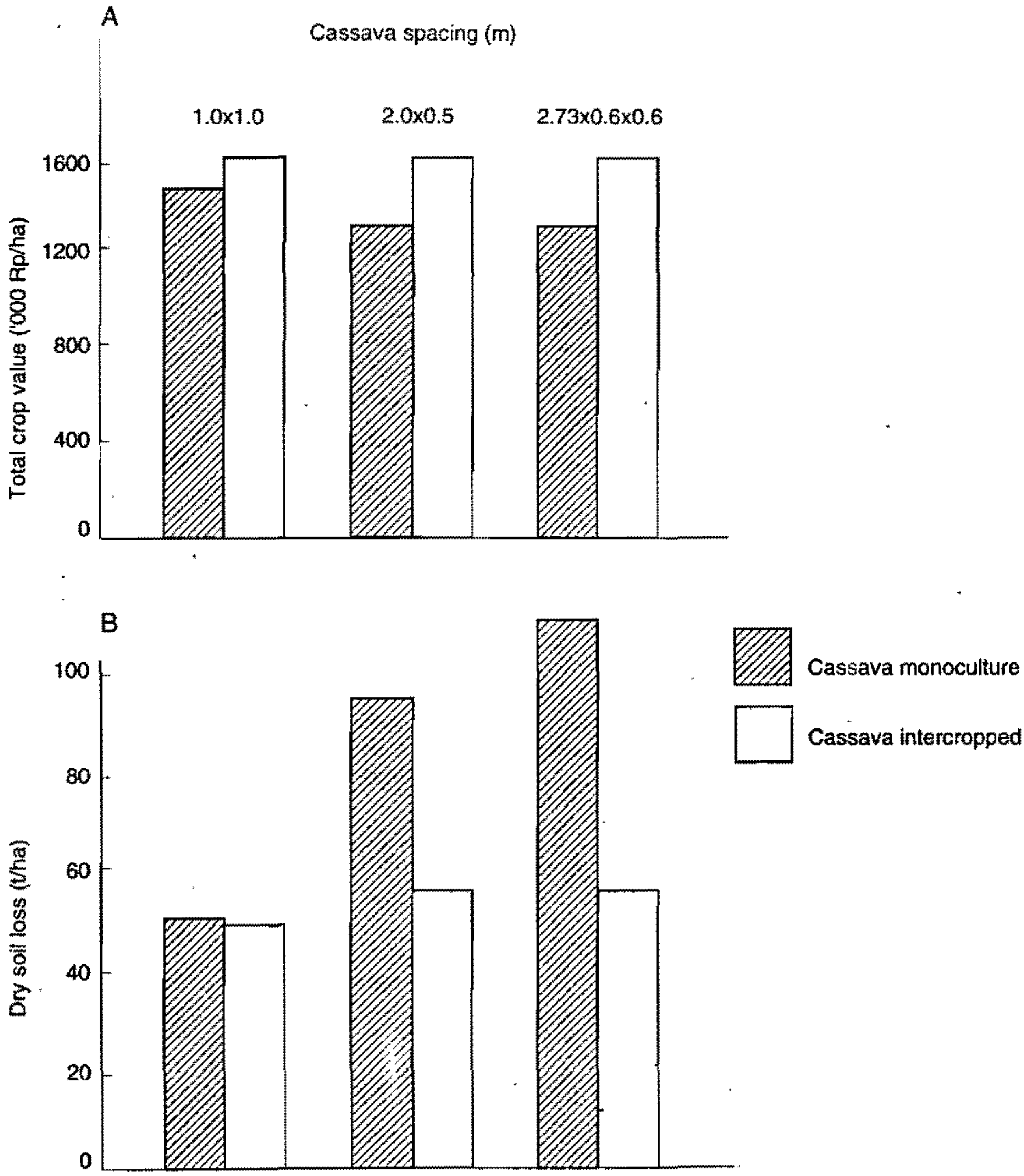


Figure 21.4. Effect of cassava planting arrangement on (A) total crop value and (B) soil losses due to erosion for either monocropped or intercropped cassava, grown in Tamanbogo, Lampung, Indonesia. Data are avg of trials conducted in 1987-89. Intercropped cassava is avg of 4 cropping systems (C+M+R-P; C+M-P; C+R-P; and C+P-Mu, where C=cassava, M=maize, R=upland rice and Mu=mung bean.

Table 21.4. Effect of various systems on cassava and maize yields, as well as on runoff and erosion, on an 8% slope at Jatikerto Experiment Station in Malang, Indonesia in 1988-89.

Treatments	Yield (t/ha) Cassava	Yield (t/ha) Maize	Runoff (% Rainfall)	Dry Soil Loss (t/ha)
Contour ridges, no live barriers	28.35	3.00	13.90	44.8
Contour ridges, elephant grass barriers	25.90	3.64	9.82	20.2
Contour ridges, setaria grass barriers	19.90	3.53	10.60	34.2
Contour ridges, peanut barriers	18.05	3.25	12.17	37.4
Contour ridges, *G. sepium* barriers	17.80	3.20	12.48	39.0
Contour ridges, *L. leucocephala* barriers	24.55	3.15	13.10	40.6
No ridges, peanut barriers	25.10	2.83	16.64	54.5
No ridges, setaria grass barriers	26.50	2.91	15.52	49.2
Fallow plot	-	-	-	119.0

effective in reducing erosion, but usually reduced cassava RY slightly. Intercropping with pigeon peas markedly reduced yields, making this practice unacceptable to farmers. Reduced tillage, subsoiling or zero tillage were practices that generally reduced erosion and sometimes (but not always) increased yields. Live barriers of elephant or king grass were less effective in controlling erosion and usually reduced cassava RY. Table 21.6 ranks these practices in terms of erosion control, yield and costs. Complete land preparation followed by contour ridging was very effective in reducing erosion and increasing yield but was relatively costly. In contrast, complete land preparation without ridging and no fertilization was the least costly, but also the least effective in reducing erosion or increasing yield. An intermediate practice of no-tillage, closer plant spacing and fertilizer application was quite effective in reducing erosion and produced reasonably good yields, making this an attractive practice for farmers with limited resources. However, adequate crop residue management and weed control are crucial for this practice to be successful.

After several years of conducting erosion-control trials at various experiment stations in Asia, some soil and crop management practices have been identified that seem promising in terms of erosion control and yield enhancement. The next step will be to test some of these practices on farmers' fields in collaboration with the extension services in order to obtain the opinion of farmers and extension agents on which practices may/may not be adoptable and why. In Thailand 4 such trials have been established on farmers' fields in Rayong Province in collaboration with the Depts. of Agriculture, Land Development and Agricultural Extension. Depending on the outcome of these trials and the interest shown by farmers and extension agents, these trials may be expanded in the future into other cassava-growing areas of the country. Field days and the publication of simple pamphlets or booklets on cassava production and soil conservation are planned for the future. Similar extension activities are also planned in other countries.

Table 21.5. Effect of soil and crop management on soil loss (t/ha) and cassava RY (t/ha) in 4 experiments at Sriracha Research Station, Chonburi, Thailand.

Soil and Crop Management	1987 SL[1]	1987 Yield	1988[2] SL	1988[2] Yield	1989[2] SL	1989[2] Yield	1990[2] SL	1990[2] Yield
No tillage	93.8	30.7	5.7	26.2	11.6	11.4	7.4	18.2
2 plowings followed by 2 diskings, no ridging	30.5	25.8	11.1	31.1	6.0	12.0	10.4	16.0
2 plowings and 2 diskings followed by contour ridging	11.1	35.5	5.1	29.6	4.1	11.4	3.9	18.1
Subsoiling at 40-cm depth, 80-cm row width, cassava at 80 x 125 cm	22.2	34.3	4.6	22.5	6.9	11.7	6.4	17.3
Treat. 2 but with contour bank every 10 m grown with *L. leucocephala*								
Strip preparation with 4-disk plow, preparing 2-m contour strips alternated with 1-m unprepared strip; cassava at 100 x 67 cm	-	-	17.7	27.4	3.9	12.4	4.5	11.0
Plowing only once with 4-disk plow	42.1	26.7	-	-	-	-	-	-
2 plowings and diskings followed by up-and-down ridging	37.5	22.3	-	-	-	-	-	-
Treat. 2 with cassava in double rows and intercropped with 2 rows of maize	35.4	25.6	11.8	33.2	-	-	-	-
Treat. 2 with cassava in double rows and intercropped with 2 rows of peanuts	44.9	22.5	-	-	-	-	-	-
Treat. 2 and intercropped with 1 row of *Arachis pintoi*	17.2	22.8	4.7	26.4	-	-	-	-
Treat. 2 and intercropped with 1 row of pigeon peas	-	-	-	-	5.4	11.9	-	-
Live barrier of *Brachiaria* grass, 2-m wide contour strip every 10 m	-	-	-	-	-	-	7.1	2.4
Live barrier of elephant grass, 2-m wide contour strip every 10 m	52.7	22.6	-	-	-	-	-	-
Live barrier of king grass, 2-m wide contour strip every 10 m	36.5	23.3	-	-	5.1	12.0	10.6	11.7
Treat. 2 but without fertilizer application	-	-	-	-	9.4	11.0	12.0	12.8
Treat. 2 but planted at 80x80 cm (15,625 pl/ha)	54.9	18.8	16.7	24.1	-	-	-	-
Treat. 2 but chemical weed control	24.4	25.4	-	-	-	-	-	-
LSD ($P < 0.10$)	25.7	30.9	-	-	-	-	-	-
	-	-	2.7	5.3	3.9	NS	1.6	1.2

[1] SL = Soil loss due to erosion

[2] Avg of 2 reps.

Table 21.6. Ranking[1] of cassava cultural practices in terms of erosion control and yield, based on 9 erosion control trials conducted at 3 locations in Thailand.

	Erosion Control	Yield	Cost
Plowing, disking, contour ridging	1	1	8
Plowing, disking, peanut intercropping	2	7	5
Plowing, disking, planting cassava at closer spacing	3	5	4
No tillage	4	4	2
Plowing, disking, elephant grass barrier	5	6	6
Plowing, disking, no ridging	6	3	3
Plowing, disking, up-and-down ridging	7	2	7
Plowing, disking, no fertilizer application	8	8	1

[1] The lower the score the better.

21.3 Soil Fertility Maintenance

Most cassava soils in Asia are characterized by low soil fertility (Table 21.1); moreover, cassava is often grown on severely eroded slopes with very low levels of OM and plant nutrients. Many short-term fertilizer trials conducted by national programs have shown that cassava responds mainly to the application of N; significant responses to P and K are much less common. Long-term fertilizer trials conducted in Thailand (3 locations), India and Malaysia, however, indicate that after several years of continuous cassava production, K deficiency became the main limiting factor and high cassava RYs could be maintained only through adequate K fertilization. This is because cassava extracts relatively large amounts of K from the soil, most (60-70%) of which is removed from the field in the root harvest. As most tropical soils contain only limited reserves of K-bearing minerals, the K-supplying power of these soils will eventually become exhausted.

In order to sustain high yields of cassava, it is essential to maintain the productivity of the soil by applying chemical fertilizers or organic manures, by enhancing N inputs through biological N fixation, and by recycling leached nutrients. Research was conducted to determine the optimum rates and methods of fertilizer application and to develop economically feasible practices of green manuring, intercropping, cover cropping and alley cropping.

21.3.1 Fertilization

To determine both the short-term fertilizer response as well as the long-term fertilizer requirements, simple long-term NPK trials have been established at 13 locations in 5 countries. These trials generally have 12 treatments with various combinations of 4 levels of NPK, in such a way that the response to each element can be determined while the other two elements are applied at near-optimum levels.

Figure 21.5 shows the results of the second-year trial at 2 sites in China. There was a significant response to the application of N only at levels of 50 or 100 kg/ha. The combined application of high levels of NPK more than doubled yields in Guangzhou and significantly increased yields (up to 100-50-100 kg/ha of N-P_2O_5-K_2O) in Nanning. In China no significant responses to K have yet been observed. In contrast, in Bac Thai Province of northern Vietnam, K applied to these extremely poor and eroded soils quadrupled cassava RYs (from ca. 8 to 30 t/ha) the first year; there was also a significant but less dramatic response to N and P.

Despite intermediate levels (1-3%) of soil OM, there were significant first-year responses to N application in 7 out of 10 locations; while significant responses to P and K were observed only in 3 and 2 locations, resp. It is expected that K responses will become more pronounced after more years of continuous cassava production. Despite low levels of available P in most cassava soils in Asia, the response to P was seldom significant, indicating the presence of a very effective natural mycorrhizal association.

Although significant responses to some nutrients have been observed in most locations, cassava farmers seldom have the resources to buy chemical fertilizers. In India and Indonesia this is partially overcome by the application of farmyard manure and/or wood ash. While cassava responds favorably to these natural sources of plant nutrients, the level of application is seldom high enough to sustain high yields. Other practices that may supply additional N through biological N fixation, or that recycle leached-out K, Ca and Mg, have been investigated through collaborative trials, mainly in Thailand. These trials evaluated native or introduced legume species and tested some of these species as green manures, cover crops and intercrops, or for alley cropping systems.

21.3.2 Intercropping

Intercropping cassava with various grain legumes usually decreases the yields of the component crops but increases the total productivity of the land and farmers' incomes while reducing risks. At Hung Loc Station in southern Vietnam, intercropping consistently reduced cassava yields; growing cassava in single rows (1.0 x 1.0 m) produced better yields and net income than planting cassava in double rows (2.0 x 0.8 x 0.71 m) (Fig. 21.6). Peanuts, winged beans and mung beans were the least competive intercrops, which also produced the highest net income. Cassava monocropping, however, gave higher economic returns than any of the intercropping systems.

Table 21.7 shows the effect of cassava planting arrangement on cassava and grain legume yields in 3 trials conducted in Thailand from 1988-90. Planting cassava in either single (1.8 x 0.55 m) or double (3.0 x 1.0 x 0.55 m) rows had no consistent effect on cassava or intercrop yields. The intercrop yields were significantly higher in the single-row system in 2 of the 3 yr; however, the double-row system allows the planting of a second intercrop after the first crop has been harvested, thereby increasing the farmer's total income. In general intercropping reduced cassava RY, especially in the case of the

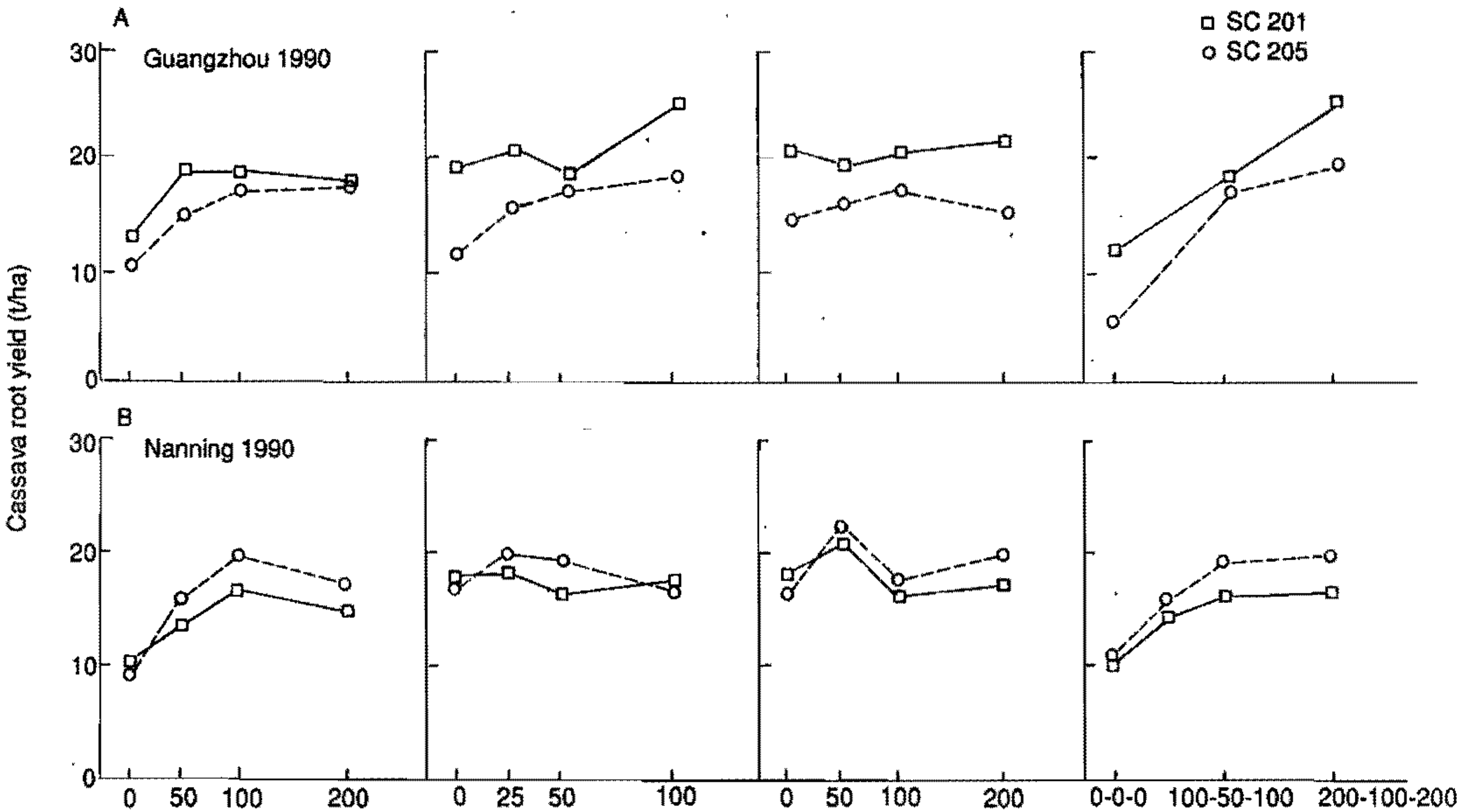


Figure 21.5. Effect of NPK application on cassava yields during the second year planting in Guangzhou, Guangdong (A) and in Nanning, Guangxi (B) China in 1990.

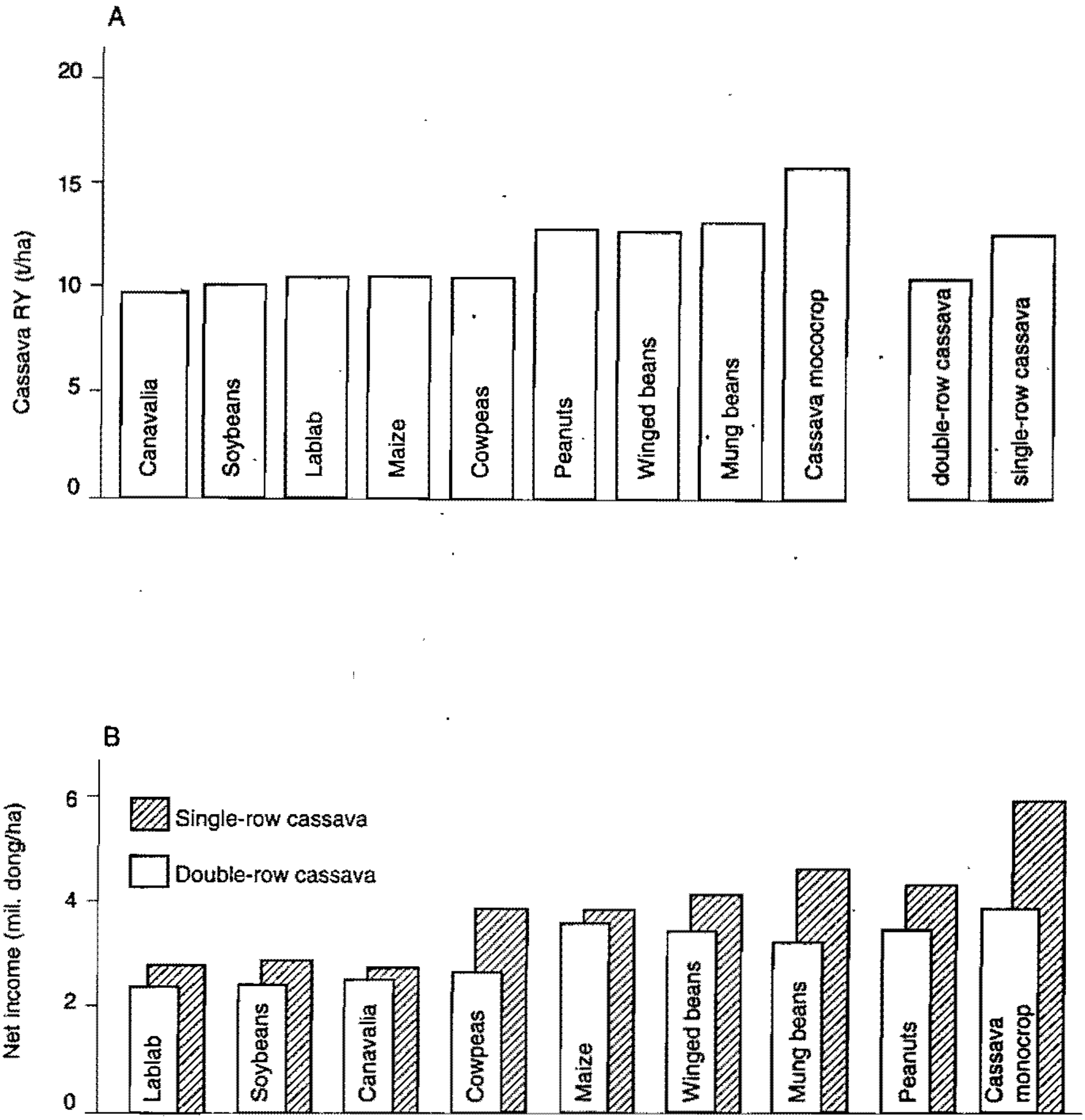


Figure 21.6. Effect of various intercropping systems on cassava yield (A) and net income (B) when cassava was planted in single or double rows in Hung Loc Center of Dong Nai Province in South Vietnam, 1990-91.

Table 21.7. Effect of cassava planting arrangement on yield in monoculture cassava and in various intercropping systems at RFCRC, Thailand.

	Cassava RY (t/ha)						Intercrop Yield (kg/ha)						
	1988-89		1989-90		1990-91		1988-89		1989-90		1990-91		
	A	B	A	B	A	B	A	B	A	B	A	B-1	B-2
Cassava monocrop	14.56	17.52	16.06	10.81	28.84	27.79	-	-	-	-	-	-	-
+ Cowpea TVX 1193-059 D	10.02	14.27	14.25	12.56	16.71	23.99	375	350	436	412	596	327	572
+ Cowpea S-11	16.16	12.28	13.69	11.56	25.58	29.45	556	406	106	164	372	205	275
+ Cowpea local variety	6.10	7.36	11.50	8.69	19.81	18.67	819	600	375	341	576	311	705
+ Cowpea Vita 3	7.49	7.96	14.69	11.94	16.85	23.69	650	544	308	289	298	277	296
+ Peanut Tainan 9	16.29	18.30	13.44	11.87	24.71	25.88	375	231	287	416	637	944	-
+ Mung bean Utong 1	11.28	18.50	17.37	14.25	27.99	24.40	519	494	128	167	827	327	427
+ Mung bean Chainat 60	-	-	17.19	12.06	25.33	23.79	-	-	234	142	388	289	489
+ Soybean SJ-5	11.47	9.02	-	-	-	-	569	362	-	-	-	-	-
Avg	11.67	13.15	14.77	11.71	23.23	24.71	552	427	268	276	528	383	395

A = Single-cassava row (1.80x0.55 m); B = double cassava rows (3x1x0.5 m); B-1 = first intercrop; B-2 = second intercrop.

local and Vita 3 cowpea varieties. Intercropping with mung beans (Utong 1) tended to result in the highest gross income.

21.3.3 Green Manuring

Planting a green manure crop in the early part of the rainy season may be one way to increase the soil OM content and supply N to the cassava crop planted after incorporating or mulching the green manure in the middle or at the end of the rainy season. Starting in 1988, ten green manure species were planted in Pluak Daeng, Thailand, in early June. In the first year the green manures were cut and incorporated into the soil after 3 mo; while in the second and third years, they were cut and left on the surface as mulch. Cassava was planted shortly after the green manure harvest in Sept. of each year.

Table 21.8 shows the effect of green manures on cassava RY for 3 years. The first two years cassava RYs were very low because cassava was planted late when the rainy season was already half over. In the first year, *Sesbania rostrata*, *Crotalaria juncea* and *C. mucronata* were quite effective in increasing cassava RYs, which were similar to those of fertilized cassava. In the second and third year, however, *C. juncea*, *Canavalia ensiformis* and *Mucuna fospeada* were most effective. *C. juncea* and *Canavalia ensiformis* appear to be the most promising species as they produce the highest levels of DM as well as NPK. Soil analyses during this 3-yr experiment indicate that soil pH and exchangeable K declined quite markedly in all treatments (Fig. 21.7); green manures and fertilizer application were only slightly effective in reducing this decline. The OM level dropped from about 1.0% to 0.4% during the first 2 yr, but increased again to 0.9% in the third yr. Green manuring or fertilizer application did not seem to have a significant effect on soil OM.

Research is presently under way to determine the best management of the green manure residue. In order to be able to plant cassava in the early part of the rainy season, it may be better to plant some of the green manure species intercropped with cassava, cutting the green manures after 2-3 mo and leaving the residue as a mulch between cassava plants to reduce weeds and erosion.

21.3.4 Cover cropping

The use of cover crops as live mulch growing between cassava is another way to control erosion and weeds and to supply N to the cassava. In 1988, nine cover crops were planted between cassava rows (1.8 x 0.55 m). During the first year, the cover crops were allowed to compete freely with cassava; however, before the second and third cassava plantings, the cover crops were cut back and about 60-cm wide strips cleared, either by a small hand tractor with rotovator or by spraying with a herbicide (paraquat). Cassava was planted in these cleared strips at 1.1 x 0.9 m. During the second and third cassava growth cycle, the cover crops were regularly slashed back to reduce competition.

Table 21.8. Effect of incorporating green manures on cassava yield in three trials at Pluak Daeng, Thailand.

	Cassava RY (t/ha)		
	1988-89[2]	1989-90[3]	1990-91[3]
No green manure, no fertilizer	3.21 cd	5.75 bcd	16.36
Sesbania rostrata, no fertilizer	9.29 a	5.37 bcd	15.04
Sesbania speciosa, no fertilizer	5.61 abcd	4.46 cd	17.52
Sesbania aculeata, no fertilizer	5.19 bcd	4.42 cd	13.23
Crotalaria juncea, no fertilizer	9.04 ab	8.83 a	17.29
Crotalaria mucronata, no fertilizer	6.71 abc	5.17 bcd	11.77
Crotalaria spectabilis, no fertilizer	5.81 abcd	3.96 d	17.64
Canavalia ensiformis, no fertilizer	5.37 bcd	7.00 abc	14.67
Indigo, no fertilizer	5.37 bcd	5.08 bcd	16.61
Mucuna fospeada, no fertilizer	5.21 bcd	6.08 abcd	16.45
Pigeon peas, no fertilizer	2.06 d	4.50 cd	14.79
No green manure, with fertilizers[1]	8.75 ab	7.71 ab	17.04
F-test	P≤0.01	P≤0.05	NS

[1] 100 N, 0 P, 50 kg K_2O/ha.
[2] Green manures incorporated.
[3] Green manures mulched.

Table 21.9 shows the effect of the cover crops on cassava RY during the first 3 yr. Yields were rather low in all trials due to low levels of fertilizer inputs. During the first year of establishment, all cover crops competed with cassava and reduced yields; but this was not significant in the case of *Stylosanthes hamata*. Most other cover crops were highly competitive. During the second year when the cover crops were partially cleared by hand tractor, all species again reduced cassava RY, but significantly only in case of *S. hamata* and *Centrosema pubescens*. As long as the growth of the other species was regularly controlled by cutting them back, they did not significantly reduce cassava RY. If the cover crops were cleared only at planting with the use of an herbicide, they caused severer cassava yield reduction due to root competition during the early growth stage. This was particularly noticeable during the third year when cassava suffered from a drought 1-2 mo after planting when drought stress was exacerbated by strong root competition from the cover crops, resulting in poor germination and/or dieback of cassava and low yields. Again, partial control of the cover crops with herbicides was not nearly as effective as mechanical control with a hand tractor; the latter temporarily reduced root competition form the cover crops. Of the cover crops tested in these trials, Indigo, *Mimosa envisa, Arachis pintoi* and *Centrosema acutifolium* appear to be the most promising species.

The use of less-aggressive cover crops, optimum cassava plant spacing, and better methods of managing the ground cover are currently being investigated.

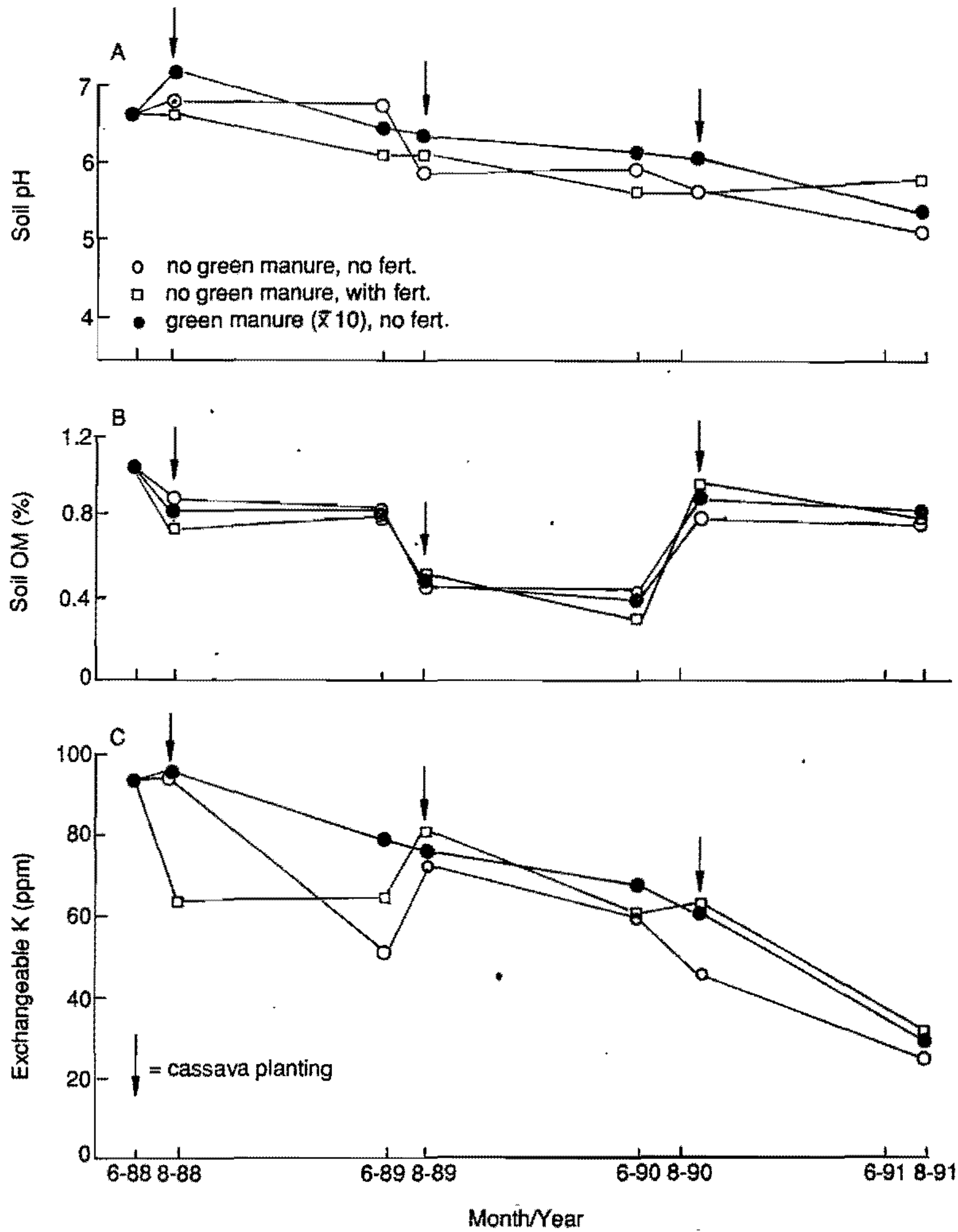


Figure 21.7. Effect of 3 yr of cassava cropping, with and without green manures (avg of 10 spp.) and with and without fertilizers on (A) soil pH, (B) OM and (C) exchangeable K content in Pluak Daeng, Thailand.

Table 21.9. Effect of intercropping cassava with leguminous cover crops on cassava RY in three trials at Pluak Daeng, Thailand.[1]

	Cassava RY (t/ha)		
	1988-89	1989-90	1990-91
No cover crop	11.68 a	7.79 a	19.62 a
Cover crop of *Stylosanthes hamata*	10.27 ab	3.91 c	4.45 de
Cover crop of *Arachis pintoi*	8.46 bc	6.56 ab	9.71 cd
Cover crop of *Centrosema acutifolium*	7.66 bc	6.69 ab	15.33 ab
Cover crop of *Centrosema pubescens*	7.51 bc	5.60 bc	6.17 d
Cover crop of *Mimosa envisa*	7.49 bc	6.48 ab	13.33 bc
Cover crop of *Desmodium ovalifolium*	7.26 bc	6.78 ab	13.46 bc
Cover crop of *Macroptillium atropurpureum*	6.61 c	7.70 a	8.96 cd
Cover crop of *Stylosanthes guianensis*	3.21 d	6.56 ab	0.83 e
Cover crop of indigo	3.05 d	6.36 ab	8.50 c
F-test	$P \leq 0.01$	$P \leq 0.05$	$P \leq 0.01$

[1] Cassava received 25 kg N, 25 kg P_2O_5, 25 kg K_2O/ha; tractor preparation of cassava planting strips in 1989-90 and 1990-91.

21.3.5 Alley cropping

Research on the use of perennial leguminous trees as hedgerows in an alley cropping system with cassava is only in its initial stages. Various species are presently being tested in Thailand to determine their productive capacity, resistance to regular pruning, persistence during the dry season, competitiveness with cassava, and ease of establishment. The two traditional alley crop species, *L. leucocephala* and *G. sepium* are difficult to establish in areas of low rainfall and acid soils. *Leucaena* is initially slow-growing but once established it is quite persistent and resistant to pruning. *Cassia siamea* can be established more rapidly, is highly productive and very acid-soil tolerant; however, it does not fix N and would be beneficial mainly for nutrient recycling and as a soil protector against erosion. Perennial pigeon pea (*Cajanus cajan*) is easily established, highly productive and allows regular pruning for 2-3 yr. Many *Sesbania* species are initially very productive but do not recuperate well after pruning. *Flemingia macrophilla* and *Thephrosia candida* seem to be promising but need further testing. Using a mixture of fast-growing pigeon peas with a slower growing but more persistent tree species like *Leucaena* may be another alternative.

The use of hedges of *Leucaena* and *Gliricidia* have also been investigated for several years in Malang, E. Java (Table 21.4). Hedgerows were intermediately effective in reducing erosion but had no effect on cassava RY. During the fourth year, however, both species were quite effective in supplying N through the leaf prunings that were spread among the cassava plants, thus preventing the severe N-deficiency that was observed in the other plots. This is likely to have a beneficial effect on cassava RY in soils with low levels of available N.

21.4 Conclusions

Collaborative research on soil erosion control and fertility maintenance in Asia has been conducted in many countries since 1987. The most effective erosion control practices identified in those trials do not always increase cassava yields or reduce production costs. If they are to be accepted by farmers, these practices must not require a lot of additional labor or money and must be economically attractive. Practices that seem very promising in this respect include the use of fertilizers, closer plant spacing, intercropping, minimum tillage, subsoiling and contour ridging.

To prevent soil degradation and nutrient exhaustion, optimum levels of fertilizer inputs are being determined, to satisfy both short- and the long-term fertilizer requirements. The judicious use of chemical fertilizers is probably the most effective and, in the long-run, the most economical way to maintain soil productivity. For those farmers who cannot afford chemical fertilizers, alternative management practices are being developed to maintain soil productivity through crop rotations, green manuring, intercropping, cover cropping and alley cropping. These aspects will need a lot of additional research before practical management practices are developed. Eventually, an integrated approach to soil management, including soil erosion control practices, fertilization, crop rotations and green manuring, will need to be developed for sustaining high cassava RY while preventing a deterioration of the natural resource base.

Although research findings are often situation-specific, the basic principles are becoming increasingly clear. One objective of these studies is to provide baseline principles that will lead to policy definitions for better natural resource management. Another necessary step is to test the results of these studies on farmers' fields to ensure that the recommended practices are applicable under local socioeconomic conditions.

22. COLLABORATION WITH IITA IN SUPPORT OF AFRICAN NATIONAL PROGRAMS

22.1 Importance and Trends of Cassava in Africa

Africa produces 42% of the world's cassava. Zaire, Nigeria and Tanzania accounted for 27, 25 and 10%, resp. of the continental production of ca. 60,000 t (Table 22.1). Per capita production was highest in Zaire, the Congo and Gabon, with 497, 379 and 246 kg, resp., in 1988. Coastal West Africa and Central Africa each account for one third of the total production. East and southern Africa and semiarid West Africa produce 30 and 5%, resp. Avg annual increases in production during the 1970s and 1980s of 2.6 and 2.7%, resp., have not kept pace with the rate of population growth in Africa's cassava belt. Avg productivity (6.8 t/ha) is lower than in Asia or Latin America.

Most of the cassava produced in Africa is consumed by humans, with less than 2% used as animal feed. It is a major staple in many countries and plays a key role in providing food security because of its resistance to drought and pests and its flexible harvest period. The area planted to cassava is very extensive (80,000 km^2), 12% of which is semiarid.

Table 22.1. Cassava production in Africa, 1966-89.

Country	1966-68	1976-78	1987-89
Zaire	9,667	11,942	16,268
Nigeria	8,588	10,633	15,167
Tanzania	3,467	5,145	6,167
Mozambique	2,225	2,800	3,390
Ghana	1,525	1,842	2,947
Madagascar	1,068	1,465	2,209
Angola	1,523	1,733	1,957
Ivory Coast d'Ivoire	522	1,008	1,309
Others	46,320	7,132	7,948
Total	36056	46,320	59,989

22.2 Areas of Collaboration

22.2.1 Biological control

Two pests of South American origin, the cassava mealybug (*P. manihoti*) and the CGM, were accidentally introduced to Africa in the 1970s. Their spread across most of the cassava belt occurred within a decade and resulted in severe crop losses. In 1990 IITA and CIAT shared the King Baudoin prize for implementing classical biological control of the cassava mealybug through the introduction of the parasite *Epidinocarsis lopezi*, discovered in Paraguay. Since the mid-1980s, IITA has coordinated the activities of a network of national and international institutions working to implement the control of CGM in Africa through introduction of phytoseiid natural enemies from South America. In order to contribute to this effort, CIAT developed methods for rearing, packing and intercontinental shipment of natural enemies, and has worked closely with EMBRAPA on the identification, characterization, selection and provision of natural enemies to IITA. Significant scientific contributions include (a) elucidation of the probable area of origin of CGM within the Neotropics and the relationship between different Neotropical populations of CGM; and (b) identification of geographic subpopulations of phytoseiid predators with differences in ecological adaptation and degree of specificity for CGM. These are key concepts in understanding the biological control status of CGM within its continent of origin and for analyzing the potential of biological control of CGM in Africa and in areas of the Americas where CGM is a pest (see Chap. 8).

22.2.2 The Collaborative Study of Cassava in Africa (COSCA)

The goal of COSCA is to increase the relevance and impact of research related to the cassava crop in Africa by providing accurate information upon which to base the research agenda. The study involves the collection of data that will be used to characterize the structure of cassava-based cropping systems in Africa, the nature and distribution of processing techniques, marketing systems, present and future demand, and the relationships between cassava consumption and nutrition.

The conceptual framework of the project is based on the Latin American cassava demand studies conducted by CIAT in the 1980s and on the expertise and experience of the CIAT ASU with Geographical Information Systems. IITA is responsible for executing COSCA in collaboration with the NRI, CIAT and several other institutions; however, CIAT's participation is limited to the first phase of the study. The ASU elaborated the sampling frame and survey method, participated in training national survey teams, and contributed to the analysis of data from the project's first phase. This work is reported in Chap. 24. CIAT will publish an atlas of cassava in Africa, featuring maps constituting the geographic database, a study of cassava diffusion and case studies of cassava-based farming systems from 3 countries.

22.2.3 Broadening the germplasm base

Cassava, which was introduced to West Africa from Brazil by slave traders in the 1500s, may have reached Central Africa along trade routes through the Congo basin. The Portuguese introduced a small no. of cassava clones to East Africa in the 1700s. Given the high heterozygosity of these clones, farmers were able to select superior seedlings arising from cross-pollination. This process resulted in the development of over 450 morphologically distinct local varieties by the 1950s. Nevertheless, the genetic diversity of African germplasm is limited compared to that of the American germplasm base, which currently stands at over 5000 accessions.

In 1989 CIAT and IITA launched a joint project to broaden the African cassava germplasm base. A CIAT scientist was stationed at IITA HQ. Crossing blocks and open-pollination fields for elite materials adapted to different ECZs were established at CIAT in order to produce botanical seeds for introduction to Africa. Resistance to ACMV, a viral disease that does not occur in Latin America, is incorporated by crossing ACMV-resistant clones obtained from IITA with the Latin American germplasm (see Chap. 2).

In Nigeria, evaluation sites in four ECZs were selected using climate homologue maps prepared by the ASU. Progenies introduced from South America are evaluated for resistance to the main African cassava pests, for plant growth and habit, and for other qualitative and quantitative traits. Over 12,000 seedlings from 289 families were evaluated in 1990 (Chap. 23).

In a related project funded by IFAD, other national programs can benefit from materials developed by EMBRAPA in NE and southern Brazil for semiarid and subtropical conditions, resp. In 1991 materials selected in NE Brazil were simultaneously evaluated in semiarid sites in Brazil, Nigeria and Colombia.

23. EXPANSION OF THE GERMPLASM BASE FOR AFRICA

Considering the specificity of adaptation of cassava varieties to the environment and the great genetic diversity found in Latin America, CIAT and IITA launched a joint project aimed at further broadening of the cassava germplasm base in Africa. The strategies being used and the first results obtained in 1990-91 are discussed here.

23.1 Strategy and Methodology

The strategy adopted for broadening the cassava germplasm base in specific ECZs of Africa has, as its main tool, maps of climatic homologues between South America and Africa produced by the CIAT ASU. Figure 23.1 shows climatically homologue areas in Brazil (A) and Africa (B).

Based on these climatic similarities and the previous selection of CIAT elite materials adapted to different ECZ, crossing blocks and open-pollination fields were established at CIAT HQ to produce botanical seeds for introduction into Africa. Resistance to ACMV, a disease not existing in Latin America, is being incorporated into the progenies by crossing ACMV-resistant IITA clones earlier introduced to CIAT, with the Latin American germplasm.

The production, introduction and evaluation of F1 progenies according to environmental adaptation involved the following steps carried out in Colombia and Nigeria:

- Selecting progenitors adapted to a given ecology by taking into consideration their performance in terms of resistance to pests, yield and quality traits
- Producing hybrid seeds from polycross and controlled hybridization blocks at CIAT HQ
- Testing mother plants and resulting seeds for presence of virus and treating seed by thermotherapy and pesticides before shipping to Africa
- Introducing seeds into Nigeria through the Nigerian Plant Quarantine Service and testing the seeds at IITA for the presence of bacterial and fungal diseases
- Sowing healthy seeds in isolation, after treatment with hot water (60°C for 20 min) and inspecting the resulting seedlings in the screenhouse for presence of viral diseases

A

B

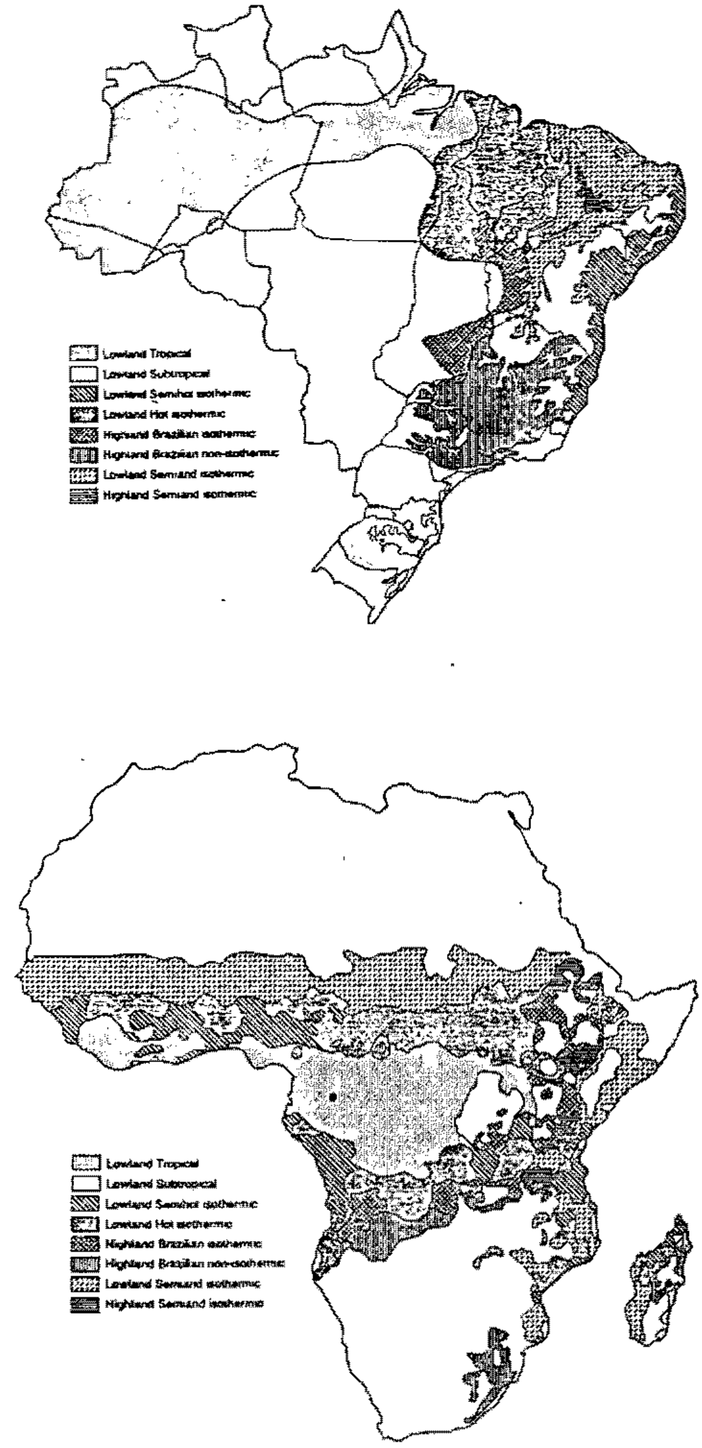


Figure 23.1. Climatic homologues for cassava between (A) Brazil and (B) Africa.

- Transplanting healthy seedlings to the field and inspecting them closely under field conditions in the first month after planting, followed by monthly evaluations for the main pests occurring in each ecosystem

By following this scheme the probabilities of introducing any exotic diseases into Africa are minimal, and the opportunity to eliminate diseased individuals occurs at various stages of the process.

The selection of the evaluation sites in Nigeria was made on the basis of the maps of the climatic homologues (Fig. 23.1) according to the cassava climates defined by Carter (1987).[23.1] The 4 evaluation sites in Nigeria are: Ibadan (Lowland Semihot Isothermic); Onne (Lowland Tropical); Kano (Lowland Semiarid Isothermic); and Jos (Mid-alt.).

Evaluation of the progenies introduced in each of these ecologies was based on the reaction of families and individuals within families to the main diseases and pests of cassava in Africa (ACMV, CBB, anthracnose, CGM and cassava mealybug), plant growth and habit, and qualitative and quantitative traits measured at harvest. The characteristics being evaluated and the frequency of evaluations are shown in Table 23.1.

Monthly measurements of individual plant ht and no. of leaves/pl on 10 pl/family were used as estimates of plant growth. These measurements are useful in identifying genotypic differences in plant vigor. Evaluations for host plant resistance were made on individual seedlings, thereby obtaining data on incidence and severity within and across families.

Evaluation for leaf retention (i.e., the portion of the plant with leaves at harvest or the thickness of the canopy) provides an indication of the plant's ability to retain its leaves at the end of the growth period. This ability is expected to be reduced by environmental factors such as drought and biotic constraints.

The no. of families introduced at Ibadan, Onne and Kano were 149, 78 and 62, resp. The total no. of seedlings transplanted and harvested at each location in 1990 were, resp., 5400 and 2993 in Ibadan; 3699 and 3010 in Onne; and 3288 and 2458 in Kano. Differences between no. of seedlings transplanted and evaluated at harvest were due to losses during establishment and, in Ibadan, by severe incidence of CBB immediately after transplanting. Rainfall distribution at the 3 locations is presented in Figure 23.2. Seedlings from seeds introduced to the 3 locations and at Jos (mid-alt.) in 1991 are still under evaluation.

[23.1] Carter, S.E. 1987. Collecting and organizing data on the agro-socio-economic environment of the cassava crop: Case study of a method. In: Bunting, A.H., (ed.) Proc. Workshop on agro-ecological characterization, classification and mapping. FAO. Rome. 1986. CABI. U.K. pp. 11-29.

Table 23.1. Evaluation parameters determined in cassava germplasm of Latin American origin.

Parameter	Frequency/Time of Evaluation
Reaction to pests	Monthly
Plant ht	Monthly
Ht of 1st branch	At harvest
Branch levels	At harvest
Lodging	At harvest
Stakes/pl	At harvest
Leaf retention	At harvest
Root skin color	At harvest
Root flesh color	At harvest
Root cortex color	At harvest
Root constrictions	At harvest
Root fresh wt	At harvest
Roots/pl	At harvest
HCN content (roots)	At harvest
Mealiness	At harvest

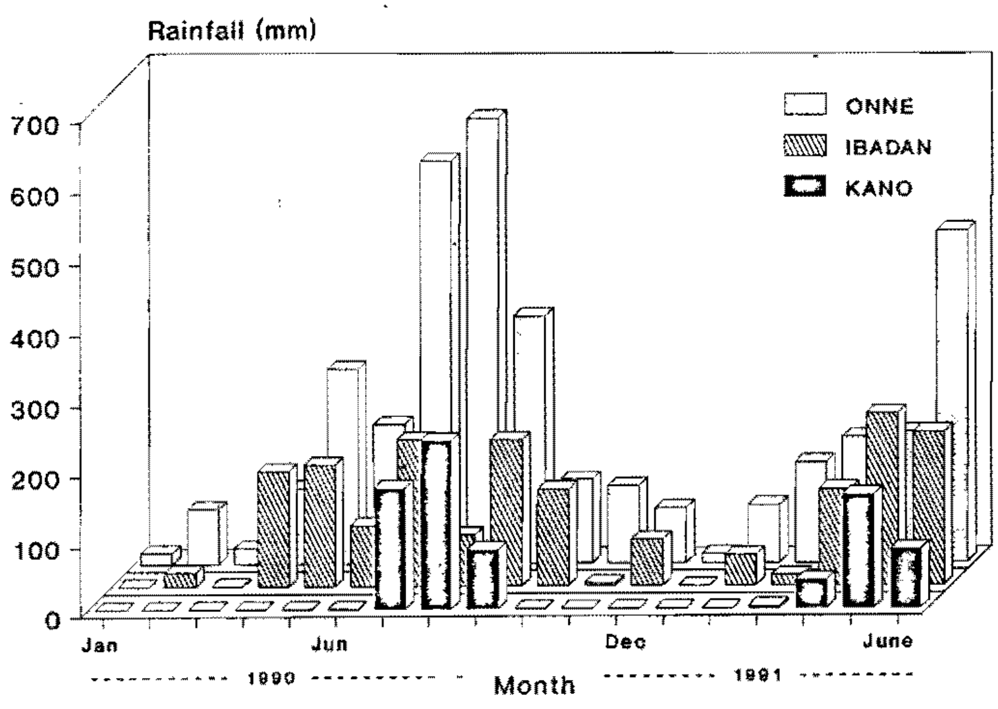


Figure 23.2. Distribution of rainfall from Jan. 1990 to June 1991 at 3 locations in Nigeria.

23.2 Reaction to Pests

Data on incidence and severity of ACMV, CBB and CGM at various stages of the growth period are presented. Incidence is represented by the no. of seedlings showing symptoms in relation to the total no. of individuals evaluated. Severity is the degree of susceptibility of plants showing symptoms measured on a scale of 1 (no symptoms) to 5.

23.2.1 ACMV

Under conditions of high pressure from ACMV, the Latin American germplasm showed a high degree of susceptibility, particularly at Ibadan. Seedlings started showing symptoms of mosaic as early as 2 wk after transplanting. Progenies from crosses involving TMS 30001 and TMS 30572 showed a higher degree of resistance to ACMV.

Severity of ACMV infection at Ibadan and Kano is shown in Tables 23.2 and 23.3. As the disease pressure increased, there was a tendency for fewer seedlings in Class 1, but more in classes 4 and 5. At the end of the rainy season (mo 5), at Ibadan, only 0.65% of the seedlings evaluated were in Class 1. During the dry season an increase in the no. of seedlings with no or few symptoms was observed as a result of the recovery of seedlings previously showing severe symptoms. At the beginning of the second rainy season, the level of symptoms increased again, suggesting a relationship between symptom expression and high rainfall.

Table 23.2. Severity of ACMV and CBB at Ibadan; % individuals in each class of the evaluation scale.

	Evaluation Scale									
	1		2		3		4		5	
MAT[1]	ACMV	CBB	ACMV	CBB	ACMV	CBB	ACMV	CBB	ACMV	CBB
1	34.1	-	23.5	-	27.7	-	14.3	-	0.3	-
2	2.2	40.2	1.2	22.1	7.8	3.6	40.0	121.9	48.7	21.2
3	1.5	63.3	4.0	15.6	25.2	4.7	43.4	8.3	25.9	8.0
4	1.1	30.8	2.4	57.8	8.8	8.1	26.6	2.7	61.1	0.5
5	0.6	53.1	3.8	32.1	26.0	11.1	42.5	2.3	27.0	1.3
6	1.3	64.1	5.2	31.1	35.3	3.7	47.7	1.1	10.4	0.3
7	5.8	58.9	15.9	32.7	64.2	7.6	13.5	0.6	0.6	0.2
8	6.3	62.6	11.0	29.9	50.1	6.4	30.0	0.7	2.1	0.3
9[2]	3.1	82.5	22.3	13.8	51.8	3.2	19.6	0.4	3.2	0.1
10	0.4	-	14.2	-	60.3	-	23.9	-	1.2	-

[1] Month after transplanting.
[2] Evaluation for CBB was not done after the 8th MAT.

Table 23.3. Severity of ACMV and CBB at Onne; % individuals in each class of the evaluation scale.

	Evaluation Scale									
	1		2		3		4		5	
MAT	ACMV	CBB	ACMV	CBB	ACMV	CBB	ACMV	CBB	ACMV	CBB
2	96.7	93.9	2.4	5.4	0.8	0.5	0.2	0.1	-	-
3	94.1	96.2	0.9	3.5	1.6	0.3	1.4	-	2.0	0.1
4	87.7	94.5	2.1	5.3	3.0	0.2	3.3	-	4.0	-
5	76.9	94.3	3.9	4.7	8.3	0.4	7.2	0.3	3.7	0.1
6	57.3	88.5	9.5	9.9	19.8	0.9	10.5	0.4	2.8	0.3
7	34.1	96.8	6.2	1.8	42.8	1.0	15.7	0.3	1.2	0.1
8	36.7	55.2	27.8	37.6	29.8	5.4	6.0	1.5	0.2	-
9	69.6	79.4	9.6	16.3	20.8	3.5	-	0.3	-	0.5
10	4.4	3.0	11.8	60.4	39.6	31.4	27.2	4.2	17.0	0.9

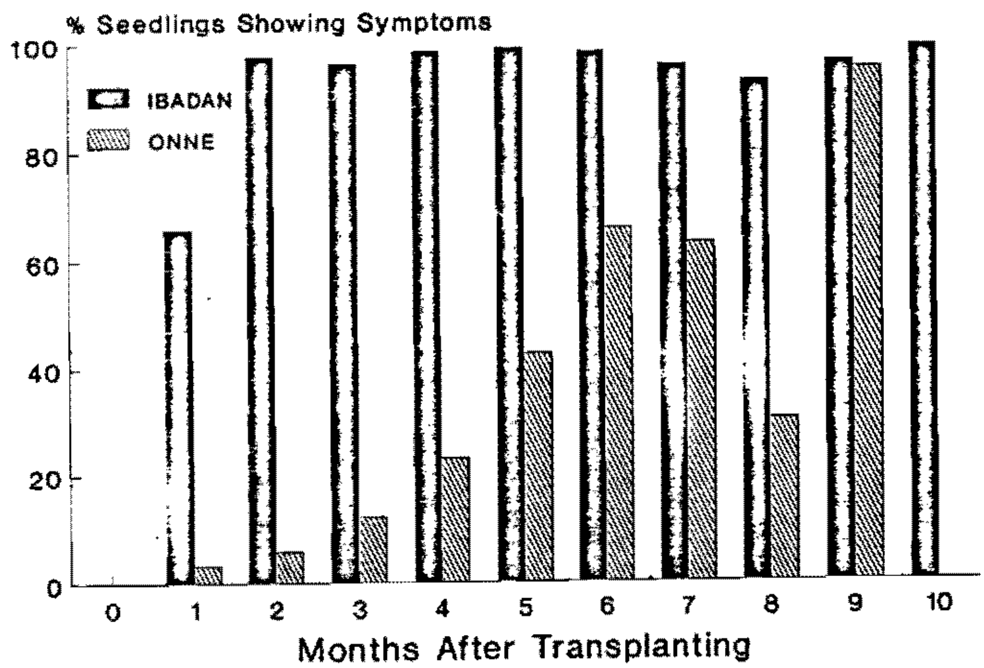


Figure 23.3. Incidence of ACMV on cassava seedlings growing at Ibadan and Onne, 1990-91.

Differences across locations for severity and incidence of ACMV infection were great. The level of symptom expression was higher at Ibadan than at Onne (Table 23.3), where a max. incidence (65%) was attained at 9 MAT (Fig. 23.3). These differences were probably caused by a higher concn. of inoculum in the surrounding cassava fields. It may be that the high temp observed at Kano during the dry season inhibited symptom expression of ACMV.

Given that the period of highest ACMV pressure was between July and Nov. 1991 (2-6 MAT), comparison of the families' reaction to the disease was made considering the avg no. of individuals showing no or light symptoms (classes 1 and 2 of the evaluation scale) per family (Table 23.4). Families with more than 10% of the individuals showing few or no ACMV symptoms were predominantly progenies derived from clones TMS 30001 and TMS 30572.

23.2.2 CBB

The incidence of CBB was also higher at Ibadan than at Onne (Tables 23.2 & 23.3). After a severe outbreak of CBB in the first MAT at Ibadan, which contributed to the death of approx. 20% of the seedlings, levels of incidence were reduced. Contrary to what happened in relation to ACMV, the levels of resistance to CBB were maintained as a result of previous selection of parents from Latin American and African origin for resistance to this disease. As shown in Figure 23.4, CBB incidence was always higher at Ibadan until the 8th MAT (Jan. 1991). At the onset of the 1991 rainy season at Onne,

Table 23.4. Comparison across families showing more than 10% of the individuals with few or no ACMV symptoms during the period of max. disease pressure at Ibadan.

Family	Parents		% Indiv. in Classes 1-2
	Female	Male	
SM 1275	TMS 3001 (IITA)	-	41.4
CM 7499	TMS 3001 (IITA)	CM 2909-36 (2)	29.0
CM 7965B	M Col 638 (2)	TMS 30001 (IITA)	25.0
CM 7965A	TMS 30001 (IITA)	M Col 638 (2)	24.4
CM 7966A	M Col 638 (2)	TMS 30572 (IITA)	23.6
SM 1276	TMS 30572 (IITA)	-	21.0
CM 7558	M Bra 12 (1)	TMS 30001 (IITA)	17.4
SM 1179	TMS 30572 (IITA)	-	17.2
CM 7600B	TMS 30001 (IITA)	CM 2771-3 (2)	16.6
CM 7500A	TMS 30572 (IITA)	CM 2909-36 (2)	16.6
CM 7446	CG 489-34 (2)	TMS 30001 (IITA)	13.4
CM 7559	TMS 30001 (IITA)	M Bra 12 (1)	12.8
CM 7500B	TMS 30572 (IITA)	CM 2909-36 (2)	10.4
CM 6971	CM 507-37 (2)	HMC-1	10.2
	Overall avg of 140 families		3.9

No. between parentheses refers to the ECZ of each parent.

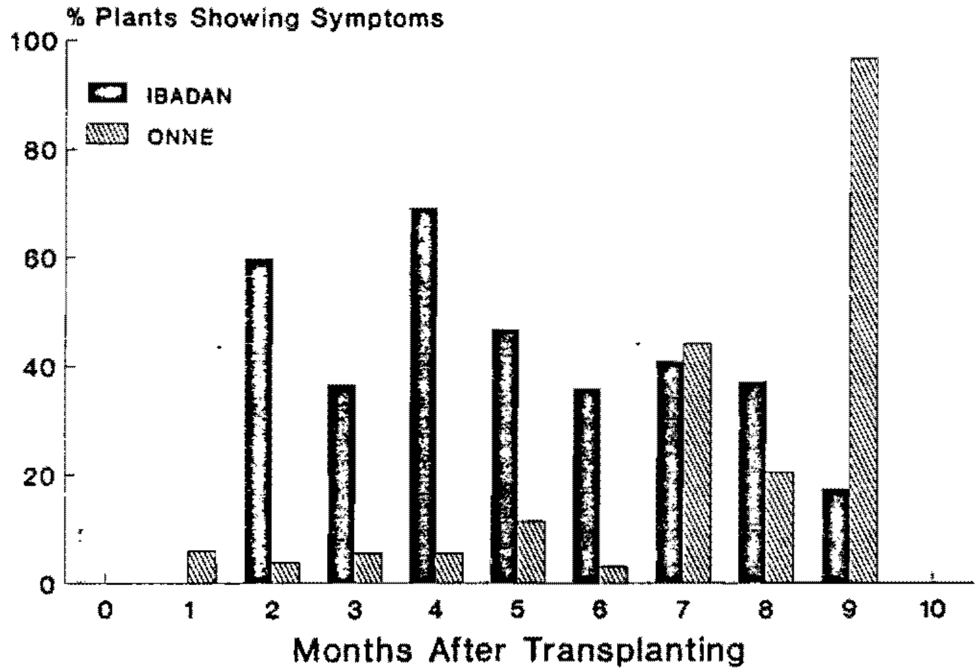


Figure 23.4. Incidence of CBB in cassava seedlings growing at Ibadan and Onne, 1990-91.

the levels of CBB incidence increased dramatically as a result of heavy rains and low night temp. As in the case of ACMV, CBB was insignificant at Kano during the 1990-91 growing season, which was to be expected given the climatic conditions typical of that location.

As the main cause for seedling death during the first 2 MAT was the severe attack of CBB occurring in June 1990. The survival rate for each family at 2 MAT gives an indication of the susceptibility of the several families evaluated for CBB. Of the 31 families that showed a survival rate ≥ 90% in relation to the total no. of seedlings transplanted (Table 23.5), 28 are derived from crosses involving CIAT elite materials adapted to the acid-soils savannas of South America (ECZ 2), where CBB is the major biotic constraint. Twelve families involving IITA elite materials are also among the families with a high survival rate under severe CBB attack.

Table 23.5. Survival rate of selected families after a severe attack of CBB at Ibadan.

Family	Parents		% Survival
	Female	Male	
CM 7600B	TMS 30001 (IITA)	CM 2772-3 (2)	100
CM 7859	TMS 30572 (IITA)	M Pan 51 (2)	100
CM 7921	CM 2466-5 (2)	TMS 30572 (IITA)	100
CM 7968	M Col 2215 (1)	TMS 30572 (IITA)	100
SM 1382	M Arg 13 (2-6)	-	100
SM 1387	M Bra 715 (2-6)	-	100
SM 1399	CM 2909-36 (2-6)	-	100
SM 1401	M Bra 5 (2-6)	-	100
SM 979	CM 2298-3 (2)	-	98
CM 7977	TMS 30572 (IITA)	CM 2952-1 (2)	95
SM 1231	CM 2774-11 (2-3)	-	95
CM 7748	CM 3408-1 (1-4)	SG 104-284 (1)	94
CM 7857	TMS 30572 (IITA)	CM 2177-2 (2)	94
SM 1225	CM 2452-5 (2-3)	-	93
SM 1348	M Arg 13 (2-6)	-	93
CM 7965A	M Col 638 (2)	TMS 30001 (IITA)	92
SM 909	CM 2087-101 (2)	-	92
SM 1147	CM 1999-5 (2)	-	92
SM 1177	SG 623-29 (2)	-	92
SM 1216	CG 165-7 (2-3)	-	92
SM 1219	CG 1450-4 (2-3)	-	92
SM 1223	CM 2174-7 (2-3)	-	92
SM 1243	SG 104-284 (2-3)	-	92
SM 1245	SG 250-3 (2-3)	-	92
SM 1275	TMS 30572 (IITA)	-	92
CM 7500B	TMS 30572 (IITA)	CM 2909-36 (2)	90
CM 7600A	CM 2772-3 (2)	TMS 30001 (IITA)	90
CM 7904A	CM 507-37 (2)	TMS 30001 (IITA)	90
CM 7904B	TMS 30001 (IITA)	CM 507-37 (2)	90
SM 1009	CM 2087-101 (2-5)	-	90
SM 1332	CG 896-2 (2-3)	-	90
	Overall avg of 116 families		79

No. between parentheses refers to ECZ of each parent.

23.2.3. CGM

CGM was the pest that occurred at the highest level of attack at both locations, particularly during the dry season. Table 23.6 lists those families with 10% or more of the individuals within classes 1 and 2 of the evaluation scale and above, at Ibadan. Of the 21 families listed, 9 are derived from parents adapted to the dry areas of Latin America (ECZ 1), where mites are the most serious cassava arthropod pest.

23.3 Agronomic Characteristics

The agronomic characteristics measured at monthly intervals and at harvest are described in Table 23.1. With the information obtained at harvest, based on 538, 474 and 311

Table 23.6. Comparison across families showing more than 10% of the individuals with few or no symptoms typical of a CGM attack during the period of max. pressure at Ibadan.

Family	Parents		% Indiv. in Classes 1-2
	Female	Male	
CM 7968	M Col 2215 (1)	TMS 30572 (IITA)	50.0
CM 6069	M Bra 12 (MON)	M Pan 51 (2-3)	50.0
CM 6815	CM 1849-3 (2)	CM 2144-2 (2)	40.0
CM 6781	CM 2087-1 (2)	CM 507-37 (2)	39.5
CM 7417	CG 5-79 (MON)	TMS 30001 (IITA)	23.5
CM 7745	CM 3408-1 (1-4)	CM 3064-4 (2-3)	21.5
SM 905	CM 996-6 (2)	-	20.0
SM 1150	CM 2563-5 (2)	-	20.0
CM 6971	CM 507-37 (2-3)	HMC 1 (1-4)	17.0
CM 7221	CM 681-2 (1-4)	CM 2174-7 (2-3)	16.5
CM 6822	CM 1851-4 (2)	CM 2144-1 (2)	16.5
SM 827	CM 966-2 (2)	-	16.5
SM 1009	CM 2087-101 (2-5)	-	15.5
SM 1141	CM 879-19 (2)	-	15.5
CM 7559	M Bra 12 (MON)	TMS 30572 (IITA)	15.5
CM 7741	CM 3408-1 (1-4)	CM 507-37 (2-3)	14.0
SM 1363	SG 495-19 (2-3)	-	14.0
CM 7460	TMS 30572 (IITA)	CM 523-7 (2)	12.5
CM 7976	TMS 30572 (IITA)	CM 2766-5 (2)	11.5
SM 1003	M Col 1522 (2-5)	-	10.5
CM 7744	CM 3408-1 (1-4)	CM 2774-11 (2-3)	10.0
	Overall avg of 116 families		5.5

No. between parentheses refers to ECZ of each parent; MON = CIAT code for germplasm resistant to CGM.

seedlings selected at Ibadan, Kano and Onne, resp., it was possible to draw examples of the typical seedlings selected at each location based on the means for each characteristic (Fig. 23.6). Seedlings harvested at Onne were taller and branched at a higher ht than those harvested at Ibadan and Kano. An avg of 3 forking points was found in the seedlings selected at Ibadan and Onne, differing from those selected at Kano, with only 2 branching levels. Avg no. of storage roots was 6 in Onne and Ibadan; 7 at Kano. Because of rains during the last 3 mo of the growth period in Kano, seedlings harvested at that location showed the highest leaf retention.

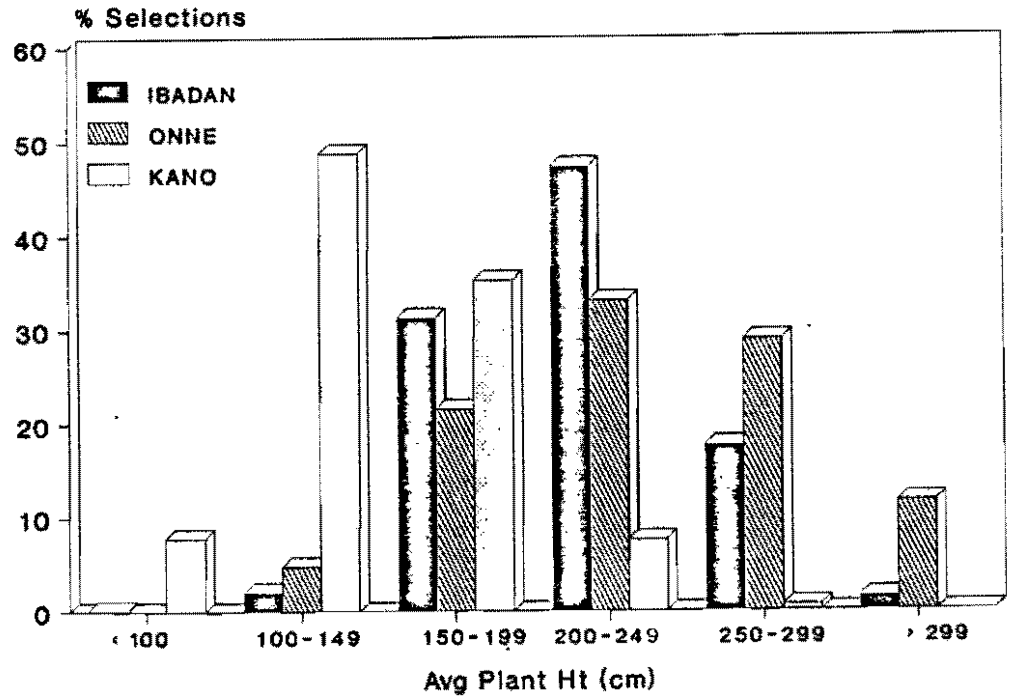
A brief discussion of each characteristic measured at the 3 sites follows.

23.3.1 Plant height, height of first branch and branching levels

Comparisons of the population's morphological characteristics take into consideration:

- The similarity of the populations introduced at Ibadan and Onne: 94% of the families were common to the 2 locations.

A



B

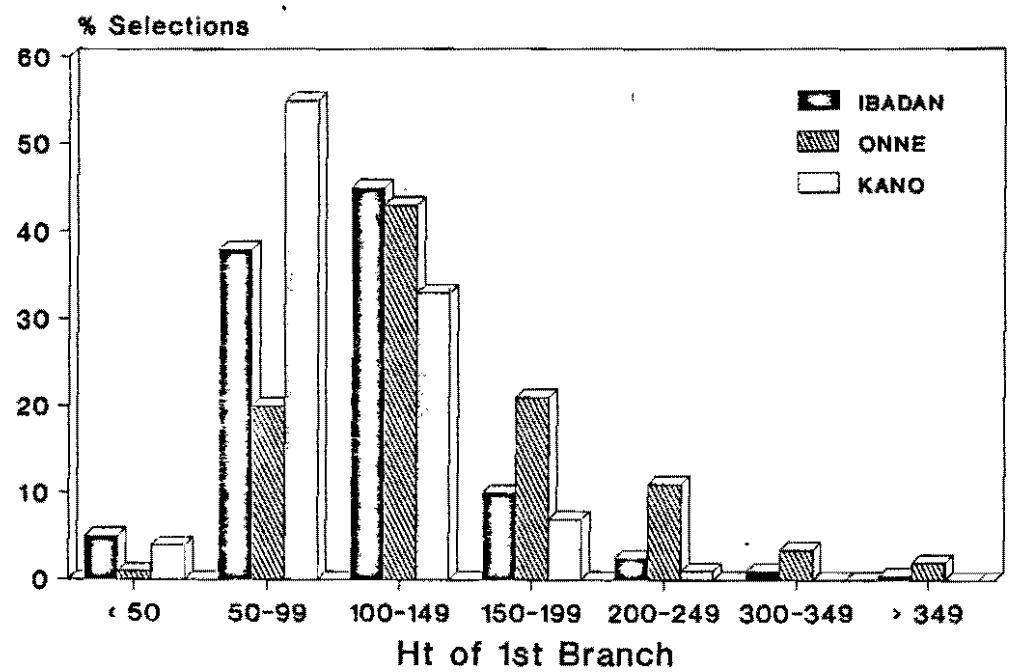


Figure 23.5. Frequency distribution of (A) plant ht and (B) ht of the first branch in cassava seedlings selected at 3 locations of Nigeria, 1990-91.

- A completely different population evaluated at Kano, obtained from parents adapted to the ecosystem represented by the Colombian North Coast (ECZ 1). As a result differences observed between Ibadan and Onne are strongly influenced by differences in the environmental conditions of the 2 locations.

The frequency distributions shown in Figures 23.5-23.6 reflect the differences in plant ht, ht at first branching and no. of branching levels/pl at harvest, resp. Plants grown at Kano were smaller than those evaluated at the other 2 locations. Avg plant ht at Kano was 145 cm, while those grown at Onne and Ibadan showed avg of 236 and 213 cm, resp. The higher frequencies of avg plant ht in the range of 100-140 cm at Kano contrast with the distribution observed at the other sites.

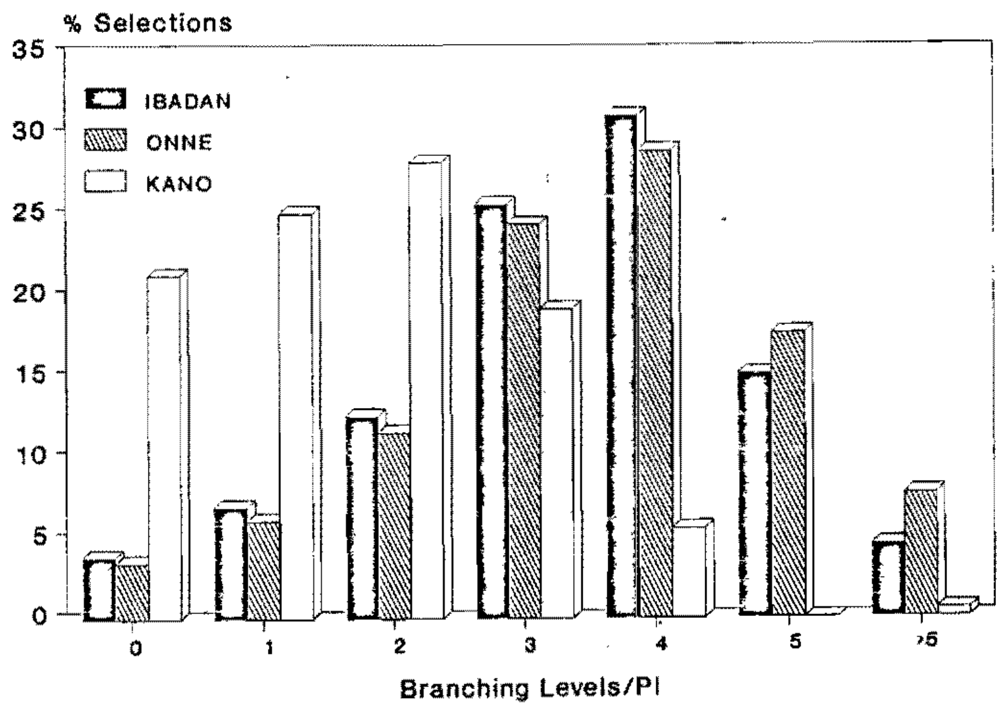


Figure 23.6. Frequency distribution of no. of branching levels in cassava seedlings selected at 3 locations of Nigeria, 1990-91.

Figure 23.7 shows the growth patterns of the seedlings planted at the 3 locations based on monthly measurements of plant ht taken from the first 10 plants of each family. The values at the end of the cycle differ from those avg calculated from the selections (Fig. 23.5A) because not all the 10 plants measured each month were selected at harvest. It is particularly interesting to note that the seedlings growing at Kano were able to grow (although at lower rates) even during the long dry season experienced at that location, showing the adaptation of the populations to dry conditions.

Avg values for ht at the first branch and no. of branching levels at Kano were 97 cm and 1.6 m, resp., compared with 141 cm and 3.5 m for Onne and 113 cm and 3.4 m at Ibadan. In general plants harvested at Onne were taller than those growing at Ibadan and branched at a higher level. The no. of branching levels did not differ at the 2 locations, both showing a high concn. of individuals between 3 and 4 branching levels (Fig. 23.6). These differences can be partially explained by 2 factors: the better distribution of rainfall at Onne during the growth period (Fig. 23.2), and the lower pressure of pests at Onne. Both factors can be considered as major components of the 2 environments.

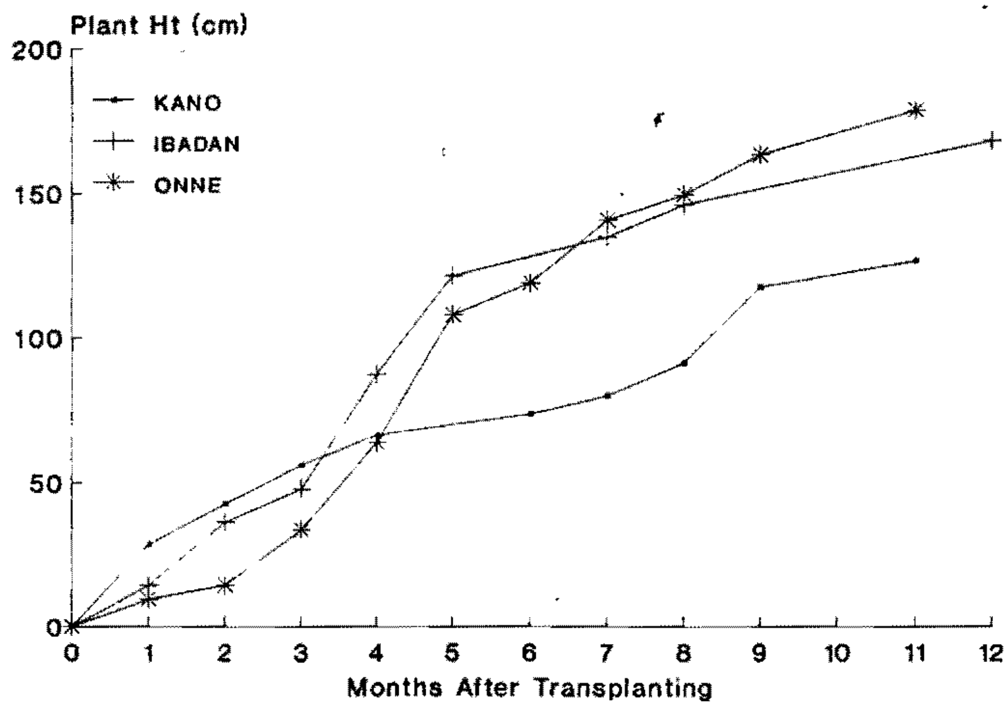


Figure 23.7. Avg plant ht of cassava seedlings growing at 3 locations of Nigeria on several occasions during the growth period, 1990-91.

23.3.2 Lodging

Figure 23.8A shows that at all locations, plants were not severely affected by lodging. The higher frequency of plants within classes 2 (intermediate lodging) and 3 (severe lodging) observed at Ibadan was due to strong winds during the rainy season.

23.3.3 Leaf Retention

Leaf retention gives an indication of the plant's ability to keep functional photosynthetic area at the end of the growth cycle. Figure 23.8B shows the frequency distribution of leaf retention in the plants selected at the 3 locations. As a result of the unusually high rainfall that occurred during the last 3 mo of the growth cycle at Kano (Fig. 23.2), the seedlings selected there had a thicker canopy (57 cm) when compared with the data obtained at Ibadan (51 cm) and Onne (36 cm). These differences may also be due to the effects of pests and diseases. At Onne the 1991 rainy season started in March (before that in Ibadan), resulting in increased pressure from CBB and mosaic and lower leaf retention at harvest time.

23.3.4 Root Characteristics

Root characteristics such as color of skin, flesh and cortex are not expected to change as a result of the environment. The data presented in Figures 23.9-23.10A show that at both Ibadan and Onne (where similar populations were evaluated), the majority of the selections had dark-skinned roots with white flesh and no or light pigmentation of the cortex. Selections from Kano, on the other hand, showed a tendency for having lighter skin, cream flesh and a high degree of pigmentation in the cortex.

As a general rule, most of the selections showed none or few of the root constrictions that are detrimental for the processing of cassava (Fig. 23.10B) although there were a high no. of constrictions in plants evaluated at Kano. As the population introduced there is different from those evaluated at Ibadan and Onne, it is not possible to affirm whether the no. of constrictions was influenced by the environment or if it reflects the population evaluated at Kano.

RY was measured by weighing roots from all selected plants at each site. Although not the sole factor, RY was also taken into consideration in the selections done at the 3 sites. Seedlings selected at Ibadan showed the highest avg root fresh wt (2.9 kg/pl), followed by the selections harvested at Kano (2.5 kg/pl) and Onne (2.2 kg/pl). The frequency distributions shown in Figure 23.11A show that the majority of the individuals selected had avg root wts between 1 and 2 kg/pl although some outstanding values were recorded at the 3 locations, especially at Ibadan, where over 40% of the plants selected had ≥ 3 kg roots/pl (Fig. 23.11B). The lower RYs obtained at Onne, although under a situation of lower pressure from ACMV and CBB throughout the growth cycle, may be due to the

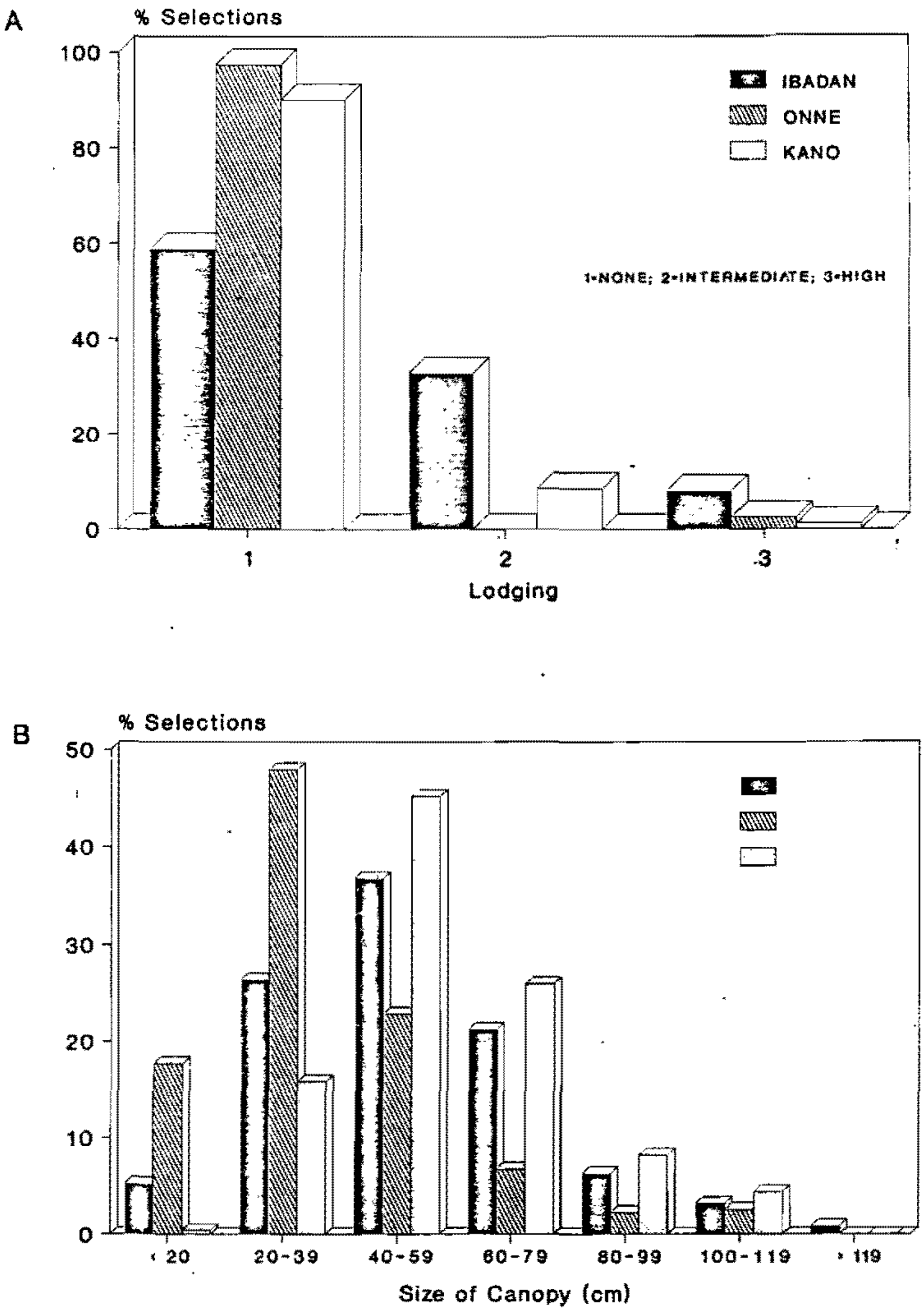


Figure 23.8. Frequency distribution of (A) lodging and (B) leaf retention in cassava seedlings grown at 3 locations of Nigeria, 1990-91.

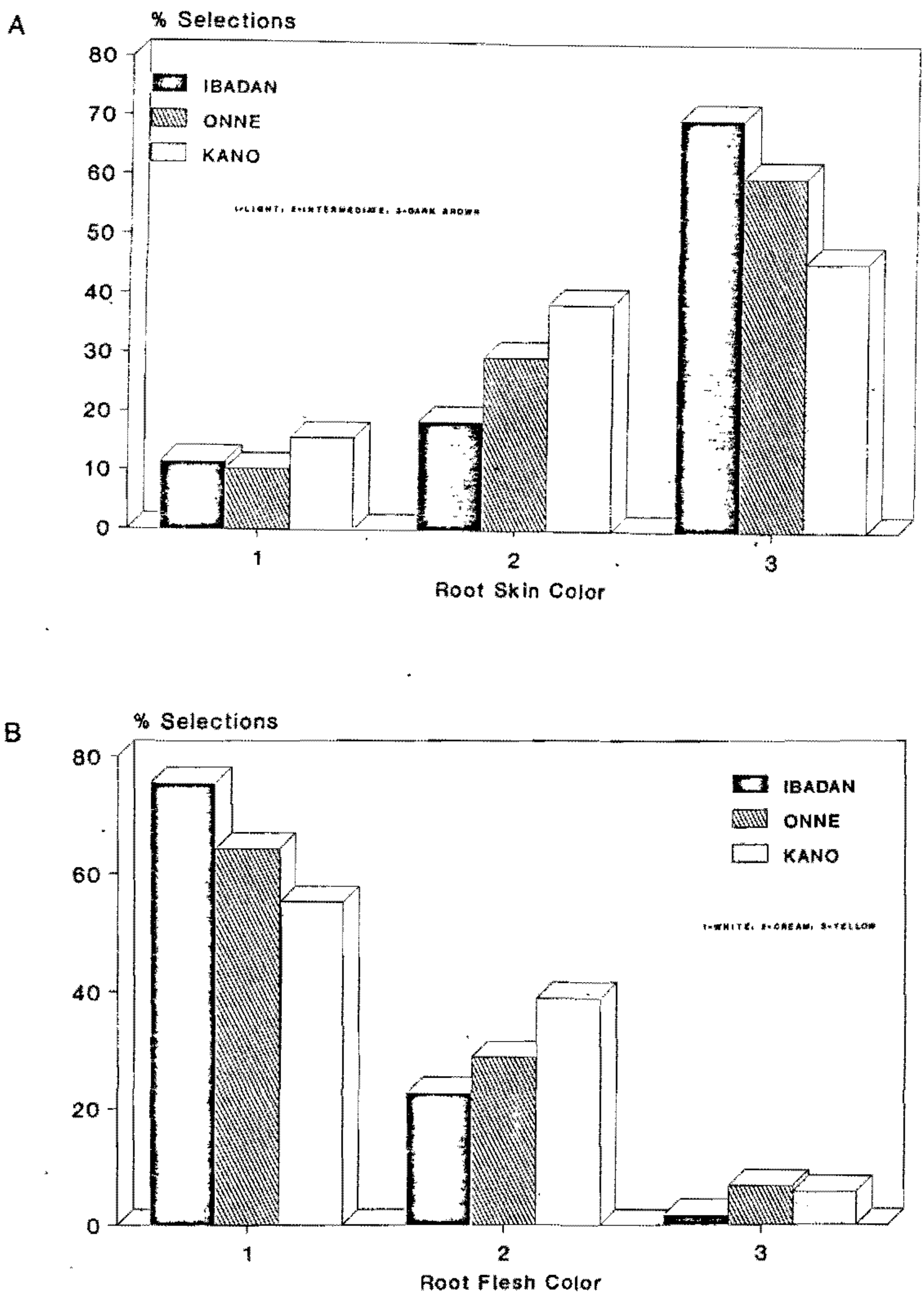


Figure 23.9. Frequency distribution of (A) root skin and (B) root flesh color in cassava seedlings grown at 3 locations of Nigeria, 1990-91.

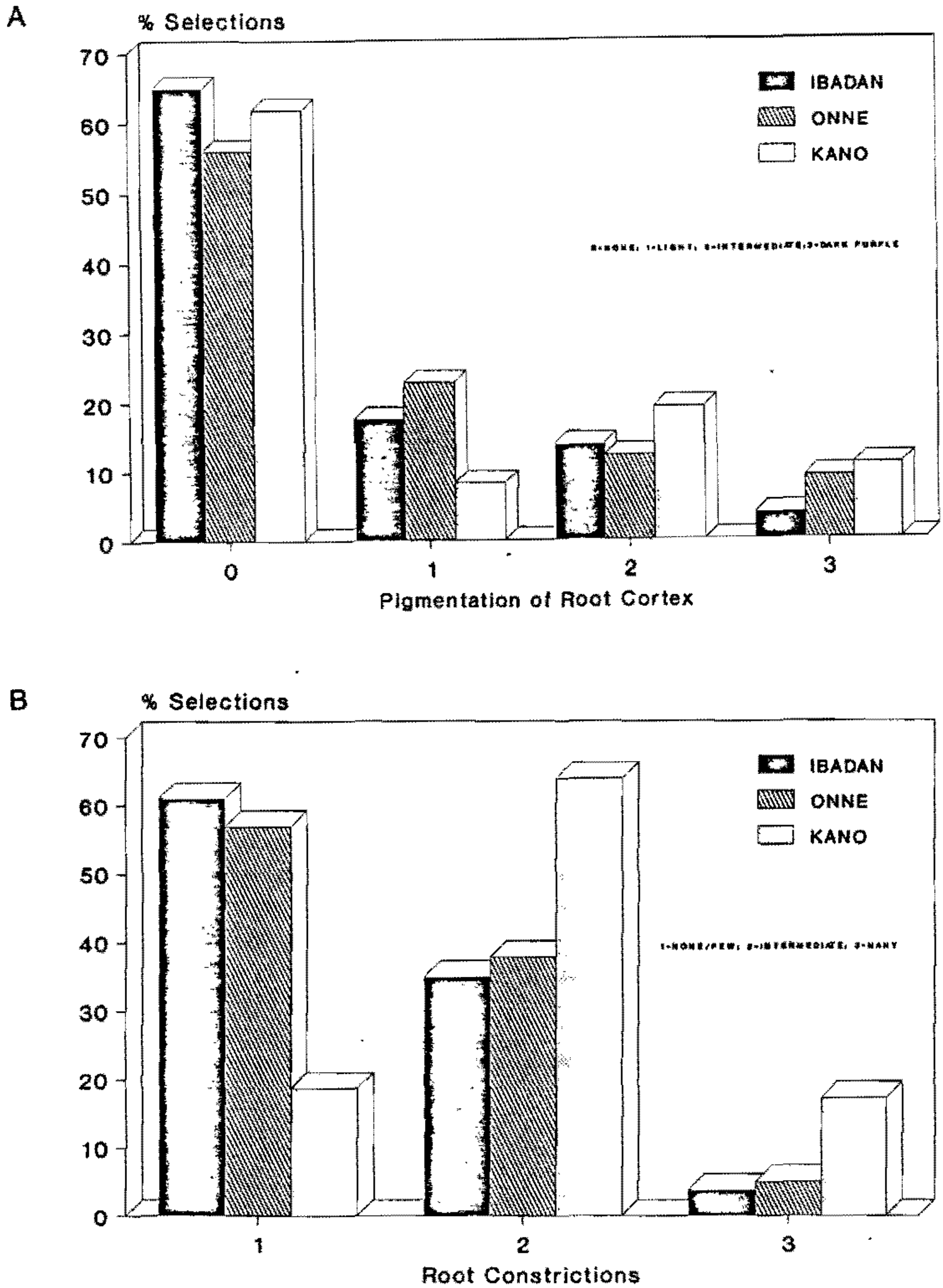


Figure 23.10. Frequency distribution of (A) pigmentation of root cortex and (B) root constrictions in cassava seedlings grown at 3 locations of Nigeria, 1990-91.

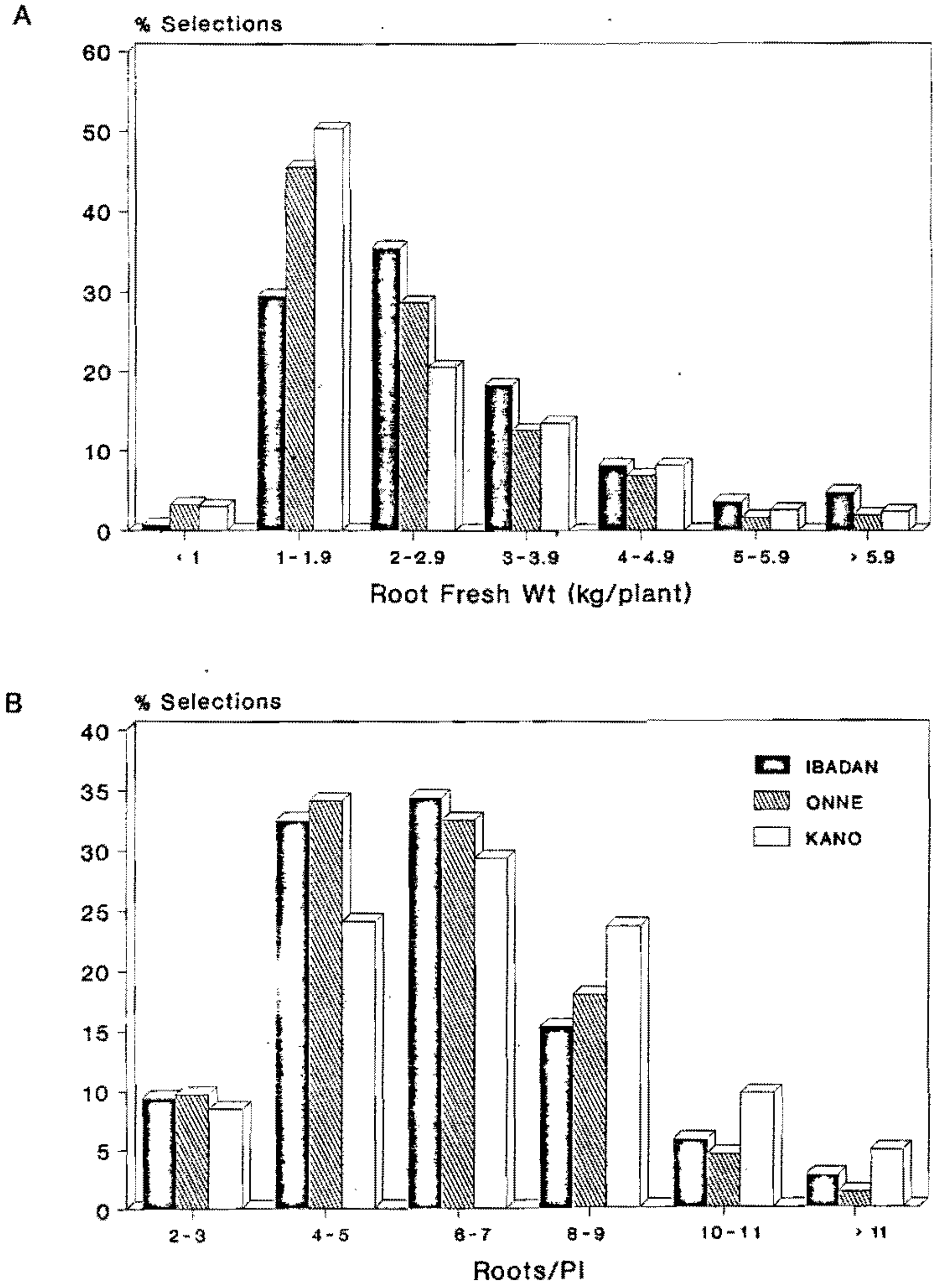


Figure 23.11. Frequency distribution of (A) fresh root wt and (B) no. of roots/pl in seedlings selected at 3 locations of Nigeria, 1990-91.

extremely vigorous vegetative organs observed in the plants selected at that location, which may cause a situation of competition for photosynthates between roots and tops.

The avg no. of storage roots/pl in the selections made at Ibadan, Onne and Kano were 5.8, 5.9 and 6.9, resp. According to Figure 23.11B, there was a tendency for a higher no. of plants with 4-7 roots both at Ibadan and Onne (as indicated, with 94% of families common to the 2 sites); whereas in Kano a larger no. of plants with 8 or more roots were harvested. As the data do not refer to the no. of commercial roots but to the total no. of storage roots/pl, this can be a result of new roots formed after the second rainy season in Kano.

The results obtained thus far from this large-scale germplasm introduction support the feasibility of such a program and suggest that a previous selection of parents according to agroecological adaptation is an adequate strategy for transferring genes from Latin America to Africa.

The population evaluated at Kano, formed by seedlings resulting from crosses using cassava germplasm adapted to dry areas of Latin America, showed a remarkable ability to withstand a dry season of 6 mo established after 2 MAT. A total of 474 seedlings were cloned and planted at Kano and Zaria (Nigeria) for further evaluation under dry conditions.

The use of IITA elite clones as a source of resistance to ACMV has proved to be a good strategy as the progenies resulting from crosses involving IITA ACMV-resistant clones proved to have a higher level of resistance. Together with CIAT elite clones adapted to the acid-soil savannas of South America, IITA clones also proved to be effective in producing families with a higher degree of resistance to CBB.

24. COLLABORATIVE STUDY OF CASSAVA IN AFRICA

COSCA is an interinstitutional effort to provide basic information about cassava in Africa, to increase the relevance and impact of research related to the crop, and to help increase income and food security for people in Africa. The study began as a joint collaborative project between CIAT and IITA (charged with the project's execution). A number of other institutions have collaborated to date, including the NRI (ODA, UK). The study involves the collection of data which will be utilized to characterize:

- the structure of cassava-based cropping systems in Africa
- the nature and distribution of various cassava processing techniques
- the marketing systems for cassava
- present and future demand for cassava in rural and urban areas
- the relationships between cassava consumption and nutrition

When the study began in 1989, it was originally to be conducted in 6 countries: Ghana, Ivory Coast, Nigeria, Tanzania, Uganda and Zaire. In 1990-91 it was extended to Liberia and Sierra Leone, Burundi, Cameroon, Congo, Kenya, Malawi and Zambia.

Data are collected at two levels. In the first phase, generalized, mostly qualitative information was gathered from group interviews at the village-level. The second and third phases, which are currently being implemented, will generate information specific to the household, farm or processing unit. The CIAT ASU elaborated a sampling frame and survey method for the project's first phase. Unit members have subsequently participated in training exercises for phase one, and in some of the data analysis. A description of CIAT's contribution and a selection of results from this phase are presented below.

24.1 Site Selection for Phase One

As the goal of the first phase was to characterize many aspects of cassava production and use across large geographic areas, a spatial sampling frame was required to ensure a representative picture for every country. At the Third Planning Meeting for the project (Sept. 1988), participants from the countries involved and members of the SC selected 4 factors with which to subdivide cassava-growing areas to be surveyed: Distribution of the crop, agroecological conditions, density of human population and accessibility.

The COSCA project began at a time of important methodological developments in the ASU. The Unit had begun to implement its first microcomputer system for handling geographic information, both for digitizing paper maps and for simple geographic analyses. These new packages were quickly interfaced with CIAT's mainframe climatic database and mapping facilities. Powerful new techniques for managing large datasets therefore influenced the methodology for site selection in COSCA, by facilitating the combination of the environmental and socioeconomic variables required to build a spatial sampling frame.

These same techniques have provided the basis for rapid mapping of the processed survey data using microcomputers. The ASU had developed a spatial survey method based on village-level questionnaires to generate information for stratifications and for research orientation. The method was directly compatible with the type of grid-based geographic information system required for the COSCA Phase-One sampling frame. By geo-referencing survey sites, results of the Phase-One questionnaire can be mapped for visual interpretation or overlayed onto other maps for statistical comparisons.

24.1.1 Construction of the sampling frame

The ASU produced a map of cassava distribution for Africa (Fig. 24.1), using the most recent census statistics and other information. This map served to identify the main cassava-producing areas of each of the project countries and to exclude areas where cassava was not grown.

The climatic classification devised for cassava in Latin America was used to subdivide the range of agroecological conditions in which cassava was found (see Cassava Program Annual Report, 1986, pp. 43-52). Climatic classes were mapped via a set of interpolated grid files created from CIAT's mean monthly meteorological database.

Human population density was considered to be the most important socioeconomic factor to take into account for stratification in the Phase-One survey. Population density has a strong influence upon the intensity of land use, though not in isolation. Secondary-level administrative units were digitized for each of the 6 countries, and their respective areas calculated. The US Census Bureau provided population totals for these units from recent censuses which were then projected forward to 1990 using avg annual population growth rates for each country. Population densities were then calculated and mapped on a microcomputer.

The final factor used to stratify the countries in the survey was accessibility, which was considered as likely to be an important determinant of commercialization and migration. All-weather roads, railways and navigable rivers were digitized. Places within 20 km of these were considered to have easy access; those further away, difficult. This crude measure proved more reliable, once fieldwork began, in countries with a well-developed network (e.g., Nigeria and Ivory Coast) than in countries with a sparse network (e.g., Tanzania).

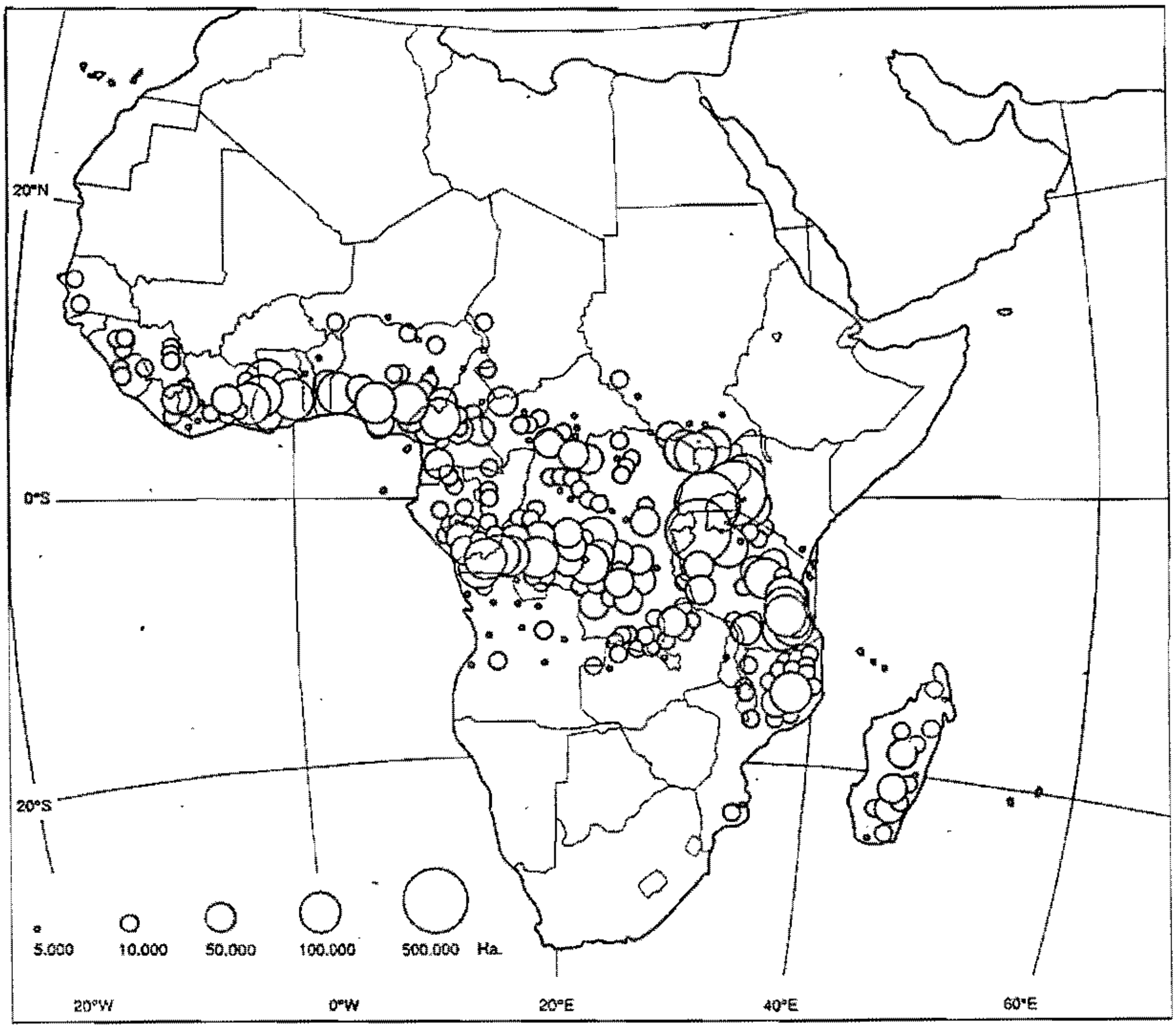


Figure 24.1. Cassava distribution in Africa, 1980.

Maps of cassava distribution, infrastructure and administrative units were turned into grid cell maps (rasterized) to correspond exactly to the grid created for the climatic map (cells had dimensions of 12 min lat. by 12 min long.). For any one cell, therefore, there existed a hectarage of cassava on one computer map, a population density on another, a climatic class on another and an accessibility factor on a fourth map. Population density and accessibility were simplified into 2 classes each (low/high, poor/good, resp.). The climate, population and access maps were then superimposed to create a series of homogeneous regions for each country. Cassava area was then totaled for each region, and maps of these were produced from which survey locations could then be selected.

24.1.2 Identification of survey regions and villages

The site-selection procedure began at the first COSCA training meeting, held in April 1989. Project management and national coordinators used the information generated about the relative distribution of cassava in the different geographic areas of each country to identify the areas that they would survey.

Throughout the first week of the meeting, national survey teams refined estimates of the no. of sites they could survey in the time available, based on budgeting and manpower limitations, seasonal weather conditions and the distances to be covered. The total no. of sites was then apportioned among the different regions to be surveyed. A total of 294 sites were selected for each of the 6 countries as follows: Ghana, 30; Ivory Coast, 40; Nigeria, 65; Tanzania, 42; Uganda, 37; and Zaire, 80.

The 12-min grid used to construct the maps of homogeneous regions provided a frame from which a stratified random selection of general locations was made for administering Phase-One questionnaires. The method used ensured an even spread of survey points across each region. Each grid cell selected then had to be transferred to larger scale maps of the respective survey region from which individual villages could be identified. Although survey teams were able to practice this during the training week, they selected sites on return to their respective countries. Finally, various methods for selecting a survey village at random within each grid cell were discussed.

24.2 Data Analysis

Fieldwork for Phase One began in June 1989 and continued in some cases until Feb. 1990. By March 1990 most of the questionnaires had been coded and entered on a microcomputer at IITA. A second training meeting was held that month to introduce the national survey teams to techniques of database management, statistical analysis and mapping of the survey data. Participants were required to present a preliminary report on the findings of the study in their respective countries, including a set of maps to represent geographically significant aspects of these results.
The ASU provided relevant environmental and socioeconomic computer maps to test some of the hypotheses that Phase One was expected to answer and also helped participants map the data they chose to present.

During the remainder of 1990, the Unit cooperated in data cleaning and analysis. Analysis focused on relationships between aspects of cassava production and environmental and socioeconomic conditions. Some of the results are outlined here.

24.2.1 Distribution of bitter and sweet varieties of cassava

Little was known previously about the distribution of bitter and sweet var. of cassava in Africa, and the COSCA survey has provided some detailed information about this for the countries covered. To distinguish bitter from sweet var., those that can be eaten raw without causing intoxication were defined as sweet. In 103 of the villages visited, both bitter and sweet var. were cultivated. At 38 sites, only bitter var. were recorded--largely in Ivory Coast and southern Nigeria, with a few sites in Zaire. At 83 sites, only sweet var. were recorded: all places visited in Ghana, most in Uganda and northern Nigeria, and a few in Zaire and Tanzania.

For the data set as a whole, the total no. of bitter var. at a site was found to be independent of dry-season length; whereas the total no. of sweet var. recorded was slightly greater in humid climates (0-3 dry mo). Factors that were positively related to the no. of sweet var. grown were total area in cassava and elevation. Sweet var. were found to be less common at sites with seasonal climates. The total no. of bitter var. was negatively correlated with altitude.

With respect to the type of variety that occupies the greatest area in each village surveyed, the relative area in bitter and sweet var. at a site was found to be independent of length of dry season; however, this masked different situations within each country. In Ivory Coast and Ghana, the predominance of sweet var. was independent of climate. In Uganda, where sweet var. predominated, all sites had humid climates. In Tanzania and Zaire bitter var. predominated, but climates were mostly seasonally dry and humid, resp.; and it was not possible to detect any interaction due to the small sample size in these countries. In the case of Nigeria, climate could not be discounted as a determining factor, but it was not clear why it should only have an influence there, and not in other parts of West Africa, for example. A fuller understanding of interactions between varietal type and environmental conditions required estimates of the actual area sown to sweet and bitter var. (data to be gathered in household-level surveys in the project's second phase).

Sites with > 2 bitter var. tended to have acid soils; very few sites (5 of 58) with unrestricted soils had no sweet var. The probability of sites having no sweet var. was significantly higher for those with acid soils than for sites whose soils presented no restrictions for cassava.

The overall impression given by these data was one of diversity and complexity in the choice of cassava var. and the relative importance of the crop.

24.2.2 Influence of biophysical and human environments upon age of cassava at harvest

For many rural people flexibility of harvest period is one of the most important qualities of cassava. The COSCA study identified a wide range of harvest periods (3 mo to ≥ 3 yr) in the countries surveyed.

Information from the African geographic database permitted comparisons of the age-at-harvest data with environmental variables and population density. Age at harvest was positively correlated with the total area of cassava around each survey village (within approx. 10 km). Most of the late-harvested var. (24 mo or longer) were found in areas of low population density (<50 persons/km^2).

24.2.3 Abandonment of cassava varieties

The reasons for abandoning up to 4 cassava var. were elicited in the questionnaire. Cassava var. were abandoned most frequently because their growth cycle was too long. In humid climates, competition from weeds was the second most common reason. In dry areas, processing problems and pests were cited as frequently as weeds, as secondary reasons for abandonment. When examined in relation to soils, weed competition was cited as the major reason for abandoning varieties at sites with acid soils. Similarly, this reason was cited most frequently in areas of low population density, probably where labor was scarcest. In areas of high population density, by contrast, long growing cycle was most commonly cited, presumably because land was scarcer.

Having examined data on cassava varieties in the 6 COSCA countries, the most salient point appears to be the significant variation that exists in all the findings. There are few clear, strong relationships with environmental or population density that cut across all countries studied initially. This indicates a very complex interaction of factors determining cassava's status, uses and importance in different parts of different countries. It emphasizes the need for further studies to understand local variation within particular cultural, economic and environmental contexts, which can then be brought together to increase overall understanding of cassava in Africa. Analysis of the Phase-One results from countries new to the study, in conjunction with the data from the first 6 countries, may identify relationships with broad geographic factors more clearly. The second phase will provide the details necessary for a deeper understanding of the local situation to Noradd depth to the results from the first phase.

24.3 Further Analysis of the African Geographic Information System for Cassava

Much of the work undertaken for the COSCA project by the ASU was not limited to the 6 original countries. Cassava distribution, climate classification, administrative units and infrastructure were originally mapped for the whole continent. Together with digital soil and elevation maps acquired after the sampling frame had been designed for COSCA, relationships between the distribution of cassava, population and environment were explored for all of Africa.

The proportion of land area devoted to cassava, length of dry season (from the climatic classification), soil restriction type, and population density were calculated. A new map of unique polygons was created in which the above factors were all homogeneous. The population and area in cassava was then calculated for each polygon; and a regression model was constructed with area in cassava as the dependent variable, population density as the independent variable, and the two environmental variables as factors of the independent variable.

The model shows that the proportion of land devoted to cassava increases with population density. The relationship is described by a quadratic curve. The model has served as a check for the area data used in the original cassava distribution map (Fig. 24.1). It was used to extrapolate cassava distribution for the year 2000, using population projections. Spatial residuals--areas where the model does not fit well--have been identified using the model. These are concentrated around the Great Lakes, where the original distribution map showed the highest spatial concentrations of cassava. This finding suggests either that cassava area is overestimated, yields are significantly lower than elsewhere (necessitating a larger area to support a given population), or there are strong cultural reasons for higher cassava production in this region. Other areas of unexpectedly high cassava production are southeastern Tanzania, NE Mozambique and Bas Zaire. Possible explanations in these cases are lower productivity or cultural factors in the first case, the war in Mozambique and the large market demand of Kinshasa.

Significant differences were found in the amount of cassava grown between climate types. Humid climates had the largest percentage areas, followed by seasonal climates. Dry climates had the lowest areas in cassava. These differences were largely a function of population distribution and the agricultural systems upon which people depend for livelihood, in part determined by climate. Cassava introduced to Africa by the Portuguese was more adapted to humid and seasonal climates, and only recently has CIAT begun to take material from drier areas of NE Brazil to test in similar climates in Africa.

The findings from this study have implications for the geographic focus of cassava research in Africa. Areas of highest population density, around the Great Lakes and in SW Nigeria, for example, are predicted to see cassava area increase considerably this decade. This expansion will probably accompany the intensification of the areas' farming systems. In the Sahel belt and much of the Zaire basin, expansion of cassava over much broader areas is also likely. This may take place as an extensification of farming systems.

CIAT will publish an atlas of cassava in Africa, featuring maps that made up the geographic database, a study of the diffusion of cassava in Africa, and a series of case studies of cassava-based farming systems in 3 producer countries.

25. ADOPTION AND IMPACT STUDIES

The role of socioeconomics in the Cassava Program is to collaborate in the development of cost-effective appropriate technology components and their efficient diffusion in order to maximize impact on preselected target areas and audiences. As such, its activities include identification and analysis of problems and opportunities, experimental design and data analysis, monitoring the release and adoption of technology components, impact, and priority setting.

During the 1987-89 period the Economics Section allocated most of its resources to Integrated Cassava Projects R&D and monitoring activities. The Section collaborated intensively with the Utilization Section in alternative product and market assessment and validation in Colombia, Ecuador and Paraguay. In addition, socioeconomic inputs have been given in the M&E of pre-production plots (PPPs), in collaboration with the Agronomy and Breeding sections. The majority of these studies were of an ex-ante nature.

Some emphasis on ex-post adoption and impact was given to project monitoring. Especially in the pilot and semicommercial phases of the Integrated Cassava Projects, monitoring activities have proven to be crucial to ensure the feedback of processing plant performance data in order to fine-tune short-term objectives. Monitoring also serves to check longer term objectives related to the distribution of benefits and overall adoption.

Given a lack of quantitative information on past and current performance of cassava technology and the urgency to become more resource accountable, the Economics Section reassessed its research priorities at the beginning of 1990. Thus in 1990-91 most of the research[25.1] has focused on ex-post technology adoption and impact assessment. These studies cover varietal adoption, production management and cassava processing technologies, both in Asia and Latin America. In addition, the studies have both a micro (farm household) and macro (aggregate) focus. Although several studies are still in progress, this report highlights some of the exciting findings, showing a very significant adoption and impact of different cassava technologies in Colombia.

25.1 Integrated Cassava Projects

The underlying philosophy behind the Integrated Cassava Projects first developed in Colombia was that declining traditional cassava markets did not offer incentives for cassava farmers to adopt technologies to increase production and that therefore the introduction of dried cassava chips could broaden demand and create adoption incentives at the farm level.

[25.1] For a partial listing of the economics research issues, see the Cassava Program Annual Report 1990.

After discussing the diffusion of the Integrated Cassava Project model, the relative performance of cassava processing plants is analyzed. Then the way in which on-farm cassava consumption and sales have changed as a result of the broader market is studied. This is followed by a section on the adoption of cassava production technologies, concluding by showing how Cassava Integrated Projects have served as a vehicle for technology diffusion.

25.1.1 Adoption of drying technology

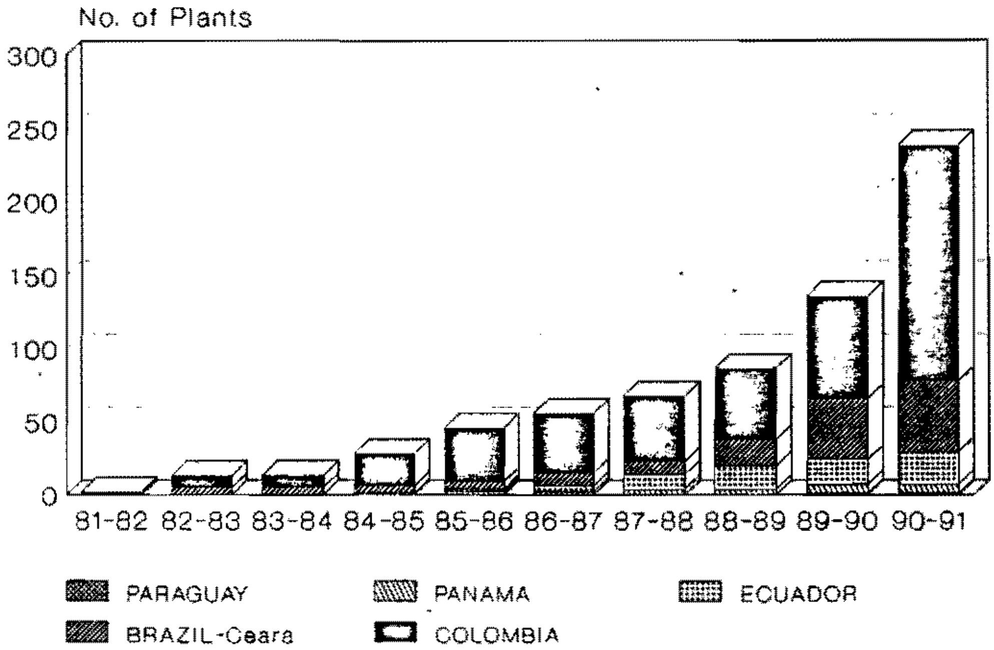
In the previous chapters on regional collaboration some information was presented on the rapid diffusion and adoption of cassava drying plants in Latin America (see also the Cassava Program Annual Report, 1990). In this section it will be shown that besides a rapid adoption in time and location, there has been a very dynamic adoption by different user groups. Also, the basic "coop model" has been adapted by the commercial sector to serve different objectives and market structures.

Figure 25.1A shows the total no. of cassava processing plants in Latin America. The acceleration of plant adoption has been very clear during the last 2 yr. To a major extent this has been caused by the rapid adoption of coops by Brazil, and the acceleration of commercial plants in Colombia (Fig. 25.1B). The data for 1991 are estimates, however, as it has no longer been possible to keep an accurate count through monitoring activities because of the fast, widespread and diverse types of cassava drying adoption.

During the initial phase of the project in Colombia, the cassava drying coops sold the dried chips to several large animal feed manufacturers near large urban centers (i.e., Barranquilla, Bucaramanga and Medellín) and the North Coast of Colombia. During the last couple of years, however, several changes have been observed.

- The market for dried chips has broadened towards central and southern Colombia, including large feed companies in Bogotá, Buga and Cali. It is estimated that the majority of the chips for these latter markets are being supplied by plants on the North Coast. However, the share supplied by plants and private chippers in the southern part of the country has been increasing significantly. This is another indication that the cassava processing technology is spreading into new areas.

- While the buyers of chips were largely animal feed factories, the current user group is much less homogenous. There is a strong demand from (a) swine, broilers and egg producers, who mix their own feed rations; and (b) cattle operations that need an energy source (on-farm) to reduce animal wt losses during the dry season, which coincides with the cassava processing season. In addition, a growing demand has become evident from cassava starch producers, who have started buying cassava chips in addition to fresh roots.



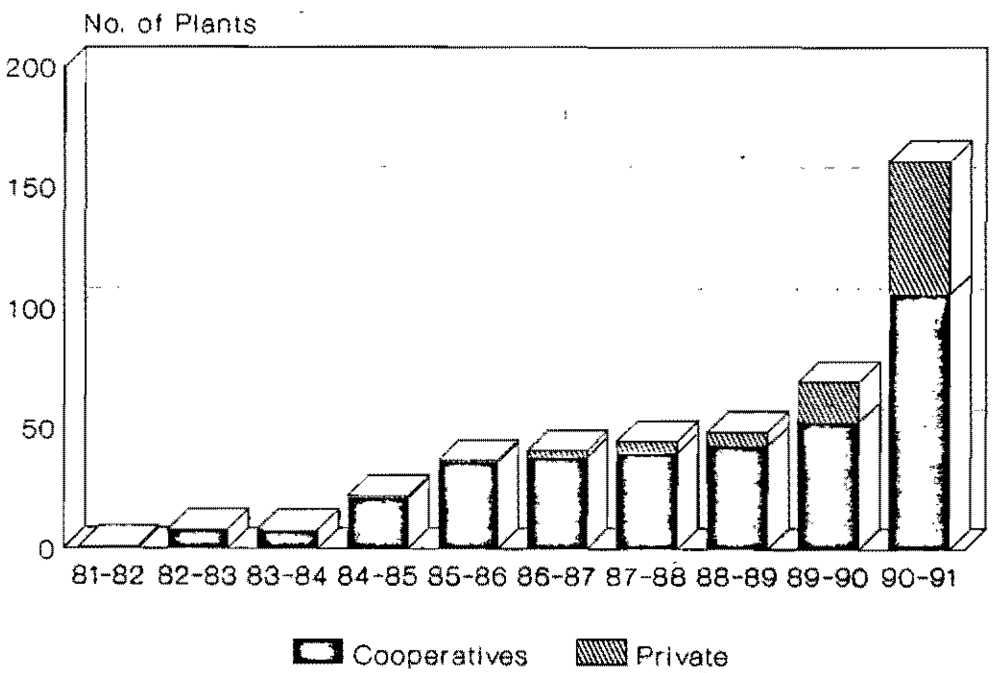


Figure 25.1. Adoption of cassava drying plants in (A) Latin America and (B) Colombia, 1981-91.

- The initial cassava processing "model" as started in Sucre in 1982 was based on a small-scale cassava farmer coop concept. However, during the last couple of years this model has been modified because of different commercial objectives and markets. In 1990 only an estimated 60% of dry chips (sold to factories only)[25.2], were produced according to the basic model (Fig. 25.2); the rest was produced by a heterogenous group of processors based on a large variety of "models." For 1991 it is estimated that the latter group has surpassed production of the former. Currently the following cassava drying "models" have been identified:

  - A small-scale cassava farmer coop, with an avg of 20 (legal) members
  - A coop as above but with 200-400 members
  - An association with 2-4 members who on the avg cultivate more land; the drying plant is on one of the members' farms (typical for Santander)

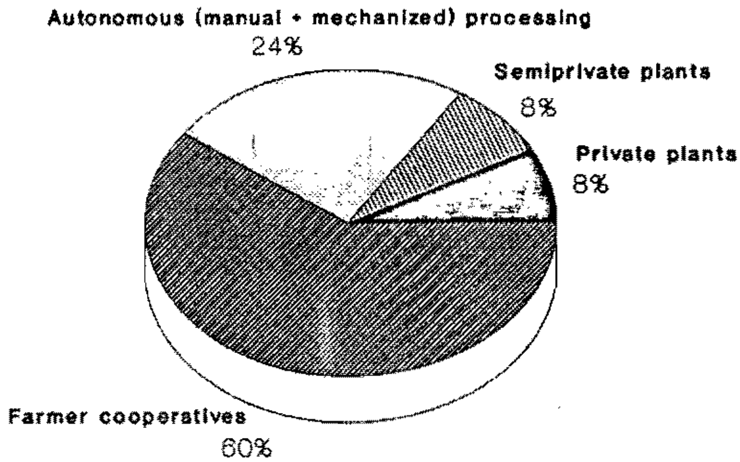


Figure 25.2. Adoption of cassava drying technology in Colombia by user groups, 1990. (Total feed industry usage, 16,500 t.).

[25.2] Sales to feed factories is the only reliable information that currently exists. It is estimated that these sales comprise 50-75% of total chip production.

- Both large and small private commercial plants, owned by one or more persons, purchasing all roots from local farmers

- Private entrepreneurs, who rent the floor and chipper by unit of wt (or time) to local cassava farmers

- Large-scale drying plant, vertically integrated with an animal feed company, which is the owner and manager

- On-farm small and medium drying plants as part of a cattle operation

- Cassava starch processors (Cauca) who, when starch prices are low, produce dried cassava chips

- Individual small-scale cassava farmers, who manually chip and dry (on any kind of surface) cassava from secondary quality roots, and/or when the cassava fresh price is too low, or because they are isolated from the fresh cassava market

■ Initial dry chip marketing was basically direct negotiating between chip-producing plants (or its marketing association) and feed factories. Given the increasing diversity of producers and "consumers," volumes traded and the geographic dispersion of demand and supply zones, intermediaries have entered the marketing channels, introducing one or more pricing points. Among other things, this has made it possible for isolated small-scale, sporadic and low-vol. cassava chippers to sell their product. The introduction of intermediation has naturally increased marketing margins.

It is evident that this cassava processing technology has been rapidly and widely adopted, in time and space, for different uses and user groups. Strong commercial interest and adoption is probably a fair indicator of the potential benefits to be gained from the technology. Moreover, the adaptation of the original model into a wide array of "applied models" increases the sustainability of the technology, *ceteris paribus*.

Although basic data on adoption has been shown, there still exists a lack of quantified impact data, both at the farm and the aggregate levels. A study has been started to analyze this impact. Given the evolution of the basic technology concept into various models, there is a need to assess the differences in structure, management, efficiency and especially the distribution of benefits "across" these models. A study to assess this will be started next year.

The sustainability of the cassava drying technology depends to a large extent on the sustained demand for chips (and other cassava-based products), which in turn depend on relative price competitiveness. Hence a study was started to assess the future impact of government policies such as the liberation of imports on the potential of cassava vis-à-vis competing products. This is a kind of monitoring that is needed for timely decision-making regarding cassava product and market strategies.

25.1.2 Relative performance of drying plants

As part of long-term monitoring, the drying plants on the North Coast of Colombia were assessed for their individual performance. The objective was to identify and analyze the most important factors that contribute to the success (or failure) of a cassava drying plant. As such, in 1991, 29 cassava coops were surveyed. Criteria for success were: dried cassava production, profits, capacity utilization, and profits per ton of dried cassava. The general conclusion is that the prevailing factor for a plant's success is adequate root supply commensurate with its floor size and sufficient working capital.

With respect to output efficiency, it was concluded that drying plants situated in the savannas were more successful than plants in other areas (cassava is a more predominant crop in the savannas because of harsh agroclimatic conditions). Some correlation (positive) existed between dried cassava production and profits. Assured root supply is more important than processing efficiency, being directly related to the importance of the plant's location. The degree of utilized capacity has some influence on success. It was found that more than 60% of the successful plants in the savanna utilized at least 50% of their capacity.

When looking at profits per ton of dried cassava, the issue of plant size became apparent. It was found that a large drying floor and large production were not necessarily a key for success. Although in theory larger plants should enjoy some economies of scale, this was being offset by the major problem of coordinating a sufficient supply of fresh roots. Larger plants have had problems with limited transportation (no. of tractors) and hauling larger supplies over larger distances.

When it was established that root supply and working capital were the critical factors for plant success, both were analyzed further, across individual plants. Factors that directly influenced fresh root supply were:

- Competitiveness of fresh root purchase price. During the processing season, drying plants compete for supplies with the demand for fresh roots from urban centers, and to a lesser extent, with the roots for starch processing. It was found that during the main harvest, root prices allowed healthy competition. During the dry season, the price offered at the plants justified the transport of roots from > 250 km.

- Farm-size distribution near the drying plant. It was found that two types of farm-size distribution had a positive effect on assured root supplies: a large no. of small (1-2 ha) farms within a 1-5 km distance from the plant and a smaller (15-25) no. of medium (5-12 ha)-sized farms within a 5-10 km radius. It was also demonstrated that a concentration of production in the vicinity of the plant is of importance.

- Tractor availability is an important factor for land preparation as well as for the transportation of roots from farms to the plant. Under existing conditions, farmers need tractors in order to expand planted area.

- Collective cassava fields. A drying plant with collective cassava plantings increases its independence from competing markets. As such, it increases its self-produced supplies and lowers the risk of undersupply. In addition, cooperative cassava plots are a way for farmers to increase production in the absence of titled land for individuals. Especially in Sucre, with the assistance of low-cost financing by local institutions, 25-60 ha cooperative plots are common. The majority of these plots produce cassava with improved cassava technologies.

Besides an assured root supply, sufficient working capital has proven to be a major critical factor in the success of a plant. When plants have insufficient funds, the purchasing of roots is hampered, which directly influences production efficiency. The principal issues behind this are: (a) the absence of savings from the previous processing season; (b) delays in the release of loans to purchase roots; and (c) delays in payments for dried chip sales by feed factories or marketing organizations.

The information that has been generated with this study is of great value in the decision-making process for expanding old plants and establishing new ones. The feedback of monitoring information serves to increase the successful performance and continued adoption and impact of cassava drying plants.

25.1.3 Production technology adoption

The formula of integrating cassava utilization, marketing and production aspects in this research has offered the opportunity to use the drying plants (farmer associations) as a vehicle for developing, testing and diffusing improved cassava production and management technologies. One methodology for accomplishing this is with the PPPs, where the best available production recommendations are tested and validated on-farm on commercial-size plots in areas where drying plants have been established (see Chap. 9). Another method has been to involve drying plants directly in the multiplication and diffusion of improved cassava (and maize) varieties, and in stake selection and treatment methodologies (see Chap. 18).

ICA, the Colombian national program, has for many years been developing and diffusing technology components including several improved varieties through its Technology Transfer Division. As a result, a wide array of cassava technologies have been adopted throughout Colombia, but especially in the predominant cassava-producing states of the Atlantic Coast. It has become impossible to distinguish one specific technology, in a defined area, introduced in a specific year, from others in other areas and years; rather there is a mixture of different technologies, with different levels of diffusion, adoption and impact.

In assessing the adoption of cassava technology on the North Coast, the first step was to define objectives and specific hypotheses to be tested. The objective of the study was to analyze the adoption of improved cassava production technologies and their effect on the farm production, marketing and utilization system, given increased cassava demand after introducing the drying plants.

Figure 25.3 presents a simplified scheme of how production and processing technologies and their adoption and impact are interrelated. At the adoption level there are two technologies: dried cassava and the cassava production package. The newly created demand will influence on-farm cassava consumption and sales, as well as stimulate cassava production at the farm level in two ways. In the short term, the farmer is able to react by increasing cassava area in the production system, using traditional technology. In the intermediate term, the farmer will attempt to increase productivity, which increases the demand for improved cassava production technology. In the intermediate to long run, both productivity and area expansion will increase aggregate supply. The following hypotheses were tested:

- Increased cassava demand creates demand for improved production technology at the farm level.

- In the short term, farmers increase planted cassava area, decrease fallow period and area, and decrease nonharvested cassava area.

- In the intermediate term, the adoption of technologies will increase cassava productivity.

- Increased expected returns on cassava and possibilities of obtaining cooperative credit will intensify cassava production through increased input and tractor usage.

- In areas with cassava drying plants, the rate and extent of production technology adoption is greater than in areas without drying plants.

As can be seen from the hypotheses, the current study does not limit itself to adoption only, but includes certain **on-farm** production, utilization and marketing systems impact.

The second step in organizing this study for analyzing adoption of these technologies was to make an inventory of (a) baseline studies, (b) released technologies, (c) time-series data on cassava planted area and production, and (d) primary and secondary data on adoption levels and rates. In the case of the Atlantic Coast, it was found that many studies and surveys had been conducted on cassava production, consumption and

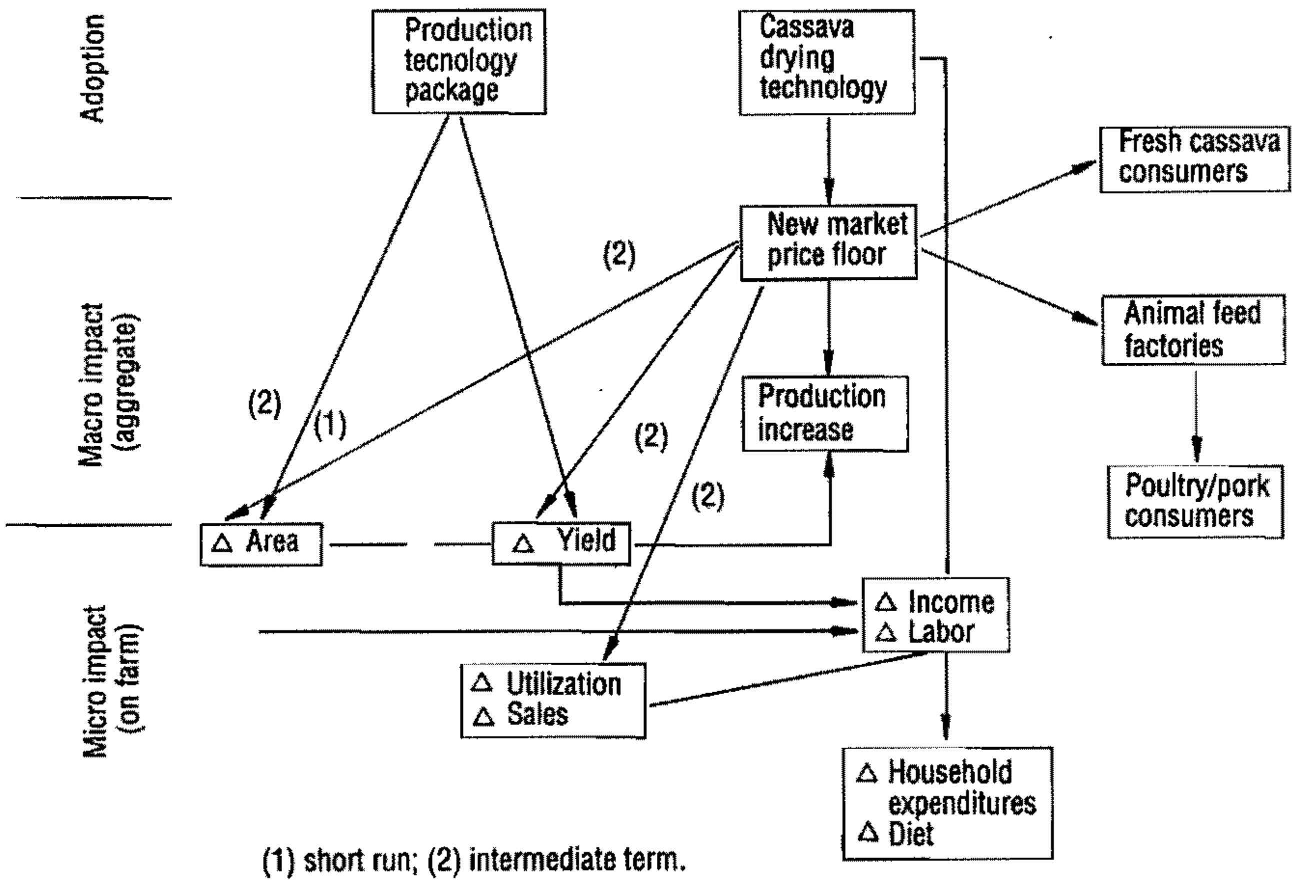


Figure 25.3. Flow diagram of the adoption and impact of cassava technologies regarding Integrated Cassava Projects, Colombia, 1991.

marketing aspects since 1974. However, a representative baseline study did not exist. Given this lack of essential data, the assumption was made that possibly a traditional cassava-growing area that had not experienced any (cassava) technological influence over the last decade, could serve as an approximation of the "pre-technology influence" situation of the beginning 1980s. In order to identify these areas, an inventory was made for the Coastal states of all cassava studies, experiments, presence and activities of ICA, CIAT, DRI, Caja Agraria, Secretariat of Agriculture, etc. over the last 10 yr. This information was analyzed and checked during a Rapid Rural Appraisal. The following "levels of technology influence" were classified (by municipality):

Level 1: Municipalities with cassava drying plants, started before 1988, with good institutional presence, and that have had farmers participating in experiments, studies, etc.

Level 2: Municipalities with cassava drying plants built after 1988, with institutional presence through cassava drying activities

Level 3: Municipalities without drying plants and with low or nonexisting institutional presence

With this prestratification, it is assumed that Level 1 has enjoyed the largest technology influence and that Level 3 has experienced the least. Consequently, the latter will be assumed to approximate traditional cassava farming, and function as the baseline area (Yr 0), to which technology adoption data from Level 1 are compared. Level 2 is assumed to be an intermediate area that has received some direct technology influence.

This ex-ante classification and 1985 census data on cassava area by municipality formed the base for a representative sample frame and size selection, covering 7 states in Northern Colombia. A farm household survey was developed and tested. Surveying of the first 5 states took place in July-Aug. 1991. The preliminary results[25.3] that follow are from the states of Sucre, Bolívar and Córdoba only (N=299).

25.1.3.1 On-farm consumption and marketing system change. The newly created demand for cassava dried chips will have an immediate effect on on-farm cassava consumption and sales. Table 25.1 shows that farmers consumed 22% of their cassava production on-farm, mostly for human consumption. While on-farm cassava consumption by farm animals is virtually the same across levels, Level 1 typically retains less cassava for on-farm household consumption and sells more to the market than Level 3. In other words, cassava farmers in high technology-influence areas have become more market oriented.

[25.3] It must be noted that as data for only 3 states are available, the results have been adjusted accordingly.

Table 25.1. Comparison of cassava on-farm consumption and sales in selected states of Colombia by level of technology influence, 1991.

		Technology Influence Level		
	Avg	1	2	3
		% Total Production		
On-farm consumption:				
- family	16	12	19	16
- animals	6	5	6	7
Subtotal	22	17	25	23
Sales to:				
- fresh market	55	42	67	56
- drying plants	22	40	8	19
- other	1	1	-	2
Subtotal	78	83	75	77
Total Production	100	100	100	100

Source: Technology Adoption Survey, CIAT Cassava Economics, 1991.

What is even more striking is that currently 22% of cassava production is sold to drying plants; the remainder is sold to the fresh consumption market. Given the criteria for selecting the different levels used in this study, it is consistent to observe that Level 1 farmers sell twice as much cassava to drying plants as Level 3 farmers. Subsequently, the latter still sell relatively more cassava to the fresh market.

Given the strong influence of the drying technology and its demand across technology levels, it would be useful to compare the few existing data over time. Table 25.2 compares cassava consumption and sales data between 1982 and 1991. The differences are significant and consistent with the analysis across levels. It shows that the share of cassava production consumed on the farm (as percent of total production) has been halved during this period. While the production share sold to the fresh market in Córdoba and Bolívar virtually remained the same, Sucre experienced a major decline in this market, from 62% in 1982 to 35% in 1991. The major and most obvious explanation for this is the high concentration of drying plants in this state, which is also the reason for 47% of the production being sold to drying plants there. While Córdoba shows a respectable 24%, farmers in Bolívar sell only 2% for chip production. Compared to 9 yr ago, this trend is evidence of the adoption of cassava drying technology. In addition, effects of this adoption have not been restricted to areas with a relatively higher level of technology influence and institutional presence, but also to areas with fewer or no processing plants or institutional presence.

Table 25.2. Comparison of cassava yield, consumption and sales in selected states of Colombia, 1982 and 1991.

	Sucre	Córdoba	Bolívar
On-farm cassava consumption[2] (% total production)			
1982 study[1]	34	38	37
1991 study[3]	17	18	28
Sale to fresh market (% total production)			
1982 study[1]	62	53	60
1991 study[3]	35	57	69
Sales to drying plants (% total production)			
1982 study[1]	0	0	0
1991 study[3]	47	24	2

1 Janssen, W., 1982, "Producción, mercadeo y el potencial industrial de la yuca en los departamentos de Atlántico, Bolívar, Sucre y Córdoba, CIAT, mimeograph.

2 This includes both human and animal cassava consumption.

3 Preliminary data, Cassava Adoption Survey, CIAT Cassava Economics, 1991.

25.1.3.2 Technology adoption rate and area. During the last decade a wide array of improved cassava production technology components have been introduced, either officially or unofficially through spontaneous farmer adoption (Table 25.3).

Table 25.3. Various cassava improved-technology components released on the North Coast of Colombia.

Technology Component	Released in Year	Released in
1. Variety Venezolana (M Col 2215)	1983[1]	Magdalena
2. Variety ICA P12 "Verdecita" (M Col 1505)	1984[2]	Magdalena
3. Stake selection	1974	Magdalena
4. Stake treatment	1980	Sucre
5. Planting density	1986	Córdoba
6. Weed control	1986	Córdoba
7. Stake storage	1980	Magdalena

Source: Cassava technology monitoring, Cassava Economics, 1991.

1 Scattered usage of this var. was already reported during the mid 1970s.

2 This var. "escaped" from regional trials and was subsequently reported during early 1980s.

Although var. Venezolana was not developed by ICA/CIAT, they were instrumental in its diffusion. As shown in Table 25.4, Venezolana has been adopted by 91% of the surveyed farmers, covering an avg of 73% of the area planted to cassava. Given this adoption level, it is estimated that Venezolana currently covers approx. 44,000 ha in the 3 principal cassava-producing states of Colombia. It is striking to see that this variety was adopted by more farmers and planted in a larger area in Level 1 than in the other levels. It can be assumed that Venezolana is currently close to its adoption ceiling.

The var. Verdecita (ICA P12) "escaped" from on-farm trials during the early 1980s, but was not officially released until 1984. Currently it has been adopted by only 5% of the farmers in the sample (2% of cassava area). The majority of adopters are in Level 1 (13%), which can be explained by the fact that diffusion was started in areas with a relatively high concentration of drying plants and institutional support. In the absence of this (Level 3), no adoption has occurred[25.4]. It is expected that ICA P12 will gain only slightly more adoption before leveling off as a highly promising variety (ICA-Costeña) has recently been released, which is greatly preferred by farmers. Notwithstanding, Venezolana and Verdecita together represent 75% of the area planted to cassava in the sample; the remainder is made up of traditional local varieties.

Table 25.4. Adoption of new cassava var.[1] in selected states of Colombia, by level of technology influence, 1991.

		Technology Influence Level		
	Avg	1	2	3
Percent farmers planting:				
- Venezolana	91	98	83	91
- ICA P12 "Verdecita"	5	13	2	0
- Regional	43	26	59	45
Avg area (ha) with:				
- Venezolana	1.8	2.1	1.8	1.7
- ICA P12 "Verdecita"	1.1	1.3	0.3	-
- Regional	1.4	0.9	1.7	1.3
Percent total cassava area with:				
- Venezolana	73	85	58	72
- ICA P12 "Verdecita"	2	4	1	0
- Regional	25	11	41	28

Source: Preliminary results from Cassava Technology Adoption Survey in Colombia, CIAT Cassava Economics, 1991.

1 Introduced var. are Venezolana (M Col 2215) and Verdecita (ICA P12 = M Col 1505); "regional" comprises several local traditional var.

25.4 Levels of institutional presence are shown in Table 26.5, showing 61% and 12% of the respondents receiving technical assistance in levels 1 and 3, resp.

Table 25.5 shows the adoption levels of several production technology components. Stake treatment and storage show an overall adoption rate of 10% and 71%, resp. As was hypothesized, Level 1 shows significantly higher rates than the other levels. Stake treatment adoption appears rather low given that the technology was released in 1980. The major constraining factor in its adoption has been the technical (and structural) problem of the absence of water in farmers' fields after harvesting (the dry season). On the other hand, stake storage methodologies have been adopted quickly.

Increased planting density and chemical weed control are components from a "package" released in 1986 (in Córdoba), which shows a very high adoption rate across technology levels, of 60% and 53%, resp. Herbicide usage demonstrates larger differences between technology levels than planting density. This can be explained by the increased financial resources needed to adopt herbicide usage, which is relatively more accessible through credit for drying coops (Level 1). In addition, the higher expected returns from cassava production at Level 1 warrant relatively higher input purchases.

Tractor usage for land preparation has never been an official recommendation; however, cassava drying plants have increasingly made tractors available at cost to members and nonmembers. In addition relative labor scarcity, expanded cultivated areas and greater cassava revenues have increased tractor usage. Table 25.5 shows that 41% of the farmers are using tractors for all or part of their land preparation. Even more significant is the fact that 82% of Level 1 farmers are using tractors, as could be expected from this reasoning.

Table 25.5. Adoption of cassava production technologies in selected states of Colombia, by level of technology influence, 1991.

		Technology Influence Level		
	Avg	1 N=96	2 N=100	3 N=103
			% Respondents	
Tractor use in land preparation	41	82	20	15
Stake treatment	10	19	5	5
Stake storage	71	81	61	72
Herbicide use	53	69	50	39
Increased planting density	60	65	68	46
Technical assistance	40	61	45	12

Source: Preliminary data, Cassava Technology Adoption Survey, CIAT Cassava Economics, 1991.

The aforementioned technology components are all production focused. Further evidence of the adoption of these technology components is the change in yield and, of course, the change in cassava net revenues. Data, by level, show an overall cassava yield avg of 12.0 t/ha (for cassava/maize intercrop). Given the fact that significant technology adoption has also taken place in Level 3, this will not serve as an approximation of a traditional (absolute) base. Hence, the data were analyzed by state and compared with results from a 1982 survey.[25.5] As can be seen in Table 25.6, since 1982 cassava yields have increased by 52%, 56% and 76%, resp., in Bolívar, Sucre and Córdoba. In addition, comparing current yield averages with the national statistics (Table 25.7) does not show any significant differences. Nevertheless, the yield results of the studies need to be interpreted with caution as they do not capture any fluctuations due to climatological factors.

25.1.3.3 Cassava area increase in the short run. A farmer can increase cassava production by expanding cassava area in several ways, assuming that in the short run, total farm size remains the same and that improved technology is not yet adopted. These options are to increase planted area by (a) reducing area in fallow, pasture or other crops; and (b) increasing area in cassava monoculture. In addition, traditionally noncassava growing farmers start to plant cassava.

Table 25.8 shows that total crop area both in absolute terms (ha) and as percent of total farm area is greater at Level 1 than at Level 3. Hence cassava farmers in areas of technology influence plant, on the avg, a larger area with crops; and the share of crops vs other farm activities is larger than cassava farms in areas with low technology influence. This seems consistent with the observation that farmers at Level 3 dedicate relatively more of their farm area to pastures than Level 1 (68% and 58%, resp.); and the absolute size of pasture land is more than twice as large as at Level 1.

Table 25.6. Comparison of cassava yields (cassava/maize intercrop) among selected states in Colombia, 1982 and 1991.

	Sucre	Córdoba	Bolívar
Yield (t/ha)			
1982 study[1]	7.0	6.8	7.5
1991 study[2]	10.7	12.0	11.4

[1] Janssen, W., 1982, "Producción, mercadeo y el potencial industrial de la yuca en los departamentos de Atlántico, Bolívar, Sucre y Córdoba, CIAT, mimeograph.
[2] Preliminary data, Cassava Adoption Survey, CIAT Cassava Economics, 1991.

[25.5] W. Janssen, 1982, "Producción, mercadeo, y el potencial industrial de la yuca en los departamentos de Atlántico, Córdoba, Sucre y Bolívar", CIAT mimeograph.

Table 25.7. Cassava area, yield and production in Colombia, 1991.

	1986	1987	1988	1989	1990	1991[1]	% Annual Growth	% Absolute Growth
				AREA (100 ha)				
Sucre	8.0	11.5	7.1	11.0	17.0	20.0	17.7	150
Córdoba	7.3	10.0	6.9	14.0	16.8	15.9	17.5	118
Bolívar	17.0	20.0	18.0	23.0	26.4	24.2	8.7	42
Atlantic Coast	61.1	8.7	69.8	84.5	109.1	112.4	12.0	84
Colombia	153.3	159.1	148.8	170.6	207.3	219.7	7.8	43
				YIELD (t/ha)				
Sucre	8.0	8.9	10.0	11.0	10.0	12.0	17.7	50
Córdoba	7.3	7.0	5.0	8.3	11.3	11.3	11.8	55
Bolívar	7.5	7.0	7.5	8.5	9.2	9.3	5.8	24
Atlantic Coast	7.8	7.7	8.1	8.7	9.1	9.8	4.9	26
Colombia	8.7	7.9	8.6	8.8	9.3	9.5	2.7	9
				PRODUCTION ('000 t)				
Sucre	64.0	102	71.0	121.0	170.0	240.0	24.8	275
Córdoba	53.3	70	34.5	116.2	190.0	179.5	29.4	237
Bolívar	127.5	140	135.0	195.5	261.7	226.4	14.6	78
Atlantic Coast	475.0	604.0	568.4	734.4	990.6	1097.9	16.9	131
Colombia	1335	1260	1282	1509	1939	2079	10.5	56

[1] Preliminary estimate.

Source: Ministry of Agriculture, Bogotá, 1991.

Table 25.8. Changes in area utilization of cassava farms by level of technology influence in several states of Colombia, 1991.

		Technology Influence Level		
	Avg	1	2	3
- Total crop area (ha)	3.5	4.1	3.4	3.1
- Crop area, % total farm area	29.0	34.0	35.0	22.0
- % farmers with pasture	55.0	71.0	49.5	45.5
- Avg pasture area (ha)	13.7	9.9	11.8	21.1
- Pastures, % total farm area	62.6	57.8	60.0	68.0
- Avg cassava area (ha)	2.5	2.7	2.4	2.3
- Cassava area, % total crop area	70.0	66.5	70.0	74.0
- % farmers with fallow land	27.7	25.5	19.6	37.6
- Avg fallow area (ha)	2.5	2.3	1.4	3.3
- Fallow area, % total crop area	20.0	14.0	8.1	40.0

Source: Cassava Adoption Survey, CIAT Cassava Economics, 1991.

On the avg 28% of cassava farmers in the sample keep land in fallow (20% of the arable land); for Level 1 farmers this is only 14% vs 40% for Level 3. This implies that cassava farmers in high technology-influence areas have significantly decreased their fallow land. Percentagewise, more Level 3 farmers have more land in fallow than Level 1 farmers.

When analyzing the relative importance of cassava in the cropping system (Table 25.8), cassava is important at all levels. The cassava area as share of crop land is largest with Level 3 farmers.

Information from previous cassava production surveys showed that because of large cassava price fluctuations, it was not economical at times to harvest part of the cassava area. Harvesting labor outweighed the low revenues from cassava sales. However, when the current data were analyzed, 86% of the farmers in the sample said they always harvest the same cassava area as was planted (98% of Level 1 farmers vs 89% for Level 3 farmers). The fact that there is hardly any difference between these two levels is because of the influence that all levels enjoy from stabilized cassava prices, resulting from the dried cassava price functioning as a price floor in the fresh cassava market.

These data show for all aspects that cassava farmers are increasing cassava production by reorganizing cassava area, fallow land and harvested area, in the short run. Secondary time-series data on cassava area, yield and production seem consistent with this notion. Table 25.7 demonstrates that between 1986-91, the cassava area in the states of Sucre and Córdoba experienced an annual growth of 17.7% and 17.5%, resp.

25.1.3.4 Conclusions. In the previous sections it was shown that different improved production technology components have achieved significant adoption levels. It was also demonstrated that on-farm consumption and sales patterns have changed. Cassava farmers can currently maximize cassava sales by selling their roots to either the fresh or dried cassava markets.

Thus far this study has analyzed technology components. When looking at overall adoption figures, Table 25.9 shows that 71% of the surveyed farmers had adopted at least one production technology component. Again, this figure was significantly higher at Level 1. It also shows that 59% of the cassava farmers have experienced increased cassava demand and a broader market over the last half decade. In order to capture the effect of the introduced technologies, the farmers were asked if they had experienced a gain in cassava revenues resulting from technology adoption. The majority (80%) agreed to this statement. The reasons for this income improvement were better markets and prices (83%); better cassava production (9%) It was found that more farmers at Level 3 find better cassava prices important for income improvement than at Level 1; the latter showed a relatively higher response for better production. This is consistent with observed adoption levels: Level 1 farmers have adopted more production technologies than Level 3 farmers.

Table 25.9. Comparison of cassava technology component adoption in selected states of Colombia, by level of technology influence, 1991.

		Technology Influence Level		
	Avg	1	2	3
		—— % Respondents ——		
Adoption of at least one production technology component	71	85	69	59
Increased demand and broader market	59	71	57	49
Income improvement from cassava technology	80	91	73	75
Reasons for income improvement:				
. better prices	43	33	53	49
. better markets	40	48	26	41
. better production	9	16	7	1

Source: Cassava technology adoption survey, CIAT cassava economics, 1991.

When relating these results with the stated hypotheses, it can be concluded that all the hypotheses hold. The data have shown that when there is increased cassava demand, farmers expand cassava production area and adopt technology components to increase productivity. It also holds that in areas with a higher concentration of cassava drying plants and institutional presence, the level of production technology adoption is greater than in areas with few or no drying plants and little institutional presence. It also seems that cassava drying coops can very well serve as an efficient and effective vehicle for production technology diffusion. This analysis is, however, based on an incomplete sample. As soon as all the data are collected and analyzed, a more in-depth study of some of these aspects can be made.

There is also a need to assess how the changes in the cassava production system affect the preservation of the natural resource base. This is of importance as cassava-production areas are mostly on highly fragile soils. Another aspect regarding the sustainability of cassava improved technologies is the effect of governmental policies on the comparative cost advantage that cassava enjoys as a substitute for sorghum in animal feed rations. The opening of Latin American economies to world markets and its effect on the future potential of cassava is a subject for further investigation.

25.2 Varietal Adoption in Asia

25.2.1 Adoption of Rayong 3 in Thailand

After Brazil, Thailand is the most important cassava producer in the world. Thai cassava has been used predominantly for processing into chips, pellets and starch. The bulk of chips and pellets are exported. Local cassava var. Rayong 1 is planted throughout Thailand because of its adaptation to existing harsh conditions. In collaboration with CIAT scientists, Thai breeders selected a cassava var. Rayong 3 (a CIAT-developed clone, CM 407-7), which has a significantly higher starch content than the local variety (see CIAT Report 1991). Rayong 3 chips also drying faster (2 vs 3 days). These advantages have been the main driving force behind its rapid adoption.

After several years of testing on experiment stations and farms, Rayong 3 was released in 4 provinces of NE Thailand in 1984, but initial diffusion was very slow. The Thai Agricultural Extension Service (Promotion Division) supplied innovative farmers with 600 stakes each. These farmers in turn gave 80% of the harvested stakes to neighbors. In 1986 the area for stake multiplication covered only 16 ha. By 1990 it was estimated that between 66,000 and 80,000 ha were planted with the new variety (4%-5% of the total Thai cassava hectareage), a significant accomplishment given the crop's adoption constraints. The question that arises is: who has benefitted from this adoption?

Farmers planting Rayong 3 can increase cassava revenues by 10%-15%, based on a 5% difference in starch content (with respect to Rayong 1), which translates into a price premium at the processing factory. In the aggregate, adopting farmers currently accrue US$3.8-US$4.6 million/yr from the new variety (internal Cassava Program data). Cassava processors gain considerable benefits from lowered drying time and a higher starch extraction rate. Also, in the intermediate to long run, with lower cassava product costs, Thai cassava exports to non-EC markets will become even more competitive. It is envisioned that EC consumers of meat products will not benefit greatly as the benefits from cost savings will remain predominantly at the various pricing points in the (inter)national marketing channel. Besides, EC cassava imports constitute only a small share of their total feedstuff requirements.

In collaboration with the Thai Extension Service, a study is being conducted to analyze Rayong 3 adoption levels. A similar study is under way in Indonesia to analyze Adira 4 adoption.

THE WAY AHEAD

26. THE CASSAVA PROGRAM IN THE 1990s

Cassava research strategies must be formulated in the light of changes in the various environments which, to a greater or lesser extent, influence the role that the crop may play in contributing to meet specific economic and social development goals. Government policies, trade balances and foreign debt pressures influence the market potential of the crop. The changing scope of international agricultural research--which has been broadened to encompass not only food supply but also income generation and a greater concern for the environment--also has to be taken into account. Finally, the relative strengths and weaknesses of national program partners and the level of interest shown by advanced research labs are key factors in determining an appropriate research strategy for the coming decade.

In the following sections, a short assessment will be made of cassava's socioeconomic and political environment by reevaluating cassava's demand potential, as analyzed in 1987, in the light of current conditions. This will be followed by a brief statement on cassava in the context of the evolution of the CGIAR and on the perceived institutional environment within which international cassava research will take place.

26.1 Cassava's Socioeconomic and Political Environment

26.1.1 Latin America

In the Americas the trend of decreasing cassava production during the 1970s and early 1980s has gradually changed into one of slow growth in the late 80s. FAO data show that during the period 1985-90 cassava production increased by 9.6%, from 29.6 million t to 33.7 million t (Table 26.1). Brazil, Paraguay and Colombia--which together represent 92% of total cassava production on the continent--have all experienced production growth.

The removal of government wheat subsidies in 1988 has increased wheat flour prices to above those of farinha, and this has likely influenced the stabilization of cassava production in Brazil. The increased cassava production in Paraguay is based on traditional usage; i.e., human consumption and on-farm animal feeding. Besides population growth, reasons for production increases in Colombia include increased consumption resulting from improved incomes (offsetting to a certain degree the negative effect that urbanization has on cassava consumption). In addition, the increasing importance of dried cassava for the animal feed industry has provided a new market outlet and stabilized prices. The demand for and adoption of improved cassava production technologies has been an important factor in increasing yields (see Chap. 25). Relative to several competing starchy products such as maize and potatoes, cassava retail prices have been relatively lower which has led to increased consumption,

Table 26.1. World cassava production (million t).

	1985	1986	1987	1988	1989	1990	Annual Growth Rate (%)
World	136.6	133.6	136.8	141.3	148.6	150.0	2.34
Africa	58.2	58.6	58.4	59.6	62.9	64.1	2.04
Ghana	3.1	2.9	2.7	2.8	3.3	3.0	0.95
Madagascar	2.1	2.4	2.2	2.2	2.3	2.3	0.93
Mozambique	3.2	3.3	3.4	3.2	3.5	3.6	2.01
Nigeria	13.5	14.7	14.0	15.0	16.5	17.6	4.97
Tanzania	6.8	6.2	6.0	6.1	6.2	5.5	-2.98
Uganda	2.7	1.9	2.8	2.5	3.1	3.2	6.30
Zaire	15.5	16.2	16.2	16.3	16.4	17.0	1.44
Asia	48.5	42.7	47.6	52.3	54.1	52.0	3.29
China	3.6	3.5	3.3	3.3	3.2	3.2	-2.45
India	5.7	4.9	4.8	5.4	4.5	4.6	-3.46
Indonesia	14.0	13.3	14.3	15.5	17.1	16.3	4.56
Philippines	1.7	1.7	1.8	1.8	1.8	1.9	2.08
Thailand	19.3	15.2	19.5	22.3	23.5	21.9	5.92
Vietnam	2.9	2.8	2.7	2.8	2.9	3.0	0.89
Latin America	29.6	32.1	30.6	29.2	31.4	33.7	1.53
Brazil	23.1	25.6	23.5	21.7	23.4	25.4	0.35
Colombia	1.4	1.3	1.3	1.3	1.5	1.7	4.00
Paraguay	2.9	2.9	3.5	3.9	4.0	4.0	7.60

Source: FAO Production Yearbooks.

especially among the urban poor. This phenomenon has occurred exclusively in those areas where there has been a strong adoption of cassava drying technology. In other regions of Colombia, cassava prices have increased relative to its substitutes in the diet.

The demand for meats, which remained strong in Latin America during the last decade, is expected to remain buoyant for the coming decade, especially for poultry. Consequently the derived demand for feed grains will follow similar trends although course grain production has shown a downward trend. Animal feedstuffs are generally supplied through increasingly costly imports, which will have an even greater effect on diminishing trade surpluses. Hence the demand for feed grain substitutes such as cassava will continue to have great potential.

Government policies indirectly affecting cassava's comparative advantage to substitute food and feed grains have been under strong pressure within the import liberation philosophy that many countries are currently following. Transportation subsidies, support prices and input price subsidies for the major grains are being lowered in several countries. This will indirectly favor the potential demand for cassava in alternative markets, thereby strengthening traditional demand. Thus the premise formulated in 1987 that alternative cassava markets such as the animal feed industry showed great potential in strengthening traditional demand remains valid.

Besides the animal feed market, cassava continues to be a strong price competitor for imported starches, principally maize. From the late 1980s onward, cassava starch has started to penetrate markets for industrial usage in Colombia and Ecuador. A similar trend can be envisaged for cassava flour as a substitute for wheat flours in bakery products, soups, processed meats, etc.

26.1.2 Asia

In Asia strong industrial growth has been the major factor behind overall economic growth and development. The agricultural sector has not remained behind during the last decade. The self-sufficiency philosophy has continued to boost production of primary crops.

Cassava production in Asia rose from 48.5 million t in 1985 to 52.0 million t in 1990--almost 1.5% above the annual population growth rate. The largest increases have taken place in Thailand and Indonesia, the two major Asian cassava-growing countries (Table 26.1). The Thai cassava industry used to be largely based on the export of cassava pellets to the EC. During the mid 1980s, it was predicted that the imposition of quotas by the EC would put a ceiling on this growth market. Nevertheless, Thailand's comparative cost price advantage has made it possible to make heavy inroads into other export markets in Asia, Eastern Europe and the USSR. Thai cassava exports have experienced a continued annual growth rate of 7% from 1985-90 (Table 26.2). The last 5 yr has also seen an increase in cassava starch manufacture, with the Japanese investing in plants for producing modified starches and other starch-derived products.

Although export volumes from Indonesia are only one tenth of those from Thailand, the former has experienced an even stronger growth (17.1%) during this period. The observed decline in cassava production in China is not substantiated by local figures, which report a significant increase. In fact, China and Vietnam together are seen as having a high potential for cassava development given the gradual liberalizing of their economies. The situation of cassava in India will depend largely upon government policies toward competing crops. The decline observed over the past 5 yr is almost entirely due to the subsidized replacement of cassava by rubber in Kerala and very favorable policies that maintain rice prices low. Nevertheless, there are some indications that cassava production is expanding in nontraditional growing regions, where it will be used as a raw material for industrial purposes.

Table 26.2. World trade in cassava[1] (000 t).

	1985	1986	1987	1988	1989	1990	Annual growth rates 1985-90 (%)
World exports	8130	7600	7900	10050	11930	10200	7.79
Thailand	7410	6760	6572	8580	10340	8945	7.09
Indonesia	600	425	783	1086	1200	1000	17.13
China	100	280	340	320	200	180	5.34
Vietnam	-	50	40	20	150	30	3.00
Others	20	85	165	44	40	45	1.35
World imports	9000	7840	7900	10440	11950	10200	6.20
EC	6730	6225	6990	7025	6982	6000	-0.60
China (Taiwan)	470	265	192	500	960	900	23.05
Japan	650	370	215	600	650	500	4.00
Korea Rep. of	240	260	138	40	930	900	32.80
USA	70	70	72	75	260	245	29.26
USSR	-	-	-	988	861	750	-13.78
Others	840	650	293	852	1307	905	10.10

Source: FAO

[1] Includes pellets, "native" pellets and dried cassava chips.

Government agricultural policies have always played an important role for cassava in Asia. Historically, policies have been oriented toward boosting primary commodity production (rice); however, during the last few years, several Asian governments have been lifting such policies. Fertilizer subsidies and support prices have been decreased in countries such as Indonesia and Vietnam, directly affecting production costs and market prices for high input-dependent crops such as rice. Consequently, low input-dependent crops such as cassava have become more price competitive. This is leading to an increased demand for cassava products to substitute for rice, maize and wheat in processed products for human consumption and in animal feeds.

26.1.3 Africa

Cassava production in Africa increased from 58.2 million t in 1985 to 64.1 million t in 1990, a growth rate of 2% yearly. The most significant increase in production was recorded by Uganda, with a growth rate of 6.3% yearly. In Nigeria the ban on wheat imports has been a stimulus to cassava production, which went from 13.5 million t in 1985 to 17.6 million t in 1990 (Table 26.1).

The results of the COSCA study will provide a much clearer picture of the demand potential for cassava in Africa. It is, however, safe to predict that cassava will continue to play its role as a major food-security crop. The rapidly urbanizing environment will present new demands as cassava makes the transition from a food staple to a carbohydrate source with multiple end uses.

26.2 Cassava Within the Context of International Agricultural Research

The CGIAR is in the process of undertaking radical changes with respect to its objectives, scope and role. Since its founding in the early 1970s, priority setting has evolved from being based purely on food production potential to include income- and employment-generating opportunities and the long-term sustainability of agricultural production. What was essentially a system that provided improved genetic materials and associated management practices to national programs is now diversifying--both in terms of its mandated commodities and its research focus. New commodities such as fisheries and forestry have been included in the portfolio, and an increasingly greater proportion of activities will be oriented toward resource management research. This general trend has been wholeheartedly embraced by CIAT, with plans for the 1990s to "...move assertively to combine commodity and resource management into an integrated systems approach in its efforts to increase food production and economic growth without jeopardizing the natio. al resource base..." (CIAT in the 1990s and Beyond: A Strategic Plan).

Within the changing context of international agricultural research, where does cassava stand? The foregoing chapters of this report have demonstrated the importance of the crop in providing food for millions of people in developing countries and described some of the advances being made to overcome the principal production and utilization constraints. The integrated cassava projects established in Latin America have highlighted the tremendous potential that the crop has for income and employment generation in some of the most marginal areas of the tropics through the integration of small-scale agriculture with more comprehensive forms of productive rural development including postharvest processing and other rural service activities. Cassava is therefore undoubtedly a crop that can significantly contribute to alleviating hunger and poverty--the goal of the CGIAR system. Both internal CIAT analysis[26.1] and recent TAC priorities and strategies documents support this view, the latter ranking cassava among the top 10 commodities in terms of priority and indicating that roots and tubers have been underfunded with respect to other groups of commodities such as cereals and food legumes. This is in marked contrast to the situation 8 yr ago when a reduction in investment in cassava research at the international level was seriously considered.

In light of evident overall donor fatigue, the broadened scope of activities contemplated by the CGIAR system in general and CIAT in particular means that core resources available for cassava research at CIAT will decline slightly over the next 10 yr unless the

[26.1] Janssen, W., Sanint L.R., Rivas, L. and Henry, G. 1991. CIAT's Commodity Portfolio Revisited: Indicators of Present and Future Importance. CIAT in the 1990s and Beyond: A Strategic Plan. Supplement. pp 15-50.

CGIAR sees fit to make shifts in resource allocation among its mandated commodities in the line with TAC's latest priority assessment.

26.3 The Institutional Environment

26.3.1 National cassava R&D systems

The strength of national cassava R&D systems is highly variable; and at the present time, with the exception of Thailand and India in Asia and Brazil in Latin America,[26.2] none of the countries has the capacity to conduct R&D activities across the whole spectrum of basic, strategic, applied and adaptive research.

26.3.1.1 Latin America. With the exception of Brazil, the national cassava research programs in the Americas are relatively weak and poorly funded. Few nongovernment institutions are involved in cassava-related research activities. The importance of cassava as a vehicle for promoting rural welfare was first recognized by development agencies and associated extension services. During the 1980s these institutions became the principal counterparts of the Cassava Program in the endeavor to link resource-poor cassava farmers to expanding markets. The interinstitutional model that was subsequently developed to integrate cassava production, processing and marketing activities in specific cassava-growing regions has provided a framework for:

- financing research activities within a development context
- linking research and extension activities oriented toward resolving the most immediate problems of the cassava farmer
- identifying, through feedback, priorities for longer term research

The fact that there is an almost total absence of postharvest research within the national programs has led to the need for identifying nonconventional partners with whom to interact. Experiences in Colombia, Ecuador and more recently Brazil suggest that second-order farmer organizations may have an important role to play in the future.

In the medium term, the Cassava Program's partners in Latin America will continue to be a range of institutions from both the public and private sectors. Public cassava research programs are likely to remain underfunded although opportunities do exist for financing research activities through integrated cassava projects.

26.3.1.2 Asia. The major cassava-producing countries in Asia have competent cassava research programs that vary in size, depending upon the relative importance of cassava

[26.2] This discussion excludes national programs in Africa, where IITA has responsibility.

and that include both official and private institutions (e.g., universities). Research does cover both production and postharvest processing aspects, either within the same institute or among various separate institutions. Interaction and complementarity among institutions and groups working in the same country are sometimes lacking. The Cassava Program has interacted principally with those institutions involved in production research; but although links between research and extension obviously do exist, it would appear that they are not organized in such a way as to permit a flow of feedback information on the constraints to adoption of improved production components. This aspect requires attention so as to improve technology design criteria.

26.3.2 IITA

The overwhelming importance of cassava in Africa determines that a significant proportion of the resources allocated to international research on the crop must be dedicated to relieving constraints to improved cassava production and utilization on that continent. In the past collaboration between IITA and CIAT scientists has clearly demonstrated the contribution that CIAT's Cassava Program, located in the center of origin of the crop, can make in this regard (see Chap. 22). With the inevitable tightening of core resources for commodity research, the need for the Centers to complement each other's work will become greater in order to make the most efficient and effective use of the available human and financial resources.

26.3.3 Advanced research institutions

Cassava's status as an "orphan" crop in terms of research interest in advanced labs in both developed and developing countries is slowly changing. It is expected that the formal organization of the Cassava Biotechnology Network (see Chap. 5) will greatly enhance that interest and attract additional donor funds for new initiatives. The Cassava Program has an important role to play within the CBN in ensuring that the efforts of advanced labs are directed toward those problems whose resolution will bring direct benefits to small-scale cassava farmers.

26.4 Cassava Program Strategies in the 1990s

The strategies of the Cassava Program formulated 5 yr ago (see Chap. 1) were based on the experience accumulated by the Program since its inception in 1973 and on the results of the demand studies. These strategies have produced tangible results both in terms of technology generation and institutional cooperation. Since the cassava demand situation today is as least as favorable as it was 5 yr ago, it is felt that these basic strategies will remain valid through the 90s. However, the aforementioned changes that have occurred in the external environment will require modifications in emphasis and reprioritization of activities. In the 1990s the Program will continue to promote the consolidation and integration of national cassava R&D systems in Latin America and Asia and to facilitate linkages between these systems and institutes undertaking advanced research on cassava through the CBN. Closer collaboration will be sought with IITA to help meet the needs of African programs. While maintaining a commodity-system perspective, the Program will emphasize germplasm resource development. Crop management, utilization and market research will concentrate on strategic issues of global importance. Applied research in these areas will be gradually devolved to national organizations, with horizontal cooperation encouraged among countries at the regional level. The Program will focus on crop management research for the subhumid, semiarid and subtropical ecosystems of the Americas and Asia, interacting closely with CIAT's new Resource Management Research Division on hillside, savanna and forest margin ecosystems, where an estimated 25-30% of cassava is produced in Latin America.

The goal, objectives and an overview of the Program's activities contemplated for the period 1992-2002 are described in "CIAT in the 1990s and Beyond: A Strategic Plan." Table 26.3 summarizes the expected outputs and impact of the four specific objectives that will be pursued by the Program during this period. The key areas of activity can be grouped as follows:

- Building the knowledge base

- Development of component technologies

- Regional collaboration

These activities are briefly described below.[26.3]

26.4.1 Building the knowledge base

This area of activity generates widely applicable basic knowledge about cassava that can be subsequently employed to develop component production and utilization technologies. Now that the most critical constraints to cassava production and utilization have been better defined, emphasis will be placed on expanding the knowledge of those crop characteristics that may be manipulated to relieve those constraints. Among the activities to be undertaken are:

- More precise characterization of cassava and wild *Manihot* spp. including agronomic, biochemical and molecular traits

- Development of improved screening methods for root quality (HCN, starch and eating quality), drought tolerance and nutrient-use efficiency

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[26.3] For a more complete description, see "Program Plans and Resource Requirements 1992-1996. CIAT, May 1991.

Table 26.3. Outputs and impact of the Cassava Program.

Objective	Output	Impact	Assumptions
1. Improve productivity and yield stability of cassava genetically 2. Develop crop management practices for sustainable cassava production in selected ecosystems 3. Improve cassava quality for diverse end uses	- High-yielding parental materials tolerant of biotic and abiotic stresses and with desirable quality characteristics for specific end uses - Technology for the commercial production of cassava, using true seed - Principles and technology components for the design of cassava-based cropping systems, emphasizing: . soil fertility maintenance . soil conservation . integrated pest and disease management - Consumer-acceptable cassava-based products	- Increased overall cassava production, stability and quality - Economically and environmentally sustainable cassava production, especially under adverse edaphoclimatic conditions - Increased incomes for the rural population in cassava-growing regions - Increased market potential for cassava and cassava-based products - Cheaper cassava for direct and indirect human consumption in urban areas	- Continued and increasing interest in cassava research by advanced labs - Adequate funding for cassava research at the international level - Commitment of national govts to invest in the development of marginal areas where cassava is a principal crop - Govt policies that are not biased in favor of competing carbohydrate sources
4. Strengthen national cassava R&D systems	- Trained national program personnel - Regional cassava R&D networks - Integrated cassava production, processing and marketing projects	- More effective and integrated national systems	- Minimum investment in cassava R&D at the national level

- Manipulation of the unique cassava photosynthetic system

- Research into mechanisms of resistance/tolerance to drought and to pests and diseases

- Development of improved diagnostic methods and refinement of ecosystem definitions in conjunction with the Institutional Development Support Program and the Land Use Program, resp.

26.4.2 Development of component technologies

Sound knowledge of the crop and the environments in which it is grown is the basis for developing component technologies. Work will be carried out in three areas: genetic improvement, crop management, and utilization and marketing research.

26.4.2.1 Genetic improvement. The aim is to provide national programs in the Americas and Asia, as well as IITA in Africa, with basic and improved germplasm. Progressive incorporation of molecular tools and support methodologies resulting from activities developed by the CBN will be sought. Activities will include:

- Development of broadly based gene pools targeted to regional needs with subdivisions for high and low HCN and an additional gene pool for the semiarid tropics

- Basic genetic and breeding methodology research

- Exploratory research on a TCS production alternative

26.4.2.2 Crop management. Research and development of research methodologies in this area will be undertaken at specific, but representative sites in close collaboration with national programs in Latin America and Asia. Emphasis will be placed on subhumid, semiarid and subtropical ecosystems, while providing support to the Resource Management Research Division in hillside, savanna and forest margin ecosystems. Comparative studies across ecosystems will generate greater understanding of the interactions among plant growth, the physical and biological environment and the socioeconomic factors that determine management practices, thereby providing a sounder basis on which to design improved technology components. Activities will cover:

- Development of soil fertility management and erosion control practices

- Integrated pest and disease management emphasizing root-rot pathogens, the chinch bug and dry season pests such as mites, mealybugs and whiteflies

- Rotation and mixed cropping of cassava with other species

- Integration of soil fertility, crop protection and cropping systems research

26.4.2.3 Utilization and market research. The Program's core resources dedicated to this area will be reduced as research on quality-related activities is increased. Links already established with developed country institutions (e.g., NRI, London and CEEMAT, Montpelier) will be maintained through hosting of visiting scientists to work on process and product development issues of mutual interest. The principal activities will cover:

- Identification of appropriate national institutions with which to undertake and integrate market, processing and product research

- Continued development of appropriate cassava flour and starch-processing technology

26.4.3 Regional collaboration

The consolidation and vertical integration of national cassava R&D systems remains a prime objective, which will be achieved through collaborative projects, regional networks and training. The aim will be to devolve applied research activities to national systems wherever possible and through regional networks identify opportunities for horizontal collaboration among countries. With the support of the Institutional Development Support Program, activities will encompass:

- Better targeted and more relevant information exchange

- In-service, discipline-oriented training in conventional and advanced research techniques

- Development of appropriate cassava seed-supply systems to facilitate the adoption of improved varieties

- Support for ex-ante and ex-post analyses of adoption and impact of technology components to facilitate priority setting at national and Cassava Program levels

- Transitory intensification of efforts to improve skills of national personnel in technology transfer (training of trainers), problem and opportunity diagnosis, cassava research methods, and the conceptualization, formulation, execution and evaluation of integrated cassava projects

26.5 Program Organization and Resource Allocation

The basic structure of the Program will remain the same, with a critical mass of HQ-based scientists undertaking strategic and applied research of global significance, an Asian regional office in Bangkok, and a CIAT/IITA scientist stationed at IITA.

The annual core budget for the Cassava Program (excluding resources allocated to the research support units for cassava-related activities) are projected to decrease from their present level of US$2.504 million (1991) to US$2.446 million in 1996. This budget reduction will require a continuous process of assessing priorities and reorienting activities. The Program will progressively move towards a system of resource allocation by objectives as a means of facilitating priority setting and increasing flexibility.

26.6 Complementary Activities

Special project funds will be sought to finance a number of activities in support of the foregoing core activities (Box 26.1). The budget required to fund these initiatives varies between US$1.078 million and US$2.124 million/yr.

BOX 26.1 COMPLEMENTARY ACTIVITIES

Genetic improvement	Collection, characterization and evaluation of germplasm for semiarid and subtropical ecosystems and the development of improved gene pools for these environments. Decentralized activities will be based at CNPMF (semiarid) and EMPASC (subtropical), Brazil (5 yr).
Soil fertility and conservation	Research on the basic mechanisms controlling nutrient-use efficiency in cassava and identification of plant characteristics related to nutrient use that may be employed as selection criteria for cassava improvement. Development of appropriate soil fertility maintenance and erosion control measures. Focus will be on hillside, subhumid and semiarid ecosystems (5 yr).
Cassava integrated pest and disease management	Research with IITA on the implementation of integrated management of the IPDM, including diagnosis of farmers' pest control practices, augmentation and conservation of natural enemies, classical biological control, and effect of cropping systems on pest populations (5 yr).
Cassava Biotechnology Network (CBN)	Joint coordination with the BRU and research institution members of the CBN to identify new initiatives in cassava-related biotechnology (5 yr)
Cassava propagation from true seed	Overall coordination of interdisciplinary research, with emphasis on biotechnological techniques, to define an appropriate genetic structure for cassava propagation from true seed (5 yr).
Africa - Germplasm (E and S)	Joint project with IITA for the introduction and evaluation of germplasm, adapted to mid-altitude and seasonally dry environments, from homologous areas in the Americas (5 yr).

BOX 26.1 COMPLEMENTARY ACTIVITIES (Cont.)

Asia - Socioeconomic research	Establishment of a regional macroeconomic database for ongoing evaluation of the dynamics of cassava development in Asia and promotion of farm-level research to determine the effectiveness of new production technology (3 yr).
Asia - Utilization and marketing	Joint activity with the Centro Internacional de la Papa (CIP) to establish a regional information exchange network and define regional research priorities and opportunities for horizontal cooperation (3 yr).
Integrated cassava projects in tropical America	Transfer of knowledge to national programs on project conceptualization, design, execution and evaluation, together with preparation of training materials and guidelines for R&D personnel working on projects (3 yr).

APPENDICES

ACRONYMS

AGROESTACION	Asociación de Productores de Yuca de la Estación (Colombia)
AIDAB	Australian International Development Assistance Bureau (Australia)
ANPPY	Associación Nacional de Productores y Procesadores de Yuca (Colombia)
APPY	Associación de Productores y Procesadores de Yuca (Ecuador)
APROSOCORRO	Asociación de Productores de Yuca del Socorro (Colombia)
ASOCOSTA	Asociación de Cooperativas de la Costa (Colombia)
ASOQUINDIA	Asociación de Agrónomos Quindianos (Colombia)
ASU	Agroecological Studies Unit (CIAT)
BNB/ETENE	Banco do Nordeste do Brasil/Escritorio Técnico de Estudos Económicos do Nordeste
BRU	Biotechnology Research Unit (CIAT)
Caja Agraria	Caja de Crédito Agrario, Industrial y Minero (Colombia)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CBN	Cassava Biotechnology Network (CIAT)
CCC	Comite de Mandioca do Ceará (Brazil)
CECORA	Central de Cooperativas de la Reforma Agraria Ltda. (Colombia)
CEEMAT	Centre d'Etudes et d'Experimentation du Machine Agricole (CIRAD-France)
CENARGEN	Centro Nacional de Recursos Genéticos (EMPASC-Brazil)
CENDES	Centro Nacional de Desarrollo (Ecuador)
CEPA	Comissão Estadual de Planejamento Agricola (Brazil)
CETEC	Corporación para Estudios Interdisciplinarios y Asesoría Técnica (Colombia)
CGIAR	Consultative Group on International Agricultural Research (USA)
CGPRT	Regional Centre for Research and Development of Coarse Grain, Pulses, Roots and Tubers (Indonesia)
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CIDA	Canadian International Development Agency (Canada)
CIP	Centro Internacional de la Papa (Peru)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (France)
CNPMF	Centro Nacional de Pesquisas em Mandioca e Fruticultura (Brazil)
COAGRO-ALBANIA	Cooperativa de Productores de Yuca de Albania (Colombia)
COAGROARAUCA	Cooperativa Agrícola Integral de Arauca (Colombia)
COAGROCASIBARE	Cooperativa de Productores de Yuca de Casibare (Colombia)
COOCENTRAL	Cooperativa Central dos Produtores de Algodão (Brazil)
COOPROALGA	Cooperativo de Productores de Algarrobos (Colombia)
COOPROMERCAR	Cooperativa de Producción y Mercadeo de Repelón (Colombia)
COOTRADECO	Coperativa de Trabajadores y Agricultores de Codazzi (Colombia)

COPROSAN	Cooperativa de Productores de Yuca de San Andrés (Colombia)
COPROTUCHIN	Cooperativa de Productores de Yuca de Tuchín (Colombia)
CORFAS	Corporación Fondo de Apoyo a Empresas Asociativas (Colombia)
CORPONOR	Corporación Autónoma Regional de la Frontera Nor-Oriental (Colombia)
COSCA	Collaborative Studies of Cassava in Africa (IITA-CIAT)
CPAA	Centro de Pesquisa Agroforestal de la Amazonia (Brazil)
CPATSA	Centro de Pesquisa do Trópico Semi-Arido (Brazil)
CPATU	Centro de Pesquisa Agroforestal del Tropico Umedo (Brazil)
CRECED	Centro Regional de Capacitación, Extensión y Difusión de Tecnología (ICA-Colombia)
CRIFC	Central Research Institute for Food Crops (Indonesia)
CTCRI	Central Tuber Crops Research Institute (India)
CVC	Corporación Autónoma Regional del Cauca (Colombia)
DAMA	Dirección y Administración de Mercados de Abasto (Paraguay)
DGIS	Netherlands Agency for International Cooperation
DRI	Fondo de Desarrollo Rural Integrado (Colombia)
DSU	Data Services Unit (CIAT)
EC	European Community
EDO	Extensión Dirigida a Objetivos (Caja Agraria, Colombia)
EMATERCE	Empresa de Assistencia Técnica e Extensão Rural do Ceará (Brazil)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazil)
EMBRATER	Empresa Brasileira de Asistencia Técnica e Extensão Rural (Brazil)
EMEPA	Empresa Estadual de Pesquisa Agropecuária (Brazil)
EMPASC	Empresa de Pesquisa Agropecuária de Santa Catarina (Brazil)
ENDAGRO	Empresa de Desenvolvimeno Agricola, Rural e Operacional (Brazil)
EPABA	Empresa de Pesquisa Agropecuária do Estado da Bahia (Brazil)
EPACE	Empresa de Pesquisa Agropecuária do Ceará (Brazil)
EPEAL	Empresa de Pesquisa Agricola (Brazil)
ESCAP	Economic and Social Commission for Asia and the Pacific (CGPRT-Indonesia)
FAGROCOL	Federación de Organizaciones Agropecuarias de Colombia
FAO	United Nations Food and Agricultural Organization (Italy)
FIDES	Fundación para la Investigación y el Desarrollo de Sucre (Colombia)
FINANCIACOOP	Fondo Financiero Nacional de Cooperativas (Colombia)
FODERUMA	Fondo de Desarrollo Rural Marginado (Ecuador)
FONDISER	Fondo de Desarrollo Industrial de Santander (Colombia)
FUNDAEC	Fundación para la Educación y la Ciencia (Colombia)
FUNDAGRO	Fundación Ecuatoriana de Investigaciones Agropecuarias (Ecuador)
GRU	Germplasm Resources Unit (CIAT)
GRUYA	Grupo de Yuca y Asociados (Colombia)

GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Fed. Rep. of Germany)
IAC	Instituto Agropecuário de Campinas (Brazil)
IAEC	International Atomic Energy Commission (Austria)
IAN	Instituto Agronómico Nacional (Paraguay)
IAPAR	Instituto Agronomico do Paraná (Brazil)
IAS	Institute of Agricultural Science (Vietnam)
IBC	Institutional Biosafety Committee (CIAT)
IBGE	Instituto Brasileiro de Geografía e Estadísticas
IBPGR	International Board for Plant Genetic Resources (Italy)
IBRD	International Bank for Reconstruction and Development (World Bank)
IBTA	Instituto Boliviano de Tecnología Agropecuaria (Bolivia)
ICA	Instituto Colombiano Agropecuario (Colombia)
ICONTEC	Instituto Colombiano de Normas Técnicas
IDB	Inter-American Development Bank
IDEMA	Instituto de Mercadeo Agropecuario (Colombia)
IDRC	International Development Research Centre (Canada)
IDIAP	Instituto de Investigación Agropecuaria de Panamá
IFAD	International Fund for Agricultural Development (Italy)
IIT	Instituto de Investigaciones Tecnológicas (Colombia)
IITA	International Institute of Tropical Agriculture (Nigeria)
INCORA	Instituto Nacional de la Reforma Agraria (Colombia)
INIA	Instituto Nacional de Investigaciones Agropecuarias (Mexico)
INIAP	Instituto Nacional de Investigaciones Agropecuarias (Ecuador)
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias (Mexico)
IPA	Instituto Pernambuco de Pesquisa Agropecuária (Brazil)
IPAGRO	Instituto de Pesquisas Agropecuárias (Brazil)
ISTRC	International Society for Tropical Root Crops
IVAG	In Vitro Active Gene Bank Project (CIAT)
KF	W.K. Kellogg Foundation (USA)
KU	Kasetsart University (Thailand)
MAG	Ministerio de Agricultura y Ganadería (Ecuador)
MARDI	Malaysian Agricultural Research and Development Institute
MIDA	Ministerio de Desarrollo Agropecuario (Panama)
NRI	Natural Resources Institute (UK)
ODA	Overseas Development Administration (UK)
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer (France)
PAPP	Programa de Apoio ao Pequeno Produtor (SUDENE-Brazil)
PGS	Plant Genetics System (Belgium)
PNP	Programa Nacional de Pesquisa (Brazil)
PNR	Plan Nacional de Rehabilitación (Colombia)

PRCRTC	Philippine Root Crop Research and Training Centre
PROACOL	Productora Agrícola de Colombia (Colombia)
PROTECA	Programa de Desarrollo Tecnológico Agropecuario (World Bank-Ecuador)
RCC	Regional Cassava Committee (Brazil)
RF	Rockefeller Foundation (USA)
RFCRC	Rayong Field Crop Research Center (Thailand)
SCATC	South China Academy of Tropical Crops
SCIB	South China Institute of Botany
SCRI	Scottish Crop Research Institute
SEAG	Servicio de Extensión Agrícola y Ganadera (Paraguay)
SEARA	Secretaria de Agricultura y Reforma Agrária (Brazil)
SEDECOM	Servicio de Desarrollo y Consultoría para el Sector Cooperativo y de Microempresas (Colombia)
SENA	Servicio Nacional de Aprendizaje (Colombia)
SIC	Secretaria de Indústria y Comércio (Brazil)
SUDENE	Superintendência do Desenvolvimento do Nordeste (Brazil)
TAC	Technical Advisory Committee (FAO)
TSCP	Training and Communication Support Program (CIAT)
UAPPY	Unión de Associaciones de Productores y Procesadores de Yuca (Ecuador)
UJF	Umas Jaya Farm (Indonesia)
UNDP	United Nations Development Programme (USA)
UNESP	Universidade Estadual Paulista (Brazil)
UNIVALLE	Universidad del Valle (Colombia)
USAID	United States Agency for International Development
USDA	United States Dept. of Agriculture
UTM	Universidad Técnica de Manabí (Ecuador)
VISCA	Visayas State College of Agriculture (Philippines)
VRU	Virology Research Unit (CIAT)

ABBREVIATIONS

ACMD	African cassava mosaic disease
ACMV	African cassava mosaic virus
AcP	acid phosphatase
alt.	altitude
ANOVA	analysis of variance
approx.	approximately
avg	average
BU	Brabender Unit(s)
ca.	circa
CALV	cassava American latent virus
CBB	cassava bacterial blight
CCMV	cassava common mosaic virus
CCSpV	cassava Colombian symptomless virus
cDNA	complementary DNA
cfb	colony fluid bacteria
CGM	cassava green mite
Chap.	chapter
chl	chlorophyll
cm	centimeter(s)
CMD	Caribbean mosaic disease
CN	cyanide
CO	field observation trials
concn.	concentration
coop	cooperative
CRI	competitive ratio index
CsXV	cassava X virus
CVMV	cassava vein mosaic virus
°D	degree-days
DAP	days after planting
Dept.	department
DIA	diaphorase
DM	dry matter
DMRT	Duncan's Multiple Range Test
DMSO	dimethyl sulfoxide
DNA	deoxyribonucleic acid
DSC	differential scanning calorimetry
ds-RNA	double-stranded ribonucleic acid
ECZ	edaphoclimatic zone
ELISA	
EPR	preliminary yield trials
ER	advanced yield trials

EST	α-β-esterase
FC	foot-candle(s)
FFR	financial rate of return
FSD	frogskin disease
g	gram(s)
grw	grams fresh weight
GOT	glutamate oxaloacetate
Govt.	Government
GUS	β-glucuronidase
h	hour(s)
ha	hectare(s)
HCN	hydrocyanic acid
HI	harvest index
HPR	host plant resistance
HQ	headquarters
ht	height
IAA	indoleacetic acid
ICMV	Indian cassava mosaic geminivirus
IPM	integrated pest management
J	joule(s)
Kb	kilobase(s)
KB	King's B medium
lab	laboratory
LAI	leaf area index
LBA	lima bean agar
LC_{50}	median lethal concentration
LD_{50}	median lethal dose
LER	land equivalency ratio
long.	longitude
LSD	least significant difference
lt	liter(s)
lx	lux
m	meter(s)
MAT	months after transplanting
max.	maximum
MC	moisture content
MCP	meristem-culture derived plant(s)
M&E	monitoring and evaluation
min	minute(s)
MJ	
ml	mililiter(s)
MLO	mycoplasmlike organism(s)
mm	milimeter(s)
mo	month(s)

MTT	minimum temperature threshold
NGO	nongovernment organization
no.	number
NS	not significant
OM	organic matter
PCR	polymerase chain reaction
PDA	potato-dextrose-agar
PI	production index
pl	plant(s)
ppm	parts per million
PPP	pre-production plot
PrX	peroxidase
PUE	phosphorus use efficiency
PVX	potato virus X
R&D	research and development
RAPD	random amplified polymorphic DNA
R-DNA	recombinant DNA
reps	replications
RFLP	restriction fragment length polymorphism
RH	relative humidity
RLD	root length density
RY	root yield
SC	steering committee
SD	standard deviation
sec	second(s)
SED	superelongation disease
sp./spp.	species
ss-RNA	single-stranded ribonucleic acid
SSS	seed supply systems
t	metric ton(s)
TCS	true cassava seed
TEM	transmission electron microscopy
temp	temperature(s)
U.	University
USLE	universal soil loss equation
UV	ultraviolet
VAM	vesicular-arbuscular mycorrhiza
var.	variety
vs.	versus
vol.	volume
v/w	volume/weight
wk	week(s)
wt.	weight
WUE	water use efficiency

w/w	weight/weight
YAC	yeast artificial chromosomes
yr	year(s)

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