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CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

The International Center for Tropical Agriculture (CIAT, its Spanish acronym) is dedicated to the alleviation of hunger and poverty in developing countries of the tropics. CIAT applies science to agriculture to increase food production while sustaining the natural resource base.

CIAT is one of 16 international agricultural research centers sponsored by the Consultative Group on International Agricultural Research (CGIAR).

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CASSAVA PROGRAM ANNUAL REPORT

1992

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EXECUTIVE SUMMARY

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SUMMARY OF HIGHLIGHTS

1992 was a year of transition for the Cassava Program as CIAT faced the challenge of reorienting its activities in accordance with the new strategic plan: "CIAT in the 1990s and Beyond." The move toward an integrated systems approach--which combines commodity and resource management research--together with severe centerwide financial restrictions, has led to a phasing out of core-funded regional agronomy research both in Latin America and Asia and of process and product development activities at HQ. Intensive efforts are being made both to seek complementary funding and identify appropriate institutional arrangements that will permit the continuance of these activities as they are seen as fundamental in ensuring a balanced approach to cassava technology development. In line with the strategic changes occurring at CIAT, the Program is placing greater emphasis on genetics and quality research as a means of advancing our knowledge of basic crop characteristics and consequently accelerating the development of gene pools for specific environments and end uses.

Goals and Objectives

The Cassava Program and its partner institutions in both developing and developed countries seek a common goal: to increase incomes and agricultural sustainability in less-favored rural areas by improving the level and stability of cassava production and quality for different end uses. The Program's principal contribution toward achieving this goal is through the development and supply of germplasm adapted to the biotic and abiotic conditions of the tropical and subtropical environments where cassava is produced and its different end uses. The Program also interacts with and provides support to national cassava research and development (R&D) programs in developing crop management, processing and marketing components of the commodity system. In addition the Program plays an important catalytic and convening role in bringing together the diverse range of institutions involved in cassava R&D. Support to national programs and regional and global networks is provided through training and information exchange activities and participation in joint R&D projects. The Program's operational objectives are to:

- Generate basic knowledge on the crop
- Develop technology components for sustainable production in major cassava-growing ecosystems
- Contribute to the consolidation and integration of national, regional and global cassava R&D systems

The following summary highlights the major progress achieved during 1992 with respect to each of these objectives.

Basic Knowledge Generation

Germplasm collection characterization and conservation

The core germplasm collection of 630 accessions is proving to be a more manageable sample for evaluating the total genetic diversity present in the entire collection. The collection has been screened for root quality traits at CIAT and screening for agronomic traits is under way. Further screening will take place at the two other locations where the core collection has been planted. Indexing of the core collection is complete and arrangements are being made for its duplication at the Centro Nacional de Recursos Genéticos (CENARGEN), Brazil and the Field Crops Research Institute (FCRI), Thailand.

Half of the 5263 accessions that make up the entire germplasm collection have been checked for duplicates. More than 200 have been confirmed as duplicates at the field level. Before their removal, further checking will be carried out at the biochemical and molecular level.

Conservation of pollen at low temperatures (-12°C and -70°C) to facilitate pollination work and germplasm conservation and exchange has not produced favorable results as the pollen appears to be recalcitrant to conservation methodologies.

Intermediate levels of polymorphism have been demonstrated among clones, indicating that a large number of segregating progenies from crosses between the most polymorphic parents will be required in order to construct a highly saturated molecular map for cassava. As expected, evaluation of the genetic diversity among wild relatives of cassava has shown a higher degree of polymorphism for three isozyme systems studied than for cultivated cassava.

Physiology

Screening core germplasm for photosynthetic capacity has revealed a wide range of variation among genotypes, with the highest capacity in Argentine materials.

Basic research on the biochemistry of cassava photosynthesis has confirmed that it has elevated activities--as compared to typical C_3 spp.--of the C_4 enzyme PEPC. The ratio of the PEPC/RuBPC activity was intermediate between that of typical C_3 and C_4 spp. The activities of the C_4 decarboxylating enzymes NAD-ME and NADP-ME were also higher in cassava than in typical C_3 spp.

Research on cassava's response to prolonged early, midseason and terminal water stress has confirmed that once the crop is established, prolonged water deficits would not

seriously limit productivity. This fact points to the great potential of cassava in the seasonally dry and semiarid tropical and subtropical regions where other food crops would fail.

Plant nutrition

Germplasm with high levels of adaptation to low-P and low-K soils has been identified. Among the new genotypes adapted to low P were CM 489-1 and CG 913-4--both CIAT clones. The genotypes with a high level of adaptation to low-K soils were CM 507-37, a CIAT clone, and M Ven 25, a local variety.

Studies on the mechanisms underlying genotypic differences in response to low-P soils have shown that yield depends on the balance between top growth and storage root sink strength. Clone CM 489-1 showed high adaptability to low P as well as good response to fertilizer application suggesting better P-use efficiency (PUE). On the other hand, M Col 1684 was less responsive to P application and had lower PUE.

Initial studies on the agronomic feasibility of a true seeded crop have shown that early vigor is enhanced by coating with rock phosphate and that the positive effect was reflected in final root yield. This suggests that placing less mobile elements and potential growth stimulators close to the seed could enhance the ability of a true seeded crop to compete with weeds and cover the soil at an early stage.

Quality

Characterization of the core germplasm collection for cyanogen content, dry matter (DM) and percent amylose has identified 10 clusters representing interesting combinations of desired characteristics (e.g., high DM but low in total cyanogens). Further evaluation of these clusters will make it possible to select potential clones of interest to breeding programs and research materials for in-depth study of specific root quality characteristics.

Significant differences for all starch viscosity variables, ease of cooking, gel instability and gelification index, but not for percent amylose were found between mean values of 15 high- and 15 low-cyanogen content clones. The results suggest a relationship between root cyanogen content and starch functionality, which requires further research.

An evaluation of the variability among elite clones for postharvest physiological deterioration has identified a range of genetic diversity that will make it possible to select materials with minimal deterioration after 8 days' storage. This opens ups the possibility for a program of recurrent selection to extend shelf life even more.

Diseases

Clones that maintain excellent resistance stability to the mycoplasm witches'-broom disease have been identified and introduced both to CIAT and the Centro Nacional de Pesquisas em Mandioca e Fruticultura (CNPMF), Brazil for producing hybrids. Furthermore, a technique to identify mycoplasmlike causal agents using light microscopes has been developed. This method is feasible for scientists working in most developing country plant pathology labs.

One of the most important problems encountered in the use of fluorescent pseudomonads as biocontrol agents of root rots is their survival on a substrate that permits their handling and commercialization. *Pseudomonas fluorescens* (C 58) and *P. putida* (F 44) remained viable for 3 mo when maintained on a powdered mixture of sorghum, peptone and sucrose.

Field trials in a soil naturally infested with the root rot pathogen *Fusarium solani* showed a significant increase in cassava yield in plots treated with the mycoparasite *Trichoderma harzianum*. The biological control of *F. solani* provided by *T. harzianum* was much more effective when cassava was planted on ridges.

Viruses

Cytological studies undertaken in the search for the causal agent of frogskin disease (FSD) have revealed viruslike particles 80 nm in diameter and inclusionlike bodies in FSD-infected plants. Nine ds-RNA segments are consistently found in the affected plants. Based on the morphology of the viruslike particles and ds-RNAs, the virus associated with FSD should be classified in a new genus of the reoviruses. Screenhouse studies have confirmed that the whitefly *Bemisia tuberculata* is the vector of this reoviruslike virus; infected plants expressed typical FSD symptoms.

The primary molecular characterization of cassava common mosaic virus (CCMV) has been completed. The complete sequence of CCMV is 6387 in length and encodes for six proteins. Most of the sequencing of CCMV was carried out by the VRU at CIAT--perhaps the first plant virus to be sequenced in Latin America. The coat protein gene of CCMV has been successfully introduced into *Nicotiana benthamiana* at the Scripps Institute, San Diego. These plants show almost complete immunity to CCMV. Once transformation and regeneration protocols are available for cassava, coat protein-mediated cross protection will be an additional method for developing CCMV-resistant germplasm.

Pests

Continued characterization of lines that show resistance to the cassava mealybug indicate that a tolerance mechanism is involved, rather than true resistance. Vigorous, high-

yielding varieties, combined with biological control may be sufficient to maintain cassava mealybugs below economic injury levels.

Studies with whitefly-resistant clones have revealed antibiosis--an indication of the presence of true resistance, thereby opening up the possibility of transferring this trait genetically to commercial varieties.

Further indication that root cyanogen levels are a factor in the development and behavior of the burrowing bug was made evident through a comparison of ovipositional rate on maize and cassava. Egg laying was reduced by 44.5 and 98.6% on low- and high-cyanogen clones, resp.

Nematodes offer a potential method for biological control of the burrowing bug. Parasitism has been obtained in lab studies with commercial entomopathogenic nematodes. A collection of native nematode spp. has now been established through field sampling at several locations. These spp. are being identified and will subsequently be evaluated for their parasitic effectiveness.

Technology Component Development

Germplasm

Genotype-by-environment interaction studies have demonstrated that the selection of elite clones at specific sites increases adaptation to the predominant conditions at those sites, while maintaining flexibility for adaptation to the conditions prevailing at other sites not as representative of a given ecosystem. Testing at sites representing a range of conditions within a given ecosystem has resulted in germplasm with broader adaptation.

Cassava bacterial blight (CBB) continues to be a sporadic, but nevertheless serious production constraint for seasonally dry environments. The germplasm being tested on the Colombian North (Atlantic) Coast has shown a range of reactions to CBB, which has permitted the selection of elite clones with good levels of resistance. For this ecosystem, Program selections outyield local clones, but it is still difficult to improve root quality parameters consistently to levels above those of the local materials.

A large number of elite clones with good adaptation, yield potential and quality traits were selected this year for the lowland tropics, with the acid soil savannas representing the gene pool with the most consistent improvement during the last few years.

The genetic base for highland germplasm has been expanded with the introduction of materials that show good adaptation to intermediate altitudes (1400 m).

Evaluation of germplasm under semiarid conditions in NE Brazil has resulted in the selection of clones combining resistance/tolerance to mites, yield and DM accumulation potential, and low levels of cyanogens in the roots.

The Thai-CIAT regional breeding program at Rayong is proving to be a major gene pool source for the semiarid lowland tropics of Asia. Hybrid populations prepared at Rayong using Thai clones and locally selected CIAT materials as cross parents show superior germination, survival ability after planting, plant type and root DM content, compared to CIAT HQ populations. Transfer of these materials--both in the form of hybrid seed and meristem culture--is providing the basis for promising varietal selection in Vietnam, Indonesia, the Philippines and China.

Kasetsart 50, a hybrid prepared by Kasetsart U. (Thailand) using cross parents provided by the Dept. of Agriculture (DOA) and CIAT, was released in 1992. In 60 on-farm and regional trials, this hybrid outperformed the predominant local cv. Rayong 1 in every agronomic trait.

From the 1990 introductions of botanical seeds (TCS) from CIAT to the International Institute of Tropical Agriculture (IITA), 538, 311 and 474 clones were advanced to the clonal evaluation trials at Ibadan, Onne and Kano/Zaria, resp. in 1991. At Ibadan and Onne, where selection pressure for ACMV is very high, 9 and 17 of these clones were selected in 1992 for establishment in preliminary yield trials. Between 70 and 30% of these selections, resp., were from crosses with elite IITA materials. At Kano and Zaria, where ACMV is not as limiting a constraint, 38 and 53 materials were selected; 100% of these materials were Latin American in origin. This confirms that for areas where ACMV is not limiting, direct introductions from Latin America can provide potentially promising selections.

Of the 1992 introductions to Africa, 13,863 seeds representing 147 families were sent to Mzuzu, Malawi in coordination with the East and Southern Africa Root Crops Research Network. Families to be tested in Malawi are potentially adapted to semiarid and high-altitude areas. Through this introduction mechanism, it is hoped to accelerate the selection of promising materials for these important cassava-growing ecologies in Africa.

Crop management

A network for research on controlling root rots was organized, with trials at 19 different sites throughout N and NE Brazil and Colombia. The results of these trials has made it possible to identify:

- Resistant clones for several root rot pathogens. This year the clone EMBRAPA-8 was released in cooperation with the Empresa Brasileira de Pesquisa Agropecuária-Centro de Pesquisa Agroforestal de la Amazonia (EMBRAPA-CPAA)

and CNPMF for the varzea region of the Amazon. This clone has yielded 80% more than farmers' best variety over three consecutive cycles.

- Several cultural components for integrated control of root rots. These have been grouped as universal (i.e., recommended to be implemented in all affected plantations) and as regional (i.e., for plantations affected by one or more pathogens controlled by specific methods).

Establishment of the cassava mealybug parasite *Aenasius vexans* was realized in Villavicencio, Colombia. This parasite is potentially important for controlling the mealybug in NE Brazil. Additional studies on the interactions of parasite and prey population density are required in order to determine an appropriate release strategy.

Successful biological control of the cassava green mite (CGM) requires an appropriate methodology for predator release and establishment. The multiplication of *Neoseiulus idaeus* and *Typhlodromalus tenuiscutus* in field cages prior to release provides greater flexibility in timing release and a means of adapting lab-reared phytoseiids to field conditions. *N. idaeus* may suppress native phytoseiid fauna--a factor that should be taken into consideration before releases in areas where an alternative strategy may be to enhance the effect of the native natural enemies of CGM. This latter strategy can be achieved through manipulation of the habitat so as to increase the relative humidity in the leaf canopy. Vigorous plant type favored phytoseiid population increase and inhibited CGM; low and intermediate planting densities favored CGM and phytoseiids, resp.

Research on soil-crop management systems in poor sandy soils at La Colorada (North Coast of Colombia) has revealed that yields could be greatly enhanced by applying moderate levels of NPK fertilizer or plant mulch. Mulch appears to be beneficial in improving soil fertility as indicated by the buildup of organic matter (OM) and K over the years. Moreover, mulch alleviated heat and water stress in the surface soil and led to a dramatic reduction in the level of cyanogens in cassava roots at final harvest. Clones CG 1141-1 and CM 3306-4 had higher yields and DM content, with or without application of fertilizer, compared with local varieties.

Research on soil conservation practices for hillside or upland cassava-based cropping systems has continued both in Colombia and several Asian countries. This work centers on identifying and evaluating appropriate forage legume cover crops and live barriers. The effect of cassava plant type on erosion was also studied.

In Santander de Quilichao (Colombia), *Centrosema acutifolium* and *Zornia glabra* provided the best soil cover in the first year, with yield reductions for cassava on the order of 25%. In Pluak Daeng (Thailand), indigo and *Mimosa invisa* developed a rapid soil cover but competed strongly with cassava. *Z. glabra* was the only cover crop to increase cassava yields significantly; however, its establishment was slow.

By interrupting and shortening slope length and therefore reducing runoff, live barriers with grasses could reduce soil erosion considerably on slopes planted to cassava. *Brachiaria decumbens, Cymbopogon citratus, Cymbopogon nardus and Vetiveria zizanioides* established well on acid soils when planted in the rainy season. Vetiver grass formed the most effective barriers when planted at 20 cm within the rows; but as collaborative trials with farmers' groups showed, selection of the most appropriate barrier will depend on individual needs and preferences.

Plant type can also have a significant effect on soil losses. Varieties with early vigor and more rapid canopy closure cover the soil more rapidly after planting, thereby preventing soil erosion. This characteristic, associated with high productivity, would be an important additional selection criterion for hilly areas.

Preliminary results of erosion trials on farmers' fields in Rayong Province have demonstrated that these Thai farmers are already using many practices that minimize soil erosion, such as fertilizer application and the use of high plant populations.

Utilization and marketing

The development of high-quality cassava flour for human consumption in Colombia has now entered a semicommercial phase with batches of flour being sold to a number of food industries with excellent acceptance. The flour is being used mainly to prepare processed meats. Pricing and cost information required to formulate a full feasibility study on the expansion of this new rural agroindustry will be available in 1993.

Further improvements to traditional small-scale starch extraction equipment have been made. An improved root grater increased starch recovery from 81 to 90%; and modifications to the traditional cylindrical water extractor improved the starch extraction rate by 10%. Studies on "sour" starch quality confirmed the influence of solar drying on the functional behavior of these modified starches. Baking power increased during the solar drying step, with specific volume of breads increasing from 2.2 to 6.1 cm^3/g.

An interinstitutional project involving research institutions from France, the UK, Colombia, Brazil and Argentina and funded by the European Community (EC) was initiated to expand cassava flour and starch process and product development. CIAT will be directly involved in the areas of (a) raw material and process effects on quality of starch and flour, and (b) market research for new products and markets.

Consolidating and Integrating R&D Systems

Latin America

The first three-year phase of the cassava integrated production, processing and commercialization project in the State of Ceará, Brazil terminated. There are now 158

producer groups organized around dry cassava agroindustries; 75% of these groups were established during the final year and have yet to be consolidated. The long-term sustainability of the project will depend on:

- Further strengthening of local institutional and farmer organizational and operational capacity

- Consolidation of marketing channels for dry cassava and the identification of additional market opportunities for cassava

- Advances in the design, testing and adoption of production components that stabilize or increase yields, reduce costs and maintain or improve the productivity of the natural resource base

A second phase of the project, which is being formulated for presentation to the Kellogg Foundation (KF), will address these issues. Based on the successful institutional model developed in Ceará, EMBRAPA-CNPMF prepared a project for expanding the integrated project concept to Bahia, Pernambuco and Paraíba.

The Ecuador Integrated Cassava Program based in Manabí Province made significant progress on a number of fronts during 1992. The first new cv. Portoviejo 650 (introduced from Colombia) was released by the Tropical Roots and Tuber Program at the Instituto Nacional de Investigaciones Agropecuarias (INIAP). This variety has achieved rapid acceptance by farmers for its higher DM, earliness and better yield under low rainfall conditions.

Studies on the potential of cassava flour in a number of industries have opened up several new market opportunities, one of these being for making ice-cream cones. The Union de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY) has negotiated an initial contract to sell 600 t of white cassava flour to Colombia with further contracts to follow. The UATAPPY, with support from the Fundación Ecuatoriana de Investigaciones (FUNDAGRO) and CIAT, is actively seeking international financial support to diversify its agroindustrial activities.

The third Integrated Cassava Projects Network meeting was held in Fortaleza (Ceará) from 28 Sept-2 Oct. The meeting brought together 50 participants representing 12 projects in 8 countries. The principal outcome was the identification of individual projects' needs in terms of methodological, technical, organizational and financial support. The network will be developed to respond efficiently to these needs, taking advantage of the expertise already existing in current projects.

Activities within the framework of the Southern Cone Cassava Development Network included two training-of-trainer events. From 27 April to 8 May, 36 Brazilian, Paraguayan and Argentine professionals participated in a first phase workshop held in Argentina,

during which six learning units were prepared. These units were reviewed, revised and subsequently used as instructional materials during the second phase workshop and course held in Paraguay from 12-30 Oct. In 1993 another course using these materials will be held in S. Brazil.

Asia

The Second Asian Cassava Advisory Committee Meeting was held in Malaysia from 15-17 June. Each country representative briefly reviewed research progress and outlined future priorities. The need to seek special project funding to continue the CIAT-supported regional research program on soil-crop management was discussed and endorsed by the Committee. No immediate need was seen for shifting the present emphasis on breeding and soil fertility/erosion control research at the regional level. The focus of the next Asian Cassava Research Workshop, to be hosted by India in Nov 1993, will be technology transfer.

The Second National Chinese Cassava Research and Technology Workshop was held in Hainan from 19-24 Oct. The workshop brought together R&D workers from Guangxi, Guangdong and Hainan provinces. Papers were presented on the situation of cassava in different regions and progress made in breeding, agronomy and utilization research. A decision was taken at the meeting to initiate a series of socioeconomic studies to characterize the cassava sector better, given the present dynamic situation and the good future prospects for growth in production and utilization.

The First Vietnamese Cassava Workshop was held in Hanoi from 29 Oct-1 Nov, with the objective of presenting and analyzing the results of the socioeconomic benchmark studies carried out to characterize cassava production, processing and marketing in Vietnam. The studies confirmed cassava's role as an important secondary staple and highlighted the constraints associated with its potential transition to a multipurpose carbohydrate source.

Global networks

An international workshop on cassava genetic resources co-sponsored by CIAT, IITA and the International Board for Plant Genetic Resources (IBPGR) was held at CIAT from 18-22 Aug, with the purpose of evaluating the current status of germplasm conservation and use and the possibility of establishing an International Cassava Genetic Resources Network. The global situation with respect to *Manihot* germplasm collection, characterization, conservation and exchange was reviewed by 14 scientists from 12 national programs in Latin America, Africa and Asia. Recommendations were made for advancing research in each of these areas through a networking approach.

The First International Scientific Meeting of the Cassava Biotechnology Network (CBN), held in Cartagena, Colombia from 24-28 Aug, brought together 125 scientists from 28

countries. Advances in methods of germplasm conservation using cryopreservation techniques, germplasm characterization and use, construction of molecular maps, and a repeatable protocol for cassava transformation and regeneration were reported. New information was presented on the biochemical basis of root-quality factors, in particular cyanogenesis. The meeting not only provided an important forum for information exchange among scientists from both developing and developed countries, but also contributed to the initiation of closer ties among many institutions working on similar problems.

Program Developments

Raul Moreno, agronomist for the Latin American region since 1984, was transferred to CIAT's new Hillsides Program as of 1 Sept. Merideth Bonierbale joined the Program on 15 Oct to take up the position of geneticist, and Ann Marie Thro was appointed coordinator of the Cassava Biotechnology Network on 1 Aug. Dominique Dufour of the Centre de Coopération Internationale en Recherche Agronomique pour le Développement-Systems Agro-alimentation et Ruraux (CIRAD-SAR) joined CIAT on 3 Nov as an associate member of the senior staff in the Quality/Utilization Sect. to replace Gerard Chuzel, who will move to the Universidade Estadual Paulista (UNESP), Sao Paulo in Jan 1993. Gerard O'Brien of the Natural Resources Institute (NRI), UK, joined the Cassava Program as a postdoc, also in the Quality/Utilization Sect., on 20 Jan.

GENERATION OF BASIC KNOWLEDGE ON THE CASSAVA CROP

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1. DEFINING RESEARCH NEEDS AND PRIORITIES

The definition of research needs and priorities is an ongoing process carried out by the Cassava Program at different levels and through different means. The most important of these mechanisms is the feedback information obtained from national program partners on the performance of technology components that have been adopted by farmers or not, as the case may be. The Cassava Program is also collaborating in the formal study of the adoption and impact of certain technology components, which are described in Chap. 26. Informal feedback is also obtained through close interaction with the Program's research collaborators in the national programs, as well as through regional and global networks (Chap. 24 & 25).

At the national level, the Cassava Program assists and provides technical support to strategic cassava research and development planning exercises aimed at identifying the major constraints to and opportunities for cassava production and utilization in a particular country. One such study is ongoing in Vietnam and another has been proposed for China. In both cases the methodology for strategic agricultural research planning developed by the International Service for National Agricultural Research (ISNAR) is being followed.

Another important activity related to the correct identification of research needs and the subsequent design of technology is the development of appropriate methodologies for assessing the criteria that "clients" (which, in the case of cassava, can be farmers, processors and consumers) use to accept or reject a particular technological component. Over the past five years, the Cassava Program has developed a participatory research methodology to determine farmers' selection criteria for new cultivars. In the future these participatory techniques will be adapted for use in other areas of technology development.

1.1 Strategic Research Planning in Vietnam

As a major part of this planning exercise, a cassava benchmark study was developed in order to (a) characterize the cassava sector and (b) identify and analyze the major constraints to and opportunities for cassava production, processing/utilization and marketing in Vietnam.

The type of data needed to generate information for these analyses includes the following: (a) national- and regional-level strategic (political) information; (b) institutional-level strategic and organization data; (c) regional and farmer/processor-level socioeconomic information; and (d) farmer/processor-level production and processing data.

1.1.1 Primary data collection studies

The studies undertaken in Vietnam were aimed at generating data concerning the last two types of information. In order to identify and analyze constraints and opportunities for the Vietnamese cassava sector, scarce existing secondary data needed to be complemented by primary data. Hence a cassava benchmark study was proposed to characterizes cassava production, processing and marketing aspects, which provides the basis from which to analyze constraints and opportunities. As such, a benchmark study is both descriptive and analytical; moreover, it serves as a base study for the future analysis of the impact of technology. The cassava benchmark study included the following surveys:

- Farm-level survey, focusing on cassava production, on-farm processing, utilization and consumption. This included first order marketing strategies, farm-gate prices, production and processing costs. In addition, farmers were asked to rank major constraints.

- Semiurban processor survey, focusing on both technical and socioeconomic aspects of the different cassava processed products.

- Rural and semiurban marketing survey, focusing on cassava product flows, prices, destination, pricing points, marketing agents and marketing margins.

1.1.2 Project organization

Given the objectives and the type of studies that were identified, the first priority was to seek appropriate project collaborators. As most research institutes are staffed mostly by biological scientists, the lack of socioeconomists became quickly apparent. However, experienced collaborators were identified at the U. of Agriculture and Forestry #4 (UAF#4) in Ho Chi Minh City (Thu Duc). Following preliminary discussions in 1990, the project was organized with the following collaborating institutions, each bringing a range of experiences and capabilities for conducting the surveys.

- National Institute of Agricultural Sciences (INSA), Hanoi, provided in-house experienced knowledge on most aspects of cassava postharvest utilization and processing.

- The National Root and Tuber Research Program (NRTRP), Hanoi, has cassava production experience.

- Food Crops Research Institute (FCRI) in Hai Hung has expertise in North Vietnamese production aspects.

- U. of Agriculture (UA#3) in Bac Thai, which has both crop production and experienced socioeconomists.

- Institute of Agriculture Sciences (IAS), Ho Chi Minh City, with extensive experience in cassava production and some experience in cassava processing.

- UAF#4 in Ho Chi Minh City has experience in agricultural production, socioeconomics and data processing aspects.

The NRTRP assumed overall project leadership; IAS was given coordinating responsibility in Southern Vietnam; and UAF#4 had the overall responsibility for data processing and analysis.

1.1.3 Research methodology

The identification of available resources for carrying out the studies took into account the relative comparative advantage of each collaborating institute with respect to appropriate available personnel, transport facilities, knowledge of the research areas, etc. The Cassava Program committed itself both to a major share of the project expenses and to twice-yearly input from its agronomist outposted in Asia and the HQ-based economist.

1.1.3.1 Farm level production/processing survey. Survey areas were selected on the basis of the available secondary cassava area data for Vietnam. In order to develop as "rich" and as representative data as possible, the major criteria were the relative importance of cassava and the homogeneity vs. heterogeneity of production or processing systems in the areas. The following agroecological zones were selected:

- Northern Mountains
- Red River Delta
- North Central Coast
- South Central Coast
- Central Highlands
- Southeastern Zone

The calculation of sample size and selection of the sample unit were a direct consequence of the available resources. As always in surveying, the trade-off is between statistical error and available resources. It was decided that in each zone 3 provinces were to be selected randomly (in addition to one district that was of interest because of its export position); in each province, 1-3 districts; in each district 2-3 villages; in each village, 5-15 cassava production and/or processing households. The final sample unit was a "cassava household". The total number of surveys that were conducted amounted to 1076.

1.1.3.2 Rural, semiurban and urban marketing and semiurban and urban processing survey in South Vietnam. While in the aforementioned rural household survey all collaborating institutes assisted and covered the whole of Vietnam, this marketing survey was conducted by UAF#4 and covered several selected Southern zones only. The

selection of the zones was based on specific processing characteristics that were identified in the previous survey and included the following zones:

- Ho Chi Minh City
- Southeastern Zone
- South Central Coast
- Central Highlands

Rather than using a formal questionnaire, interviews were held with 76 key informants including farmers, wholesale and retail traders, middlemen and further processors.

1.1.3.3 Rural, semiurban and urban cassava marketing and processing survey in North Vietnam. The organization of this survey took much more time as it was difficult to identify experienced socioeconomists to coordinate it. Finally the Dept. of Agricultural Economics at UA#3 assumed the coordinating role, with collaboration from INSA and the NRTRP. The survey, which began late in 1991, was conducted in the following areas:

- Ha Bac province
- Bac Thai province
- Vinh Phu province
- Ha Tuyen province
- Hanoi

The research area was prestratified in order to capture high and intermediate altitudes, as well as lowland areas. This survey was based on a short formal questionnaire that was directed to farmers, traders, middlemen and processors. A total of 158 questionnaires were completed.

After surveying was completed and the data checked and cleaned, the questionnaires were sent to UAF#4 to be coded, transcribed and computer analyzed. Preliminary tables were distributed to all project collaborators. During the summer one of the economists from UAF#4 came to CIAT HQ for further training in the analysis of survey data with SAS statistical packages for microcomputers. Both production function and factor efficiency analyses were conducted at CIAT. The trainee now has the knowledge and experience to analyze the Vietnamese cassava data further (by farm size, region, etc.).

After data analysis was completed at UAF#4, collaborators were supplied with complete data sets and tables on their specific areas of interest in order to write the research papers for the Vietnamese Cassava Research Workshop held in Hanoi from 29 Oct-1 Nov. The workshop had the following objectives:

- Present the cassava benchmark survey data in order to characterize the Vietnamese cassava sector

- Analyze cassava research constraints and opportunities based on these data

- Learn about the national strategy regarding future agricultural R&D and agricultural extension organization and activities

- Have Cassava Program scientists present a research strategy, organization and activities as an example of cassava R&D by a fellow cassava research program.

- Discuss the conclusions of cassava constraints and opportunities and suggest recommendations for follow-up activities toward the formulation of a long-term cassava R&D program in Vietnam.

The resulting conclusions and recommendations were presented to the Vietnamese Vice-Minister of Agriculture and Food Industry (MAFI) at the closing session of the workshop.

1.1.4 General conclusions

- Cassava plays an important socioeconomic role as a secondary crop in Vietnam. In the North the crop is not only an important source of food and feed at the household level but also a source of cash income. In the South, cassava is predominantly used as a raw material for processing into a wide range of products, both at the household and small-scale processor level, generating employment in the rural sector.

- Over the last ten years, total area of secondary food crops has decreased, especially for sweet potatoes and cassava; whereas the area under maize has increased.

- Cassava area decreased across all zones annually by 5.65%; however, in mountainous areas it increased by 1.5%, indicating a shift in production from the more fertile lowlands. In all zones cassava yields increased, especially in the Red River Delta and the Southeast.

- Cassava farmers identified market-related aspects--i.e., profitability, demand and price fluctuations--as the major production constraints. Soil fertility problems are also important.

- There exists the potential to increase cassava productivity through the introduction of improved varieties, appropriate fertilizer use and improved management (especial labor).

- Processing is constrained particularly by raw material supply fluctuations and quality. Potential for processing technology is significant. Cassava product

marketing efficiency can be improved significantly by information (price) systems and the management of marketing systems.

- There exists a potential demand for cassava in the following areas of utilization: (a) animal feed at the household level, especially for the poorer sector of the rural population; (b) animal feed (dry) for animal feed concentrates; (c) starch and starch-derived products. The size of the demand in these areas of utilization needs to be quantified.

1.1.5 Recommendations

- The results of the present surveys need to be evaluated critically by local experts and analyzed further at the district level. On some aspects, questionable results need to be verified.

- Additional studies need to be conducted in order to understand better the future demand potential of cassava processed products and determine the relative processing/production research focus.

- The role and influence of government policies also need to be analyzed in light of the future role of cassava products in the economic development of the country.

- The appropriateness of conducting the demand and policy studies for cassava together with other root and tuber crops, particularly sweet potatoes, should be investigated.

- The aforementioned studies need to be conducted before a long-term research program can be finalized.

- The present emphasis on research in the areas of varietal evaluation and crop management should be maintained given the significant contribution that the adoption of appropriate production technologies in these areas will have on increasing productivity and reducing costs, thereby maintaining the competitiveness of cassava.

- Research on cassava processing and marketing requires significantly greater attention.

- While increasing yield and quality remain valid objectives, in the future greater emphasis should be placed on preserving the natural resource base in cassava production systems.

- Several issues related to organizational structure and comparative research advantages of collaborating institutions need to be addressed:

- Cassava processing and marketing research needs to be more fully integrated with production research.

- The links between cassava research and extension need to be strengthened.

- More information is needed on the role of cassava in animal production for generating on-farm income.

1.2 Strategic Research Planning in China

In 1991 cassava scientists in South China expressed their interest in conducting a research planning exercise in collaboration with the CIAT Cassava Program. During the second Chinese Cassava Research and Technology Workshop in Hainan, 19-22 Oct, a formal paper was presented outlining the objectives, methodology and proposed work plan for such a study.

The representatives of several South Chinese research institutions were very enthusiastic about the strategic planning exercise. The Cassava Program will therefore develop a proposal for this project, together with the Chinese collaborators, and identify donor funds. Depending on the identification of these funds, a rapid rural appraisal is planned for Hainan, Guangxi and Guangdong provinces in October 1993. Collaboration in this project will also be sought with ISNAR, the National Resources Institute (NRI), the International Potato Center (CIP) and the Regional Centre for Research and Development of Coarse Grain, Pulses, Roots and Tubers (CGPRT).

1.3 Participatory Research for Varietal Improvement

Over the past five years the Cassava Program's Breeding Section has developed and perfected a methodology for integrating farmers' criteria into the varietal evaluation and selection process. This methodology has been described in previous reports (Cassava Program Annual Report 1990 and Cassava Program Report 1987-91) and documented in a working publication titled "Evaluation of new varieties with farmer participation." This document--which is directed at those researchers, extension agents and other technology intermediaries who are interested in implementing a participatory cassava research model--has the following objectives:

- Present a strategy for integrating the expectations of cassava farmers and breeders for cassava varietal development in a given region

- Link experimental station research with production reality, through an interactive information mechanism

- Introduce acceptability evaluation into traditional breeding schemes as an effective tool for preselecting varieties

- Serve as a text for training in the methodology

In line with the priorities identified by the Southern Cone Cassava Development Network (see Chap. 24), a specific learning unit on "Cassava varietal evaluation with farmer participation," which combines theory, practice and audiovisual aids, was prepared jointly with cassava workers in that region. This training unit was tested successfully with a group of Paraguayan extension agents.

2. GERMPLASM COLLECTION, CONSERVATION AND EXCHANGE

The CIAT cassava germplasm collection is constituted mainly (96%) by accessions from Latin America (**Table 2.1**), recognized as the primary center of diversity. Within Latin America gap areas have already been identified, and the Cassava Program together with the Genetic Resources Unit (GRU) has worked to cover these areas this year. The introduction of approx. 800 accessions from the germplasm collection maintained at the Centro Nacional de Mandioca e Fruticultura Tropical (CNPMF) in Brazil will provide CIAT with a more representative sample of genetic diversity, particularly from NE Brazil. Having a germplasm base in common with one of the most important national programs will also allow the use of clones selected from evaluations made in Brazil as parental material, in combination with elite germplasm from other sources at CIAT. It will also facilitate studies in the area of genotype-by-environment interaction among different sites in Colombia and Brazil. Brazil represents one of the largest reservoirs of genetic diversity for cassava. As such, it has been subjected to extensive collection particularly in coastal areas and in some states such as Sao Paulo and Santa Catarina. There are gap areas for future collections in NE semiarid environments and in humid tropical areas, particularly in the Amazon basin. Last year 178 accessions were collected within an International Fund for Agricultural Development (IFAD)-funded project for germplasm development and are being multiplied for inclusion in evaluation trials and future in vitro shipment to CIAT.

Other countries in need of further collection are Argentina (collection projected for May 1993), Bolivia, Haiti, Nicaragua, Salvador and Honduras.

The most elite genotypes (23 clones) from the Asian national breeding programs were introduced from Thailand this year. Landraces from China, Vietnam, Thailand and the Philippines are among the priorities for germplasm acquisition in the near future in order to have good representation from the Asian secondary center of diversity.

The absence of a centralized African germplasm collection has restricted the representation from that continent. The efforts of the International Institute of Tropical Agriculture (IITA) to compile information on national collections and to consolidate regional African germplasm collections, together with recent advances in virus indexing techniques, will allow better representation of the genetic variability available in Africa in the near future.

CIAT has assumed the world mandate for conserving genetic resources in cassava. In order to fulfill this responsibility, there is not only a need to gather a representative sample of the overall diversity but also to maintain it, ensuring long-term availability with low risk of loss, contamination by pests or pathogens, or genetic modification. Accessions are maintained in the field using 6-plant plots with spacing depending on the competitive

Table 2.1. No. of cassava accessions by country of origin maintained in CIAT's field-active gene bank.

Country of Origin	Total No. Accessions	Last Code Assigned at CIAT
Argentina	16	M Arg 16
Bolivia	3	M Bol 3
Brazil	1288	M Bra 1386
Colombia	2008	M Col 2732
China	2	M Chn 2
Costa Rica	147	M CR 149
Cuba	74	M Cub 74
Dominican Republic	5	M Dom 5
Ecuador	117	M Ecu 200
Fiji Island	6	M Fji 6
Guatemala	91	M Gua 92
Indonesia	51	M Ind 51
Malaysia	67	M Mal 69
Mexico	100	M Mex 111
Nigeria	19	M Nga 19
Panama	42	M Pan 139
Paraguay	192	M Par 195
Peru	405	M Per 615
Philippines	6	M Phi 6
Puerto Rico	15	M PtR 102
Thailand	31	M Tai 31
United States	9	M USA 9
Venezuela	240	M Ven 332
Elite Hybrids-CIAT	329	SM 524-1
TOTAL	5263	

ability of the plant (i.e., based on its vigor and architecture). In this way, competition among genotypes is minimized, reducing the risk of losing those materials with poor adaptation. At the same time it minimizes the chances of making mistakes when planting material is prepared for multiplication and provides more effective weed control. The field collection represents a working collection as it provides planting material for experimental purposes and direct characterization and evaluation.

CIAT's core collection (**Table 2.2**) constitutes a sample of accessions assembled to represent the genetic diversity available at CIAT with a minimum of repetitiveness. Several traits of importance for breeding require highly specific, costly evaluations, and may be difficult to apply to the entire germplasm collection. Among these traits are photosynthetic rate, activity of C_4 enzymes, root amylose/amylopectin rations, nutrient and water-use

Table 2.2. Accessions included in the core collection according to different parameters.

Origin	No. of Clones for Distinct Parameters				
	Geographic Origin	Morphological Diversity	Diversity of Esterase	A Priori Selections	Final No. in Core
Argentina	2	4	0	3	8
Bolivia	1	2	0	3	3
Brazil	110	13	15	20	101
China	1	0	0	2	2
Colombia	111	15	13	14	146
Costa Rica	9	7	5	4	23
Cuba	10	5	1	2	18
Dom. Rep.	2	2	0	4	5
Ecuador	25	6	0	4	32
Fiji	1	0	0	2	2
Guatemala	8	6	0	2	15
Indonesia	1	0	2	5	7
Malaysia	8	0	1	6	15
Mexico	14	6	0	2	20
Panama	6	2	0	2	9
Paraguay	25	8	3	7	40
Peru	63	10	3	2	76
Philippines	1	0	0	2	2
Puerto Rico	1	2	0	4	7
Thailand	0	0	0	4	4
United States	0	0	0	4	4
Venezuela	41	9	3	3	55
CIAT clones	0	3	5	27	33
IITA clones	0	0	0	3	3
TOTALS	440	100	51	121	630

efficiency (WUE), quantitative levels of HCN, resistance to diseases and pests not yet evaluated. In order to incorporate these traits effectively as selection criteria for genetic improvement, there is a need to assess the existing genetic diversity within cassava and to search more intensively where promising preliminary results are obtained.

This preliminary core collection of 630 accessions is expected to be dynamic for the first few years as a consequence of the elimination of duplicates, acquisition of other sets of valuable genetic variability, better characterization of genetic diversity and the inclusion of wild relatives.

In order to determine how representative the chosen sample of accessions was, a study was conducted on the frequency of α-β esterase bands in the overall collection (n=4300), the set of genotypes in the core collection chosen without considering frequency of bands (n=519), and 5 random samples of the same size (n=519) (**Table 2.3**).

The frequency of α-β esterase bands can be considered as a neutral trait for selection. Although there are deviations for a number of bands, this could be a consequence of the selection process followed to define the core collection. When selecting for geographical origin, the level of duplication within countries was taken into consideration, as well as the importance of the country as a source of genetic diversity. As a result the core collection

Table 2.3. Comparison of α-β esterase banding frequency among the whole population, core collection and random samples.

Esterase Bands	Entire Collection (n=4304)	Core Collection (n=519)	Core Collection (n=519)	Random Sample 1 (n=519)	Random Sample 2 (n=519)	Random Sample 3 (n=519)	Random Sample 4 (n=519)	Random Sample 5 (n=519)
1	10.6	7.9*	7.3*	11.4	10.4	8.5	9.8	13.5
2	13.0	9.8*	10.2*	11.8	12.1	11.4	13.9	13.3
3	42.1	44.5	44.1	40.5	42.6	42.8	43.5	41.0
4	45.8	38.7*	39.5*	50.1	42.0	49.1	43.0	47.8
5	17.4	17.6	16.6	14.6	14.1*	16.6	18.5	16.2
6	52.3	48.0	47.6*	55.3	53.4	53.2	53.0	51.8
7	5.5	5.1	4.4	6.4	4.4	4.8	5.2	5.4
8	38.1	43.2*	43.2*	36.8	38.9	34.3	40.8	38.3
9	33.5	35.9	36.6	35.3	33.3	33.9	34.9	33.3
10	73.0	71.2	71.9	73.8	73.0	72.8	72.6	72.4
11	0.1	0.2	0.0*	0.0*	0.0*	0.0*	0.0*	0.0*
12	7.3	3.9*	3.7*	7.1	7.1	6.6	8.1	6.2
13	11.3	8.4*	8.3*	10.8	10.4	8.7	11.0	9.4
14	1.6	1.2	1.2	1.7	1.5	2.7	1.5	1.7
15	52.1	48.7	48.6	49.7	53.8	52.8	54.9	55.5
16	0.1	0.2	0.0*	0.0*	0.0*	0.0*	0.0*	0.0*
17	1.1	0.7	0.6	1.7	1.0	1.3	1.7	0.2*
18	12.6	14.8	14.5	13.1	12.3	11.0	15.0	12.5
19	27.8	27.4	27.0	27.0	27.9	30.1	31.8	26.8
20	26.6	22.8	22.2*	26.8	28.1	25.4	26.2	28.9
21	26.5	29.2	28.1	26.2	27.0	24.5	27.6	27.0
22	67.2	65.6	67.1	66.1	67.6	67.6	64.5	67.1
No. bands with different frequency		6	10	2	3	2	2	3

* Frequency different from entire collection.

represents a closer sample for the genetic diversity existing at the field level in the countries that have been collected than the whole collection at CIAT. The overall relative frequency of bands is maintained in the core collection, indicating a proper sampling.

A more manageable sample of genotypes can be evaluated across different ecosystems and years in order to determine the genotype-by-environment effects for the traits of importance. The majority of accessions were evaluated for root quality traits at HQ this year (see Sect. 6.2). The core collection was planted in Palmira, Villavicencio and Media Luna for its evaluation across different environments next year. The core collection is being indexed for major viruses in order to be able to duplicate it at other institutions. The target is to transfer it to CNPMF (Brazil) and Rayong Experimental Station (Thailand) next year. This will represent the first portion of CIAT's germplasm collection to be duplicated outside Colombia. It will also allow for evaluation in other environments and the national programs involved may be able to use this sample of genetic diversity as one of the bases for their breeding efforts.

In vitro conservation provides a secure means of conservation and it represents one of the most important forms for international germplasm exchange. Refinements in the methodology have defined general slow growth conditions for germplasm maintenance. Under these conditions accessions are subcultured every 14 mo on average, ranging from 12 to 19 mo, depending on the genotype. The level of contamination has been considerably reduced over the years. Technically the in vitro collection represents a duplication of the field collection. Duplication at the same location is not recommended as major calamities can affect both field and in vitro collections. The development of standard and reliable cryopreservation methodologies for shoot tip culture will facilitate long-term, low-cost germplasm conservation. The long-term objective is to duplicate the whole collection at another institution, maintaining it by cryopreservation, in order to minimize the cost of duplication.

The objective of germplasm exchange is to transfer desirable genetic diversity without any pathogens or pests. Only those clones that are originated from meristem culture and have been subjected to thermotherapy (40°C day and 35°C night for 3-4 wk) and posterior indexing for viruses and viruslike diseases are shipped as in vitro cultures. Sensitive virus diagnostic techniques developed by the Virology Research Unit (VRU) have allowed the production of pathogen-tested clones for cassava common mosaic virus (CCMV), cassava Colombian symptomless virus (CCSPv), cassava X virus (CsXV), frogskin disease (FSD), cassava American latent virus (CALV) and other latent agents. At present 49.5% of the germplasm collection has been indexed for the first three viruses. Priority was given this year to indexing the core collection.

Germplasm movement to Africa has always been restricted by the potential diffusion of viruses present in one continent and absent in the other. To date, the only channel available for introducing genetic diversity to Africa is through sexual seed (TCS). The

process followed for producing segregating progenies at CIAT consists of several controlled steps to prevent the dissemination of undesirable organisms:

- Crossing blocks are planted at CIAT HQ, a site that is free from several major cassava diseases.

- Any plant showing virus symptoms is eliminated.

- At harvest roots are checked for the presence of FSD, and the seed from affected plants is eliminated.

- Samples from TCS lots are tested for CALV.

- TCS is subjected to floatation in order to discard empty seeds, which are the ones that have probably been affected by pathogens.

- Each package (50 seeds) is treated with 1 g of a mixture of captan (20%) and carboxin (20%).

- Treatment at 60°C for 2 wk precedes shipment. After receiving the seed at IITA, it is inspected by quarantine officers and treated in hot water (60°C) for 20 min. The families are planted in a screenhouse and inspected frequently for 6 wk. Seedlings with strange symptoms are discarded. The interaction between the fungicide and heat treatment seems to affect subsequent germination. In the future these steps will be reverted, applying the heat treatment first and then the fungicide prior to shipment.

Aside from in vitro indexed material and TCS, a few elite clones are available for distribution as stakes derived from virus-indexed mother plants. This method allows for simpler handling of the material by national programs than in vitro cultured material. This method is recommended for shipment to countries with homologous disease spectra--mainly the Caribbean, Central America and Andean regions. **Table 2.4** summarizes the germplasm introduced from CIAT to national programs, IITA and advanced research institutes in developed countries. In the case of in vitro culture and indexed stakes, the germplasm introduced to national programs represents a sample of elite clones developed by CIAT HQ, with possibilities of adaptation to homologous ecosystems. A group of recently developed elite clones have been indexed, multiplied for introduction to several countries in Asia and Cuba, and are available for introduction to other countries. Those clones will be evaluated under representative conditions after recovering from in vitro culture and subsequent multiplication. Some may show promise for direct release; others could be recycled through complementary crosses with local germplasm. More basic germplasm was shipped to advanced institutes looking for particular traits or genetically diverse stocks for their studies in cassava biotechnology.

Table 2.4. Summary of cassava seed shipments in 1992.

Region	No. of Shipments	No. of Crosses	No. of Seeds	No. of Clones
Africa	3	286	69,647	-
Asia	19	769	46,971	9
Caribbean	4	106	7,111	22
Meso-America	1			10
South America	12	135	11,202	186
North America	7	23	5,500	3
Europe	5	12	590	12
TOTALS	51	1,331	141,021	252

The introduction of segregating populations has allowed the development of a full range of breeding activities by national programs and IITA, based on a wide range of genetic diversity. Clones from national programs and others providing overall adaptation or resistance to major biotic or abiotic constraints are usually used as components of crossing blocks targeted to certain cassava-producing regions. Segregating populations can be generated either by open-pollination among a group of selected parents (polycrosses) or by pair-crossing selected material (controlled crosses). In the former case there are always a few early-branching parents that flower more profusely--an undesirable trait for field production. This results in a lower proportion of selection from progenies originated in polycrosses than from controlled crosses. Starting next year, major emphasis will be given to controlled crosses, requiring substantial strengthening in terms of personnel, given the lower efficiency compared to producing seed from polycrosses.

The wide range of genetic diversity available within CIAT's germplasm collection has deterred interest in wild relatives of cassava as a source of valuable traits. In the past, characterization of and accessibility to the existing genetic diversity were seen as more of a problem than the range of available variability. After more than 20 years of breeding and through the evaluation of the core collection, the better insight that is being gained is allowing attention to be focused on wild relatives in a search for those traits for which restricted variability is found within cassava or when new sources are desirable. CIAT maintains a total of 34 species in vitro and in the field (**Table 2.5**). Despite the restricted no. of genotypes per species, the level of polymorphism for allozymes within species seems to be greater than for cassava. Of the 15 species analyzed, major polymorphism has been detected for α-β ACP in 7 of them, for GOT in 11 of them and for α-β esterase in 14 of them (**Table 2.5**).

Germplasm collection for the wild relatives of cassava will receive greater attention in the future. The strategy is to work in close cooperation with IITA and the national programs in Mexico and Brazil for collecting a wide number of species, evaluating their potential and building a subsequent intensive collection within the most promising species.

A set of characters that are less influenced in their expression by environmental changes were used for preliminary grouping of accessions that might be potential duplicates. After analyzing 78% of the total germplasm collection (n=5263), 1282 single clone groups were detected. The other groups included from 2 to 39 potentially duplicated genotypes. The first batch of groups planted in the field showed an apparent 31.2% duplication, when observing aerial part traits; but when root traits were considered, the level of duplication dropped to 22.6 % (**Table 2.6**). Detected duplicates will be subjected to esterase analysis, and those that are confirmed will be fingerprinted using restriction fragment length polymorphism (RFLP). Duplicates will be eliminated from the field but maintained in vitro until identity at the molecular level can be assessed at a significant level of confidence.

An international workshop on cassava genetic resources was held at CIAT in August. The main objectives of the meeting were to assess the present status of germplasm conservation and use, and to explore the possibility of establishing a global network for cassava genetic resources. The present status of national and international genetic resources programs was presented. Priorities were set for future collecting expeditions and the sharing of the conservation workload among institutions for both cassava and wild *Manihot* germplasm. The discussion on a global strategy involved areas such as studies on genetic diversity, definition of core collection, identification of duplicated accessions, standardization and expansion of in vitro and cryopreservation techniques, duplication of germplasm collection at different institutions, etc. The two international centers dealing with germplasm will be strengthened in their capacity to test germplasm for major pathogens in order to ensure safe movement of germplasm. They will also coordinate the centralization of germplasm collections and the development of regional data bases and human resources.

Table 2.5. Isozyme intraspecific polymorphism in wild *Manihot* species maintained at CIAT.

Species	No. of Accessions		Accessions Fingerprinted by Isozymes		Intraspecific Polymorphism		
	Field	In Vitro	No.	%	αß-ACP	GOT	αß-Est.
M. aesculifolia	1	3	3	100	A	A	P
M. alutacea	7	7	5	71	P	P	P
M. anomala		3	0	0	*	*	*
M. brachiioba	1	1	1	100	*	*	*
M. caerulescens	2	28	3	11	P	P	P
M. carthaginensis	28	112	10	9	A	P	P
M. cecropiafolia		6	0	0	*	*	*
M. chlorosticta	7	7	6	86	P	P	P
M. epruinosa	1	1	1	100	*	*	*
M. filamentosa	4	5	5	100	P	P	P
M. flabellifolia	30	30	16	53	P	P	P
M. fruticulosa	1	1	1	100	*	*	*
M. glaziovii	1	5	1	20	*	*	*
M. guaranitica	3	40	4	10	A	P	P
M. hastatiloba	1	4	1	25	*	*	*
M. irwinii	2	2	1	50	*	*	*
M. jacobinensis	7	21	19	90	P	P	P
M. longipetiolata	1	7	2	29	A	A	P
M. orbicularis	2	9	4	44	A	A	P
M. peltata		1	1	100	*	*	*
M. pentaphylla		2	1	50	*	*	*
M. pilosa		2	1	50	*	*	*
M. pseudoglaziovii	10	1	1	100	*	*	*
M. purpureo-costata	1	1	1	100	*	*	*
M. rubricaulis	9	18	7	39	A	P	P
M. sparsifolia		3	0	0	*	*	*
M. triphylla	5	24	7	29	A	A	A
M. tristis	26	41	31	76	A	P	P
M. violacea	4	4	2	50	P	P	P

A = absent; P = present; * = not tested or insufficient sampling data to determine polymorphism.

Table 2.6. Identification of duplicated accessions in the whole germplasm collection.

Accessions/Group	No. of Groups	Total No. of Accessions	Potential Duplicates	% Duplication
2	119	238	48	20.2
3	71	213	38	17.8
4	37	148	46	31.1
5	18	90	22	24.4
6	9	54	11	20.4
7	7	49	9	18.3
8	6	48	7	14.5
9	6	54	10	18.5
12	4	48	15	31.2
13	2	26	9	34.6
16	1	16	7	43.0
TOTALS	280	984	222	22.6

3. GENETICS AND RELATED STUDIES

Basic studies of factors determining genetic variation within the area of cassava genetic enhancement are currently being emphasized. Collaboration among the Genotype-by-Environment Specialist, the Geneticist and the Biotechnology Research Unit (BRU) will make it possible to identify critical genetic variation for cassava improvement and its precise manipulation. Through molecular mapping, for example, it is hoped to develop markers for genes of interest that can be used to simplify the selection process. As genetic mapping may reveal the genetic basis of quantitative traits, it is also likely that breeding methods will be refined accordingly. This strategy will be applied to the introgression of genes from wild species. Another facility of biotech research is the modification of the expression of existing genes in cultivated germplasm. For this approach it is essential to have a basic understanding of specific biochemical processes critical to cassava development, and new techniques of genetic engineering can be directed at these processes. This strategy will be valuable especially in cases where natural genetic variation has not been identified and/or cases for which a single genetic change will improve the utility of an existing cv. significantly.

3.1 Population Development for Initiating Genetic Mapping

Several sexual progenies from controlled hybridizations have been provided to the BRU for joint consideration as potential mapping populations (**Table 3.1**). Priority characteristics for selecting a mapping population are high levels of DNA polymorphism between the parents and high levels of heterozygosity in at least one of the parents. If these conditions are met, it will be possible to analyze the segregation of alleles from the more heterozygous parent in the F_1 progeny. The ability to screen individuals of the same progeny for agronomic characters of interest for cassava improvement, conferred by the parents, will allow the localization (i.e., "tagging") of genes controlling these traits.

Table 3.1. Segregating progenies being considered as potential mapping populations.

Progeny	BRU Designation	Female Parent	Male Parent	No. of Individuals
CM 7857	K	M Nga 2	CM 2177- 2	150
CM 8382	L	M Nga 2	CM 3299- 4	151
AM 244	M	M Col 1505 (self-pollination)		92
CM 8233	CM	M Col 1522	CM 2772- 3	86
CW 001	-	M Col 1505	*M. aesculifolia*	56

A first priority has been set on the cross CM 7857 because of the characteristics contributed by the parents: M Nga 2 for resistance to ACMV from *M. glaziovii* and CM 2177-2, a recently released clone in Colombia presenting partial resistance to mealybugs and whiteflies, and resistance to gallflies. More than one progeny has been suggested for the project because they might serve as "backups" to the first cross should DNA polymorphism be limiting.

In collaboration with the BRU, several cultivated genotypes and one wild species have been evaluated for DNA polymorphism with respect to each other, using random genomic DNA probes with different restriction enzymes. Selected probes from this preliminary survey are being used to quantify polymorphism and verify Mendelian segregation of DNA fragments in the mapping progeny. RFLP and RAPD analyses of the same progeny will be combined to construct the map (see BRU report for 1992).

3.2 Postharvest Deterioration

The capacity of cassava roots to be stored without deterioration is an important trait that may affect the acceptability and commercialization of any genotype. A project is being elaborated to approach this problem through molecular techniques, with the objective of obtaining cassava that does not deteriorate for at least 2 wk. In order to assess existing variability among elite clones, postharvest deterioration was evaluated at three sites using the methodology developed by Wheatley and Lozano.[3.1] The methodology consists of using nondamaged roots, cutting both ends to obtain a 14- to 15-cm piece and covering the distal end with plastic film. Ten roots were sampled every 2 days, starting the second day after harvest until the eighth day. **Table 3.2** shows the results for the clones that were in common in at least 2 of the 3 sites, together with DM content.

There are clones that have the capacity to maintain low levels of deterioration (i.e., CM 4484-2 and M Col 1505); whereas others deteriorate very fast (i.e., CM 3306-4 and CM 5253-4). Clones and progenies from crosses among them may constitute the basis for detecting biochemical differences responsible for the differential performance. The instability of clone M Col 2215 may also contribute to the study of the influence of environmental conditions on the process of physiological deterioration. Although the relationship between deterioration and DM content was positive, the coefficient of determination was not so high, allowing for independent selection of high DM genotypes with good conservation capacity.

[3.1] WHEATLEY, C. & LOZANO, J.C. 1980. Susceptibilidad de los genotipos de yuca a la deterioración fisiológica. Yuca. Boletín Informativo no. 8:15.

Table 3.2. Percent of cut surface showing physiological deterioration (PHD) in clones at different locations.

	CIAT HQ		Media Luna (Magdalena)		Villavicencio (Meta)	
Clone	% PHD at 8 days	% DM	% PHD at 8 days	% DM	% PHD at 8 days	% DM
CG 1141-1	54.7	38.9	46.0	34.2		
CM 523-7	36.4	38.4			4.0	38.8
CM 2177-2	23.0	34.0			35.1	36.4
CM 2766-5	29.0	32.0			9.7	35.1
CM 3306-4	69.9	39.2	78.0	34.3		
CM 3997-1	44.0	35.7	60.6	27.8		
CM 4042-4	26.7	30.9	54.6	28.0		
CM 4484-2	20.7	34.4			2.9	34.0
CM 5253-1	67.4	36.4			61.4	38.0
SM 494-2	30.4	31.7			29.7	35.0
M Bra 12	37.7	31.7	60.6	29.1	20.6	33.1
M Col 1505	22.3	35.9	24.3	30.0		
M Col 2215	13.7	38.1	81.4	35.2		

3.3 Pollen Conservation

Conservation of pollen is important for the Program in three aspects: (a) to facilitate crossing of genotypes that flower at different times; (b) to maintain a backup sample of genes from the germplasm collection; and (c) to facilitate the safe and effective movement of germplasm across continents. Pollen dehydration has failed as a conservation methodology[3.2]. During 1992, the effectiveness of different low-temp treatments was evaluated in field pollinations. Temp of -12°C and -70°C were used over two periods of time (5 and 14 days); and conservation in liquid nitrogen was assayed in a combination of rapid or slow freezing and thawing treatments. None of the treatments resulted in seed formation (**Table 3.3**). The check, consisting of fresh pollen, did produce seeds but with low efficiency (0.63 seeds/pollination, on the avg vs. the max. potential of 3). The prolonged dry season may have had an effect on the efficiency of pollination. The capacity of the pollen to induce fruit formation is not completely lost with temp treatments as at least some fruits were observed in every case. Results at the field level showed that it is relatively difficult to maintain pollen for extended periods of time. Cassava behaves as a recalcitrant species in terms of pollen conservation.

[3.2] ORREGO, A. & C.H. HERSHEY, 1984. Almacenamiento del polen de yuca (*Manihot esculenta* Crantz) por medio de liofilización y varios regímenes de humedad y temperatura. Acta Agronómica 34(1):21-25.

Table 3.3. Results from field pollination using pollen preserved at low temp.

Treatment	No. of Pollinated Flowers	No. of Fruits	No. of Seeds
Check	247	82	155
-12°C/5 days	119	8	0
-12°C/14 days	19	22	0
-70°C/5 days	117	9	0
-70°C/14 days	114	9	0
-196°C/RF-RT	127	7	0
-196°C/RF-ST	119	8	0
-196°C/SF-RT	112	3	0
-196°C/SF-ST	119	1	0

RF= rapid freezing; SF= slow freezing; RT= rapid thawing; ST= slow thawing.

3.4 True Cassava Seed Propagation

Phosphorus is a scarce nutrient element in acid savanna soils and given cassava's dependency on an effective mycorrhizal association for absorption of P,[3.3] this might result in severe deficiency for the early development of cassava seedlings. Coating of seeds with phosphates can improve early crop development from TCS. Open-pollinated (SM 1557 & SM 1559) seed from two clones (CM 4729-4 % CM 5278-3, resp.) was coated with two sources of phosphate (rock and superphosphate); uncoated seed was used as the check. The trial was planted at Villavicencio (acid soil savanna) in a randomized complete block design with 4 reps, evaluating germination (%), initial vigor (scale: 1 = poor, 5 = excellent), root and foliage yield (t/ha) and root DM content (%). Results (**Table 3.4**) showed that the more soluble source of P (superphosphate) seems to affect TCS germination negatively; whereas the less soluble source (rock phosphate) significantly improved germination and early vigor, which may result in an improved ability for the crop to compete with weeds. Although there is a tendency (significant at the 15% level of probability) for improved root and foliage yield when coating with rock phosphate, the difference with respect to the check is not so clear as in the case of early crop development traits.

Coating the seed with limiting nutrient elements and possibly with herbicides and growth enhancers may result in more rapid initial crop development, leading TCS to succeed as

[3.3] HOWELER, R.H., C.J. ASHER & D.G. EDWARDS. 1982. Establishment of an effective endomycorrhizal association on cassava in flowing solution culture and its effects on phosphorus nutrition. New Phytologist 90:229-238.

a propagation system. The improvement of seed germination and early vigor of the crop is one of the most important objectives for TCS research.

Table 3.4. Effect of seed coating with two seed populations.

TCS Population	Source of P	Germination (%)	Plant Vigor[1]	RY (t/ha)	Foliage Wt (t/ha)
SM 1557	None	39.4	3.2	22.7	19.6
	Rock phosphate	48.7	4.3	24.7	21.1
	Superphosphate	11.7	3.5	10.8	8.4
	Mean	33.3	3.7	19.4	16.4
SM 1559	None	49.3	3.5	22.7	22.2
	Rock phosphate	40.2	4.6	24.4	20.6
	Superphosphate	7.2	3.6	7.1	6.8
	Mean	32.2	3.9	19.0	16.5
LSD (0.05) TCS population		9.2	0.9	5.1	6.3
LSD (0.05) Source of P		9.3	1.0	5.2	6.4
LSD (0.05) TCS x P		13.2	1.4	7.4	9.0

[1] 1 = very poor, 5 = very good.

4. PHYSIOLOGY

The 1992 working plan of the Cassava Physiology Sect. covered a wide range of activities, including:

- Germplasm characterization for adaptation to low-P and low-K infertile soils
- Basic research on photosynthetic potential of cassava
- Response of germplasm to prolonged water stress
- Crop management research on acidic, infertile Inceptisols at Santander de Quilichao (Cauca Depto.) and on sandy, very poor soils on the North Coast of Colombia (Media Luna, Magdalena Depto.)
- Soil fertility management and plant nutrition research at both Santander de Quilichao and on the Atlantic Coast of Colombia
- Soil conservation/crop management research on Inceptisols of the Andean hillsides of the Cauca Depto., conducted by scientists from the U. of Hohenheim and funded by the BMZ
- Training pre- and postgraduate Colombian and international students

Results of some of these research activities are highlighted here as well as elsewhere in this report (see Chap. 5 & 17). The postgraduate international and Colombian students have either completed writing their theses or are currently analyzing their data.

4.1 Germplasm Characterization for Adaptation to Low-P Soils

In continuation of the effort to characterize germplasm for tolerance to low-P soils, a new group of advanced breeding lines and clones were screened during 1989-90 at Santander de Quilichao station. The screened accessions were planted (10,000 pl/ha) in plots (4 reps) with low available P (< 4 ppm), which had received no P for 8 yr. Half the plots received 75 kg P/ha applied at planting in the form of triple superphosphate. Adequate levels of N and K (100 kg/ha) were applied to the entire experimental area. During the growing season, data on net leaf photosynthesis were collected by measuring the upper canopy leaves with a portable infrared gas analyzer. Measurements were conducted between 0800 and 1300 h when light intensity exceeded 1000 $\mu mol\ m^{-2}s^{-1}$. At 11 months after planting (MAP), RY and total biomass were determined by harvesting the central 8 plants.

4.1.1 RY and low-P adaptation index

Table 4.1 shows fresh root yield (RY) at 11 MAP along with the calculated P adaptation indices. At both levels of P, there were significant differences in yield among clones. The overall mean yield of all clones at low P (28 t/ha) was significantly lower than with adequate P (35 t/ha); however, the yields without P were relatively high, considering the low level of available P in this soil (< 4 ppm). These yields suggest that native P uptake by cassava was effective, probably the result of infection with efficient vesicular-arbuscular mycorrhizal (VAM) strains.

Among this group of clones, adaptation to low-P soils varied widely (indices ranging from 0.57 to 1.74). The highly adapted clones with low-P adaptation (indices greater than 1.5) were CM 489-1 and CG 913-4. CM 489-1 was previously identified as one of the highly productive clones under both low and adequate P (CIAT Cassava Annual Reports 1988-91). It has both high leaf photosynthesis and large root sink (storage root no. > 15). The remaining clones showed either intermediate (indices from 1.46 to 1.01) or low adaptation levels (indices from 0.93 to 0.57). Considering the continuous cultivation of cassava at this site for 10 yr, the moderate level of productivity without P application suggests that acid soils with low available P but with high organic matter (OM) can support sustainable yields; nevertheless, the significant response to applied P indicates that cassava still benefits from chemical fertilization. The genotypes highly adapted to low-P soils should be exploited as genetic resources for developing materials better adapted to low-P soils.

4.1.2 Physiological and growth characteristics of cassava as affected by P levels

Table 4.2 summarizes data on some physiological and growth parameters across all 33 clones as affected by P levels in the soil at Santander de Quilichao. Under P stress there were significant reductions in total harvestable biomass, mean leaf area index (LAI) and no. of storage roots; but the percent partitioning of biomass to storage roots (HI) increased significantly. Cassava appears to restrict top growth (stems and leaves) under low soil fertility. A significant increase in leaf photosynthesis occurred under low P, but it was apparently not associated with any significant changes in stomatal and mesophyll conductances, internal CO_2 or specific leaf area. It appears therefore that the observed enhancement in leaf photosynthesis under low P in the field was likely due to storage-root sink effect. Under low P, LAI was significantly reduced; and this might have resulted, partially, in a higher root sink demand for assimilates. This phenomenon suggests that leaf photosynthesis in field-grown cassava might be manipulated by the sink-source relationship. It was previously reported that leaf photosynthesis could be enhanced by increasing sink demand (CIAT Cassava Annual Reports 1989-91). It is also possible that under low P, an increasing demand for assimilates occurred due to an active VAM-cassava association.

Table 4.1 RY and low-P adaptation index of 33 clones at Santander de Quilichao (1989-90); values are means of 4 reps.

Clone	RY (t/ha)		Low-P Adaptation Index[1]
	Zero P	75 kg P/ha	
CM 489-1	41	41	1.74
CG 913-4	40	41	1.65 HA[2]
CM 4063-6	35	40	1.46
CM 523-7	34	41	1.42
CG 1370-5	30	43	1.34
CM 1457-34	31	41	1.31 IA
SM 328-1	31	40	1.24
CG 936-7	32	37	1.23
CM 507-37	33	36	1.22
M Col 1684	30	37	1.15
CG 1403-6	27	40	1.13
CM 5317-2	32	34	1.12
CM 1442-204	30	36	1.11
CM 3285-7	30	34	1.05
M Cub 32	27	37	1.02
CM 4042-4	24	41	1.01
CM 4313-2	27	36	1.01
SG 695-1	28	32	0.93
CG 1457-2	26	35	0.93
CG 1450-4	26	34	0.92
SG 731-4	25	35	0.89 LA
SG 761-4	28	31	0.87
CM 3974-1	23	35	0.82
CM 5431-2	25	31	0.80
CM 4420-1	27	29	0.79
CM 4030-1	22	35	0.79
CG 1413-3	25	30	0.77
CG 1287-5	25	29	0.75
CM 2766-3	25	27	0.69
M Col 1468	23	29	0.66
CM 1286-7	24	25	0.60
SG 104-264	25	23	0.57
CG 668-4	16	34	0.57
Mean of all clones	28	35	1.0
LSD 5% (P)	1.4		
LSD 5% (clones)	4.5		0.32

1 Low-P adaptation index was calculated for each clone using the ratio:

$$\frac{\text{(Yield at zero P) (Yield at 75 kg P/ha)}}{\text{(Mean yield at zero P) (Mean yield at 75 kg P)}}$$

2 HA = High Adaptation, IA = Intermediate Adaptation, LA = Low Adaptation

Table 4.2 Some physiological and growth characteristics of cassava grown at low and adequate P at Santander de Quilichao (1989-90); values are avg of 33 clones.

Parameter	Zero P	75 kg P/ha	LSD 5%
Leaf photosynthesis (μmol CO_2 $m^{-2}s^{-1}$)	31*	27	3.4
Stomatal conductance (mmol $m^{-2}s^{-1}$)	928	851	NS
Internal CO_2 (μmol mol^{-1})	188	195	NS
Mesophyll conductance (mmol $m^{-2}s^{-1}$)	206	178	NS
Specific leaf area (cm^2 g^{-1})	213	211	NS
Mean LAI (m m^{-2})	2.0*	3.1	0.4
HI (% root/biomass)	0.81*	0.70	0.03
Root DM (%)	36.7	36.9	NS
No. of storage roots	9*	12	2
Total harvestable biomass (t/ha)	12.6*	18.2	3.8

* Significantly different.

4.2 Germplasm Characterization for Adaptation to Low-K Soils

Given that more than 60% of total K uptake is removed along with the harvested roots of cassava, productivity decreases with continuous cultivation in poor soils low in K. In view of this fact, yield shows a remarkable response to K fertilizer in many areas where cassava is widely grown. In soils where OM is high (e.g., soils at Quilichao), continuous cassava production for more than 8 yr (CIAT Cassava Annual Reports 1982-92) clearly demonstrated that productivity was mainly limited by K level in the soil. Genotypic differences in tolerance to low K and in K-use efficiency were not previously examined. A field trial was conducted over the past 3 yr (1989-92) at Santander de Quilichao to test whether genotypic differences exist. **Table 4.3** contains data on RY of 14 clones grown at low K (soil K level was depleted by the two previous cassava crops to < 0.11 meq/100 g of soil) and at adequate K level. Among this group of clones, low-K adaptation indices varied widely (0.65 to 2.22). There were two clones (CM 507-37 & M Ven 25) with very high adaptation indices and relatively high yields--as compared with all accessions--at both low and adequate K. The remaining accessions showed either intermediate or low adaptation levels. Across all genotypes, productivity was reasonable (6.7 t/ha) at low K; and the yields were almost doubled at adequate K. These data suggest that genotypic differences in adaptation to low K exist among germplasm and point to the need for screening and selecting for high adaptation to low K in a wider range of germplasm.

4.3 Screening Core Germplasm for Photosynthetic Capacity under Field Conditions at CIAT HQ (1991-92)

Research on cassava photosynthesis at CIAT has revealed a close relationship between leaf net photosynthesis as measured under field conditions and yield (CIAT Cassava

Table 4.3. Dry root yield (DRY) and low-K adaptation index for 14 clones at Santander de Quilichao (1991-92); values are means of 4 reps.

Clone	DRY (t/ha)		Low-K Adaptation Index[1]
	Zero K	100 kg K/ha	
CM 507-37	9.5	19.7	2.22
M Ven 25	9.3	15.8	1.74 HA[2]
M Col 1684	7.1	13.1	1.10
CM 489-1	7.0	13.2	1.09
M Pan 70	7.9	11.5	1.08 IA
HMC-1	7.2	12.5	1.07
CM 91-3	7.2	12.1	1.03
M Cub 74	6.8	10.8	0.87
CMC 76	5.7	11.5	0.78 LA
HMC-2	5.7	11.4	0.77
SG 105-35	5.1	12.1	0.73
CM 1585-13	5.2	11.2	0.69
M Col 1468	6.2	9.2	0.68
CM 523-7	4.3	12.8	0.65
Mean of all clones	6.7	12.6	1.0

[1] Low-K adaptation index was calculated for each clone using the ratio:

$$\frac{\text{(Yield at zero K) (Yield at 100 kg K/ha)}}{\text{(Mean yield at zero K) (Mean yield at 100 kg K/ha)}}$$

[2] HA = High Adaptation, IA = Intermediate Adaptation, LA = Low Adaptation.

Annual Reports 1988-91). It has been suggested that selection for high net photosynthesis in parental materials may lead to higher yields when combined with other yield determinants (e.g., high HI and high to moderate LAI). A number of clones of the germplasm core collection were grown at CIAT HQ during the 1991-92 season. Leaf gas exchange (CO_2 uptake and H_2O loss) was monitored from 100 to 180 days after planting (DAP), using a portable infrared gas analyzer. The fully expanded upper canopy leaves were used for gas exchange measurements from 0900 to 1200 h local time when solar radiation was greater than 1000 μmol $m^{-2}s^{-1}$ in the photosynthetic active range.

Table 4.4 summarizes data on leaf photosynthesis and on the intercellular CO_2 of this group of accessions. The photosynthetic rates and the intercellular CO_2 concentration varied widely from 32 to 14 μmol CO_2 $m^{-2}s^{-1}$ and from 73 to 187 μmol mol^{-1}, resp. There were significant differences in leaf gas exchange characteristics among this group of accessions. The clones collected from Argentina had significantly higher rates of leaf photosynthesis and lower intercellular CO_2 than those collected from Brazil. Clones with high photosynthetic capacities should be used as genetic resources for developing new cultivars with improved productivity.

Table 4.4. Avg leaf photosynthesis (Pn; µmol CO_2 $m^{-2}s^{-1}$) and intercellular CO_2 (µmol mol^{-1}) for 53 accessions of the core collection, CIAT HQ 1991-92.

Accession	Pn	Intercellular CO_2	Accession	Pn	Intercellular CO_2
M Arg 11	32	73	M Bra 258	22	143
M Bra 12	30	82	M Bra 273	22	128
M Bra 110	30	74	M Bra 77	22	145
HMC 1	29	87	M Bra 233	22	144
M Arg 2	28	95	M Arg 12	22	146
M Bra 132	28	88	M Bra 416	22	151
M Bra 172	27	83	M Arg 15	22	139
M Arg 13	27	105	M Bra 356	22	156
M Bra 359	27	127	M Bra 191	21	145
M Bra 71	26	111	M Bra 383	21	162
M Arg 7	26	119	M Bol 1	21	147
M Bra 85	26	112	M Bra 309	21	148
M Arg 9	26	110	M Bra 453	21	159
M Bra 190	26	97	M Bra 400	21	169
M Bra 124	26	100	M Bra 329	20	159
M Bra 403	25	131	M Bra 435	20	173
M Bra 162	25	108	M Bra 337	19	177
M Arg 6	25	115	M Bra 158	19	137
M Bra 242	24	133	M Bra 325	18	169
M Bra 299	24	133	M Bra 237	17	173
M Bra 165	24	114	M Bra 355	17	195
M Bra 243	23	132	M Bra 450	17	196
M Bra 405	23	143	M Bra 328	17	182
M Bra 73	23	134	M Bra 311	16	188
M Bra 217	23	140	M Bra 315	16	191
M Bra 404	23	151	M Bra 335	14	187
M Bra 125	23	129			
LSD 5%	6.2	44			
Avg of accessions according to origin:					
Argentina	26	112			
Brazil	22	141			
P <	0.0001	0.0001			

4.4 Activities of Some Photosynthetic Enzymes of Cassava

Basic information on the biochemistry of cassava photosynthesis is sporadic and limited. In order to understand better the mechanisms underlying the crop's relatively high photosynthetic capacity, research was initiated to examine the activities of some key photosynthetic enzymes. Four clones were grown at Santander de Quilichao during the 1992 season, and upper canopy mature leaves were periodically measured for enzyme

activities in collaboration with the BRU and the School of Agronomy at Palmira. **Table 4.5** summarizes data of enzyme activities in leaf extracts. Among the four clones tested, activity ranged from 1.6 to 3 μmol mg chl^{-1} min^{-1} for the C_4 enzyme PEPC and from 3.6 to 8.2 μmol mg chl^{-1} min^{-1} for the C_3 enzyme RuBPC. Across all four clones the ratio of the PEPC/RuBPC activity was 0.3 to 0.4. In typical C_3 species this ratio is from 0.05 to 0.1; whereas in typical C_4 species it ranges from 2 to 5. These data suggest that cassava has an intermediate ratio of PEPC/RuBPC, between that of typical C_3 and C_4 species. The elevated activity of the C_4 enzyme PEPC in cassava may indicate that it is involved, to a certain extent, in transporting CO_2 from the intercellular spaces of the leaves toward the chloroplasts where the C_3 RuBPC enzyme is located. Another possible role of the PEPC is the refixation of respiratory CO_2 during photosynthesis and the consequent reduction of the CO_2 photorespiratory losses. This ability to recycle respiratory CO_2 is of paramount importance in increasing photosynthetic efficiency, particularly during prolonged drought, which is normally encountered in the areas where cassava is produced. It has been previously reported that cassava leaves have low photorespiration rates as compared to typical C_3 species (CIAT Cassava Annual Reports 1987-91). The two C_4-decarboxylating enzymes--NAD-ME and NADP-ME--also showed elevated activities as compared to typical C_3 species, suggesting that a limited degree of C_4 metabolism may occur in cassava. Further research in that area is warranted in order to uncover wider genetic variation in both cultivated germplasm and wild *Manihot* spp.

Table 4.5. Activities of some photosynthetic enzymes in leaf extracts of field-grown cassava at Santander de Quilichao, 1992; values are means ± SD.

	Activities (μ mol mg chl^{-1} min^{-1})				PEPC/ RuBPC
Clone	PEPC	RuBPC	NAD-ME	NADP-ME	
CM 523-7	1.57 ± 0.10	3.62 ± 0.62	1.84 ± 0.1	0.41 ± 0.04	0.43
CM 507-37	1.91 ± 0.10	6.84 ± 0.66	1.37 ± 0.4	0.46 ± 0.18	0.28
M Col 1684	2.90 ± 0.19	6.96 ± 1.18	2.05 ± 0.8	0.36 ± 0.03	0.42
M Col 1468	3.07 ± 0.27	8.16 ± 0.71	1.84 ± 0.6	0.24 ± 0.05	0.38

4.5 Response of Cassava to Prolonged Midseason Water Stress

Research on cassava productivity as affected by prolonged drought showed that cassava yields reasonably well under stressful environments (CIAT Cassava Annual Reports 1987-91). A new group of clones from the Atlantic Coast of Colombia were grown in the field drainage lysimeter at Santander de Quilichao during the 1991-92 growing season. At 90 DAP half the lysimeter area (1000 m^2) was covered with white plastic sheets to deprive the plants of rainfall for 3 mo. The second half of the lysimeter received normal rainfall plus supplementary irrigation whenever rainfall was less than evaporation. At 6 MAP the

stress treatment was terminated, and the crop was allowed to recover for the rest of the growth cycle with the aid of supplementary irrigation. Final root yield (DRY), top and total biomass on a dry basis are presented in **Table 4.6**. Across all clones, reductions due to water stress were 14% in DRY, 38% in top growth and 22% in total biomass; however, water stress increased HI by 9%. These data confirm that prolonged midseason water deficit does not seriously limit productivity and that cassava can be a highly productive crop where a long dry season occurs in areas such as the semiarid tropics and subtropics.

Table 4.6. DRY, harvestable biomass (t DM/ha) at final harvest (11 mo) as affected by 3-mo midseason water stress commencing 90 DAP at Santander de Quilichao, 1991-92.

	Unstressed				Stressed			
Clone	Roots	Tops	Total	HI	Roots	Tops	Total	HI
CM 4013-1	10.9	7.5	18.4	0.59	11.5	3.9	15.4	0.75
CM 4063-6	13.3	3.7	17.0	0.78	11.9	2.2	14.1	0.84
SG 536-1	12.2	4.5	16.7	0.73	9.9	3.8	13.7	0.72
M Col 1505	11.1	5.2	16.3	0.68	7.3	2.9	10.2	0.72
Avg	11.9	5.2	17.1	0.70	10.2	3.2	13.4	0.76
% change due to stress					-14	-38	-22	+9

Genotypic differences in response to water stress also exist. Clone CM 4013-1 showed no reduction in DRY due to stress (10.9 t/ha unstressed vs. 11.5 t/ha with stress). On the other hand, the local clone M Col 1505 showed considerable reduction (34%) in DRY due to stress. The other two clones (CM 4063-6 & SG 536-1) were intermediate with reductions of 11% and 19%, resp. It is noteworthy that CM 4013-1 also had the highest increase in HI due to water stress (HI of 0.59 unstressed vs. HI of 0.75 under stress). CIAT breeding clones (CM 4013-1, CM 4063-6 and SG 536-1) have been evaluated for several years at Media Luna (Atlantic Coast of Colombia) by the Cassava Breeding Sect. It appears therefore that this site is appropriate for selecting for adaptation to moderate water stress.

4.6 Response of Cassava to Prolonged Early, Midseason and Terminal Water Stress

Field trials were established at Santander de Quilichao in the 1990-91 growing season to studv the effect of prolonged water deficits at early, midseason and terminal growth stages. Four clones (CM 523-7, CM 507-37, M Col 1468 & M Col 1684) were planted in a split block design with 4 reps. The water regime treatments were (a) unstressed; (b) early stress with the crops deprived of water for 102 days commencing 79 DAP; (c)

midseason stress with the crops deprived of water for 93 days commencing 140 DAP; and (d) terminal stress with crops deprived of water for 157 days commencing 198 DAP. Before initiating the water stress treatments, all plots received supplementary irrigation to bring the root zone to field capacity. White plastic sheets were used to eliminate rainfall during the entire stress period. The previously stressed crops were allowed to recover during the rest of the growing cycle by receiving normal rainfall plus supplementary irrigation. The experimental plots received 0.5 t/ha lime before planting and 75, 65 and 125 kg/ha NPK at 30 DAP. Just after installing the first water stress treatment (79 DAP), a hailstorm (9 July 1990) caused significant damage to the crops through defoliation and breakage of apices. Three weeks later, however, the crops recovered by forming new canopy; thus in this case the hailstorm damage was an additional constraint for productivity. **Table 4.7** shows data on DRY, dry top biomass and the HI of these trials. It is clear that despite the prolonged water stress at an early stage (79 DAP) and at terminal stage (198 DAP), the avg DRY across all clones was not significantly different from the unstressed crops. The yields with midseason water stress were significantly higher (14%) than the unstressed crops. These data again confirm the high degree of tolerance to prolonged water stress in cassava. During stress the plant restricts top growth (stems and leaves) and increases the percent partitioning of DM toward storage roots. Once the crop is established, intermittent or prolonged water deficits would not limit productivity seriously. This fact points to the great potential of cassava in semiarid tropical and subtropical regions where no other food crop could produce reasonable yield during prolonged drought. In areas where shortage of food is acute (e.g., Sub-Saharan African countries and NE Brazil), cassava can contribute substantially to alleviate food shortage.

During prolonged water stress, cassava reduces its leaf canopy and, consequently, light interception (**Fig. 4.1**). Although reductions in leaf canopy and light interception would result in reduction in total biomass, this phenomenon would lead to water conservation and to improved overall crop water use efficiency (CIAT Cassava Annual Reports 1987-91). Nevertheless, cassava can recover rapidly once released from stress by forming new leaf canopy, which increases light interception, and thus compensates for previous reduction in biomass and yield. Another important physiological characteristic that underlies the plant's tolerance to prolonged water deficit, is the ability of its leaves to remain photosynthetically active during stress (**Fig. 4.2**). This characteristic is of paramount importance in stabilizing productivity under stressful environments. Selection for high photosynthetic rate under stress may lead to higher yields if combined with other important yield determinants such as high HI, high LAI and better leaf retention.

Table 4.7. Yield and top biomass (t/ha) at final harvest (12 mo) as affected by early water stress (for 102 days commencing 79 DAP), midseason stress (for 93 days commencing 140 DAP), and terminal stress (for 157 days commencing 198 DAP), Santander de Quilichao, 1990-91.

	Unstressed			Early Stress			Midseason Stress			Terminal Stress		
Clone	DRY	Tops[1]	HI	DRY	Tops	HI	DRY	Tops	Hi	DRY	Tops	HI
CM 523-7	10.9	3.6	0.75	15.5	4.7	0.77	15.7	5.6	0.74	11.6	3.8	0.75
CM 507-37	14.7	4.5	0.77	12.5	3.2	0.80	14.4	5.6	0.72	12.3	3.2	0.79
M Col 1468	9.9	6.4	0.60	9.0	4.3	0.68	10.9	5.8	0.65	10.3	4.4	0.70
M Col 1684	10.3	2.6	0.80	10.5	2.0	0.84	11.4	3.3	0.78	9.9	2.6	0.79
Avg	11.5	4.3	0.73	11.9	3.6	0.77	13.1	5.1	0.72	11.0	3.5	0.76
% change due to stress				+3	-16	+5	+14	+19	-1	-4	-19	+4

LSD 5% (DRY) = 1.5 for water regime across clones.

[1] Excluding fallen leaves.

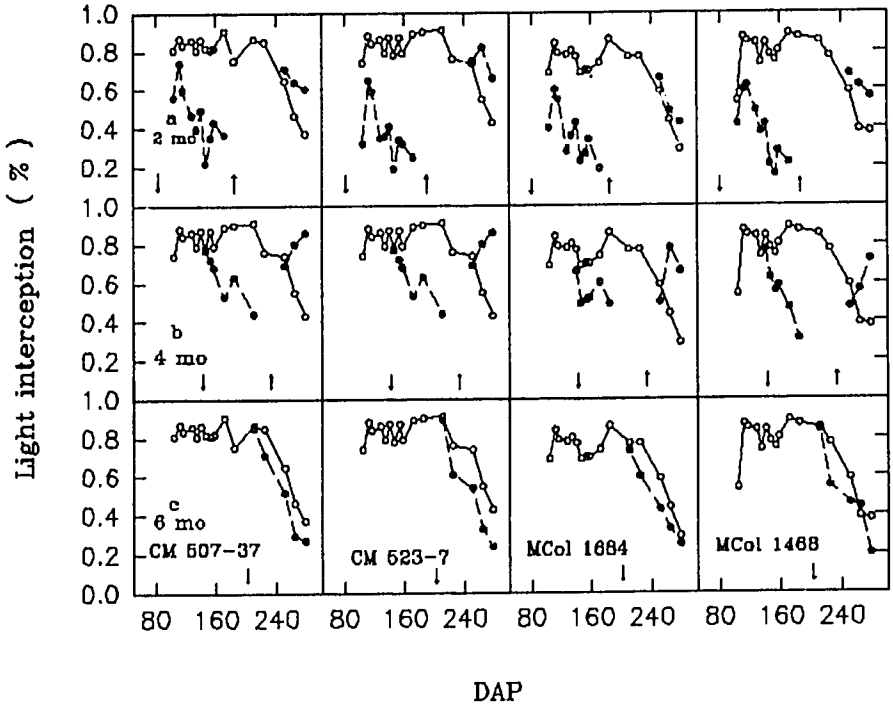


Figure 4.1 Light interception of cassava crops as affected by early water stress (a); midseason water stress (b); and terminal water stress (c). (●) stress; (o) control; (↓) stress starting; (↑) recovery.

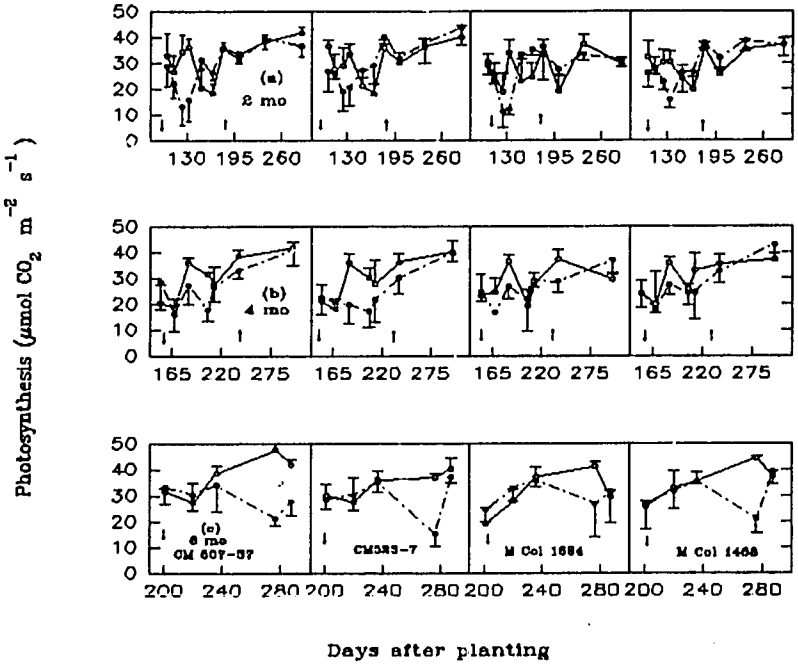


Figure 4.2 Photosynthetic rate of upper canopy leaves as affected by early water stress (a); midseason water stress (b); and terminal water stress (c). (●) stress; (o) control; (↓) stress starting; (↑) recovery. Values are average of four leaves ± s.d

5. PLANT NUTRITION

The Physiology Sect. has conducted research on nutrition and soil/crop management at both Santander de Quilichao (Cauca) and Media Luna (Magdalena). In addition to efforts to characterize germplasm for adaptation to soils low in P and K (see Chap. 4), research has also focused on (1) the long-term effects of continuous cassava cultivation on productivity in acid infertile Inceptisols; (2) the medium-term response to NPK fertilizer on infertile sandy soils; (3) the effect of plant mulch on soil fertility and cassava productivity on infertile sandy soils; and (4) mechanisms underlying genotypic differences in response to low P soils. A PhD student from the Swiss Federal Institute of Technology successfully completed his research project on the last topic. Highlights of some of the research findings are given here and in Chap. 17.

5.1 Genotypic Differences in Response to P

Four clones (CM 523-7, CM 489-1, M Col 1684 & CMC 40) were used in a 2-yr field trial at Santander de Quilichao on soils low in P (< 4 ppm). Fertilizer treatments were (a) unfertilized; (b) 100-0-100 kg/ha NPK; (c) 100-50-100 kg/ha NPK; (d) 100-100-100 kg/ha NPK. The crop was established during both years under conditions of sufficient rainfall.

Table 5.1 summarizes data on DRY, LAI, aerial and total biomass. In all clones the application of NPK fertilizer significantly increased yield, biomass and mean LAI as compared with the unfertilized crop; however, there was a differential genotypic response to P over the years. There was a significant yield response to P application in CM 489-1, CMC 40 and CM 523-7; but no significant response in M Col 1684. Similar trends were observed in aerial and total biomass. In all clones mean LAI was significantly lower in the unfertilized crops as compared with the highest NPK fertilizer level. Mean LAI response to P fertilizer was more marked in the second cycle than during the first one. CM 523-7 did not however show any significant increase in LAI in response to P in either crop cycle.

Production of flowers and fruits in all clones was strongly enhanced in the unfertilized plants (Treatment 1) (**Fig. 5.1**). There was, however, a differential genotypic response to P in terms of production of reproductive organs. CM 489-1 and CM 523-7 did not show significant changes in production of reproductive organs with P levels; on the other hand, CMC 40 and M Col 1684 produced more flowers and fruits with high P levels, with the strongest response in M Col 1684. This suggests that the lack of yield response to P in M Col 1684 may be due to allocation of P to alternative sinks.

Figure 5.2 illustrates the harvestable storage roots over time as affected by P levels. CM 489-1 showed the highest no. of roots as well as a marked response to P application. M Col 1684, on the other hand, had the lowest root no., with less response to P. Differences due to P application were more pronounced in the second crop cycle.

Table 5.1. Effect of fertilization on DRY, aerial biomass, total biomass and mean LAI over growth period; results represent final harvest (10 MAP) of two consecutive crop cycles.

	Fertilizer Treatment			DRY		Total Biomass		Aerial Biomass		Mean LAI	
	N	P	K	89	90	89	90	89	90	89	90
Cv.	(kg/ha)			DM (t/ha)							
	0	0	0	9.6	5.3	14.3	8.9	4.1	3.2	0.92	0.82
CM 523-7	100	0	100	11.5	11.6	18.1	17.7	6.1	5.5	1.35	1.50
	100	50	100	13.4	14.1	21.7	23.6	7.6	8.7	1.33	1.84
	100	100	100	16.1	14.3	25.1	23.8	8.4	8.8	1.33	1.79
	0	0	0	10.6	4.9	15.4	8.5	4.0	3.0	0.76	0.68
CM 489-1	100	0	100	13.0	9.6	19.9	15.2	6.1	4.8	0.88	0.82
	100	50	100	16.2	13.1	25.4	20.7	8.3	6.6	1.12	1.32
	100	100	100	17.3	14.0	27.4	23.1	9.0	8.1	1.19	1.49
	0	0	0	7.7	5.4	11.4	8.3	3.0	2.4	0.67	0.54
M Col 1684	100	0	100	12.9	9.8	19.8	14.2	5.9	3.7	1.02	0.86
	100	50	100	12.2	10.6	19.8	18.9	6.6	7.4	1.23	1.50
	100	100	100	11.5	11.5	18.5	20.3	6.1	7.8	0.98	1.55
	0	0	0	7.2	4.2	11.9	7.8	4.0	3.0	0.69	0.54
CMC 40	100	0	100	8.2	6.0	14.0	10.5	5.1	3.7	0.77	0.67
	100	50	100	11.5	9.6	19.3	17.5	6.9	7.1	0.93	1.00
	100	100	100	11.0	10.4	19.3	18.8	7.5	7.6	1.03	1.24
LSD 5%[1]				2.8	2.7	4.2	4.8	1.6	2.3	0.30	0.47
LSD 5%[2]				2.5	1.8	3.8	2.6	1.5	1.1	0.20	0.24

[1] LSD for fertilizer levels within cv.
[2] LSD for cv. at the same fertilizer level.

Figure 5.3 illustrates the relationship between mean LAI as affected by nutrient levels and changes in storage root no. and in HI. Changes in mean LAI indicate changes in aerial biomass, while changes in storage roots may reflect changes in RY. Changes in HI indicate changes in patterns of biomass partitioning into aboveground parts and storage roots. The regression slopes of storage roots over LAI were significantly different among clones. The largest slope (11.4 roots/unit LAI) was observed in CM 489-1, while the smallest slope (4.3 roots/unit LAI) occurred in M Col 1684. Clones CM 523-7 and CMC 40 had intermediate slopes (6-7 roots/unit LAI). In contrast with the other clones, M Col 1684 showed a sharp decline in HI as LAI increased. These data suggest that the major response to P in M Col 1684 occurred in top growth. On the other hand, clones such as CM 489-1 responded more in terms of storage root formation and consequently in yield. It appears therefore that genetic differences in response to P among this group of clones are due more to the relative balance between alternative sinks for DM allocation (storage roots vs. top growth).

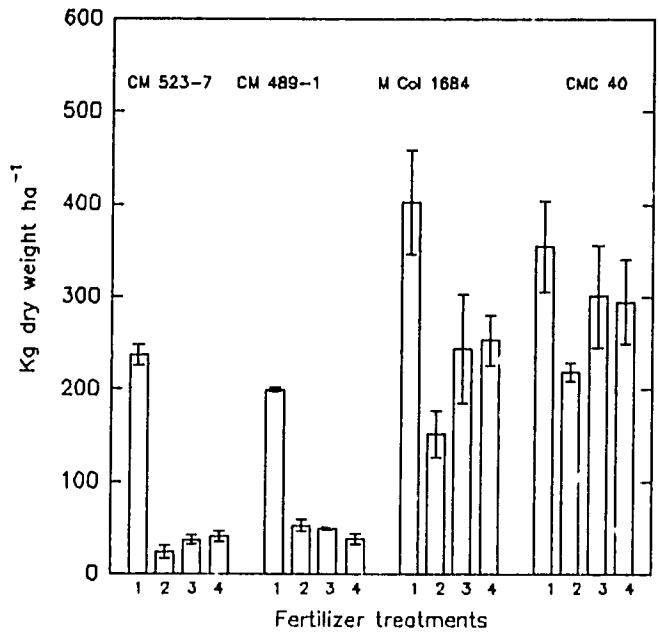


Figure 5.1. Influence of fertilizer treatments on production of reproductive organs (fruits and flowers); fertilizer treatments: (1) unfertilized; (2)100-0-100 kg/ha NPK; (3)100-50-100 kg/ha NPK; and (4)100-100-100 kg/ha NPK (vertical bars = ± SE).

Figure 5.4 illustrates the relationship between total P uptake at 10 mo and phosphorus-use efficiency (PUE = kg dry root/kg P in total biomass). This relationship may indicate differences in internal use of P. In all clones PUE decreased with increasing P accumulation. At low P accumulation (10 kg P/ha), M Col 1684 showed the highest PUE; but at higher P accumulation (25-30 kg P/ha), it had the lowest PUE. The regression slopes indicate the decline in PUE as a function of P uptake. This clone had the greatest decline in PUE with increasing P accumulation. CM 489-1 and CM 523-7 had similar slopes, with a moderate decline in PUE; whereas CMC 40 was intermediate.

Correlation coefficients among some physiological and growth parameters across all clones and fertilizer treatments are shown in **Table 5.2**. Final total biomass was the closest related parameter to final RY, indicating autocorrelation. Mean LAI (source of assimilates) and storage root no. (sink size) were significantly correlated with total biomass and DRY. Avg leaf photosynthetic rate (source activity) was also positively correlated with total biomass, DRY and storage root no.. This might indicate that yield is dependent upon the balance between sink and source and that some feedback effect may exist between root sink strength and leaf photosynthesis. Reproductive organ production was negatively correlated with leaf photosynthesis, mean LAI, total biomass, storage root no. and yield. This suggests that formation of alternative sinks for assimilates may lead to depression in RY.

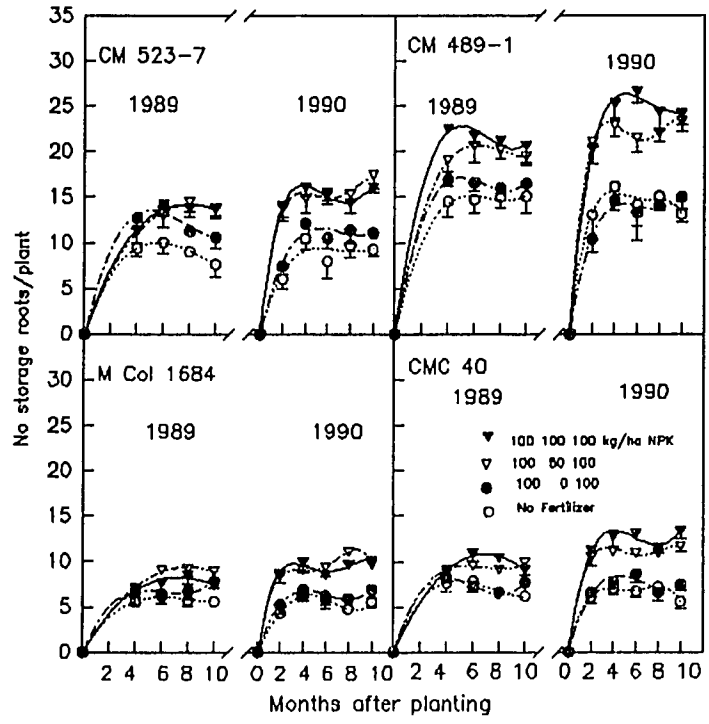


Figure 5.2. Response of storage root no. to fertilizer application during two consecutive crop cycles; vertical bars = SE.

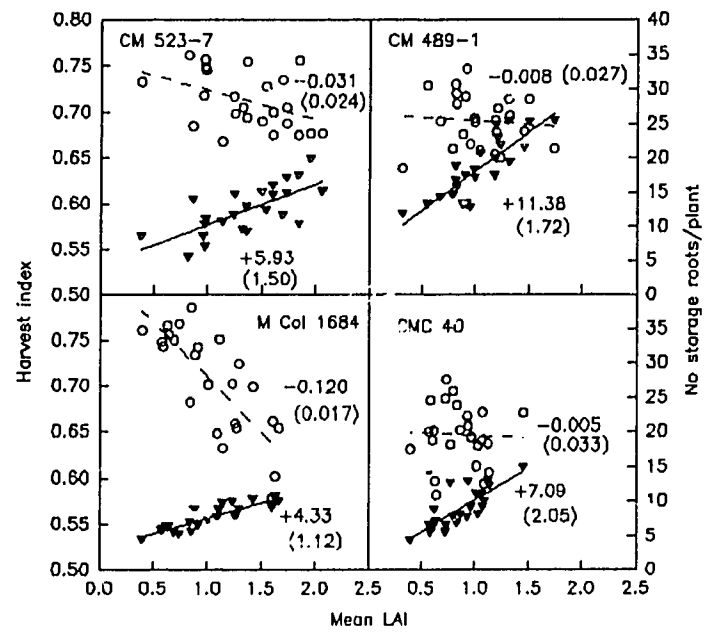


Figure 5.3. Relationship between storage root no. (▾) and HI (o) of standing biomass as a function of mean LAI (2 crop cycles together). The slope and SE (in parentheses) are indicated for each regression line. For HI, R^2 = 0.56. The slope of M Col 1684 was significantly different from CM 523-7, CM 489-1 and CMC 40 (t-test, $P<0.001$). For storage root no., R^2 = 0.87. The slope of M Col 1684 was significantly different from CM 489-1 and CMC 40, but not from CM 523-7 (t-test $P<0.05$).

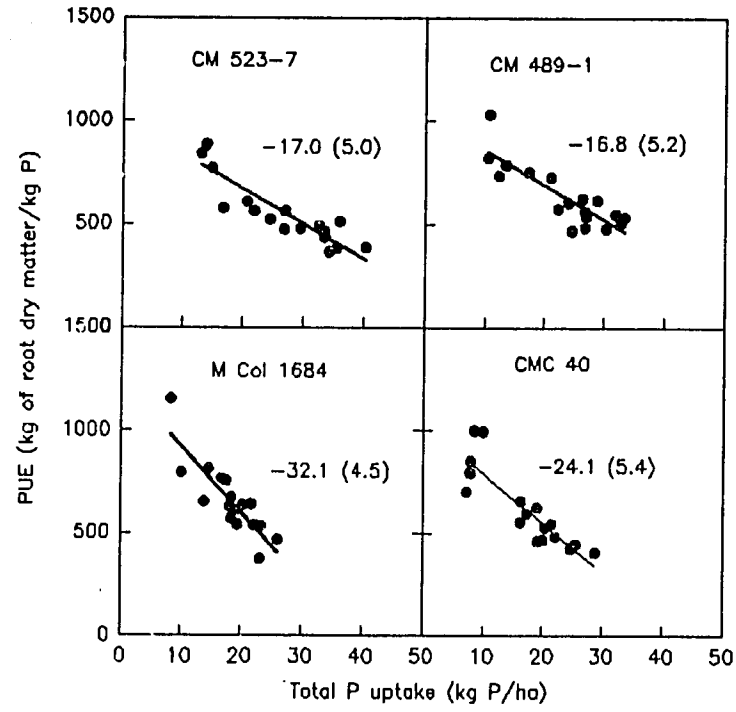


Figure 5.4. Influence of P total uptake on PUE. Data for each cv. are for two crop cycles, 10 MAP. The slope and SE of the mean (in parentheses) are indicated for each regression. The slope of M Col 1684 was significantly different from that of CM 523-7 and CM 489-1 (t-test, $P<0.01$), but not from CMC 40.

Table 5.2. Correlation coefficients for two crop cycles (n=48).

	Crop Cycle	DRY	No. of Storage Roots	Total Biomass	Reproductive Organs	Mean LAI
Photosynthesis rates	1	0.375**	0.526***	0.381**	nd	NS
	2	0.522***	0.561***	0.595***	-0.370**	0.474***
Mean LAI	1	0.647***	0.343*	0.678***	nd	-
	2	0.888***	0.547***	0.888***	-0.465***	-
Reproductive organs	1	nd	nd	nd	-	
	2	-0.573***	-0.649***	-0.489***	-	
Total biomass	1	0.977***	0.734***	-		
	2	0.974***	0.686***	-		
No. of storage roots	1	0.763***	-			
	2	0.701***	-			

nd, NS, *, **, ***: not determined, not significant, significant at $P<0.05$, 0.01, 0.001, resp.

In conclusion, it may be stated that yield response to fertilization-- particularly P--depends upon the balance between aerial growth potentials of genotype and storage root sink strength. If growth of alternative sinks (aboveground parts) is coupled with weak root sinks, a genotype may not respond to fertilizer in terms of economic yield.

6. QUALITY

"Look beneath the surface; let not the several *[sic]* quality of a thing nor its worth escape thee"

Marcus Aurelius Antonius,
Meditations VI,3.

The new strategic plan has given greater emphasis to cassava quality research, with the major objective of providing high-quality raw material (fresh roots) for each of the diverse end uses of the crop. This will be accomplished primarily through a genetic approach although crop management aspects will continue to be considered. The interaction between raw material characteristics and the process in determining end- product quality will also be studied.

During 1992 priority was given to initial characterization of the core germplasm collection for salient quality characteristics, together with the development of an improved rapid method for evaluating cyanogens in the roots. Evaluation of root quality under water stress and soil fertility experiments were continued from previous years.

6.1 Methodology Development

In previous years protocols were standardized for the routine lab determination of DM content, starch content and functional characteristics, total and reducing sugar content, % amylose, total cyanogens and HCN. In addition, a procedure for evaluating the eating quality of fresh cassava was developed using an expert taste panel. Satisfactory methods are lacking for root physiological deterioration--especially using a biochemical index--and for the rapid evaluation of root cyanogen content. This latter topic was the subject of collaborative research between CIAT and the NRI during 1992.

6.1.1 Rapid semiquantitative method for determining root parenchyma total cyanogen content (CIAT/NRI)

The objectives of this project were to develop and test a rapid assay for cyanogens in the roots, to investigate possible correlations between levels of cyanogens and the enzyme linamarase in the roots, as well as
investigate the influences of plant type and growth conditions with regard to test performance.

The tetra base method, originally proposed by Feigl & Anger (1966) as modified by Bradbury & Egan (1992), was selected for development as a rapid semiquantitative method to be used by cassava breeders and others. The Bradbury & Egan method represents an important advance in rapid cyanogen assay methodology; however, it had

been tested using only a limited no. of cv., all of low total cyanogen content. Three main areas for further research were identified:

- The assay of sufficient clones to cover the range of total cyanogen contents found in the germplasm
- The possible influence of sample linamarase activity upon the assay
- The possible influence of ambient temp variation upon the assay

These areas were investigated by means of a "three-way assay," run at different temp in the range 10-35°C. The three-way assay involved the rapid tetra base assay, with the enzymic cyanogen and enzymic linamarase assays as "controls." In addition a representative sampling technique was defined, as was the time allowed between the preparation of samples and running the test. Some comparative experimental work was carried out in the early stages to establish optimal sampling procedures and pretest periods for the assay. The relationship between the central root disc and the remainder of the parenchyma was also investigated in terms of both cyanogen content and linamarase activity. Once modified, the tetra base assay was tested by direct comparison with the picrate paper test already in use by the Breeding Sect.

It was found that the modified tetra base method functioned better if the results were viewed as pertaining to ranges or bands of cyanogen contents rather than in terms of a linear scale. The tetra base color reaction with HCN is much faster than that of picrate. It was found that the two evaluations of color intensity of a filter paper placed in a sealed vial above a 1-g cube of root tissue, after 10 and 60 min, were sufficient to distinguish 3 bands of total cyanogen content (cyanogens as HCN, fresh basis):

Less than max. color after 60 min	0 - 50 mg/kg
Max. color reached by 60 min but not by 10 min	50 - 100 mg/kg
Max. color reached by 10 min	>100 mg/kg

The assay was run on 91 samples at 6 different temp ranging from 10 to 35°C and simultaneously assayed for linamarase activity in the roots. The total cyanogen contents of the roots were in the range 10.1 to 456.7 mg/kg with linamarase activity ranging from 0.03 to 0.63 EU/g. The Spearman correlation coefficient for the relationship between the tetra base result and the quantitative analysis was 0.746. The assay functioned better at temp of 20°C and above (72 cases, Spearman correlation 0.773). The elimination of results from low-linamarase samples improved the predictability of the tetra base result. The cutoff point for defining low linamarase was set at 0.2 EU/g (43 samples included with temp above 20°C and linamarase above 0.2 EU/g, Spearman correlation 0.851).

As the release of HCN from the root tissue is autolytic, the levels of linamarase in the root (and, by inference, in the central disc taken for the rapid assay) must influence the assay

to some extent. Preliminary experimentation indicated that in terms of cyanogen content, the central disc was close to the remainder of the root (± 30%); but its linamarase activity was consistently higher, by a highly variable degree (2-10 times as high). Thus it is premature to define a linamarase cutoff point; furthermore, some roots with very low linamarase have inexplicably given satisfactory tetra base results. For this reason, further investigation of this and other aspects (e.g., conditions of plant growth) is required.

No correlation was found between total cyanogen content and linamarase activity: the Pearson correlation coefficient was 0.081.

Finally, 74 roots (24 different cv.) were sampled for both the modified tetra base and the picrate rapid methods, with the calorimetric enzymic assay as a control. Both of the rapid methods predicted ranges of total cyanogen contents rather than exact results. These were low (0-50 mg/kg), intermediate (50-100 mg/kg) and high (>100 mg/kg). The tetra base method performed better: 77% correct results vs. 68% for the picrate method.

The method requires more testing--especially in the field under different climatic conditions--before it can be recommended for routine use. It appears to offer greater accuracy than the picrate method (especially in the low range of 0-50 mg/kg); however, the rapid reaction time will require logistical adaptations to the sampling and evaluation procedures currently used for the picrate method. The development of this method has highlighted new areas for research, especially as regards root linamarase activity and its relationship to total cyanogen content.

6.1.2 Use of high-pressure liquid chromatography (HPLC) to determine cassava cyanogen contents

The NRI has been developing a rapid HPLC-based method for the quantitative determination of linamarin and cyanohydrin content of cassava. During a visit to CIAT, this method was tested using a wide variety of clones, with good results (see report of the BRU, where this work was carried out). Although an expensive capital item, HPLC offers low running and reagent costs, and a similar throughput to that already available using the enzymatic method but without the use of toxic reagents.

6.2 Quality Evaluation of Core Germplasm Collection

In 1991 a core germplasm collection (630 accessions)--which attempts to reflect the genetic diversity of the entire germplasm collection of over 5000 clones--was established at CIAT, providing an opportunity to start the characterization of salient root quality characteristics of the germplasm, many of which have never been systematically evaluated. Plants were harvested at CIAT from 10-12 mo of age, and the following evaluations undertaken:

- Total cyanogen content, root peel and parenchyma (enzymatic method)

- DM content, root peel and parenchyma (oven dried)
- % amylose of extracted starch, root parenchyma
- Starch and sugar contents, root parenchyma
- Proximal analysis (protein, fiber, lipids...)

The results of total cyanogen and DM content, and % amylose are presented here; as the remaining results are incomplete, they will be presented fully in 1993.

Table 6.1 presents basic descriptive statistics for root parenchyma and peel separately, as well as the ratio between them. The max. DM content of the parenchyma (48.9%) is the highest ever reported for cassava; 15 clones had contents over 45%. The mean and minimum values of 34.2 and 13.0% are in accordance with previous reports.[6.1] The DM content of the peel was generally lower than that of the parenchyma although the max. value of 46.1% was higher than expected. The ratio of peel to parenchyma DM contents was below 1.0 for 84% of the clones analyzed.

The total cyanogen contents are presented on a fresh and dry wt basis. On a DM basis, parenchyma total cyanogen contents ranged from 17 to 4126 mg/kg (7-1041 mg/kg on a fresh wt basis). These ranges are comparable to those reported previously (e.g., 35-3500 mg/kg dry wt basis.[6.2] The mean of 101.9 and median of 55 mg/kg fresh wt basis found in this study are both lower than expected. **Figure 6.1** shows the frequency distribution of total cyanogens (fresh wt basis). This is highly skewed and unimodal, with no separation between high and low cyanogen-containing cv. The distribution of parenchyma DM and amylose is normal.

Both the max. and minimum values for total cyanogens in the peel are higher than for the parenchyma, reaching 8415 and 1983 mg/kg on dry and fresh wt bases, resp. The ratio between peel and parenchyma is generally above 1, with a max. of 77 on a dry wt basis; nevertheless, 7 clones were identified in which the total cyanogen content of the peel was lower than that of the parenchyma. These clones all had total cyanogen contents in the parenchyma of over 200 on a fresh wt basis, except one (M Col 2526, 95 mg/kg). The clones with the highest peel:parenchyma ratio were all of low total cyanogen content in the parenchyma (< 40 mg/kg for the top 10 clones).

[6.1] WHEATLEY, C.C., J.I. ORREGO, T. SANCHEZ & E. GRANADOS. 1993. In W.M. ROCA & A.M. THRO. Proceedings of the First International Scientific Meeting of the Cassava Biotechnology Network, Cartagena, Colombia, 25-28 Aug. 1992. Cali, CIAT, pp.255-264.

[6.2] WHEATLEY et al., 1993, ibid.

Table 6.1. Descriptive statistical analysis of total cyanogen content, % DM and % amylose of root parenchyma and peel from the core germplasm collection.

Variable	N	Mean	SD	Max.	Median	Minimum	Range
Parenchyma							
DM (%)	566	34.2	6.2	48.9	34.7	13.0	35.9
Total cyanogens (mg/kg, dry wt)	566	314.5	416.8	4126.0	164.0	17.0	4109.0
Total cyanogens (mg/kg, fresh wt)	566	101.9	124.2	1041.0	55.0	7.0	1034.0
Amylose (% starch)	503	22.3	2.1	28.8	22.3	15.3	13.4
Peel							
DM (%)	566	27.0	4.5	46.1	26.9	15.4	30.7
Total cyanogens (mg/kg, dry wt)	566	1871.2	1102.9	8415.0	1638.0	204.0	8211.0
Total cyanogens (mg/kg, fresh wt)	566	498.3	287.2	1983.0	437.0	55.0	1928.0
Peel: Parenchyma							
DM (%)	566	0.8	0.1	1.4	0.8	0.5	0.1
Total cyanogens (dry wt)	566	11.0	7.4	77.6	10.5	0.5	77.2
Total cyanogens (fresh wt)	566	8.4	5.0	42.7	8.3	0.5	42.1

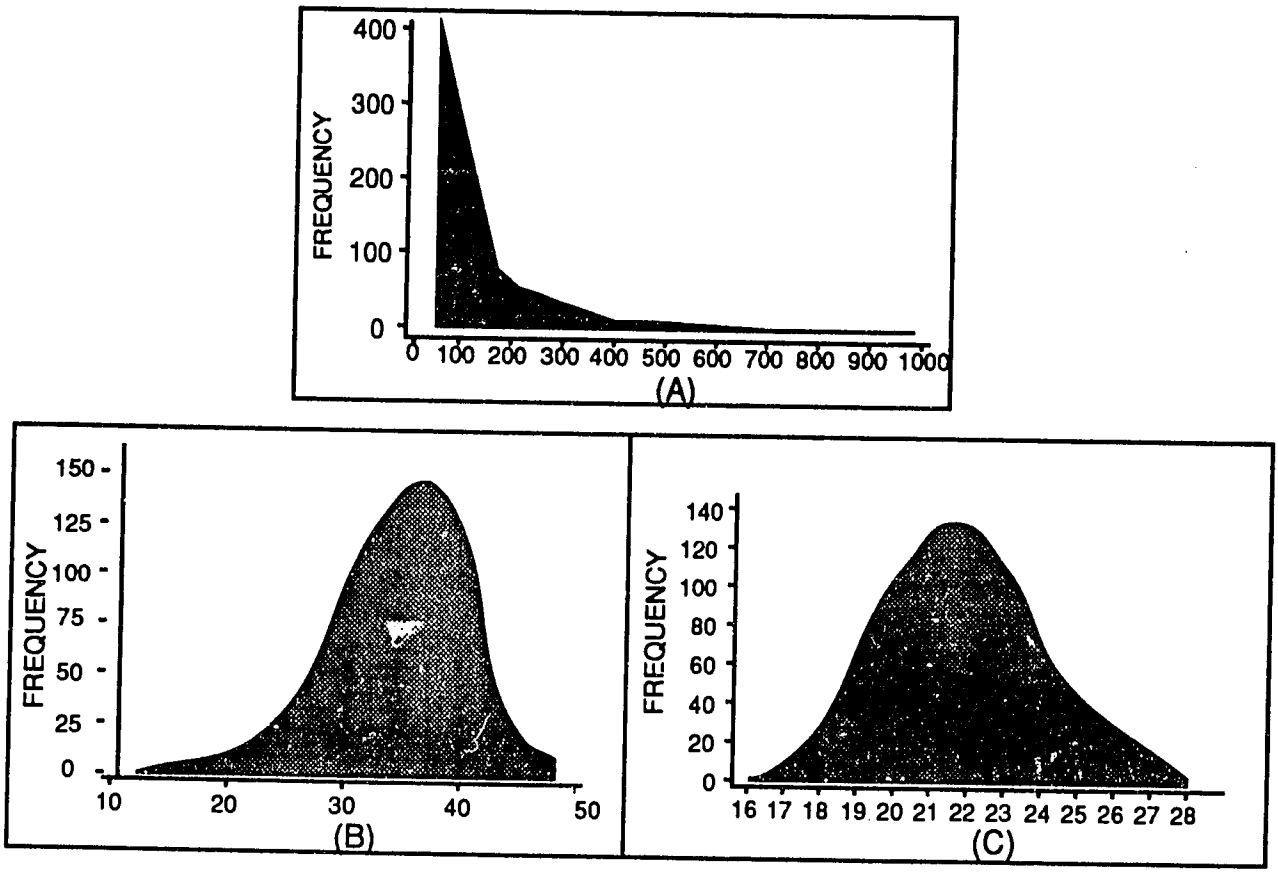


Figure 6.1. Frequency distribution diagrams of core collection cassava clones for: (A) Total cyanogen contents (NG/kg), parenchyma, fresh basis. (B) DM content (%), parenchyma. (C) Amylose (%) of starch extracted from parenchyma.

The amylose percentages in starch extracted from the parenchyma of each clone ranged from a max. of 28 to a minimum of 15%. This relatively narrow range is comparable with previous reports based on the analysis of a more restricted range of clones.

A Pearson correlation coefficient matrix was calculated for all variables (**Table 6.2**). Because of the high no. of clones (566), coefficients of only 0.150 were highly significant; nevertheless, a clear positive correlation was found between root parenchyma and peel DM content. There was a strong negative relationship between the peel:parenchyma ratio and the parenchyma DM content. The same relation was also found for peel and parenchyma total cyanogen contents. In general there were no strong relationships between % amylose and other parenchyma variables although there were some significant correlations (e.g., with DM content).

Factor analysis was used to reduce the large number of variables to three factors that encompass the variation found in the individual variables. For the purposes of this analysis, variables were selected that would be important in cassava used for processing (DM and cyanide contents of the peel and parenchyma, and % amylose). The five variables were subjected to principal component analysis to identify the important factors

Table 6.2. Correlation coefficient matrix between % DM, % amylose and total cyanogen contents in root parenchyma and peel.

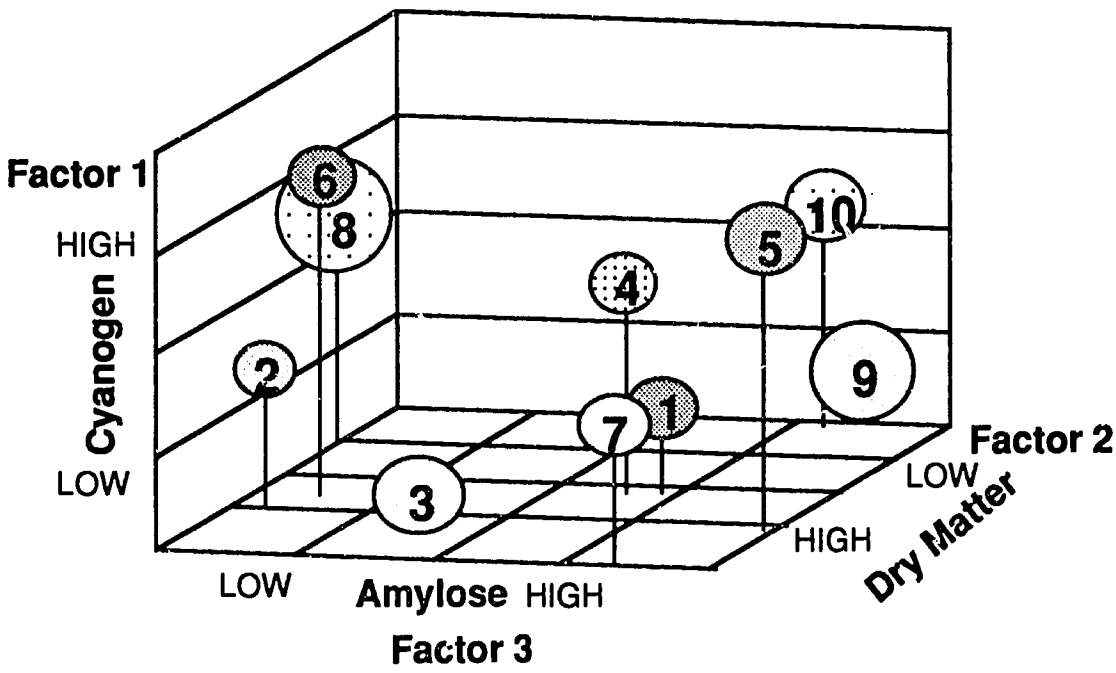
	Parenchyma			Peel		Peel: Parenchyma	
	DM	Total Cyanogens	Amylose	DM	Total Cyanogens	DM	Total Cyanogens
Parenchyma							
DM (%)	1.000	-0.005	-0.342***	0.585***	0.313***	-0.579***	0.258***
Total cyanogens		1.000	-0.232***	0.161***	0.643***	0.162***	-0.681***
Amylose			1.000	-0.342***	-0.187***	0.052	0.103
Peel							
DM (%)				1.00	0.184***	0.296***	-0.032
Total cyanogens					1.00	-0.192***	0.027
Peel: Parenchyma							
DM (%)						1.00	-0.318***
Total cyanogens							1.00

*** Significant at P = 0.001.

involved. Three factors were identified, accounting for 84.1% of the total variation occurring in the five selected variables (37.2, 32.0 and 14.9% for factors 1, 2 and 3, resp.). Factor 1 was dominated by root cyanogens, Factor 2 by root DM content and Factor 3 by % amylose. In all cases the relation between dominant variables and factors was positive.

The three factors generated in the previous analysis were used with equal weighting as the basis for identifying and defining clusters of clones with similar characteristics. On the basis of the hierarchical organization of clusters and the R^2 values of each level in the hierarchy, 10 clusters were selected for further evaluation. **Figure 6.2** provides a three-dimensional representation of the centroids of each cluster with respect to the axes provided by the three factors. It can be seen that some clusters represent interesting combinations of characteristics; e.g., relatively high in root DM content but low in total cyanogens.

The clusters identified in this and other analyses will be used to identify clones of potential interest to breeding programs and to select research materials for in-depth study of specific root quality characteristics. For example, CIAT will evaluate the functional properties of starch in the core collection based on representative clones from each of the clusters.



Note: The radius of each sphere represents the mean dispersion of each cluster

Figure 6.2. Representation of 10 clusters of clones, using three factors as axes.

6.3 Relationships Between Root Cyanogens and Starch Quality

The 15 clones with the highest and lowest total cyanogen contents from the core collection were selected for detailed starch functionality studies (**Table 6.3**). Significant differences were found between mean values of the high- and low-cyanogen clones for all starch viscosity variables determined plus the derived variables ease of cooking, gel instability and gelatification index. Only the mean gelatinization temp was similar for high- and low-cyanogen clones. The high-cyanogen clones had lower starch viscosity values (V) than those with low cyanogen.

Table 6.3. Mean values of amylose and starch functionality characteristics for 15 clones of lowest and highest total parenchyma cyanogen contents.

	Low CN Group	High CN Group	Significant Difference (P=)
Total cyanogen (mg/kg) parenchyma, fresh wt basis	13	461	0.001
% amylose	22.9	21.6	n.s.
Gelatinization temp. (°C)	64.1	64.7	n..s
Max. V	509.5	359.5	0.0001
V at 90°C	391.5	230.2	0.0001
V after 20 min at 90°C	232.6	133.5	0.0001
Viscosity at 50°C	391.3	198.7	0.0001
Ease of cooking[1]	10.2	6.3	0.0001
Gel instability[2]	276.9	222.1	0.014
Gelatification Index[3]	158.7	65.3	0.0001

[1] Ease of cooking = Time to Vmax - Time to gelatinization,
[2] Gel instability = Vmax - V90/20
[3] Gelatification Index = V50-V90/20

For example, M Col 2360 had a max. viscosity of 168 and a viscosity at 90°C of 130 BU, compared with mean values of 509 and 392 BU for low-cyanogen clones. Although taken from a restricted number of clones, these results strongly suggest that differences in starch viscosity characteristics and hence in behavior during traditional processing are significant between high- and low-cyanogen cv. It is interesting that most of the high-cyanogen cv. analyzed for their starch properties were collected in the Amazon region of Colombia and Brazil. In many crops there is a strong relationship between starch functional properties and % amylose of the starch. In the case of cassava, this has not been shown: There was no correlation between % amylose and any of the starch

functional characteristics evaluated using the Brabender, and there was no significant difference in mean % amylose between the high- and low-cyanogen clones evaluated. Possible relationships between root cyanogen content and starch functionality will be explored further.

6.4 Preharvest Environmental Effects on Root Quality

The 1991 Annual Report reviewed the results obtained to date in this area, focusing on the effects of water stress and soil fertility/fertilizer use on root cyanogen, DM and starch content/quality. In 1992 additional samples were taken for quality evaluation from the experiments of the Physiology Sect. in Media Luna (Atlantic Coast) and Santander de Quilichao (N Cauca). The principal results were:

- The use of a mulch cover for the crop in Media Luna reduced total root parenchyma DM and cyanogen contents, compared to control plots. In addition the % amylose of starch from roots with the mulch treatment was significantly lower (**Table 6.4**). These results confirm those of the previous harvest and reinforce the advantages of using mulch on cassava yield.

Table 6.4. The effect of mulch treatment on root parenchyma quality in Media Luna (cv. Verdecita, M Col 1505).

	% DM	Total CN (mg/kg, DM basis)	% Amylose Starch
Without mulch	23.5	194	25.3
With mulch	28.1	164	23.1
Significance (P =)	0.001	0.01	0.005

- Potassium fertilizer supplementation affected root quality of 14 clones harvested in Santander, resulting in increased root DM and decreased total cyanogens with increasing levels of K application (**Table 6.5**). This confirms previous findings on the importance of K in determining root quality. Similar results were obtained in a trial with 5 clones at Media Luna.

The results confirm those found previously. Now that a clear picture has emerged regarding the beneficial effects of K on root quality as well as yield, no further experiments will be analyzed. Emphasis will be placed on identifying clones with good root quality under stressed conditions, especially water stress.

Table 6.5. The effect of K application on root DM and total cyanogen content of 14 clones harvested at Bariloche, Santander.

K Application	Root Parenchyma	
(kg/ha)	% DM	Total CN Content (mg/kg fresh wt basis)
0	36.7 a	158 a
50	37.6 ba	105 b
100	38.1 bc	97 b
200	39.5 c	105 b

Note: Values with the same letter are not significantly different (P = 0.05), DMRT.

7. DISEASES

During 1992 emphasis was placed on investigating four important topics of cassava pathology: witches'-broom (WB) disease, biological control, TCS pathology and cassava endophytes. Additionally, research to control CBB and root rots through integrated approaches was also emphasized (see Chap. 14).

7.1 The Mycoplasm Witches'-Broom (WB)

7.1.1 Etiological studies

Observations of ultrathin sections under electron microscopy (EM) led to the identification of mycoplasmlike organisms (MLO). As EM is rarely available to plant pathologists in developing countries, a technique was developed to identify MLO using light microscopes (LM), found in most government organizations. Samples (1 cm^2) were taken from young apical stems and dehydrated in ascending alcohol concn. and embedded in Spurr's resin. Thin sections (1μ) were cut and stained with Diene's solution and then observed using a LM (X400). Pleomorphic membrane-bound bodies--similar to those found by using the EM in ultrathin sections--were readily observed in vascular strands of disease samples. This method is feasible for scientists working in most developing country plant pathology labs.

7.1.2 Disease transmission

In addition to transmission by grafting and dissemination through the use of infected stakes taken from diseased plants (Annual Report 1991), the MLO was also transmitted to healthy cassava and *Vinca rosea* plants through a parasitic plant (*Cuscuta* sp.) when plants were maintained in a screenhouse at 18-23°C. The first symptoms were observed 60 days after the establishment of the plant parasite on the host. MLO-like bodies were observed through both LM and EM. No transmission was obtained using a vector of a soybean MLO-like disease (*Scaphytopius fuliginosus*) after 3 mo of insect feeding.

7.1.3 Disease control

- Cultural practices. Results from replicated trials to reduce WB-incidence by planting selected stakes were similar to those of 1991 (**Table 7.1**). This control measure effectively reduces disease incidence and is independent of the environmental conditions prevalent during the growing cycles; however, it appears that total disease eradication is not possible with this control measure.

- Genetic control. Of 259 clones that were first planted in 1989 and evaluated for resistance in 1990, five have maintained excellent stability of resistance. Another 6 clones of the 154 first planted in 1990 and evaluated in 1991 (**Table 7.2**) also show good resistance.

Table 7.1. Reduction of WB symptoms over 3 cycles by planting selected stakes from visually symptomless plants.

	% Diseased Plants after Each Selection Cycle[1]		
% of Infection Source Plants	Cycle 1	Cycle 2	Cycle 3
95	26.0	12.3	7.5
50	24.5	12.0	6.9
25	12.5	7.1	6.3
5	0	0	0

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

Table 7.2. Genotype flow and WB-resistant stability through growing cycles of 11 mo each; data represent readings for over more than 20 pl/genotype.

No. of Plants Evaluated/Yr Followed by Resistant Genotype (remaining)			
1989	1990	1991	1992
259	44	7	5[1]
	154	8	6
		98	21

[1] Plants of resistant genotypes were symptomless.

Results confirm the existence of resistance to this disease in *Manihot esculenta* and the need for several growing cycles to identify WB-resistant clones under field conditions. At least two of the resistant clones will be released to growers in Feb 1993.

7.2 Biological Control

7.2.1 Biochemical studies on fluorescent pseudonomads

Preliminary research on the mode of antagonism to fungal root rot pathogens of cassava by strains of *Pseudomonas fluorescens* and *P. putida*, carried out in cooperation with the

Dept. of Plant Pathology at Cornell U., has shown that strains of both bacterial species are capable of producing volatile and nonvolatile inhibitors of *Phytophthora parasitica* mycelial growth. The nature of these products and whether they are produced in situ or play a significant role in the inhibition of the pathogen on cassava are not yet known.

7.2.2 Characterization of efficient fluorescent pseudonomads

Several hundred isolates of fluorescent bacteria were collected in different cassava-growing regions from the rhizosphere of traditional clones and were grown on King's B media. They were screened for their ability to inhibit *P. drechsleri* and *P. parasitica* strains and to produce growth regulators. Five promising strains were selected for further evaluation.

7.2.3 Biocontrol with *Trichoderma harzianum*

In field trials in a soil naturally infested with *Fusarium solani*, there was a significative increase in yield in plots treated with the mycoparasite *Trichoderma harzianum* (8.3×10^6 spores/pl). The biological control of *F. solani* provided by *T. harzianum* was much more effective when cassava was planted on ridges (**Fig. 7.1**). Commercial trials for the use of *T. harzianum* in *F. solani*-endemic areas are under way.

7.2.4 Biocontrol products for commercial use

- *P. fluorescens* (C 58) and *P. putida* (F 44) remained viable for 3 mo when maintained on a powder mixture of sorghum, peptone and sucrose. The powder-bacteria product induced similar inhibition effects on several cassava root rot pathogens after the storage period as compared with untreated controls.

- *T. harzianum* grown on sorghum grain or powder induced similar infection rates after 2 mo storage as compared to controls of fresh cultures of *Fusarium* spp., *Phytophthora* spp., *Diplodia manihotis* and *Scytalidium* sp.

7.1.3 Endophytes

The existence of fungal endophytes affecting cassava was demonstrated in 1990-91 (Annual Report 1991). During 1992, a system was developed to evaluate their beneficial/detrimental effect on cassava plantlets under controlled conditions. Rooted shoots from stems of indexed plants growing in pots with sterile soils were inoculated either by spray inoculation or by puncturing the stem and inoculating with a mycelial-water suspension from PDA-fungal cultures. Readings of the plant or root dry wt were taken 2-3 mo after inoculation, and the inoculated treatments were later compared with the uninoculated controls. Several isolates of different endophyte spp. collected from distinct edaphoclimatic regions were evaluated as detrimental; surprisingly, a few apparently induced moderate plant growth.

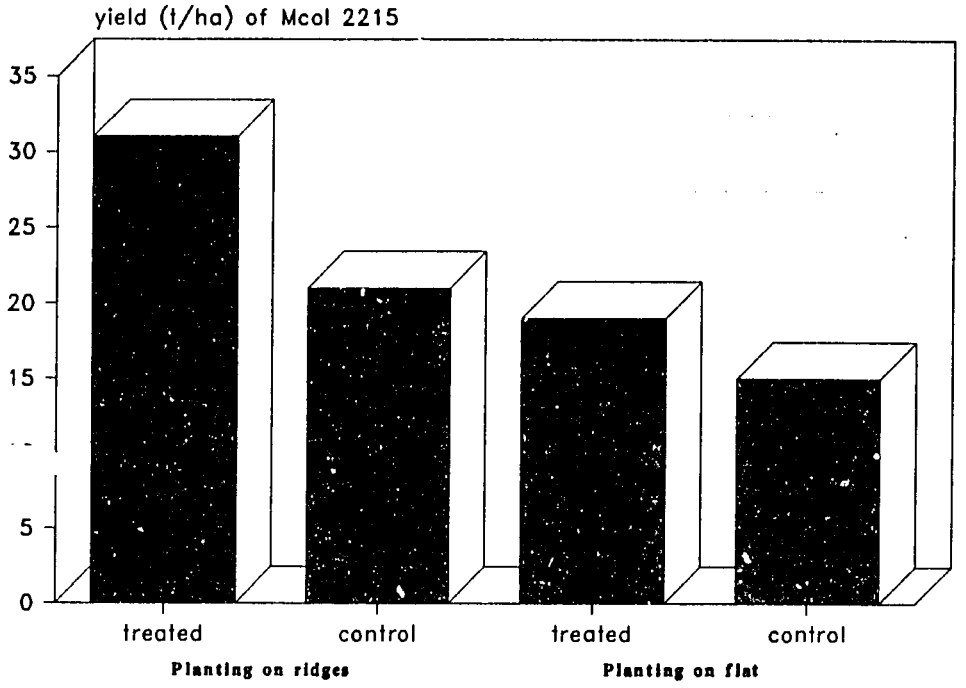


Figure 7.1 Effect of *Trichoderma harzianum* treatments on yield of cassava (M Col 2215) planted on a plot naturally infested of *Fusarium solani*, a root rot pathogen.

7.4 Seed Pathology

Previous reports on the eradication of seed-borne pathogens affecting TCS recommended dry (60°C for 2 wk) or microwave (78°C for 120 sec) heat treatments followed by dusting with a fungicide (thiram) (Annual Reports 1982-83). Recently, there have been complaints about the effect of these treatments on microbial control and/or reduction of seed germination. The following results were obtained this year:

- Both microwave and dry heat seed treatments are effective in eradicating seed-borne microorganisms infesting TCS. Reinfestations were prevented when fungicides (thiram or captan) were applied to seeds immediately after either of the heat seed treatments. These results are similar to those reported previously (Annual Reports 1982-83).

- Carboxin (Vitavax), PCNB (Brassicol), Banrot[7.1] and captafol (Difolatan) reduced seed germination. Captan (Orthocide), thiram (Arasan) and benomyl (Benlate) did not reduce seed germination; however, when seeds were dusted with these three fungicides and then heat treated, the fungicidal effect was lost and the seeds were easily reinfested.

- Increasing seed storage periods (up to 1 yr) under cool environments (6-10°C) did not reduce the level of microbial infection.

- Dry heat (60°C for 2 wk) treatments eliminated bacterial infections and greatly reduced fungal infections. Microwave treatment (78°C for 2 min) eradicated the fungi and bacteria affecting the seeds.

- By collecting only visually healthy cassava fruit balls and selecting seeds by density (discard all seeds that float on water), better seed sanitary quality is obtained, thereby decreasing the risk of getting infected seeds after the foregoing treatments.

[7.1] 5-ethoxy-3-trichloromethyl-1,2,4-thiodiazole (15%); dimethyl 4, 4-o-phenylenebis (3-thioallophanate) (25%); inert ingredients (60%).

8. ENTOMOLOGY & ACAROLOGY

8.1 Acarology

8.1.1 Phytoseiid preference studies

Phytoseiid mites associated with cassava in the Americas generally have several possible prey species available as there are six major species of tetranychids associated with cassava[8.1] and over 40 species have been reported.[8.2] Electrophoresis was investigated as a possible tool for determining phytoseiid diets under field conditions; however, the complexities of interpreting the gels have limited its usefulness.[8.3] Offering mixed diets under lab conditions and small-scale, controlled releases of phytoseiids on plants with several prey species present, followed up with electrophoresis, are alternatives for studying preference. For the preliminary phase of the lab study, prey stage preference and consumption capacity need to be known.

The capacity of adult female *Neoseiulus idaeus* (Fonseca, Guajira, Colombia and Petrolina, Pernambuco, Brazil strains), *Typhlodromalus limonicus* (Valera, Venezuela) and *T. tenuiscutus* (Quevedo, Ecuador) to consume eggs, larvae, nymphs and adult females of *M. caribbeanae* in 24 h was determined. Female predatory mites were transferred to experimental units containing superabundant prey the day following first oviposition.

All spp./strains tested consumed all stages of prey offered. The interaction of species and prey stage was significant (ANOVA; $P = 0.05$), with greater consumption of larvae and nymphs than eggs in *N. idaeus* and higher mean consumption capacity in the *Typhlodromalus* spp. than in *N. idaeus*. Biomass measurements of each prey stage are needed for further interpretation of stage-dependent differences in consumption capacity (**Table 8.1**).

8.1 CIAT. 1990. Cassava Acarology. *In* Annual Report. Cassava Program, pp. 145-171. Working Document No. 95. CIAT, Cali, Colombia.

8.2 J.M. Guerrero, expert Cassava Acarology, pers. comm.

8.3 GAIGL, A., A.R. BRAUN & H.M. POEHLING. Electrophoretic gut analysis of phytoseiid predators associated with cassava: methodology development. (in prep.)

Table 8.1. Effect of prey stage on consumption capacity of phytoseiid spp./strains during 24 h.

Prey Stage	Phytoseiid spp./strain															
	N. idaeus - Fonseca[1]				*N. idaeus* - Petrolina[2]				*T. limonicus* - Valera[3]				*T. tenuiscutus* - Quevedo[4]			
	n	d_i [5]	No. Cons.	SE	n	d_i	No. Cons.	SE	n	d_i	No. Cons.	SE	n	d_i	No. Cons.	SE
Egg	20	54	29.7	8.2	12	64	26.8	15.8	15	46	42.6	22.1	37	89	47.5	3.9
Larva	19	40	35.7	2.6	18	50	42.1	4.9	19	50	49.6	0.9	50	60	49.5	1.3
Nymph	20	40	30.8	5.0	18	40	28.3	6.0	12	50	20.9	9.1	50	60	28.3	1.7
Adult	14	40	1.6	1.1	-	-	-	-	11	30	4.4	2.0	30	20	3.1	0.3

[1] Colombia

[2] Brazil

[3] Venezuela

[4] Ecuador

[5] Initial prey density offered

8.1.2 Phytoseiid diet studies

Under seasonally dry conditions, *T. limonicus s.l.* has a protective effect of approx. 30% of RY.[8.4] This species responds numerically to increases in *M. tanajoa* numbers[8.5], and it persists when *M. tanajoa* are scarce or absent by feeding on non-acarine foods.[8.6] *T. limonicus s.l.* is not well adapted to prey on the web-forming tetranychid species associated with cassava (*Tetranychus urticae, T. tumidus, Oligonychus gossypii, O. peruvianus*). It appears to have specialized to feed on *Mononychellus* spp. and is strongly associated with cassava, as are its acarine prey. *T. limonicus s.l.* is a generalist in terms of overall diet, but specializes within the acarine component.

Several other species of *Typhlodromalus* occur in cassava. The composition of the phytoseiid complex varies locally in the Americas.[8.7] Although their impact on *Mononychellus* populations and on cassava yield is unknown, *T. tenuiscutus* and *T. rapax* may play an important role in drier environments; and *T. limonicus s.s.* may be important under subtropical conditions. To determine whether the ability to develop and reproduce on non-acarine food is a general characteristic of *Typhlodromalus* spp., survival from egg to adult, development time and fecundity were compared for *T. tenuiscutus*, *T. rapax*, *T. limonicus s.l.* and two strains of *T. limonicus s.s.* on diets of water, honey, pollen (*Rinicus communis*) and *M. caribbeanae*. One of the *T. limonicus s.s.* strains (Riverside, Calif.) was collected from citrus rather than cassava.

The ability of *Typhlodromalus* spp. other than *T. limonicus s.l.* (CIAT strain) to survive and reproduce on both acarine and non-acarine diets was confirmed. None of the spp./strains tested survived to adulthood when water was the only diet component available (**Table 8.2**). Of the mites reared on honey, 25% or less survived to adulthood; however, 50% or more survived when fed pollen. There were significant differences between spp./strains with respect to their survivorship on the diets offered (**Table 8.2**).

8.4 BRAUN, A.R., A.C. BELLOTTI, J.M. GUERRERO & L.T. WILSON. 1989. Effect of predator exclusion on cassava infested with tetranychid mites (Acari: Tetranychidae). Environ. Entomol. 18:711-714.

8.5 CIAT, 1990, op.cit.; HERRERA, C.J., J.M. GUERRERO & A.R. BRAUN Impacto de predadores (Acari: Phytoseiidae) asociados al cultivo de la yuca sobre *Mononychellus* spp. en la Costa Atlántica de Colombia. (submitted)

8.6 BAKKER, F. & M.E. KLEIN. 1992. Transtrophic interactions in cassava. Exp. Appl. Acarol. 14:293-311; CIAT, 1990, op. cit.

8.7 CIAT, 1990, op. cit.

Table 8.2. Effect of diet on survival from egg to adult of *Typhlodromalus* spp.

Species[1]	n	Diet[2]	% Survival	X^2	
T. limonicus s.s. (USA)	65	W	0.0	168.6	***
	65	C	100.0		
	65	H	15.4		
	65	P	67.7		
T. limonicus s.s. (Bra)	65	W	0.0	164.9	***
	65	C	93.8		
	65	H	6.1		
	65	P	61.5		
T. limonicus s.l. (Col)	65	W	0.0	61.0	***
	65	C	61.9		
	65	H	24.6		
	65	P	41.5		
T. rapax (Col)	65	W	0.0	144.7	***
	65	C	93.8		
	65	H	16.9		
	65	P	61.5		
T. tenuiscutus (Ecu)	100	W	0.0	177.6	***
	100	C	83.0		
	100	H	15.0		
	100	P	50.0		

1 USA = Riverside, CA; Bra = Cruz das Almas, Brazil; Col = CIAT HQ, Colombia (*T. limonicus s.l.*); Luruaco, Colombia (*T. rapax*); Ecu = Quevedo, Ecuador.

2 W = water; C = *M. caribbeanae*; H = honey; P = pollen.

*** P = 0.001.

Although *T. limonicus s.s.* (Riverside, Calif. and Jaguariuna, Sao Paulo strains) occur in zones where *M. caribbeanae* does not occur, their survivorship on a diet of this mite was equivalent to or better than that of the other species of *Typhlodromalus*. Development time for all species was shortest on the diet of *M. caribbeanae*. Intermediate and long development times were registered on pollen and honey, resp. (**Table 8.3**. *T. limonicus s.l.* (CIAT strain) and *T. rapax* had the shortest development times on all of the diets, whereas *T. tenuiscutus* had the longest (**Table 8.3**). Reproduction occurred only on diets of *M. caribbeanae* and pollen, except for *T. limonicus s.l.* which did not reproduce except on the acarine diet (**Table 8.4**). The CIAT strain of *T. limonicus s.l.* has the lowest fecundity of all the known strains.[8.8] Inability to reproduce on pollen may not be typical for the species.

[8.8] CUELLAR, M.E. 1992. Biosistemática de poblaciones de *Amblyseius limonicus* Garman & McGregor *sensu lato y sensu stricto* (Acarina: Phytoseiidae) y su importancia en el control del ácaro verde de la yuca. Tesis. UNIVALLE, Facultad de Ciencias, Depto. de Biología. Cali, Colombia.

Table 8.3. Interaction of diet and prey species on female development time of *Typhlodromalus* spp.

Diet[1]	Spp.[2]	n_i[3]	n_f[4]	Development Time[5] (days)	
H	*T. tenuiscutus* (Ecu)	100	3	11.2	A
	T. limonicus s.s. (Bra)	65	2	10.5	A
	T. rapax (Col)	65	8	8.0	B
	T. limonicus s.l. (Col)	65	4	7.4	BC
P	*T. tenuiscutus* (Ecu)	100	29	7.2	C
	T. limonicus s.s. (USA)	65	15	6.8	CD
	T. limonicus s.s. (Bra)	65	22	6.0	DE
	T. rapax (Col)	65	28	5.6	E
	T. limonicus s.l. (Col)	65	19	5.6	E
C	*T. tenuiscutus* (Ecu)	100	55	5.7	E
	T. limonicus s.s. (USA)	65	28	5.4	E
	T. limonicus s.l. (Col)	65	25	5.3	E
	T. rapax (Col)	65	47	5.1	E
	T. limonicus s.s. (Bra)	65	35	5.0	E

1 H = honey; P = pollen; C = *M. caribbeanae*.

2 Ecu = Quevedo, Ecuador; Bra = Cruz das Almas, Brazil; Col = Lururaco, Colombia (*T. rapax*); CIAT HQ, Colombia (*T. limonicus s.l.*); USA = Riverside, CA.

3 n_i = no. of eggs evaluated.

4 n_f = no. reaching adult stage.

5 Means followed by the same letter are not significantly different (Tukey; P = 0.05).

8.1.3 The cassava green mite (CGM) biotype hypothesis

Guerrero et al.[8.9] showed that CGM is a morphologically variable species in the Americas, with the length of the dorsoventral setae D1, D2 and D3 varying continuously: 17.85-54.40 mm for D1, 17.85-56.10 mm for D2 and 20.40-64.60 mm for D3. An exception to this pattern occurs in NE Brazil, where only the short extreme of this morphological variability occurs. CGM in NE Brazil also differ in that they produce webbing,[8.10] and are well adapted to semiarid conditions. Taken together, these differences suggest that a biotype has evolved in NE Brazil. The possible existence of a biotype has implications for the selection of natural enemies for controlling CGM in Brazil and Africa. The full range of morphological variability is represented in Africa, and CGM has not colonized semiarid

[8.9] GUERRERO, J.M., C.H.W. FLECHTMANN, G. DE MORAES, M.C. DUQUE, A. GAIGL, A.C. BELLOTTI, A.R. BRAUN. Biogeography and taxonomy of *Mononychellus* species associated with *Manihot esculenta* Crantz in the Americas. (submitted)

[8.10] N.C. Mesa, Research Associate, Cassava Entomology Sect., pers. obs.

areas[8.11] Evaluation of the biotype hypothesis is particularly important for the selection of *Neozygites* spp./strains as this fungus appears to have a very high degree of specificity for its host.

Table 8.4. Interaction of diet and species on fecundity of *Typhlodromalus* spp.

Diet[1]	Species[2]	n	Mean no. eggs/ ♀ /day[3]	
C	*T. limonicus s.s.* (USA)	20	3.1	a
	T. limonicus s.s. (BRA)	23	2.6	ab
	T. rapax (COL)	25	2.2	ab
	T. tenuiscutus (ECU)	45	2.2	b
	T. limonicus s.l. (COL)	21	1.8	bc
P	*T. tenuiscutus* (ECU)	19	1.1	cd
	T. limonicus s.s. (BRA)	21	1.0	d
	T. limonicus s.s. (USA)	15	0.7	de
	T. rapax (COL)	17	0.7	de
	T. limonicus s.l. (COL)	19	0.0	e

1 P = pollen; C = *M. caribbeanae*.
2 ECU = Quevedo, Ecuador; BRA = Cruz das Almas, Brazil; COL = Luruaco, Colombia (*T. rapax*); CIAT HQ, Colombia (*T.limonicus s.l.*); USA = Riverside, CA.
3 Means followed by the same letter are not significantly different (Ryan; P = 0.05).

A strategy for evaluating the biotype hypothesis could involve correlation of ribosomal RNA fingerprints to results from an a bioassay of a genetically controlled attribute characterizing each population under study. Preliminary results suggest that fecundity is a heritable trait and that a dose effect may be involved (**Table 8.5**). The CIAT strain has significantly lower fecundity than the Pivijay strain of *T. limonicus s.l.* When both parents have CIAT genes, fecundity is reduced. There is also some evidence that paternal inheritance may affect fecundity (**Table 8.5**). To distinguish between these interpretations, the study is being repeated, including all backcrosses involving a double dose of CIAT genes.

8.1.4 Effect of microhabitat conditions on Phytoseiids

A preliminary study of the effect of microhabitat on CGM and phytoseiid mites was made in Pivijay, a seasonally dry site with 4 mo of < 60 mm rainfall and 1316 mm of precipitation/yr. Three clones of low, intermediate and high vigor (CM 681-2, M Col 1505 and M Mal 2) with narrow, intermediate and wide leaf anatomy resp. and high (CM 681-2) to intermediate (M Col 1505, M Mal 2) susceptibility to mites were planted at densities of

[8.11] M. Porto, CIAT/IITA cassava physiologist/breeder, pers. comm.; YANINEK, J.S. & A. ONZO. 1988. Survey of cassava green mite in the People's Republic of Benin, Jan. (Unpublished report)

5000, 10,000 and 15,000 pl/ha. Mites were evaluated on the scale of 1-4 described in Section 15.1.3, and the values converted to mean no./leaf using the conversion factors for *M. tanajoa* estimated by Yaninek et al.[8.12] The number of phytoseiid mobile stages per leaf was determined by direct counts. Of the phytoseiids mounted for identification, 96% were *T. limonicus s.l.8.*[8.13] Total mite-days for *M. tanajoa* and phytoseiids were calculated as the mean cumulative no./leaf. Leaf area was estimated from a standard curve of leaf area vs. dry wt (**Table 8.6**) as recommended by El-Sharkawy.[8.14]

Table 8.5. Homo- and heterogamic crosses between populations of *Mononychellus tanajoa* from Pivijay (P) and CIAT HQ (C), Colombia.

Parent					
♀	♂	n	Mean eggs/♀[1]		SD[2]
C	C[2]	21	35.1	b	18.5
P	P	33	66.7	a	10.5
C	P	41	59.1	a	13.1
P	C	24	37.7	b	10.5
CP	P	30	64.5	a	22.2
PC	C	23	55.7	a	19.2
C	CP	17	39.1	b	9.4
P	PC	22	66.6	a	20.6
C	C[3]	24	39.1	b	11.7
P	P	32	60.2	a	13.4

1 Means followed by the same letter are not significantly different (Ryan-Einot-Gabriel-Welsch multiple F test, P = 0.05).
2 Control cross.
3 Control backcross.

The highest predator densities occurred at the intermediate planting density in CM 681-2 and M Col 1505; in M Mal 2; however, predator density was relatively stable over the range of planting densities studied (**Fig. 8.1, A**). *M. tanajoa* density was inversely related to planting density in M Mal 2 (**Fig 8.1, B**). The effect of clone on no. of phytoseiid-days/leaf was not significant; however, the interaction between clone and planting density was (P = 0.05), with higher CGM-days/leaf at all planting densities in M Mal 2 (**Fig. 8.1, C**). A significant correlation was found between predator/prey ratio and mean leaf size (cm^2) (**Table 8.7**).

8.12 YANINEK, J.S., G.J. DE MORAES & R.H. MARKHAM. 1989. Handbook on the cassava green mite (*Mononychellus tanajoa*) in Africa. Rome: Alphabyte Ed.

8.13 Herrera et al., op cit.

8.14 Physiologist, CIAT Cassava Physiology Sect., Pers. comm.

Table 8.6. Correlation between dry wt and leaf area of upper, intermediate and lower leaves in three clones in Pivijay, Magdalena.

Clone	Stratum[1]	Equation[2]	r
CM 681-2	U	DW = 0.0043 LA + 0.0066	0.98
	M	DW = 0.0066 LA - 0.0778	0.97
	L	DW = 0.0052 LA - 0.0597	0.98
M Mal 2	U	DW = 0.0042 LA - 0.0416	0.94
	M	DW = 0.0054 LA - 0.1622	0.97
	L	DW = 0.0053 LA - 0.1784	0.97
P-12	U	DW = 0.0030 LA + 0.1341	0.95
	M	DW = 0.0052 LA - 0.1341	0.97
	L	DW = 0.0059 LA - 0.2668	0.95

1 U = first completely open leaf with 45° angle between petiole and stem; M = mature leaf from node 20-30; L = old leaf from below node 30; 30 leaves/stratum were evaluated.

2 DW = dry wt (g); LA = leaf area (cm^2).

Phytoseiids associated with cassava have a lower tolerance to saturation vapor deficit than their tetranychid prey.[8.15] Clones with abundant foliage and good leaf retention, such as M Mal 2, provide a more favorable microhabitat for phytoseiid mites than clones with low leaf area. As CGM is favored by hot, dry conditions, the microhabitat in vigorous clones has a direct negative effect in addition to the positive effect on natural enemies. Choosing clones with large leaves and good leaf retention, and manipulation of the habitat to increase RH within the canopy [e.g., mulching (see Chap. 4 and CIAT 1991[8.16]), tolerating weeds after the crop establishment period], or creation of refuges with high RH (e.g., leaving trees standing in the field, planting patches of cassava at high density) will encourage native phytoseiids and provide more suitable conditions for survival of introduced populations.

[8.15] BAKKER, F.M., M.KLEIN, N.C. MESA & A.R. BRAUN. Drought tolerance of phytophagous mites and their phytoseiid predators on cassava. (submitted)

[8.16] CIAT. 1991. Physiology. *In* Annual Report Cassava Program 1987-1991, pp. 43-65. CIAT, Cali, Colombia.

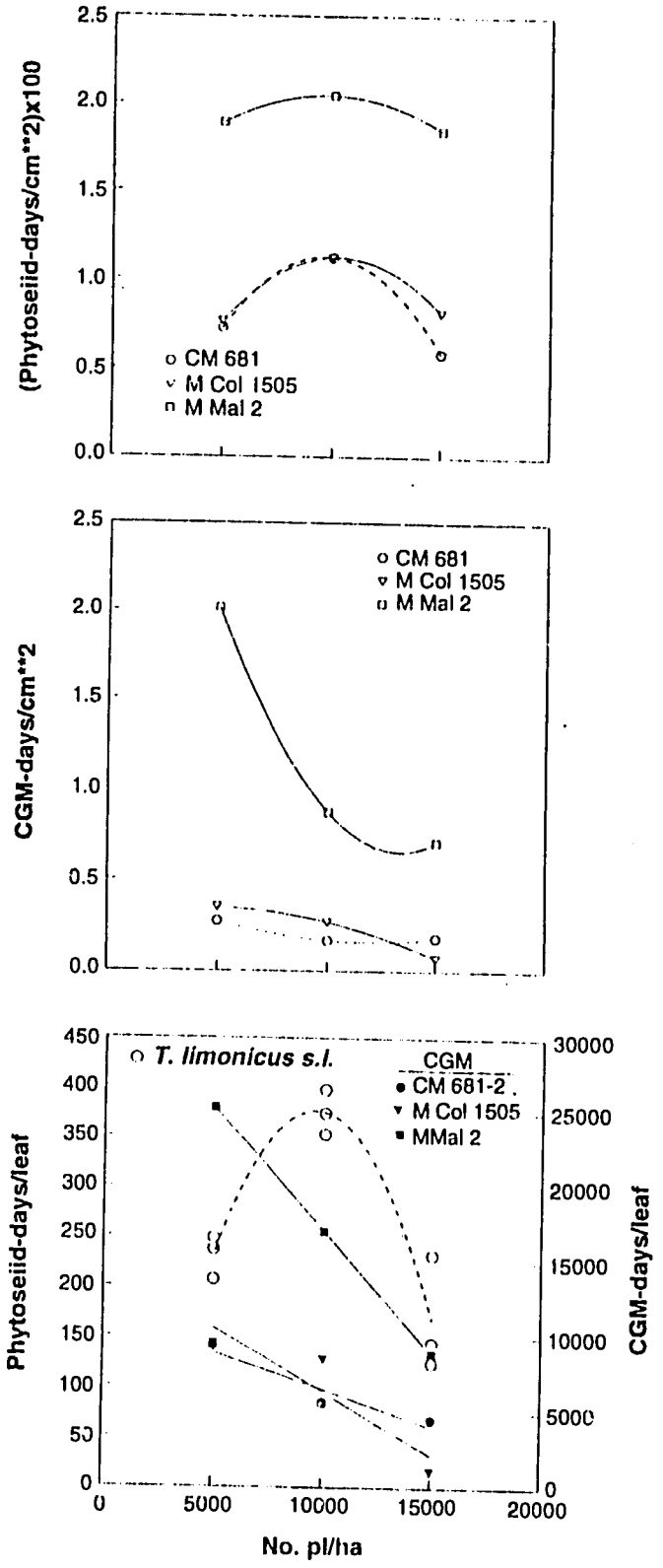


Figure 8.1. Effect of (A) planting density on phytoseiid density (B) planting density on CGM density, and (C) planting density on CGM (CGM-days/leaf) and its natural enemy *T. limonicus s.l.* (phytoseiid-days/leaf) in clones of low (CM 681-2), intermediate (M Col 1505) and high (M Mal 2) vigor; data points are the means of total mite-days/leaf of upper, intermediate and lower leaves from 3 reps/clone.

Table 8.7. Effect of planting density and clone on leaf size and predator/prey ratio *M. tanajoa* and *T. limonicus s.l* in Pivijay, Colombia.

Clone	No. pl/ha	Mean lf. Size (cm^2)	No. Pred./100 CGM
M Col 1505	5000	301.6	2.18
	10000	350.9	4.16
	15000	169.2	11.63[1]
M Mal 2	5000	139.5	0.94
	10000	216.4	2.35
	15000	139.7	2.61
CM 681-2	5000	380.8	2.65
	10000	371.8	6.65
	15000	274.9	3.20

[1] Outlier not included in regression: no. predators/100 CGM = 0.113 (leaf size) + 0.0318; r = 0.65.

8.2 Entomology

8.2.1 The cassava hornworm

Studies to determine the effect of *Eryinnis ello* baculovirus on egg production were initiated. Field observations indicate that migrating hornworm adults may be disseminating the virus between cassava fields. Studies were done in large field cages (2 x 2 m) on cassava plants (clone M Mex 59). Two 30-cc plastic vials with sponge stoppers containing a 14% solution of honey and a 2% concentration of the virus were suspended from the roof in an inverted position in 5 field cages. In two untreated cages only the honey solution was introduced. One pair of adults was introduced into each cage, and eggs were collected daily.

The baculovirus ingested by *E. ello* adults had an adverse effect on subsequent oviposition (453 vs. 196 eggs/female), larval survival (85% nontreated vs. 0.5% virus treated), avg female oviposition period (7 vs. 2.3 days) and adult female longevity (12.5 vs. 6.7 days) (**Table 8.8**). Percent egg hatch was not affected (94.2 vs. 97%). These results indicate that virus ingestion by adults affects oviposition; in subsequent trials, however, it was not possible to attain oviposition from virus fed-females, and all adults died within 48 h after initiating feeding on the virus/honey/water solution. Studies to determine whether transovarial transmission occurs are under way.

Table 8.8. The effect of baculovirus fed to *E. ello* adults on oviposition, egg hatch, larval survival and adult longevity.

Treatment	No. eggs/♀	No. eggs hatched	% Hatch	No. live larvae	No. dead larvae	% larval mortality	Average duration oviposition (days)	Average longevity female adults (days)
Control (No virus)	453	427	94.2	398.5	2	0.5	7	12.5
Treated[1] (Virus Present)	196	190	97	25	165	85.0	2.3	6.5

[1] Results based on 3 female adults; two adults did not oviposit but survived 7 and 8 days respectively.

8.2.2 Cassava Burrowing Bug

The major objectives of research with the burrowing bug *Cyrtomenus bergi* is to increase the knowledge base on this pest and explore the possibilities for biological and botanical control.

The burrowing bug feeds on cassava roots by inserting its strong stylet into the root which, combined with the introduction of soil pathogens, causes brown to black spots on the root parenchyma. Previous studies[8.17] show that there is a feeding preference for low HCN over high HCN cv. although both cause nymphal mortality. Measurements made on stylet length vs. root peel thickness indicate that in the first and second instars, the stylet is not able to penetrate to root parenchyma. Nymphal mortality due to feeding on CMC 40 and M Col 1684 was 56 and 84%, resp.; nearly all mortality occurred during the first two instars. CMC 40 contained 44 ppm HCN in the root parenchyma; M Col 1684, 275 ppm. In the root peel, however, CMC 40 contains 707 ppm HCN; M Col 1684, 627 ppm. The high mortality observed from feeding on CMC 40 during the first two instars (56%) may be due to the high HCN content in the peel.

C. bergi feeds on several hosts, and maize is a preferred host. The effect of the host species on *C. bergi* oviposition was evaluated by rearing nymphs through five instars on maize and forcing adults to feed on cassava (CMC 40 and M Col 1684) during the adult stage. Past studies showed that oviposition on maize was 300 times greater than on cassava. Experiments were done under lab conditions, placing portions of cassava root and maize seeds in plastic containers.

Highest oviposition occurred on the maize/maize sequence; oviposition was reduced by 44.5 and 98.6% on the maize/CMC 40 and maize/M Col 1684 sequence, resp. (**Table 8.9**). Female longevity on maize/CMC 40 was 14 and 52% higher than on maize/maize and maize/M Col 1684. Similar results were obtained for male longevity. Adults will feed primarily in the root parenchyma, where HCN concentration is 44 ppm in CMC 40 and 275 ppm in M Col 1684. These results indicate that HCN concentration reduces *C. bergi* oviposition and that high concentrations may cause cessation of oviposition. Of the 25 females evaluated, only one laid eggs (32) when feeding on M Col 1684. The reduction in female longevity on M Col 1684 is supported by previous data. Oviposition on CMC 40 was higher than that observed in previous studies when *C. bergi* was maintained throughout its complete development and ovipositional cycle feeding only on CMC 40. These results support the hypothesis that under field conditions *C. bergi* must feed on hosts other than cassava to maintain high field populations. The effect of root HCN concentration on *C. bergi* behavior will be evaluated further.

[8.17] CIAT, 1991, op. cit.

Table 8.9. The effect of host feeding sequence on the ovipositional behavior of *Cyrtomenus bergi* under laboratory conditions.

Feeding Sequence	No. Observations	No. Eggs/♀	% Reduction in Oviposition	Total No. Eggs	± Longevity/ Females (days)	± Ovipositional Period (days)
Maize/Maize C.V.	28	92.2 (93.8)	-0-	2582	202.3 (40.3)	30 (76.9)
Maize/CMC 40 C.V.	26	51.1 (46.6)	44.5	1329	235.6 (37.0)	23 (78.7)
Maize/M Col 1684 C.V.	25	1.3 (500)	98.6	32	112.0 (49.5)	500 (500)

The use of entomopathogenic nematodes and fungal pathogens such as *Metarrhizium* are being evaluated as potential agents for biological control. The commercially available nematode *Steineinema carpocapsae* was **Table 8.9** obtained from Bioses (Palo Alto, CA), and reared on larvae of *Galleria mellonella* (Lepidoptera) in the lab.

Infection of *C. bergi* nymphs was evaluated at four nematode concentrations (0, 2000, 4000 and 6000 nematodes/ml) in two media, filter paper and soil. Infection rates were measured 2 and 8 days after inoculation. Parasitism of *C. bergi* nymphs were highest on filter paper at 2 days; whereas in the soil, parasitism was highest at 8 days. On filter paper 80% parasitism was obtained; 50% parasitism was recorded under soil conditions. Considerable fungal and bacterial contamination of nematodes and *C. bergi* was observed on the filter paper medium so this method will be discontinued. Nematode desiccation was also noted; soil texture and humidity affect nematode-host interaction. Infection is optimal in humid soils as nematodes disseminate by way of the film of water on soil particles.

Field sampling for native nematode species parasitizing *C. bergi* was conducted in Santágueda (Caldas), Pereira (Risaralda) and Santander de Quilichao (Cauca). Entomopathogenic nematodes were recovered from soil samples from Santágueda (*C. bergi* feeding on peanuts and sorghum), Pereira (on onions) and Santander de Quilichao (on cassava). Collected nematodes are being reared in the lab on *G. mellonella* and their effectiveness will be evaluated on *C. bergi*. Samples have been sent to USDA for identification.

8.2.3 The Cassava Mealybug, *Phenacoccus herreni*

P. herreni can cause yield losses in cassava in areas of prolonged (4-6 mo) dry seasons. High populations have recently been recorded in NE Brazil. A closely related species, *P. manihoti*, still causes yield reductions in certain areas of Africa. Previous research has provided considerable information on mealybug taxonomy, development and behavior.

Recent research on *P. herreni* has concentrated on biological control and host plant resistance.

The hymenopteran parasite, *Aenasius vexans*, was released into cassava fields in Villavicencio, where field populations are being monitored. It has been recovered after two rainy seasons. Greenhouse studies with *A. vexans* evaluated parasite behavior in relation to different densities of the host, *P. herreni*. Five pairs of parasites were released in cages containing cassava leaves (from mealybug colony) with populations of 20, 50, 150, 250 and 350 second and third instar nymphs. Parasitism was measured after a 24-h exposure by dissecting individuals and counting parasite eggs.

Percent parasitism increased at lower parasite densities. Avg percent parasitism was 70, 56, 49.6, 29.6 and 25.6 for populations of 20, 50, 150, 250 and 350 nymphs, resp. (**Table 8.10**). In addition, superparasitism (more than one parasite egg oviposited in the host) occurred more frequently at lower parasite densities. This behavior was not often observed in previous experiments when sufficient host material was available. The potential importance of this parasite in *P. herreni* control, especially in NE Brazil necessitates further studies on interactions of parasite and prey population densities.

Table 8.10. The effect of *P. herreni* densities on parasitism and superparasitism of *A. vexans*[1] in greenhouse studies.

Host Density (Nymph 1&2)	Avg % Parasitism	Avg % Superparasitism
20	70.0	13.3
50	56.0	17.3
150	49.6	4.6
250	29.6	1.3
350	25.6	1.3

[1] Five pairs of parasites/replicate during a 24-h exposure.

9. VIRUSES

Cassava viruses cause important diseases in India, Africa and the Americas. There are three major viruses in the Americas, each of which is important in a distinct ecological region. In Africa and India, a complex of geminiviruses cause African and Indian mosaic diseases. Highlights are given of the work during the last four years, as well as details of the direction of current research.

9.1 The Cassava Frogskin Disease Complex

The cassava frogskin disease complex includes Caribbean mosaic (CMD), frogskin disease (FSD) and **jacare**. According to current evidence, these diseases are caused by the same etiological agent--a reolike virus transmitted by *Bemisia tuberculata*. To help explain the complex and to understand why there are several names, a brief history of these diseases is presented.

FSD is a viruslike disease of unknown etiology that was first reported from Patia in southern Colombia in 1971. 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 have been yield losses of more than 90% in areas where the disease is endemic. In most cassava clones affected by FSD, no leaf symptoms are produced; but a few cassava clones develop mosaic symptoms on the leaves and the plants are stunted.

For many years there have been reports from CIAT scientists of FSD around Leticia, Colombia. In a survey of the area in 1991, cassava plants with mild to moderate root symptoms typical of FSD were very common. When farmers were asked about the symptoms, they said the problem was physiological and called the disorder "**jacare**," which means alligator. The texture of the root cortex does look more like the ridges of an alligator than the skin of a frog. The disorder is not new, and it appears that it is endemic in the area. The symptoms are milder than the severe symptoms often associated with FSD in the mountain valleys. Later during a visit to a remote Indian village (Centro de Providencia) along the Apoporis River in the Depto. of Amazonas, cassava with FSD symptoms was found.

In 1991 FSD symptoms were reported near Belém in Brazil, and this was considered a new problem in the area. The soil was so humid that the peels of the roots of the affected plants were rotting and fell off the root easily. If this disease was FSD, then the most likely source of spread was along the Amazon River. In 1992 a trip was made to the Amazon River near Manaus, and FSD-affected roots were found at the first farm that was visited. The farmer called the root symptoms, which appeared when the roots were 6-8 mo old, **jacare**. It is significant that the same term is used in both Leticia and

Manaus. As the disease is widespread throughout the Amazonian region, has been endemic for a long time, and can be found even in remote areas, it is probable that the origin of FSD is the Amazonian region.

CMD is a viruslike disease of unknown etiology reported from the northern coastal regions of Colombia in 1981. The disease was causing foliar mosaic symptoms and significant yield loss in Secundina, a very popular landrace on the Atlantic Coast. The disease was named CMD because of the mosaic symptoms and the geographic location of the epidemic. It spread rapidly throughout the region, and the planting of Secundina declined. Most other cassava clones did not appear to be affected.

CMD was considered a different disease from FSD because the first report of CMD was in the landrace Secundina, which develops mosaic symptoms in the leaves. Moreover, the root symptoms associated with FSD are either absent or mild in plants affected with CMD on the Atlantic Coast. Several years later, when it was determined that Secundina developed mosaic symptoms when grafted with FSD-affected plants, Secundina was considered a highly susceptible clone. There was the suggestion that FSD might be a complex of two viruses: one that causes the mosaic symptom and another that interacts synergically, causing the root symptoms.

Both diseases are transmitted by grafting and the cv. Secundina has been used for several years in indexing programs to detect both CMD and FSD. Neither FSD nor CMD can be inoculated mechanically, and the only known host for both diseases is cassava. As both diseases spread rapidly in the field, insects have been suspected to be the vectors for these diseases. While the diseases are very similar, it did not eliminate the possibility that they have different etiological causes. The evidence that FSD, jacare and CMD are all caused by a reolike virus is summarized herein.

9.1.1 The effect of the environment on the expression of symptoms of FSD

To understand why FSD and CMD were considered for many years to be separate diseases, one must understand the relationship between the environment and the expression of symptoms. The critical factor that determines the severity of the symptoms is the temperature during plant growth and development. In experiments in a growth room, the mosaic symptoms on the leaves of Secundina are expressed only when the max. temp is kept below 28°C. Both air and soil temp fluctuate during the course of a day; and while the exact relationship of temp and symptom expression has not been determined, it is probable that a soil temp of ca. 28°C inhibits the expression of root symptoms.

When FSD was first described, it was from a mid-altitude mountain valley in southern Colombia. The cooler temp were favorable for the expression of severe root symptoms, but the affected cassava clones did not have leaf symptoms and the stake material was normal.

In contrast, when CMD was first seen on the Atlantic Coast of Colombia, the symptoms were mosaic symptoms in the leaves and the plants were stunted. The roots were also stunted and yields were very low, but there were no symptoms characteristic of FSD. In contrast to Secundina--a highly susceptible landrace genetically--the other cassava clones appeared to be resistant or tolerant to the disease and showed no obvious symptoms. The situation was confusing because on the Atlantic Coast of Colombia the temp are very high and are unfavorable for the expression of root symptoms.

9.1.2 Identification of viruslike particles and inclusion bodies associated with FSD

One of the most important advances in the search for the causal agent of FSD has been the cytological study of infected vs. healthy cassava using the EM. In 1990, two types of isometric viruslike particles were found in thin sections of the leaves, petioles, stems and roots of FSD- and CMD-affected plants (**Fig. 9.1**). The first type is approx. 80 nm in diameter and has an inner darker stained core and an outer lighter coat. It is often found in groups or associated with inclusionlike bodies. The second type is 40-50 nm in diameter and appears to be the darker staining core of the mature particles. These viruslike particles are either masses of particles in the cytoplasm or in inclusionlike bodies. Both types of particles are in the highest concentration in very young leaves.

Two types of inclusionlike bodies were found in the leaves and roots of the FSD- or CMD-affected plants. One type of inclusionlike body was found in the cytoplasm and appears to consist of immature virions (**Fig. 9.2A**), similar to the masses of particles in the cytoplasm, but they are more electron dense and contained some particles the size and structure of mature virions. The second type of inclusionlike body is electron dense, has regular paracrystalline structures and contains isometric particles that appear to be mature virions (**Fig. 9.2B**).

The original cytological studies were done using isolates that had been propagated vegetatively and grown in either a screen- or greenhouse. From 1990-92, new isolates of FSD were collected from the Deptos. of Tolima, Cauca, Valle and Amazonas, Colombia; and all these isolates contained the viruslike particles and inclusions. The type of viruslike particles inclusions present in cassava affected with FSD or CMD is similar to those found in reoviruses.

9.1.3 Double-stranded RNA extraction and analysis

Double-stranded RNAs were purified from cassava plants affected with either CMD or FSD and run on both agarose and polyacrylamide gels. On agarose gels there are 4 bands, which are resistant to RNase A digestion in high salt but are digested in low salt. They are not digested with DNase I. Isolate 29 had 5 bands present in agarose gels. On polyacrylamide gels there are 9 bands consistently present in plants affected with FSD or CMD (**Fig. 9.3**). The dsRNA segments are estimated to be 4000, 3900, 3700, 2600, 1900,

Figure 9.1. A group of viruslike particles, 80 nm in diameter, found in the thin section of a leaf of an FSD-affected cassava clone.

Figure 9.2. (A) Inclusion body that appears to consist primarily of immature virus particles; (B) paracyrstal inclusions that appear to contain mature virus particles.

1800, 1700,1100 and 1000 bases in length; these will be referred to as dsRNA species 1 to 9 resp. The difference in the number of bands in agarose versus polyacrylamide gels is explained by the greater resolving power of the polyacrylamide gels; and the species 1-3, 5-7 and 8-9 appear as single bands in the agarose gels. The sizes of these dsRNA species are similar to those found in the Fiji group of reoviruses.

In the isolate of FSD 29 (**Fig. 9.3**) and those from Leticia and Centro de Providencia, there are 12 species of dsRNA. In addition to the 9 species found in the other isolates, there are 3 additional bands of dsRNA, which are estimated to be 2400, 2000, and 1600 bases in length. The presence of these species appears to result in decreased amounts of the dsRNA 4, 5 and 6 in both isolates.

There is also a very large mol wt band reported as dsRNA, found in dsRNA extracts from both healthy and diseased plants. The origin of this band, which is not consistently present in dsRNAs from the same plants, is unknown.

Radioisotopic-labeled cDNA probes were prepared from the isolated dsRNA for use in hybridization analyses to determine the relatedness of the various FSD and CMD isolates. From the studies to date, there appears to be a fairly high degree of similarity among the isolates; e.g., FSD isolate 14 hybridizes with the CMD isolate 80 (**Fig. 9.4**). This is further evidence that dsRNAs associated with FSD and CMD are either identical or closely related.

9.1.4 Partial purification of the reolike virus associated with FSD

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

9.1.5 Vector transmission experiments

Although whiteflies have long been suspected as the vector of FSD, in preliminary experiments several species of whiteflies and thrips were tested. Previous studies suggested that the whitefly *Bemisia tuberculata* was the vector of FSD, and most of the vector transmission tests were done testing this hypothesis. For most of the transmission experiments, the clone Secundina was used as the mosaic leaf symptom was the marker that transmission was successful.

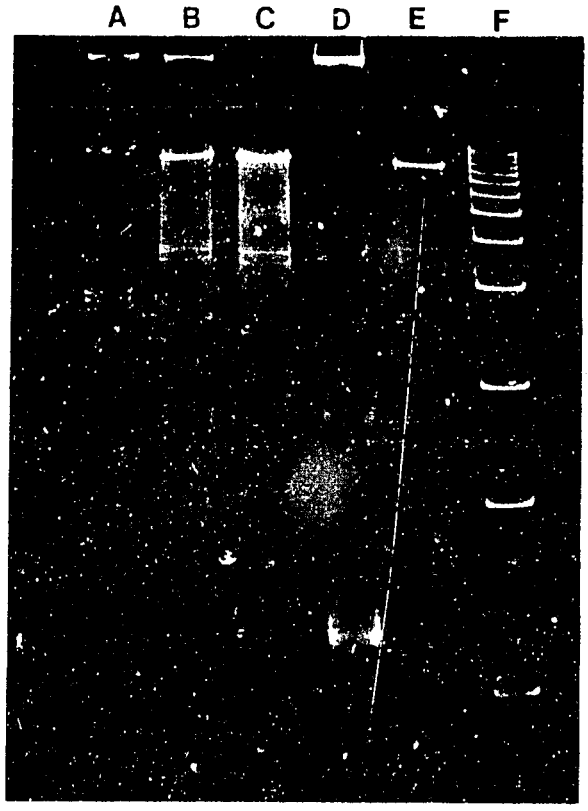


Figure 9.3. A polyacrylamide gel showing the dsRNA segments isolated from plants infected with FSD and CMD. (A) dsRNA markers, (B) CMD isolate 5, (C) FSD isolate 29; (D) FSD isolate 80; (E) CMD isolate 86, (F) dsDNA markers.

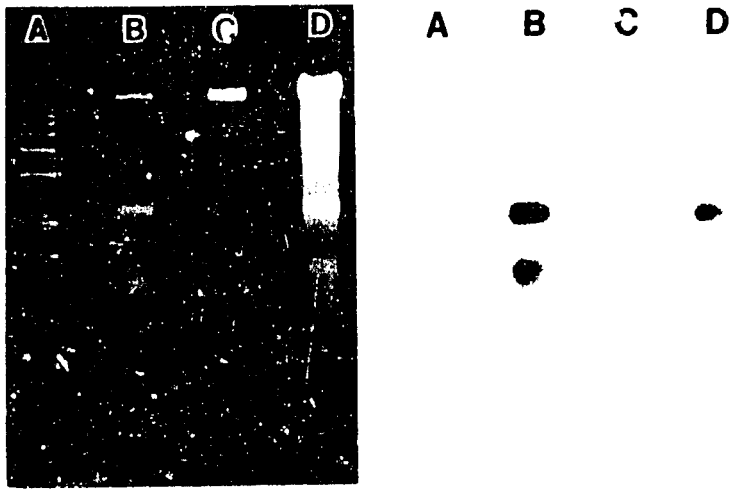


Figure 9.4. (1) An agarose gel showing the dsRNA segments extracted from plants infected with FSD and CMD; (2) blot hybridization using a first-strand cDNA probe prepared from FSD-dsRNA (isolate 14); (A) dsDNA markers; (B) FSD isolate 14; (C) FSD isolate 24; (D) CMD isolate 80.

The one-day acquisition period gave the highest rates of transmission using *B. tuberculata* as the vector. Transmission was obtained with longer acquisition times of more than one day but not less than one day. The minimum transmission time obtained was the one-day acquisition time and a three-day inoculation time. Percent transmission increased when the vectors were left on the plants for 5 days although the increase was not statistically significant. **Table 9.1** is a list of the different FSD and CMD isolates, which produced mosaic symptoms when transmitted by *B. tuberculata*.

Table 9.1. List of FSD and CMD isolates that have been transmitted to cassava by the whitefly (WF) *B. tuberculata*.

Disease	Isolate	Source Plant	Receptor 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 from the field; later experiments showed this isolate was transmitted by *B. tuberculata*.

The plants that developed the mosaic symptoms in the transmission tests were analyzed for the presence of dsRNA species. Both the mother plants used as the sources of inocula and the plants infected in the transmission experiments had the nine species of dsRNA patterns. The exception was FSD isolate 29, where the mother plant contained 12 dsRNA bands; but the plants infected in the transmission test had only 9 dsRNA species.

The plants that were positive in the transmission studies were assayed by preparing leaf dips and observing them using TEM. Viruslike particles with 80-nm diameters were found in all the infected plants. There were no viruslike particles nor the 9 dsRNA species in the healthy control plants. *B. tuberculata* were fed on plants infected with FSD and examined using insect dip preparations for viruslike particles. There were viruslike particles (80 nm in diameter) in these samples, similar in size and morphology to those found in FSD-infected plants. The structure of the viruslike particles extracted from *B. tuberculata* is more distinct than that of the particles found in the plants. Whiteflies that fed on healthy plants contained no viruslike particles. Using blind tests the whiteflies that had fed on the infected plants were consistently identified by the presence of these viruslike particles.

Plants that developed mosaic symptoms were transplanted (80 cm between plants) in a bed of soil within a screenhouse. The screen is a very fine mesh, and the temp were frequently above 30°C. The plants were grown under these conditions for 6-8 mo, and then the roots were inspected for the root symptoms associated with FSD. During the first cycle of growth, the plants were harvested at 6-9 mo; and many of the roots showed only very mild root symptoms typical of FSD. Stakes were taken from these plants, grown in the screenhouse for a second cycle, and harvested at 18 mo. Many of the plants developed moderate fissures on the roots that are characteristic of FSD.

9.1.6 Etiological agent of FSD and CMD

The tospoviruses and the reoviruses are the only two major viral groups with isometric particles ca. 80 nm in diameter that infect plants. The former are sap transmitted; the latter are not. Neither FSD nor CMD has been mechanically transmitted despite many attempts; this is consistent with the causal agent being a reovirus. The reoviruses have genomes that consist of either 10 or 12 species of dsRNA. With the exception of the type member (wound tumor virus, WTV), the reoviruses are restricted to grasses and are transmitted by leafhoppers. They are very difficult viruses to purify as they degrade readily.

In the course of these investigations into the causal agents of FSD and CMD, two types of viruslike particles were consistently found in plants affected with either FSD or CMD: The larger 80-nm particle is similar to complete reovirus particles; the smaller 50-nm particles, to the central core of reoviruses. Particles were found that appear to be the complete particles in the process of losing their outer coat. Particles 80 nm in diameter were also found in *B. tuberculata*, and they clearly showed the spikes typical of reovirus particles. Masses of viruslike particles and two types of inclusionlike bodies were found in the leaves, petioles, stem and roots of FSD- or CMD-affected plants. These particles are very labile and degrade quickly during purification procedures.

Nine species of dsRNA were consistently found in plants infected with either FSD or CMD. Additional dsRNA species are found in a few of the FSD isolates. The relative mol wt (M_r), the no. of the dsRNAs found in CMD- and FSD-infected plants are similar to genome sizes of other reoviruses.

The reoviruses that infect plants are placed in two groups based on the number of genome segments. The phytoreovirus genus contains 12 segments of dsRNA; the Fijivirus genus consists of 10 species of dsRNA. Only 9 species of dsRNA have been found consistently in FSD- or CMD-affected plants. The vectors of plant reoviruses are leafhoppers, and all except WTV infect only monocotyledon plants. Cassava is a dicotyledon plant and the vector is a species of whitefly. Because of the differences between the virus associated with FSD and the other reoviruses, it should be classified in a new genus of reoviruses.

There is a similar or identical virus associated with both FSD and CMD, both of which are vectored by *B. tuberculata*. The original description that CMD is distinct from FSD was based on differences that are now attributed to climate. Therefore the name CMD should not be discontinued, and the CMD isolates will be considered isolates of FSD.

9.1.7 Epidemiology and 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. The use of the indicator clone Secundina can facilitate the selection of clean stake material. 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 stakes. There are no leaf symptoms in most cassava clones; therefore, the selection of the stake material must be made at the time of harvest. The roots must be inspected for the symptoms of FSD. Many of the root symptoms are mild, but these can be easily recognized, and stakes from those plants must be eliminated to mitigate the losses caused by FSD.

A field study, now in its third year, is being conducted at Quilcase, Colombia. A number of different cv., some of which are resistant to whiteflies, were planted as healthy material. Each year the surviving material is replanted without selection. The plants are inspected for symptoms of FSD, and each plant is tested by grafting with Secundina for FSD infection. The disease spread slowly in the first year, and most of the infected plants were on one side of the field. This is common for a whitefly-transmitted disease, especially in a partially isolated lot. There was little effect on yield during the first year.

The second year was very dry and hot. Although many of the plants were infected during the second year, only a few showed root symptoms. The Secundina plants in the experiment all showed symptoms typical of CMD. The plants were stunted and the leaves developed mosaic symptom. The roots were stunted, but did not show typical FSD lesions. The lack of symptom expression is attributed to the extremely hot, dry weather. The third harvest will be in April 1993.

The slow rate of initial infection confirms that the introduction of clean planting material is a valuable control strategy. It appears to take several years for infection levels to reach a point where significant yield losses occur. Stake selection as a means of mitigating losses will also be validated.

9.1.8 Quarantine implications

FSD is the most serious viral disease that is endemic in Colombia and the Amazon region of Brazil, so care must be taken when exporting germplasm from these areas. There are several methods for detecting FSD including inspection of the roots, grafting the test plant

to the indicator clone Secundina, detecting dsRNA from the plants and using EM for direct observation of the particles.

CIAT's core collection is a good example of the efforts that are being made to assure that cassava germplasm can be exchanged efficiently and safely. To be certain that the field and in vitro material are identical and virus free, the entire core collection of 630 clones is being reintroduced into the in vitro collection. Roots are being inspected for FSD symptoms, and stakes from the plants are grafted to the indicator clone Secundina. Of the 58% of the clones screened, 14.9% were positive for FSD; 1.4% for CsXV; and 3.6% for CCSpV (**Table 9.2**). A total of 289 clones were found to be healthy, and these have been subjected to thermotherapy and reintroduced into the in vitro collection by the GRU. This is 46% of the core collection and 81% of the subset priority core. This part of the in vitro collection is pathogen tested and upon request will be sent as certified pathogen-free clones.

Table 9.2. Results of evaluating the core collections in the field. Only those clones that were negative for all of the viruses were introduced into the in vitro collection by the GRU. Some of the clones were infected with more virus and the clones that showed root symptoms were also evaluated by grafting for FSD.

	No.	%
Total clones in the core collection	630	100.0
Clones evaluated	369	58.6
Clones showing FSD root symptoms	18	4.9
Clones positive in graft test for FSD	655	14.9
Clones positive for CCMV	0	0
Clones positive for CsXV	9	2.4
Clones positive for CCSpV	20	5.4
Clones positive for CALV	0	0
Healthy clones	289	45.9

9.1.9 Distribution and spread of FSD

Following the assumption that the origin of FSD is the Amazon region, where temp are fairly constant, then one can speculate that there was little pressure for the virus to adapt to the very high temp found in areas like the Atlantic Coast of Colombia. The symptoms are fairly mild in the Amazon region, and the most successful pathogens coexist with their host without causing excessive harm. Therefore FSD appears to be a well-adapted pathogen for the climatic conditions of the Amazon region. When FSD became established in higher altitudes, it became a much more important disease. Temp fluctuations are greater in mid-altitude areas and are cooler during the rainy seasons. In

the cooler climate, the root symptoms are much severer and often the roots do not accumulate starch. By 1971 FSD was endemic in the mountain valleys in southern Colombia; and given the time needed for the establishment of FSD, it was probably introduced at the latest in the early 1960s. From the valleys of southern Colombia, the disease has spread to the Atlantic Coast of Colombia. After the introduction of FSD to the Atlantic Coast, the susceptible landrace Secundina was practically eliminated. The other cv. show only mild or no root symptoms. The disease is now endemic in the region, but it is causing little or no decrease in yield. There are recent reports of FSD in Honduras, Nicaragua and Cuba. The continued spread of FSD (**Fig. 9.5**) highlights the need for tolerant or resistant clones and the continued need for care when transferring germplasm.

9.2 Cassava Common Mosaic Virus

Although CCMV is found throughout South and Central America, it is most prevalent in southern Brazil, Paraguay and northern Argentina (**Fig. 9.6**). The symptoms are severest during the periods of cooler temp in the subtropical areas. Serological tests are available for detecting CCMV and screening germplasm.

9.2.1 Virus characterization

CCMV is a member of the potexvirus group. The particle morphology is a semiflexuous rod, approx. 15 X 495 nm. The viral particles contain a single coat protein with a relative mol wt (M_r) of 25,000 and an ssRNA genome of approx. 6400 bases. The coat protein is larger than the coat protein of CsXV (**Fig.9.7**). Nuclear inclusions typical of the potexvirus group can be found in cassava (**Fig. 9.8**). The RNA was translated in vitro and the largest product had an M_r of 180,000.

Not including the oligo-A 3' terminal, the complete sequence of CCMV is 6387 bases in length. Six proteins were deduced to be coded by the CCMV RNA, and the predicted M_r are 164,809 (polymerase protein), 25,349, 24,264 (coat protein), 12,009, 10,082 and 9,944. A genomic map (**Fig. 9.9**) shows the approximate amino acid homology with other potexviruses. CCMV has a genomic organization typical of other members of the potexviruses. The conserved RNA-dependent RNA polymerase motive was used to assign gene function to the 16 K protein of CCMV is shown in **Figure 9.10**. The protein with the predicted M_r of 9,944 is encoded within the coat protein and is similar to the 10 K proteins predicted for NMV. Most of the sequencing of CCMV was done at the VRU--perhaps the first plant virus to be sequenced in Latin America.

One 1200-base cDNA clone contained the 5' and 3' terminals of the CCMV genome. The clone encodes for a fusion protein consisting of the amino terminal of the polymerase protein and the carboxyl terminal of the coat protein (**Fig. 9.11**). This cDNA clone probably represents a defective interfering (DI) particle. Additional testing is needed to

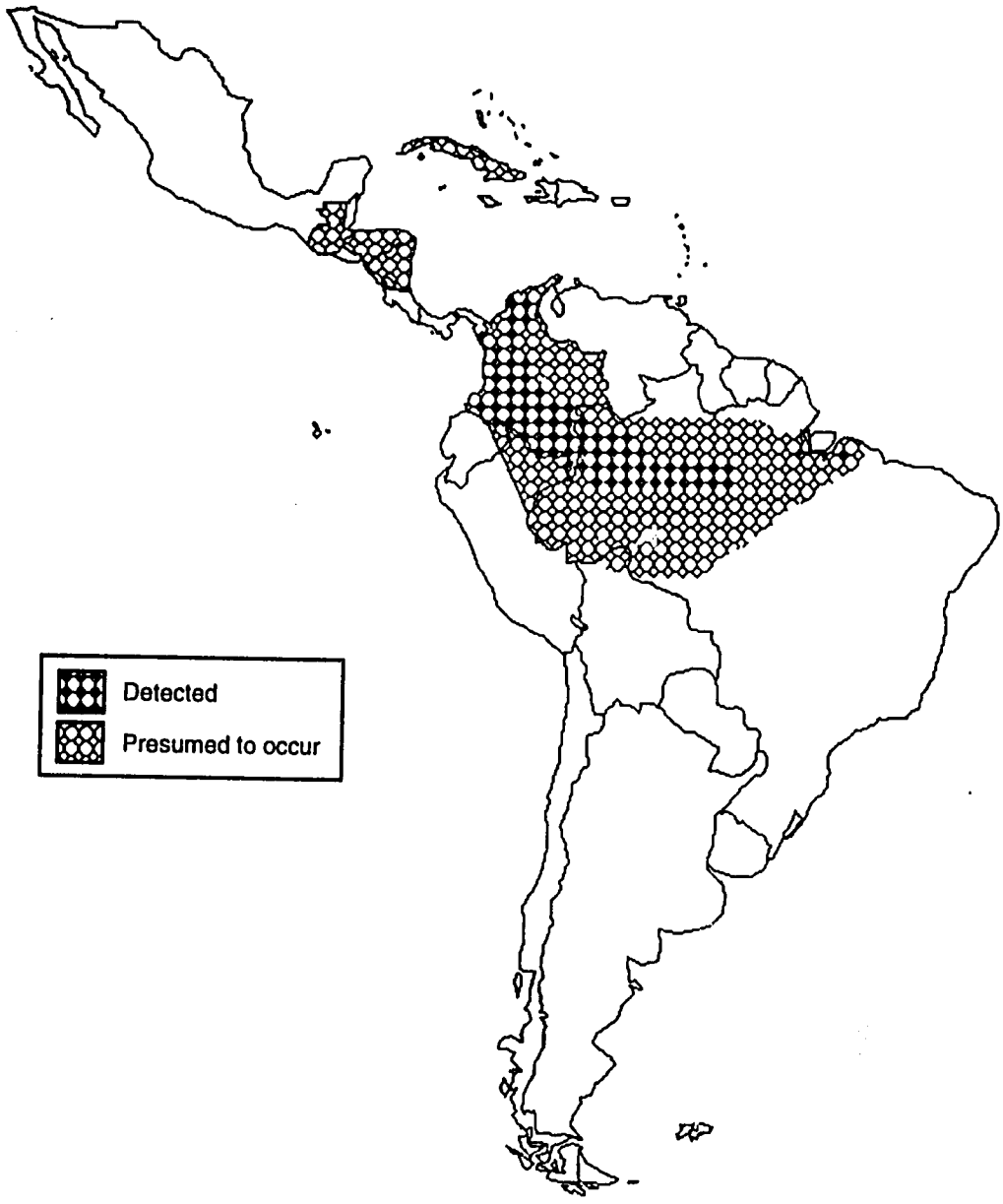


Figure 9.5. The distribution of cassava FSD.

Figure 9.6. The distribution of CCMV.

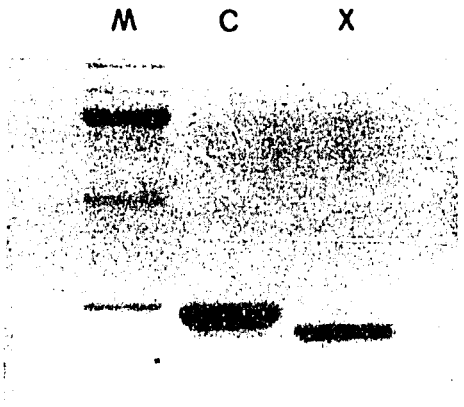


Figure 9.7. Lane M contains protein markers of 98, 68, 43, 29 18 and 14 kD; Lane C, the coat protein of CCMV; Lane X, the coat protein of cassava X virus.

Figure 9.8. A TEM of an inclusion body found in CCMV, consisting primarily of CCMV viral particles.

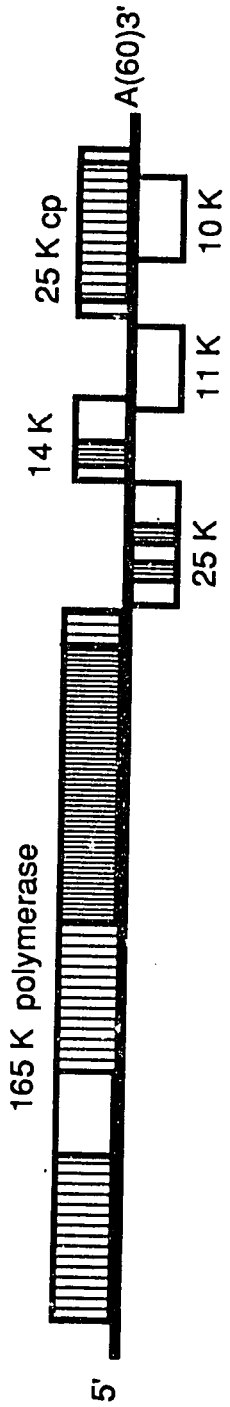


Figure 9.9. A genomic map showing relative homologies of CCMV and PVX. Within the proteins, the low density of lines represents 40-55% and the higher density of lines more than 55% amino acid homology between CCMV and PVX.

```
CCMV   166K IFLGTLSIMRLTGEYQTFDANTECNIAYTHTRFDIPEGVAQLYAGDDSAMD
PVX    166K IFLGTLSIMRLTGEGPTFDANTECNIAYTHTKFDIPAGTAQVYAGDDSALD
            **************  *************** **** * ** ******* *
NMV    186K IFLGTLGIMRLSGEGPTFDANTECSIAYNATRFHITDDTAQVYAGDDNALD
            ****** **** **  ******** ***  *** *    ** ***** * *
WClMV  146K IFLGTLSIMRLSGEGPTFDANTEANIAYTHTKFNIPCDAAQVYAGDDMSID
            *********** **  ******* ******* * **   ** *****   *
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Figure 9.10. Comparison of the region of the conserved RNA-dependent RNA polymerase motive in CCMV and other potexviruses. The * indicates direct amino acid homology between CCMV and the other potex viruses. The RNA-dependent RNA polymerase motive is underlined.

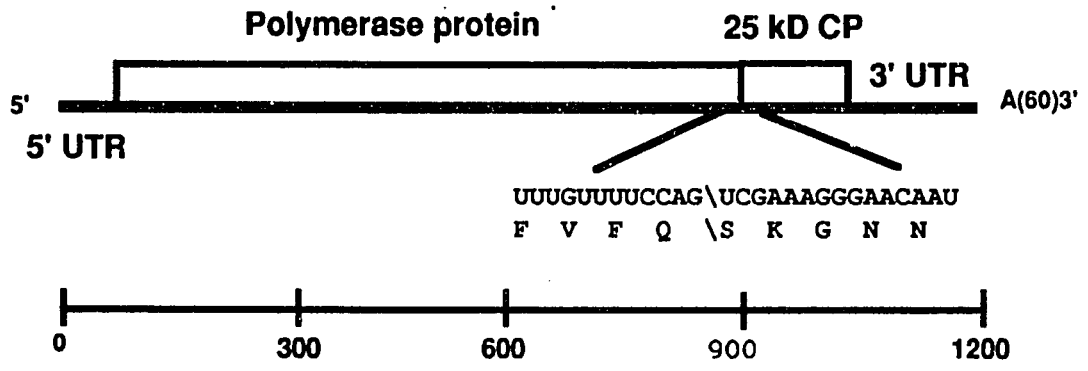

Figure 9.11. A cDNA clone of CCMV, which probably represents a DI particle. This clone has a single ORF and encodes for a fusion protein consisting of the aminoterminal of the polymerase protein and the carboxylterminus of the coat protein. The NA and AA sequences of the junction are shown in detail.

confirm this assumption. If the clone does represent the genome of a DI particle, it could be useful in innovative control strategies.

9.2.2 Control and quarantine implications

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 being exported from CIAT.

There are no reports of a vector for CCMV. In an experiment done at CIAT, there was no spread in the field, indicating that there is no vector for CCMV at CIAT. Observations at the Centro Nacional de Pesquisas em Mandioca e Fruiticultura (CNPMF) in Cruz das Almas, Bahia, Brazil, indicate that there is no field spread at that location. Additional information will be collected at the agricultural station of EPAGRI in Itajai, Santa Catarina, Brazil. The station is heavily infested with CCMV, and there have been recent introductions of TCS materials currently free of CCMV. If there is a vector in that subtropical area, then some of the newly introduced germplasm should become infected with CCMV; on the contrary, it will be assumed that there is no vector of CCMV.

The disease losses caused by CCMV can be controlled by selecting plants without leaf symptoms and using these stakes for propagation. If possible, plant selection should take place during a cool season. If the area is heavily infested, cutting tools should be disinfected for each plant.

In cooperation with a project with ITAB,[9.1] the molecular characterization and development of resistant cv. using coat protein-mediated cross protection was initiated. The coat protein gene of CCMV was successfully introduced into *Nicotiana benthamiana*, the plants showing almost complete immunity to CCMV. Coat protein-mediated cross protection is one method for developing resistant germplasm to CCMV, but the major technical bottleneck is the transformation and regeneration of cassava.

9.3 Cassava Vein Mosaic Virus

CVMV is a member of the caulimovirus group, which have isometric virions approx. 50 nm in diameter and a dsDNA genome of approx. 8000 bases. The only known host for CVMV is cassava, and the vector is unknown. Symptoms include a chlorosis of the veins that can either appear as a chevron pattern or coalesces to form a ringspot pattern. Some leaves also show a mosaic pattern over the entire leaf. There is often leaf distortion, and sometimes the young leaves show epinasty. CVMV is unusual because the expression of symptoms is severer when the temp are higher; in cooler seasons the infection can be latent. CVMV is reported in many states in Brazil, but is most prevalent

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[9.1] Project collaborators, Drs. R. Beachy and C.M. Fauquet, located at the Salk Institute.

in the hot semiarid zone of the NE states (**Fig. 9.12**). In several surveys made in NE Brazil, it was not unusual to find more than 50% of the plants infected with CVMV. Typical infection rates were 20-30%, but in some fields all the plants were infected.

Figure 9.12. The distribution of CVMC.

9.3.1 Virus characterization

A DNA clone to CVMV was provided to the VRU by the U. of Kentucky[9.2]. Nearly 3000 bases of this clone have been sequenced, and large open reading frames have been identified. There is very little homology between CVMV and the other caulimoviruses that have been sequenced. Consequently, it has been difficult to align either the nucleic acid or the putative amino acid sequences of CVMV with the other caulimoviruses. This means that it is taking longer to prepare a genome map of CVMV, but a tentative genomic map should be available in the near future. After the coat protein gene is identified, it will be subcloned into a protein expression vector, and an antiserum to the coat protein will be produced.

9.3.2 Control and quarantine implications

Caulimoviruses are not seed transmitted so it is safe to send TCS from areas infested with CVMV. As symptoms are not always present and the virus can be propagated in in vitro culture plantlets, a rapid and reliable diagnostic test is needed. The sequence analysis has enabled us to design primers for the PCR detection of the virus, and this methodology will soon be available for screening germplasm for CVMV.

As part of a new project for the integrated control of cassava pests in NE Brazil, additional emphasis will be placed on control strategies for CVMV. One of the most important questions that needs to be addressed is to determine whether there is a vector of CVMV. The virus is spread by propagating infected stake material, and there is limited evidence that there is additional spread in the field. Although the vectors of the well-characterized caulimoviruses are aphids, it is suspected that the vector of CVMV may be a different type of insect.

9.4 African and Indian Cassava Mosaic Viruses

ACMV is found throughout tropical Africa, and a similar virus, ICMV, is found in India and Sri Lanka (**Fig. 9.13**). These viruses 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, *Bemisia tabaci*. There are cv. that are resistant to these viruses, in which symptom expression is erratic, and the distribution of the virus is restricted.

9.4.1 Quarantine implications

Recently ACMV was introduced into the island Praia of Cape Verde. The origin of the germplasm was Brazil, and the losses were nearly 100%. Similar losses can be expected

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[9.2] Provided by Dr. R. Shepherd.

if ACMV and an active vector are introduced into tropical America. Monoclonal antisera to these viruses have been produced at the Scottish Crop Research Institute (SCRI). CIAT has polyclonal antisera and cDNA probes to ACMV, which can be used for detecting these geminiviruses.

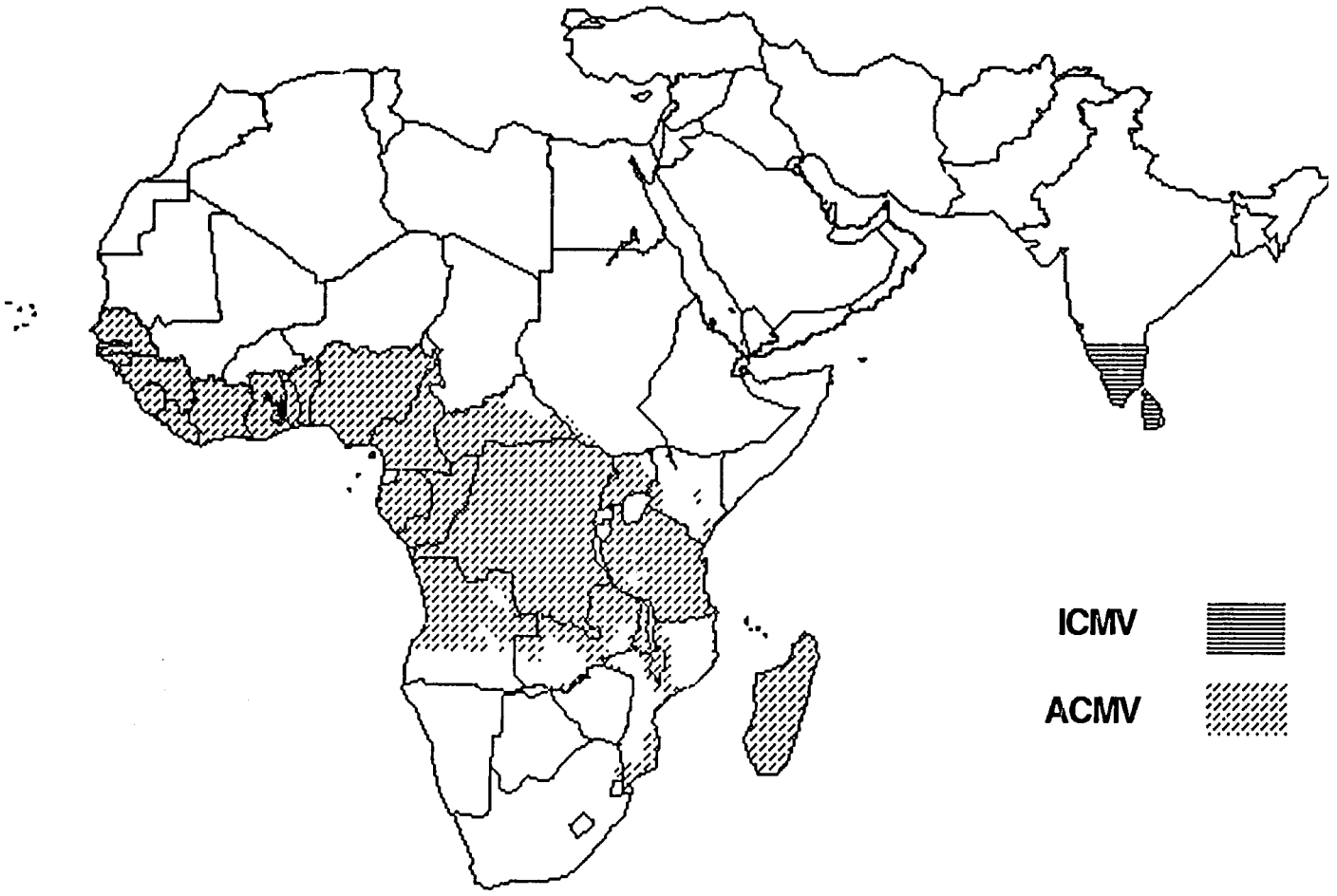

Figure 9.13. The distribution of ACMV and ICMV.

Although *B. tabaci* is common throughout the Americas, it does not normally colonize cassava. Recently a biotype of *B. tabaci* that is able to colonize cassava has become dominant in Mexico, Puerto Rico and the Dominican Republic. As this biotype is a possible vector of ACMV, its distribution needs to be monitored. An esterase isozyme test has been developed that can aid in identifying this new biotype (**Fig. 9.14**). Given the spread of this new biotype, the threat of a successful introduction of ACMV into tropical America has increased; therefore additional emphasis will be placed on identifying ACMV-resistant germplasm adapted to tropical America.

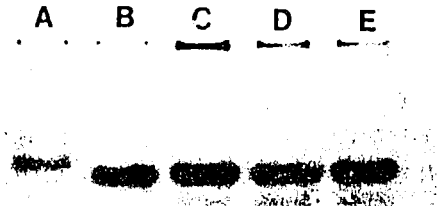

Figure 9.14. Esterase isozyme patterns of *B. tabaci* individuals: Lane A, collected from a colony at CIAT; Lanes B-E, collected from Zulia, Venezuela. An identical pattern was obtained from samples of the *B. tabaci* biotype that is able to colonize cassava in Florida.

9.4.2 Control strategies

The use of resistant clones is the most effective method of mitigating the losses caused by these geminiviruses. There are resistant clones in Africa and in India. In vitro cultures of cassava received from IITA (Nigeria) at CIAT have all been tested for the presence of these geminiviruses at SCRI[9.3]. These clones are poorly adapted to Latin America and

[9.3] Done by Dr. Harrison.

have severe agronomic and disease problems when grown in Colombia. They have been used in a breeding program, and gene pools containing resistance have been produced at CIAT and tested at IITA in Nigeria. Additional sources of resistant germplasm should become available through this joint program. A novel source of resistance could be obtained through the Cassava Trans project, which is working on coat-mediated cross protection for both CCMV and ACMV.

9.5 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 viruses or viruslike pathogens of cassava. None is known to cause disease in cassava or to have any effect on yield; but there is only limited information on their distribution. CIAT is committed to sending pathogen-free germplasm; therefore, the primary effort is to develop methods for detecting these latent viruses so that germplasm can be certified as free of them.

9.5.1 Cassava X and cassava Colombian symptomless viruses

CsXV and CCSpV are both potexviruses, discovered during attempts to identify the causal agent of FSD or CMD. Subsequent tests have shown that they are not present in most of the plants affected with FSD or CMD. Thus the discovery of these viruses occurred because they are mechanically transmitted to diagnostic hosts. Neither virus is known to cause symptoms or disease in cassava--either alone or in combination with other viruses.

9.5.2 Cassava American Latent Virus

CALV is a member of the nepovirus group, discovered by Dr. B. Walter[9.4], who isolated it from cassava infected with CCMV in Manaus (Brazil) and Guyana. While the vector of the virus is unknown, it is probably a nematode; and the virus may be seed transmitted. There are no known cassava plants that are infected with this virus in the field, which hinders testing how it is transmitted.

9.5.3 Quarantine implications and diagnostic tests

There are antisera to both potexviruses (CsXV and CCSpV), and all in vitro germplasm that originates from plants grown in the field in Colombia is checked for their presence by ELISA before being shipped internationally. During the testing of clones for reintroduction into the core collection, 5.4% of the plants were infected with CCSpV and 2.4% were infected with CsXV (**Table 9.1**).

[9.4] Institut Nacional de la Recherche Agronomique (INRA).

An antiserum to CALV provided by Dr. Walter has been used to test cassava in Colombia and Brazil. The antiserum has been useful in certifying seed lots as free of CALV. Assays of thousands of seeds and hundreds of plants grown at CIAT HQ were negative for CALV. As CALV does not appear to be present in the Cauca Valley, the further testing of materials grown at CIAT is not warranted. Approx. 200 plants (ca. 18%) of the germplasm collection at EMBRAPA/CNPMF at Cruz das Almas were tested for CALV and all plants tested negative. CALV does not appear to be present at the CNPMF farm in Cruz das Almas, but some additional testing will be done for the IFAD project. The distribution of this virus is not known, and its only reported source is from the humid tropical regions of the Amazon. The virus has not been found at the main sites where TCS are produced; therefore, the risk that this virus is contaminating these seed lots is extremely low.

DEVELOPMENT OF TECHNOLOGY COMPONENTS FOR SUSTAINABLE PRODUCTION

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10. GENOTYPE-BY-ENVIRONMENT INTERACTION

Cassava is usually grown by farmers with limited resources, most of whom are unable to assume significant risks to their income. Stability of production and quality in the face of environmental changes become an important consideration in the farmers' acceptance of a new cv. Genotypic stability of performance can be measured over sites (spatial), over years and seasons (temporal), and over cultural practices and cropping systems. The cassava farmer is usually more concerned about year-to-year variation. Mean performance of a cv. over years is important, but minimum yield in a bad year is even more so. Yield stability should always be considered in association with minimum acceptable yields. An unstable cv. that yields well in unfavorable years may be preferable to a low-yielding stable one.

Cassava is grown as a security crop in several high-stress environments, providing certain food when other crops may fail. New cv. should maintain this characteristic. Ability to yield under stressful environments depends on the genetic ability of the cv. to resist major growing constraints. It is then essential for a breeding program to evaluate the range of genetic diversity under a combination of constraints that represent growing conditions throughout predominant areas and over a series of years.

Germplasm development at CIAT has taken into consideration seven different major ecosystems for cassava cultivation. It is assumed that the variation in biotic and abiotic constraints within those ecosystems is lower than across them. Within each ecosystem one or more selection sites has been selected to represent major conditions.

10.1 Sensitivity of Genotypes to Environmental Changes

The performance of 15 genotypes was evaluated at 3 sites in Colombia over 5 yr for a total of 14 environments (Palmira 1986 was lost) in order to analyze the possibility of combining RY stability with minimum acceptable yields. The specific objectives for this study were to evaluate genotypic sensitivity to changes in the environment and to characterize and determine the representativeness of the evaluation sites. The traits evaluated for this study were FRY = t/ha; DM = % root DM content; HCN = cyanide content (scale from 1-9) in root parenchyma as determined by the picrate method; PH = pl ht (cm); LS = length of stem with attached leaves at harvest time; BI = branching index (ht of first branching/total PH); HI; and CR = no. of commercial roots/pl.

Mean performance and sensitivity coefficients for all evaluated traits for the 15 clones are presented in **Table 10.1**. A high mean performance together with a sensitivity coefficient of 1.0 is desirable for yield potential given that cassava is grown mainly in marginal environments. **Figure 10.1** presents the mean RY and sensitivity coefficients for each clone. Clones CG 915-1, CM 3306-4 and M Bra 12 can be considered as having specific adaptation to favorable environments; clones CM 3372-4 and CM 3555-6, adaptable to

Table 10.1. Means and coefficients of sensitivity (B^i) for eight traits in each of the evaluated clones.

	RY		DM		HCN		PH		LS		BI		HI		CR	
Clone	Mean (t/ha)	B^i	Mean (%)	B^i	Mean	B^i	Mean (cm)	B^i	Mean (cm)	B^i	Mean	B^i	Mean	B^i	Mean (no.)	B^i
CG 915-1	21.4	1.49	32.6	0.97	6.8	1.50	190.2	1.15	20.8	1.03	1.19	0.89	0.61	1.43	3.85	1.07
CG 1141-1	18.9	1.02	36.9	0.61	7.0	0.51	161.0	0.70	19.0	0.68	1.21	1.56	0.54	0.48	3.14	0.94
CM 3299-4	18.4	0.88	35.1	1.15	5.2	1.23	211.7	1.21	29.6	1.68	1.20	1.08	0.53	1.02	3.17	0.87
CM 3306-4	17.1	1.29	38.1	0.97	6.2	0.77	196.6	0.96	24.2	1.23	1.16	0.01	0.54	1.37	3.35	1.50
CM 3306-9	18.1	0.98	37.9	0.98	6.1	2.25	172.6	0.82	21.2	0.97	1.23	0.80	0.59	1.29	3.64	1.55
CM 3372-4	19.4	0.76	33.2	0.92	6.6	0.58	201.4	0.74	23.0	1.00	1.23	1.53	0.58	1.01	3.78	0.83
CM 3555-6	16.0	0.62	34.0	1.03	5.3	1.54	191.6	1.11	25.7	1.04	1.24	1.69	0.52	0.77	3.00	1.01
M Bra 12	18.7	1.53	31.7	1.09	8.0	1.04	197.6	1.08	24.0	1.05	1.24	0.59	0.52	1.07	3.42	1.43
M Bra 191	18.5	1.00	34.7	0.84	5.5	0.48	208.7	0.64	32.6	1.46	1.21	1.16	0.50	1.86	3.10	1.30
M Col 22	14.8	1.00	32.5	1.48	7.1	1.95	140.5	0.95	19.4	0.81	1.21	0.51	0.63	0.94	2.71	0.99
M Col 1468	15.7	0.85	28.8	1.15	6.9	0.81	210.5	1.13	22.6	0.90	1.20	1.05	0.49	0.74	2.71	0.79
M Col 1505	16.2	1.07	34.9	0.49	6.4	0.43	203.6	1.09	20.8	0.95	1.28	1.19	0.52	0.20	3.14	0.86
M Col 1684	14.8	0.91	30.2	0.63	8.7	0.01	161.5	1.27	16.8	0.42	1.12	0.79	0.55	0.07	2.42	0.40
M Col 2215	12.2	0.80	37.2	0.85	5.5	0.60	163.5	0.83	24.8	0.92	1.22	0.95	0.48	0.44	2.02	0.51
M Ven 77	10.2	0.62	28.1	1.71	7.0	0.81	229.4	1.23	19.2	0.71	1.24	1.46	0.47	1.71	2.72	0.49

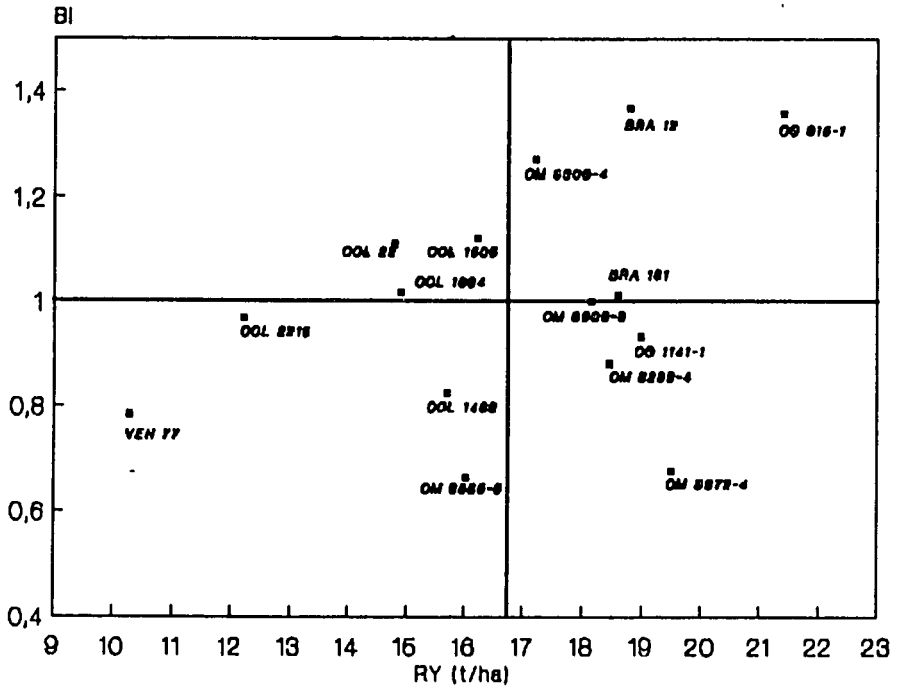

Figure 10.1. Relationship among sensitivity coefficients (BI) and average root yield.

stressful environments. Clones CG 1141-1, CM 3299-4, CM 3306-9 and M Bra 191 have a high mean RY and avg sensitivity to environmental changes; they appear to have the capacity to produce rather well under a range of environmental conditions. The correlation between sensitivity coefficients and RY potential is not significant, indicating the possibility of improving both traits independently.

The majority of clones with high DM showed avg to low sensitivity to the environment. Given the positive relationship between RY and DM, it will be possible to improve DM yield potential while reducing the sensitivity of that potential to changes in the environment. The potential of a genotype to produce HCN is an important feature that will determine both its end use and the health hazard in case of direct consumption. The most desirable combination for breeding purposes is that of low HCN and low sensitivity to environmental conditions as is the case with clones M Bra 191, M Col 1505, M Col 2215, CM 3306-4 and CM 3772-4 (**Table 10.1**).

A high and positive association between the mean and sensitivity coefficient for CR (r=0.66) and LS (r=0.90) suggests that screening for these traits will be more effective under favorable environments, where the expressed range of genetic variability and the heritability for the trait are the highest.

Once the three principal components explaining 82% of the total variability among the 14 sites and years had been identified, a cluster analysis was conducted. **Table 10.2** presents the environments that fell within each of the four distinct groups, as well as the mean for the evaluated traits in each group. Group 4 is a high DM and high yield potential environment. The other three groups can be classified as low potential environments, distinguished by differences in CR, PH and BI. Three of the groups (2, 3 & 4) reflect differences among evaluation sites across years. According to this, spatial variation appears to be more important than temporal variation. The present information seems to support CIAT's strategy of breeding cassava for stress environments. Elite clones are selected after at least a 2-yr evaluation at Media Luna and Carmen de Bolivar. Such a scheme accounts for the variation among the most representative locations for the seasonally dry ecosystem (ECZ 1) and partially for the year-to-year variation.

Table 10.2. Groups of environments after cluster analysis and mean for the evaluated traits in each group.

	Group 1		Group 2		Group 3		Group 4	
Environments	Site[1]	Yr	Site	Yr	Site	Yr	Site	Yr
	HQ	1988	CB	1986	ML	1986	HQ	1987
	HQ	1990	CB	1988	ML	1988	HQ	1989
	ML	1987	CB	1990	ML	1989		
	CB	1987			ML	1990		
	CB	1989						
Mean for Evaluated Traits								
RY	12.96		14.41		15.75		31.78	
DM	33.47		32.91		32.52		38.04	
HCN	6.97		6.54		6.76		5.57	
PH	168.78		181.11		201.27		230.13	
LS	21.88		19.99		15.52		45.03	
BI	0.51		0.57		0.35		0.48	
HI	0.49		0.58		0.58		0.55	
CR	2.05		3.63		3.38		4.23	

[1] HQ = CIAT-Palmira; ML = Media Luna; CB = Carmen de Bolivar.

Table 10.3. Trial means for RY, HI and root DM.

Site	Ecosystem	Yr	Yield (t/ha)	HI	% DM
Cruz das Almas (Bra)	ECZ 1	87	17.6	0.41	35.1
		88	21.5	0.60	26.6
Pacajus (Bra)	" "	88	16.5	0.49	34.1
		89	19.8	0.54	36.7
		90	15.1	0.51	28.6
El Carmen (Col)	" "	88	11.8	0.44	31.9
Media Luna (Col)	" "	87	10.0	0.33	33.0
		88	17.1	0.52	30.5
		90	19.4	0.65	28.6
Carimagua (Col)	ECZ 2	87	2.7	0.16	32.6
		88	14.9	0.43	28.8
La Libertad (Col)	" "	88	18.3	0.46	28.1
		90	18.1	0.47	30.4
Una (Bra)	ECZ 3	89	31.8	0.51	34.6
Palmira (Col)	ECZ 4	87	10.5	0.21	31.4
		90	13.8	0.53	28.7
Itaberaba (Bra)	ECZ 7	89	15.4	0.50	29.9
Ecosystem means:	ECZ 1		16.5	0.50	31.7
	ECZ 2		13.5	0.38	30.0
	ECZ 3		31.8	0.51	34.6
	ECZ 4		12.2	0.37	30.1
	ECZ 7		15.4	0.50	29.9
	OVERALL MEAN:		16.1	0.46	31.1

[1] ECZ 1 = subhumid; ECZ 2 = acid savanna; ECZ 3 = humid; ECZ 4 = mid-altitude; ECZ 7 = semiarid

10.2. Uniform Variety Trials to Compare Cassava-Growing Ecosystems in Brazil and Colombia

Cassava breeding at CIAT is based on the assumption that there are basic similarities between macroenvironments in Colombia and in other important cassava-growing regions. A study was conducted in order to (a) compare some of the macroenvironments thought to be similar between Brazil and Colombia, based on the performance of a common set of clones evaluated over years at various sites; (b) characterize some of the physical and biological components that influence cv. behavior; (c) improve the methodology for comparing cassava-growing environments; and (d) improve the procedures for selecting genotypes for exchange among countries or regions. Trials were planted at 9 sites in Brazil and Colombia for a total of 17 site-yr combinations. Principal evaluation criteria were RY, HI, plant and branching ht, and root DM content.

Trial and genotype means for RY, HI and DM are given in **Tables 10.3** and **10.4**. The ANOVA for these same variables showed effects of trial, cv. and interaction to be highly significant (P > 0.01).

Table 10.4. Avg performance and stability parameters for agronomic traits of 13 genotypes evaluated in 17 site-yr combinations.

		Regression Analysis Parameters:					
Clone	Name	r coef.	Intercept a	Coefficient b	Mean RY (t/ha)	Mean % DM	Mean HI
BGM 001	Aipim Bravo	0.91	-4.66	1.67	22.3	30.7	0.49
BGM 021	Cachimbo	0.64	-0.42	0.48	7.4	31.5	0.36
BGM 043	Riqueza	0.89	-1.58	1.13	16.7	30.1	0.48
BGM 080	Engana Ladrao	0.85	-0.36	1.07	16.9	34.3	0.38
BGM 120	Paulo Rosa	0.82	-5.87	1.42	17.0	29.4	0.48
BGM 152	Peru Branca	0.73	5.00	1.10	22.8	29.9	0.54
BGM 211	Mantequeira	0.82	14.18	0.09	15.6	28.3	0.52
BGM 379	Buja	0.91	-3.21	1.32	18.0	28.3	0.52
BGM 381	Aciolina	0.76	-2.97	0.90	11.6	31.1	0.33
BGM 382	Fio de Ouro	0.87	-0.87	1.24	19.1	31.3	0.54
BGM 537	Do Ceu	0.82	-3.98	0.88	10.2	34.4	0.35
BGM 555	Isabel de Souza	0.87	-6.73	1.49	17.3	32.3	0.48
BGM 890	M Ven 77	0.34	11.50	0.20	14.8	29.1	0.49

A summary of stability statistics from the regression analysis between trial means (independent variable) and individual cv. means (dependent variable) is given in **Table 10.4**. Based on the criteria of avg performance at each location, the stablest clones are BGM 043, BGM 080 and BGM 382. While the description of the ideal cv. may vary according to objectives, one can envision that it should not only perform well under stress conditions but also respond to inputs or to better conditions. In this model, such a cv. would have a Y-intercept greater than zero and a regression slope equal to or greater than one. Only BGM 152 combined these two criteria in the overall analysis of all 17 trials; it was also the clone with the highest mean yield across sites.

When considering the correlation for RY among sites, the six comparisons among Media Luna (Colombia) and CNPMF (Brazil) were all significant (**Table 10.5**). This is an encouraging finding given that these are some of the most important selection sites for the respective countries, representing a priority ecosystem. In contrast, Pacajus--considered representative of the NE littoral zone--was correlated in only one comparison (Cruz das Almas), supporting the separation of the littoral and subhumid ecosystems for breeding purposes. Una and La Libertad--both with high rainfall--were highly correlated. The 1987-88 trial in Carimagua was not correlated with any other trial, probably because of very severe disease pressure that year. Given that most of the ecosystems were represented by only one or two site-yr combinations, or in only one of the two countries, definitive testing of the hypothesis of similarity of ecosystems between the two countries is required.

As expected from previous experiences, correlations among environments for HI and DM were generally higher than for RY, an indication that these two traits may often be selected for outside the specific target area.

There continues to be an urgent need to understand better cassava's response to a range of environmental components and their interactions in order to develop plant growth models and refine the environmental classification using extensive agroecological databases. Results from this study demonstrated that no two sites were sufficiently similar that a cv. selected in one could be recommended commercially in another without further local testing. In the CIAT and CNPMF breeding programs, where extensive germplasm exchange is practiced, this should not normally be restricted to material with strict adaptation to a given ecosystem as there is considerable potential for moving materials successfully across some of the important regional soil and climatic variations. Biological constraints may be more restrictive in that resistance will be required in any region where a pest or disease has the potential to cause significant yield reduction. An effective breeding system should have as its basis, a core set of criteria for each ecosystem, while allowing extensive testing across ecosystems and genetic interchange among ecosystem-based gene pools.

10.3. Choosing Evaluation Sites Within Ecosystems

The highland tropics ecosystem includes regions between 1400 and 2200 m in altitude. The strong effect of altitude on varietal performance can be demonstrated when a set of genotypes is evaluated across a range of altitudes from 1000 (HQ-Palmira) to 1800 m (Popayán). It is difficult to delineate borders between intermediate- and high-altitude tropics. The CIAT breeding program has developed gene pools at Popayán for 15 yr; and as a result, several elite clones have been selected. Given the importance of cassava at lower altitudes (1200-1600 m) in Colombia, a set of 27 elite clones and 4 checks were evaluated at Mondomo (1400 m, harvest at 14.5 mo) and Cajibio (1800 m, harvest at 17.5 mo). With the exception of cyanide content (**Table 10.6**), correlations between the performance of genotypes at both sites was significant ($P > 0.05$). It seems that

Table 10.5. Linear correlations among trials (site-yr combinations) for RY (n=13).[1]

	ML 87	ML 88	ML 90	LL 88	LL 90	CR 88	CB 88	CR 87	HQ 87	HQ 90	CN 88	PC 87	PC 89	CN 89	UN 89	IT89
ML 88	0.70**															
ML 90	0.60 *	0.33														
LL 88	0.65 *	0.42	0.32													
LL 90	0.53	0.41	0.44	0.59 *												
CR 88	0.52	0.39	0.11	0.64 *	0.83 **											
CB 88	0.49	0.81 **	0.13	0.64 *	0.64 *	0.61 *										
CR 87	0.24	0.10	-0.08	0.19	0.27	0.51	0.09									
HQ 87	0.63 *	0.58 *	0.10	0.49	0.35	0.54	0.52	0.42								
HQ 90	0.28	0.24	0.06	0.60 *	0.41	0.43	0.54	0.22	0.04							
CN 88	0.57	0.56 *	0.63 *	0.61 *	0.66 *	0.45	0.70 **	0.11	0.44	0.44						
PC 87	-0.17	-0.12	-0.10	0.30	0.21	0.35	0.28	-0.15	-0.09	0.67 *	0.37					
PC 89	0.10	0.26	0.13	0.20	0.34	0.26	0.53	0.27	-0.09	0.46	0.61 *	0.69 *				
CN 89	0.62 *	0.57 *	0.59 *	0.44	0.62 *	0 50	0.52	0.22	0.73 **	0.09	0.80 **	0.08	0.25			
UN 89	0.20	0.00	0.28	0.60 *	0.62 *	0.55 *	0.43	-0.25	0.10	0.72 **	0.68	0.76	0.60	0.39		
IT 89	0.30	0.28	0.07	0.71 **	0.23	0.33	0.54	-0.05	0.21	0.60 *	0.48	0.47	0.48	0.04	0.51	
PC 90	0.08	0.26	0.19	0.31	0.35	0.37	0.48	-0.12	0.03	0.51	0.66 *	0.78 **	0.85 **	0.40	0.65 *	0.35

[1] ML = Media Luna; LL = La Libertad; CR = Carimagua; CB = Carmen de Bolivar; HQ = CIAT-Palmira; CN = Cruz das Almas; PC = Pacajus; UN = Una; IT= Itaberaba.

* Significant at 0.

** Significant at 0.

Table 10.6. Comparison of genotypes at Mondomo (1400 m) and Popayán (1800 m).

	Mondomo				Popayán			
Clone	RY (t/ha)	HI	% DM	HCN[1]	RY (t/ha)	HI	% DM	HCN
CG 354-2	16.9	0.51	33.0	5	10.7	0.52	37.9	4
CG 358-3	4.1	0.21	33.6	3	4.6	0.17	35.5	2
CG 401-3	7.8	0.34	32.6	8	6.0	0.27	34.2	4
CG 401-6	11.1	0.47	33.9	3	6.3	0.34	35.3	2
CG 402-11	34.8	0.70	31.1	6	35.2	0.64	35.8	6
CG 403-18	19.9	0.59	33.2	6	16.1	0.54	34.1	6
CG 406-5	15.5	0.57	37.8	6	16.6	0.44	38.0	5
CG 406-6	15.6	0.64	35.8	5	21.9	0.55	38.9	3
CG 481-3	10.6	0.41	36.2	5	20.7	0.43	38.1	2
CG 501-2	10.2	0.61	34.2	6	10.2	0.41	36.8	3
CG 501-18	7.7	0.46	35.0	5	12.0	0.32	36.8	3
CG 502-1	27.3	0.61	38.9	4	18.3	0.46	38.6	2
CG 1118-118	16.5	0.54	34.3	6	27.7	0.42	40.5	3
CG 1118-121	14.1	0.60	35.1	8	16.8	0.38	38.2	2
CG 1231-3	14.9	0.58	33.1	6	18.5	0.46	37.7	3
CM 4488-4	24.8	0.59	31.6	5	24.4	0.43	34.5	6
SG 350-23	15.1	0.42	37.2	8	8.7	0.22	36.8	3
SG 350-42	10.1	0.47	35.2	7	25.2	0.66	39.2	5
SG 427-87	32.1	0.64	38.8	7	31.5	0.49	38.9	5
SG 638-6	18.1	0.59	34.1	4	23.5	0.54	34.5	3
SM 524-1	17.5	0.62	32.9	5	34.6	0.53	36.0	5
M Col 262	13.6	0.57	34.7	7	12.6	0.47	37.4	5
M Col 2261	11.9	0.50	33.4	6	37.7	0.54	35.1	4
M Col 1522 (check)	19.7	0.47	33.5	3	9.8	0.34	30.2	5
M Col 2059 (check)	6.5	0.48	35.0	6	8.7	0.48	35.7	3
M Col 2060 (check)	11.7	0.42	34.4	3	9.2	0.20	35.3	3
M Col 2061 (check)	25.7	0.72	31.9	2	20.5	0.62	37.3	3
SD of the mean	4.7	0.07	2.1		5.2	0.08	1.9	

[1] Scale of 1 to 9 for the picrate method.

selection conducted at high altitude retained several genotypes that could adapt well to lower altitudes. Clones CG 402-11, CG 502-1, CM 4488-4 and SG 427-87 showed good overall adaptation (**Table 10.6**). The first clone has demonstrated a good level of resistance to CBB and good cooking quality despite its intermediate DM content. SG 427- 87 appears to be an ideal clone for starch production purposes, having a stable yield and DM potential across sites. Both clones are being intensively multiplied for future on-farm and pre-production plot evaluation (PPP). M Col 1522 (Algodona) is the most widely grown cv. in the highlands, but seems to perform better at lower altitudes. The check M Col 2061 appears to be a better check for evaluations across sites. The data indicate that using the Mondomo area as a secondary evaluation site is a valid strategy for evaluating the capacity for broad adaptation of clones selected at the main selection site in Popayán.

One of the highest priorities within the Cassava Program is gene pool development for semiarid conditions. There is a need to select one or several sites with representative climatic and soil conditions, homologous to the ones found in NE Brazil, Sub-Sahelian Africa and N Thailand. In terms of amount and distribution of rainfall in Colombia, there is a decreasing gradient toward the Guajira peninsula. The ideal conditions for screening germplasm do not coincide with one agricultural region; there is a lack of basic infrastructure for leading research to success. From previous experiences it was known that second-semester crops in Media Luna (ECZ 1) have been usually subjected to 4-5 mo of drought (less than 60 mm/mo) and severe mite attack. A second screening site (Santo Tomás) close to Barranquilla was considered this year for second-semester evaluations. The main difference between this site and Media Luna is that soils have a greater proportion of sand and lower capacity for water retention, resulting in a more stressful environment than Media Luna, which is reflected in lower RY, DM content and PH (see **Table 11.1**).

At harvest a larger proportion of stem with leaves was observed on the avg at Santo Tomás. There was a significant correlation among observations recorded at both sites for the 66 genotypes evaluated with regard to PH ($r = 0.61^{**}$), RY ($r = 0.58^{**}$), HI ($r = 0.45^{*}$) and HCN content ($r = 0.39^{*}$), but with relatively low determination coefficients. DM content was extremely affected at both sites as the result of profuse foliage growth after the rains started, which may have resulted in a low relationship among sites ($r = 0.16$). Most of that growth was at the expense of root reserves. **Table 10.7** presents information on the clones that were pre-selected in common at the field level for the subsequent testing of DM and HCN content. Except for SM 1079-2, which seems to adapt very well to both sites, the clones showed specific adaptation to Media Luna (site for which they were previously selected) or poor performance at both sites. The genetic base to be evaluated at Santo Tomás should come from germplasm originated under semiarid conditions. Screening conditions at Santo Tomás seemed to be representative of a transition area between seasonally dry and semiarid ecosystems. It could well complement Media Luna and the new site at the Guajira (semiarid) for selecting genotypes with a broad adaptation spectrum in terms of water availability. In that way

clones such as SM 1079-2 can be selected to expand the range of adaptation of current gene pools.

Table 10.7. Comparison of genotypes at Media Luna (ECZ 1) and Santo Tomás (ECZ 1/7).

	Media Luna				Santo Tomás			
Clone	RY (t/ha)	HI	% DM	HCN[1]	RY (t/ha)	HI	% DM	HCN
CG 1141-1	10.0	0.33	32.3	8	10.6	0.42	32.9	8
CM 3306-4	12.1	0.39	33.0	7	2.7	0.19	29.9	2
CM 7213-2	19.2	0.49	31.1	9	12.5	0.52	26.7	8
CM 7413-7	18.3	0.26	28.3	7	23.3	0.50	25.6	8
SM 690-6	24.2	0.46	33.4	8	18.3	0.48	24.4	5
SM 729-18	15.8	0.31	29.7	8	21.0	0.44	26.7	8
SM 937-19	15.4	0.38	30.9	9	10.4	0.34	29.8	8
SM 1014-3	14.8	0.35	28.2	7	9.2	0.34	29.8	8
SM 1015-12	15.0	0.42	33.5	7	6.9	0.31	30.5	8
SM 1023-23	18.8	0.45	30.5	9	6.3	0.28	28.5	6
SM 1066-2	20.4	0.41	29.3	6	12.7	0.29	25.9	6
SM 1068-4	20.2	0.35	34.6	8	13.1	0.28	29.3	5
SM 1073-1	13.5	0.32	23.1	5	6.7	0.28	29.5	8
SM 1077-7	15.0	0.30	29.3	8	6.0	0.20	24.0	9
SM 1079-2	28.5	0.56	32.2	6	21.3	0.58	31.3	7
SM 1093-1	10.4	0.27	27.8	9	12.5	0.34	26.9	9
SM 1113-2	15.4	0.38	33.6	5	4.2	0.34	27.6	8
M Bra 12	22.5	0.39	28.8	9	11.0	0.27	25.9	8
M Col 22	20.2	0.51	31.1	8	8.1	0.46	28.4	8
M Col 1468	8.3	0.33	22.3	6	7.7	0.36	26.9	6
M Col 1505	9.4	0.28	32.8	4	1.5	0.16	20.1	5
M Col 1684	15.0	0.41	31.1	9	11.9	0.48	25.1	8
M Col 2215	12.5	0.45	25.9	6	2.3	0.37	29.0	7
SD checks	3.6	0.15	2.8		4.4	0.12	3.2	

[1] Scale from 1 to 9 for the picrate method.

10.4. Searching for Broad Adaptation Within Elite Germplasm

As a result of more than 10 yr of improving germplasm for specific ECZs, more than 200 elite clones have been selected. These clones not only have the potential to become new

cv. after intense testing at the regional and farm levels, but they also represent the basis from which new gene pools will be developed. It is expected that the clones selected at a representative site within a specific ECZ will adapt well in other homologous areas, but they will show restricted adaptation when evaluated in different ECZs. The breeding scheme used by CIAT allows for testing segregating progenies across ECZ 1 (Media Luna), ECZ 2 (La Libertad) and ECZ 4 (CIAT HQ) at early stages. Progenies from some of the elite clones presented an intermediate to high frequency of selections in at least 2 of the 3 sites, suggesting that some of the parental clones may adapt well to more than one ecosystem. A group of 200 elite clones was evaluated at the 3 sites (2 reps) during 1991-92. A cluster analysis using DM production/ha resulted in 6 groups, explaining 69% of the total variation. The majority of the clones showed specific adaptation to the ECZ for which they had been selected (**Table 10.8**). The most important group of clones is Group 5, showing good adaptation to Media Luna (ECZ 1) and La Libertad (ECZ 2). These clones will be the basis for constructing gene pools with broad adaptation across lowland tropical ecosystems. This gene pool will be particularly useful for transition areas between different ECZs.

Table 10.8. Grouping of elite clones according to their DM production (t/ha) at three sites.

Group	CIAT HQ	La Libertad	Media Luna
1	2.01	5.96	2.49
2	3.96	2.83	3.14
3	2.28	4.43	5.84
4	1.40	2.79	2.61
5	6.89	4.17	4.17
6	2.20	8.97	5.05
Clones in Group 5			
M Bra 383	4.89	4.68	4.29
CG 1-37	4.52	7.05	3.51
CG 1-48	4.23	7.32	3.36
CC 6-71	2.77	6.15	4.70
CG 1372-5	6.70	6.87	2.99
CG 1534-10	2.70	6.65	3.18
CM 955-2	4.53	6.17	2.65
CM 1305-3	3.77	5.82	5.09
CM 2146-3	5.19	6.34	5.09
CM 2772-3	6.11	5.54	3.72
CM 2967-8	2.66	7.17	3.42
CM 3171-8	7.31	5.78	3.86
CM 3294-1	4.11	8.49	2.76
CM 3299-4	3.40	11.35	4.59
CM 3306-4	3.20	7.36	3.85
CM 3306-9	3.22	7.52	4.95
CM 3306-19	6.49	7.28	4.14
CM 3320-4	5.98	10.36	4.37
CM 3997-1	4.47	7.54	3.66
CM 4157-34	4.24	10.65	8.79
CM 4843-1	5.80	5.00	4.61
SG 557-6	5.82	6.81	4.84
SG 756-7	7.78	6.45	4.10

11. GENE POOL DEVELOPMENT FOR LATIN AMERICA

The evolution of cassava across a range of edaphoclimatic conditions has resulted in a wide diversity of clones adapted to specific environments. This constitutes the basis upon which genetic improvement has proceeded at CIAT. The principal characteristics and problems of the major cassava growing regions were taken into consideration for the design of a breeding project. Cassava is generally cultivated under marginal conditions, subject to fluctuations in physical and biotic factors, most of which are beyond the farmers' control. One of the main objectives is to obtain improved cultivars that can be produced reliably under the worst situation the crop can encounter. Given the wide range of environmental and production systems, it is impossible to obtain a single genotype with adaptation to the majority of growing conditions.

Cassava-growing environments were classified into edaphoclimatic zones so that the expected variation among regions would be greater than the variability within regions. This classification was based on the association of climatic, soil and biotic factors over extensive areas in the Tropics (see previous Annual Reports for description of ECZs). The strategy was to select one or more testing sites in Colombia representing the major conditions for growing cassava in a defined zone. The basic hypothesis behind the strategy is that the gene pools developed at those sites will provide an improved genetic base for starting adaptive selection in regions with homologous conditions.

Table 11.1 describes the major conditions present at evaluation sites in Colombia for the period 1991-92. Summer (dry) periods extended more than expected during this period influenced by "El Niño" phenomenon. The typical biotic constraints for the different ecosystems were present, with the addition of CBB for the seasonally dry tropics.

11.1. Lowland, Seasonally Dry Tropics (ECZ 1)

Season A was characterized by heavy incidence of CBB. Regional clones showed high susceptibility to CBB, making it difficult for farmers to gather planting material for the following cycle. A considerable proportion of the clones showed resistance to CBB, despite the fact that the disease had not been previously included as a selection criterion for this gene pool (**Table 11.2**). It seems to be even more difficult now to combine all desirable traits in one clone for the Colombian Atlantic Coast. Based on previous evaluations, it was decided to start multiplying clone CM 4777-2, which has good DM content, low HCN, intermediate yield potential, resistance to CBB and reasonably good cooking quality. The strategy for incorporating resistance to CBB on the Atlantic Coast should include routine evaluation at sites in the region and in Carimagua (Depto. Meta), which represents the hot spot for CBB. There is also a need to use clones with known resistance as parental material in crosses with genotypes adapted to ECZ 1.

Table 11.1. Monthly rainfall and soil characteristics for main evaluation sites.[1]

	ML	ST	CB	LL	HQ	M	C
ECZ	1	1/7	1	2/3	4	4/5	5
Rainfall (mm/mo)							
04/91	21		152	76	86	158	59
05/91	187		101	86	159	134	166
06/91	158		82	88	17	116	107
07/91	8	33	111	111	43	81	58
08/91	151	13	77	221	27	12	27
09/91	179	100	120	200	108	79	151
10/91	36	39	135	341	45	98	111
11/91	102	0	68	285	19	70	256
12/91	30	0	9	3	33	189	331
01/92	0	0	19	21	16	70	214
02/92	0	0	10	28	116	104	167
03/92	0	0	1	132	38	38	141
04/92	158	70	153	258	91	210	259
05/92	404	239	82	264	35	62	154
06/92	362	91	107	321	14	21	73
07/92	300	294	132	230	15		62
08/92	423	195	198	104	13		13
Avg Soil Characteristics							
pH	6.0	6.1	6.5	4.5	6.3	4.5	5.1
% OM	1.3	1.1	3.9	3.6	4.1	6.4	30.9
P ppm	7.3	2.3	78.0	8.9	45.2	2.6	1.9
K meq/100 g	0.08	0.09	7.20	0.12	0.52	0.12	0.33
Texture	Sandy	Sandy	Clay	Clay/sand	Clay	Clay	Clay/sand

1 ML = Media Luna (Magdalena); ST = Santo Tomás (Atlántico); CB = Carmen de Bolivar (Bolivar); LL = La Libertad (Meta); HQ = Palmira (Valle); M = Mondomo (Cauca); C = Cajibio (Cauca).

2 ECZ 1 = Season A May - Jan ; Season B Sept- Aug.
ECZ 2 = Season A Apr - Feb ; Season B Oct - Aug.
ECZ 4 = Season A June- Mar ; Season B Oct - Aug.
ECZ 5 = Season A Apr - July; Season B Oct - Jan.

Table 11.2. Means for selected clones and checks from the advanced yield trial (AYT) at Media Luna (ECZ 1), Season A.

Clone	Female Parent	Male Parent	CBB	RY (t/ha)	HI	% DM	HCN[1]
CM 4365-1	CM 976-15	M Col 2207	2.0	10.1	0.59	31.7	5.0
CM 4365-3	CM 976-15	M Col 2207	2.0	10.7	0.56	34.9	7.0
CM 4777-2	M Col 72	CM 523-7	1.5	8.3	0.61	34.7	6.0
CM 4793-1	M Col 72	M Ven 77	1.0	16.2	0.60	30.6	8.0
CM 4859-5	M Col 1823	CM 847-11	1.5	22.7	0.59	32.6	8.0
CM 4867-1	M Col 1823	M Col 72	1.5	10.3	0.48	32.7	7.0
CM 4917-6	M Col 2207	CM 1288-17	1.5	10.0	0.54	33.1	7.0
CM 4919-1	M Col 2207	SM 303-3	1.0	17.4	0.66	33.2	9.0
CM 4990-4	CG 1-61	M Col 1826	2.0	16.1	0.45	33.9	6.0
CM 5316-4	CM 1585-13	M Bra 9	1.5	10.6	0.55	29.7	7.0
CM 5460-5	M Col 72	CG 22-2	1.0	18.4	0.62	30.3	8.0
CM 5460-10	M Col 72	CG 22-2	1.5	13.1	0.53	36.3	9.0
CM 5586-1	CM 681-2	M Col 2215	1.5	11.9	0.53	36.7	6.0
CM 6119-5	M Col 72	CM 849-1	2.0	14.9	0.58	34.3	9.0
CM 6182-8	M Col 2215	M CR 2	2.5	14.6	0.67	36.4	5.0
SG 787-10	CM 681-2		1.0	22.5	0.55	30.3	8.0
SM 328-1	M Ven 45A		1.0	17.2	0.51	30.5	8.0
SM 643-17	CM 922-2		1.0	4.1	0.46	32.7	8.0
M Ind 39			1.0	8.3	0.50	33.9	7.0
M Mal 48			1.0	13.8	0.67	29.9	9.0
M Tai 5			1.5	9.3	0.48	29.8	8.0
M Tai 8			1.0	20.4	0.62	31.5	9.0
CG 1141-1[2]	ICA Costeña		2.0	10.3	0.62	32.2	9.0
CM 3306-4[2]	Pre-released		2.0	10.3	0.58	35.0	6.0
M Col 1505[2]	Verdecita		2.5	14.2	0.63	30.9	9.0
M Col 2215[2]	Venezolana		3.0	5.0	0.41	36.5	6.0
Trial mean			1.8	12.0	0.58	30.3	7.5
SD mean				4.1	0.06	1.2	

1 Scale from 1 to 9 for picrate method.
2 Local checks.

The second semester (season B) is usually characterized by low yield potential and DM content in the roots, higher HCN and poor cooking quality. The extended dry period, high soil temp in the middle of the growing cycle, and subsequent regrowth when the rainy period starts seem to be responsible. This is an indication of the problems to be

encountered when developing varieties for semiarid conditions. Selection of clones was based on RY and DM content, taking the avg trial means for RY as a minimum and 30% as the base level for DM in the roots. The regional cv. Venezolana (M Col 2215) and the recently released cv. ICA-Costeña (CG 1141-1) demonstrated their potential for DM accumulation in the roots although the RY potential was around the trial mean (**Table 11.3**). Improvement on the mean and stability for root quality parameters should be among the main priorities for this ecosystem in order to expand the time span for fresh cassava consumption by germplasm enhancement. Other criteria should also be incorporated to evaluate root quality for other end uses; e.g., in Africa, "poundability" is the most important trait influencing cooking quality.

Table 11.3. Means for selected clones and checks from the AYT at Media Luna (ECZ 1), Season B.

Clone	Female Parent	Male Parent	Mite Incidence[1]	RY (t/ha)	HI	% DM	HCN[2]
CM 4733-4	M Bra 12	M Col 72	1.7	8.6	0.39	35.1	9.0
CM 5665-1	CM 681-2	CM 2087-101	1.7	13.5	0.47	32.6	4.5
CT 5-5	CMR 24-63-43	CMR 27-77-10	1.3	21.9	0.54	30.2	9.0
SG 536-1	M Col 948C		1.3	7.6	0.37	32.1	6.0
SM 328-1	M Ven 45A		1.7	14.9	0.46	31.1	9.0
SM 636-8	CG 1-56		1.7	8.8	0.33	33.3	9.0
SM 736-22	M Ven 156		2.0	10.3	0.38	31.2	5.5
SM 953-11	CM 507-37		1.3	16.0	0.50	32.0	9.0
CG 1141-1[3]	ICA Costeña		1.0	8.9	0.37	33.6	7.5
CM 3306-4[3]	Pre-released		2.0	3.2	0.24	31.2	5.0
M Col 1505[3]	Verdecita		1.0	6.9	0.32	31.4	6.0
M Col 2215[3]	Venezolana		1.7	8.9	0.39	34.9	6.5
Trial mean			1.6	7.8	0.35	28.6	7.7
SD mean				2.4	0.08	1.9	

[1] 1 = resistant, 5 = highly susceptible.
[2] Scale from 1 to 9 for the picrate method.
[3] Local checks.

11.2 Lowland Tropics with Acid Soil Savannas and High Rainfall (ECZ 2)

Contrary to what has happened in ECZ 1, it has been relatively easy to select clones that combine good yield and DM potential with intermediate to low levels of HCN, good cooking quality, and resistance to the major biotic constraints for ECZ 2 (**Tables 11.4 and 11.5**). The genetic base for this gene pool being tested at La Libertad (Villavicencio, Depto. Meta) is represented by clones selected under heavy disease pressure

(particularly CBB and superelongation, SED) at Carimagua. Although good levels of infection can be obtained in susceptible check clones, the breeding lines showed intermediate to high levels of resistance to both diseases. In order to ensure that these favorable alleles are not lost, clones that reached AYTs at Villavicencio are also evaluated at Carimagua for the reaction to CBB and SED. This gene pool is also making its contribution to Africa, where it is the predominant source of CBB-resistant clones selected from Latin American germplasm.

At the local level there is a need to evaluate elite clones over a wider range of conditions, preferably under farmers' conditions. The region of the Andean Piedmont, where the testing site is located, could easily become the principal supplier of fresh cassava to Bogotá, and processed cassava could also find a market for animal feed or starch production.

Table 11.4. Means for selected clones and checks from the AYT at La Libertad (ECZ 2), Season A.

Clone	Female Parent	Male Parent	RY (t/ha)	% HI	% DM	HCN[1]	Cook. qual.[2]
CM 4400-2	CM 1335-4	M Pan 51	25.3	0.61	37.3	6.0	1.5
CM 6317-1	CM 696-1	CM 523-7	24.3	0.57	36.3	6.5	1.8
CM 6438-14	CM 1335-4	CM 2298-3	20.9	0.56	40.3	3.5	1.8
CM 6850-1	CM 2766-5	CM 523-7	19.0	0.53	37.4	6.0	1.0
CM 6855-3	CM 2766-5	CM 2298-3	23.7	0.61	33.9	6.5	1.4
SM 593-5	CM 2298-3		22.5	0.51	38.8	6.0	1.8
SM 629-6	M Col 2215		21.4	0.54	39.2	5.5	1.8
SM 670-1	CM 2088-1		21.2	0.54	37.4	3.5	1.0
SM 670-14	CM 2088-1		22.2	0.56	35.2	6.0	1.0
SM 679-3	CM 2606-6		20.0	0.59	34.3	6.5	1.4
SM 685-4	CM 2766-3		19.3	0.59	37.1	5.5	1.5
SM 686-25	CM 2766-5		20.8	0.62	36.5	5.0	1.8
SM 825-9	CM 849-1		21.6	0.54	39.6	4.0	1.8
CM 523-7[3]	ICA Catumare		18.7	0.56	39.6	5.0	1.8
CM 2177-2[3]	ICA Cebucán		21.2	0.58	36.2	5.0	3.0
Chiroza[3]			22.3	0.39	32.5	5.0	1.0
Trial mean			19.4	0.53	36.4	5.5	2.5
SD mean			3.7	.04	0.8		

[1] Scale from 1 to 9 for picrate method.
[2] 1 = excellent; 5 = very bad.
[3] Local checks.

Table 11.5. Means for selected clones and checks from the AYT at La Libertad (ECZ 2), Season B.

Clone	Female Parent	Male Parent	CBB[1]	RY (t/ha)	HI	% DM	HCN[2]	Cook. Qual.[3]
CG 1139-2	M Ecu 82	M Bra 5	1.7	27.1	0.64	35.2	6.0	3.4
CG 1450-4	M Col 1505	M Col 1940	2.3	20.8	0.62	39.0	6.0	1.0
CM 2166-6	CM 430-37	M Ven 218	1.3	27.3	0.63	36.1	5.0	1.8
CM 2766-3	CM 723-3	CM 523-7	1.3	22.4	0.51	38.0	5.5	1.0
CM 2766-5	CM 723-3	CM 523-7	1.3	17.8	0.45	36.9	5.0	1.4
CM 3320-8	M Bra 12	CM 523-7	2.0	23.5	0.49	35.0	6.0	1.4
CM 4484-2	M Col 1468	M Cub 74	1.3	23.8	0.54	37.6	7.5	1.0
CM 5620-3	CM 955-2	CM 523-7	2.0	24.7	0.56	36.1	8.0	2.6
CM 5789-1	M Col 1823	CM 2175-1	1.7	22.3	0.50	38.3	6.0	1.4
CM 5898-1	CG 32-22	CM 430-37	1.7	24.5	0.54	33.3	4.5	4.4
CM 5898-2	CG 32-22	CM 430-37	1.7	29.6	0.61	37.0	4.5	1.0
CM 5902-2	CG 32-22	M Col 638	1.0	20.6	0.48	37.5	3.5	1.0
CM 5948-1	CM 1335-4	SG 107-35	2.3	16.8	0.50	37.3	6.0	1.0
CM 6049-1	CM 2882-1	M Ven 77	1.7	18.4	0.46	32.7	6.5	3.2
CM 6061-1	SG 105-11	CM 91-3	2.0	22.3	0.59	37.1	6.5	1.0
CM 6068-3	SG 591-3	CM 2174-7	2.3	20.3	0.48	36.4	7.0	1.4
CM 6070-1	SG 591-3	SG 618-3	2.7	17.4	0.48	35.3	4.0	1.8
CM 6082-1	M Bra 5	CG 32-22	1.7	28.4	0.60	33.8	4.0	1.4
CM 6438-17	CM 2298-3	CM 1335-4	2.0	22.9	0.48	37.5	2.5	1.0
CM 6630-2	CG 165-7	CM 1335-4	2.0	27.5	0.63	35.2	5.5	1.0
CM 6664-3	CM 723-3	M Pan 51	2.3	26.1	0.61	36.2	7.0	1.0
CM 6691-2	CM 2766-3	CG 165-7	1.7	36.0	0.61	35.1	6.0	3.8
CM 7050-1	CM 2766-3	CM 1335-4	2.0	24.5	0.64	38.4	3.0	1.0
CM 7086-14	CM 2967-8	M Pan 51	2.7	26.2	0.57	37.5	6.0	1.0
SM 667-1	CM 723-3		2.7	20.3	0.53	33.7	5.0	1.0
SM 673-1	CM 2448-201		1.7	23.5	0.54	38.9	3.0	1.4
M Bra 97	Alpim Saracura		2.0	25.8	0.55	36.7	7.0	1.0
CM 523-7[4]	ICA Catumare		2.0	16.3	0.46	40.6	7.5	2.0
CM 2177-2[4]	ICA Cebucán		1.0	30.1	0.63	37.2	4.0	1.0
Trial mean			2.0	22.0	0.53	36.0	6.3	1.9
SD mean				3.2	0.06	2.1		

[1] 1 = resistant ; 5 = very susceptible.
[2] Scale from 1 to 9 for the picrate method.
[3] 1 = excellent ; 5 very bad.
[4] Local checks.

Evaluation at all breeding stages is made under intermediate application levels of lime (500 kg/ha) and fertilizer (300 kg/ha of 15-15-15). It will be important to evaluate elite material at lower levels of inputs as little fertilizer is applied to cassava in homologous regions, particularly in Africa.

11.3 Intermediate- to High-Altitude Tropics (ECZs 4 & 5)

Testing of elite clones (priority 1) selected at Popayán (ECZ 5) at an intermediate altitude (Mondomo) demonstrated the possibility of selecting for broad adaptation (see Chap. 10). In another experiment elite clones selected at CIAT HQ (priority 1) and other clones selected at Popayán (priorities 2 & 3) were tested at a low-fertility, hilly site in Mondomo. Twelve clones were selected based on RY and DM content (**Table 11.6**). M Bra 383, a landrace cv. grown for fresh consumption in southern Brazil (subtropics), seems to have a very broad range of adaptability. Selections from this trial are being evaluated in AYTs, together with selections from the yield trial reported in Chap. 10.

Table 11.6. Performance of selected clones and local checks from the PYT at Mondomo (ECZ 4/5).

Clone	ECZ[1]	RY (t/ha)	HI	% DM	HCN[2]	DM (t/ha)
CG 5-79	4	12.5	0.59	33.6	6	4.2
CG 7-66	4	12.5	0.58	34.4	9	4.3
CG 501-16	5	13.1	0.55	34.4	4	4.5
CG 913-4	4	20.0	0.72	34.1	8	6.8
CM 305-41	4	17.7	0.60	32.1	6	6.3
CM 1090-52	5	15.8	0.52	33.7	9	5.3
CM 1305-3	4	23.1	0.79	31.0	8	7.2
CM 2109-1	4	15.4	0.71	34.5	5	5.3
CM 3268-1	4	13.3	0.75	34.4	4	4.5
SG 427-64	5	15.2	0.63	37.6	9	5.7
M Bra 383	4	25.0	0.72	38.5	6	9.6
M Col 1468 (check)	2,4	5.2	0.48	31.6	7	1.6
M Col 1522 (check)	5	6.6	0.44	29.7	8	2.0
M Col 2059 (check)	5	0.5	0.15	21.0	6	0.1
M Col 2060 (check)	5	7.3	0.34	32.4	3	2.4
M Col 2061 (check)	5	12.7	0.50	29.6	6	3.8
Trial mean		11.2	0.54	31.8	7	3.7
SD check means		6.3	0.20	2.2		2.2

[1] ECZ of primary adaptation.
[2] Scale from 1 to 9 for the picrate method.

Four years ago there was a CBB outbreak at Santa Rosa Station (Popayán), making it necessary to discontinue germplasm evaluation at that site. Most of the clones had to be indexed, and the Program was obliged to look for another site to conduct the evaluation. All the selection stages have finally been assembled at Cajibio (alt. 1800 m). Several clones that were at PYT before the CBB outbreak were reintroduced for evaluation after indexing. Selected material (**Table 11.7**) compared very favorably with the predominant local cv. Algodona (M Col 1522). Other regional cv. did better than Algodona (i.e., M Col 2059 & M Col 2061), a trend that has been more or less systematic for M Col 2061 over the last 3 yr. There is a need to move to on-farm research (OFR) in order to find out why local cv. with good yield potential are not widespread, while others with restricted potential predominate. OFR will also reveal farmers' preferences toward genotypes that have demonstrated good stable performance at the experimental level.

Table 11.7. Means for selected clones and local checks from the AYT at Cajibio (ECZ 5).

Clone	Female Parent	Male Parent	RY (t/ha)	HI	% DM	HCN[1]
CG 706-5	M Col 1522	M Ven 270	21.1	0.58	38.9	3
CG 1103-4	M Col 2015	M Col 1684	26.7	0.47	34.0	5
CG 1110-3	M Col 2015	M Ven 270	20.3	0.51	37.2	4
SG 424-19	M Col 1552		34.4	0.53	36.9	4
SG 698-15	M Col 2006		25.4	0.43	36.7	6
SG 701-4	M Col 2017		26.6	0.53	35.9	3
SG 702-13	M Col 2060		20.9	0.60	38.3	2
SG 702-19	M Col 2060		31.3	0.43	38.5	3
SM 523-1	M Col 1182		22.3	0.37	37.8	3
SM 523-2	M Col 1182		24.0	0.33	36.2	3
SM 526-3	M Col 2015		31.1	0.56	33.6	7
M Col 262	Yema de Lusor		19.1	0.48	37.4	4
M Col 717	Paloma		24.8	0.42	37.5	3
M Col 1468[2]	Manihoica P-11		8.9	0.52	35.7	5
M Col 1522[2]	Algodona		7.1	0.30	32.3	7
M Col 2059[2]	Sata Dovio		19.8	0.39	36.5	3
M Col 2060[2]	Regional Amarilla		4.0	0.12	30.1	3
M Col 2061[2]	Regional Morada		28.1	0.58	37.1	2
Trial mean			21.4	0.42	35.6	4
SD			2.5	0.04	1.1	

[1] Scale from 1 to 9 for the picrate method.
[2] Local checks.

The Program is screening the available genetic base in search of clones that can produce good yields at early harvest (12 mo) and have the ability to increase that potential at normal harvest time (18 mo). Preliminary results have identified certain genotypes that may provide farmers such flexibility in harvesting time.

11.4. Germplasm Development for Semiarid Ecosystems in Brazil

Results from studies in the area of cassava physiology have demonstrated the ability of certain genotypes to withstand prolonged periods of drought, recovering to the point where there were minimal differences as compared to the unstressed treatments. Cassava could be adapted to semiarid regions based on its tolerance to both sporadic and extended drought. This is important for those regions where the population is expanding into more marginal agricultural areas, particularly the semiarid regions of Sub-Sahelian Africa.

Table 11.8 presents a description of sites in terms of rainfall distribution. Three of the sites (Petrolina, Araripina and Quixada) presented prolonged dry periods, with severe mite attack. Rains prior to harvesting promoted foliage growth, which resulted in relatively low DM content.

Table 11.8. Monthly rainfall for the period of germplasm evaluation at four sites in NE Brazil.

Month	Itaberaba (Bahia)	Petrolina (Pernambuco)	Araripina (Pernambuco)	Quixada (Ceará)
12/90	107.2_p			
01/91	20.4			
02/91	8.6		80.6	
03/91	91.4	223.7_p	234.5_p	172.7_p
04/91	31.6	50.2	51.8	72.8
05/91	74.0	59.7	23.2	154.3
06/91	79.6	9.0	0.0	68.1
07/91	30.2	0.0	0.0	2.2
08/91	40.8	4.3	6.2	0.0
09/91	6.2	0.0	0.0	0.0
10/91	0.0	0.0	0.0	0.0
11/91	207.8_h	50.0	2.2	0.0
12/91		0.0	0.0	0.0
01/92		237.9	192.3_h	130.1
02/92		118.5_h		151.5_h
TOTAL	697.8	753.5	590.8	751.7

P = planting; h = harvesting.

Table 11.9. Means for selected clones across different evaluation sites in NE Brazil (ECZ 7).

Clone	Common Name	Mites[1]	RY (kg/pl)	HI	% DM	HCN[2]	No. Selection Sites
BGM 146	Beira Mar	3.0	1.7	0.51	28.0	6.5	4
BGM 153	Platinha Preta	3.1	1.4	0.45	28.0	7.2	4
BGM 178	Mamao Branca	3.0	1.6	0.44	29.1	7.0	4
BGM 254	Saracura I	2.9	1.5	0.50	28.0	6.8	4
BGM 491	Veada	3.3	1.3	0.46	27.7	5.5	4
BGM 537	Do Ceu	2.7	1.5	0.48	30.4	6.0	4
BGM 538	Macaxeira Preta	2.9	1.8	0.50	30.1	6.2	4
BGM 544	Amazonas	3.1	1.4	0.55	29.1	7.0	4
BGM 549	Amansa Burro	3.1	1.6	0.42	28.6	6.0	4
BGM 598	Sapa R-16	2.7	1.3	0.47	29.0	5.2	4
BGM 004	Milagrosa	3.1	1.5	0.43	30.2	6.2	3
BGM 056	Mulata Boa	3.3	1.3	0.58	30.8	6.7	3
BGM 076	Platinha	3.2	1.0	0.44	28.6	7.0	3
BGM 080	Engana Ladrao	2.9	1.2	0.46	25.9	6.2	3
BGM 142	Irara	3.2	1.3	0.51	29.2	6.0	3
BGM 196	Gemedeira	3.8	1.4	0.48	28.7	6.7	3
BGM 369	Madrugada	3.4	1.5	0.54	27.6	5.0	3
BGM 384	Sacai	2.6	1.3	0.40	28.9	6.2	3
BGM 387	Mucuri	2.9	1.0	0.40	29.1	6.2	3
BGM 447	Raimunda	3.0	1.1	0.55	27.7	6.5	3
BGM 478	Manca	3.0	1.0	0.43	29.0	5.5	3
BGM 554	Itapissuma	3.0	1.5	0.44	28.5	6.8	3
BGM 560	Passarinha	3.4	1.4	0.42	27.5	7.2	3
BGM 649	Macaxeira Preta I	2.6	2.0	0.47	28.7	5.3	3
Overall mean (without checks)		3.3	0.9	0.40	25.1	6.1	
Selections at 4 sites		3.0	1.5	0.48	28.8	6.3	
Selections at 3 sites		3.1	1.4	0.47	27.4	6.4	
Selections at 2 sites		3.1	1.2	0.44	26.8	6.5	
Selections at 1 site		3.3	1.0	0.43	26.1	6.1	
Selections at 0 sites		3.4	0.7	0.36	23.5	6.0	

[1] 1 = resistant; 5= very susceptible.
[2] Scale from 1 to 9 for the picrate method.

Across-site evaluations provided the basis for identifying accessions with apparent wide adaptability. Although selection was practiced independently at each site, many accessions were selected at more than one site (4 sites = 10; 3 sites = 30; 2 sites = 71). The means of principal characteristics for the groups composed of selections across 4, 3, 2, 1 and 0 sites are shown at the bottom of **Table 11.9**. There is a clear trend for higher mean mite resistance, RY, HI and DM with greater no. of sites selected. HCN levels showed no particular trend with no. of sites selected.

Based on mean performance at all sites, 24 clones were selected for multiplication and planting in AYTs in the 1993-94 season. Traits for these clones are presented in **Table 11.9**. Aside from broad adaptability, other accessions with outstanding performance for mite resistance, DM content and low HCN were included in recombination lots.

Correlation among traits across sites was used to determine similarity among sites. Although some values were significant (P > 0.01), the coefficient of determination was always low (**Table 11.10**), leading to the conclusion that identification of similar sites is not easy.

Table 11.10. Correlation among evaluations of the same trait at different locations in NE Brazil (ECZ 7).

Trait	Itab./Arar.	Itab./Quix.	Itab./Petr.	Arar./Quix.	Arar./Petr.	Quix./Petr.
CGM	0.14	0.60**	0.13	0.16	0.00	0.15
RY (kg/pl)	0.20*	0.26**	0.25**	0.38**	0.32**	0.31**
HI	0.26**		0.39**		0.34**	
% DM	0.51**	0.31**	0.37**	0.29**	0.45**	0.48**
HCN		0.50**	0.46**			0.52**

* Significant at 0.05.
** Significant at 0.01.

11.5. Varietal Release in Ecuador

The Province of Manabí is the most important cassava production region in Ecuador. Most of the cassava is processed into dry chips or starch by farmers' coops. Local cv. have intermediate to low DM content, which reduces the efficiency for transportation and processing. Several clones from the Atlantic Coast of Colombia were introduced to Ecuador based on the homology with growing conditions at Manabí. Among those clones, the cv. Venezolana (M Col 2215) stood out from the very first evaluations for its good adaptation and excellent potential to accumulate DM in the roots. In on-farm evaluations along with local clones, M Col 2215 had an avg production of 6.5 t/ha of DM compared to 4.4 t/ha for the best local clone (**Table 11.11**). The cv. was recently

released under the name INIAP-Portoviejo 650, and planting material is being multiplied by the Union of cassava farm workers, producers and processors (UATPPY) and INIAP. If processors start paying for cassava according to its DM content, this clone may soon dominate the production area, as has been the case on the Atlantic Coast, where it represents 80% of the total cassava area. There is a need to support the national program's capacity to offer other alternatives in the short term so as to maintain a diverse genetic base at the field level, reducing the crop's vulnerability.

Table 11.11. Avg yield for local clones and the introduced clone M Col 2215 in farmers' fields over a 2-yr period.

	1989		1990		Avg	
Cv.	RY (t/ha)	% DM	RY (t/ha)	% DM	RY (t/ha)	% DM
Taureña	12.8	33.3	11.8	30.5	12.2	31.9
Amarilla	14.4	35.4	8.7	32.1	11.6	33.8
Yema de Huevo	12.6	37.3	10.9	31.3	11.8	34.3
Mulata	12.0	35.3	13.2	31.6	12.6	33.4
Quevedeña	10.0	34.4	8.3	30.8	9.2	32.6
Negra	13.7	34.7	14.1	31.2	13.9	33.0
Canela	14.8	33.9	12.5	28.8	13.7	31.4
M Col 2215	17.7	37.1	16.6	34.9	17.9	36.0
Tres Meses	12.9	37.1	13.1	30.2	13.0	33.7
Avg	13.2	35.4	12.0	31.3	12.6	33.6
CV (%)	30.4		26.7			

12. GENE POOL AND VARIETAL DEVELOPMENT IN ASIA

The objectives of the Cassava Program's genetic enhancement work in Asia include:

- Improvement of gene pool for Asian environments
- Generation and distribution of advanced breeding materials
- Strengthening of national program capacity for varietal improvement
- Selection of superior genotypes through collaborative activities
- Follow-up of and feedback from varietal adoptions

12.1 Activities

12.1.1. Gene pool improvement by the Thai-CIAT collaborative breeding program

As a result of the ongoing excellent cooperation received from the Dept. of Agriculture (DOA) and Kasetsart University (KU), the cassava breeding program at Rayong Field Crop Research Center (RFCRC) of the Field Crop Research Institute (FCRI) and the DOA, the breeding population continues to be improved for higher basic yielding ability, better root quality and higher adaptability to semiarid lowland environments. Basic productivity has showed a sustained upward improvement over the years (**Fig. 12.1**). Root DM content and total plant biomass of the breeding population continued to show an upward improvement; whereas HI remained virtually unchanged (**Figs. 12.1 & 12.2**). Work will continue on upgrading even further root DM content and total biomass of the population; and the selection emphasis--including that of cross parents--is shifting in that direction.

It has been observed that the hybrid populations prepared at Rayong--using the Thai clones and locally selected CIAT clones as cross parents--offer better selection opportunities for the semiarid climate of Thailand than the population prepared at CIAT HQ for the seasonally dry lowland tropics. This tendency still persists (**Table 12.1**), the major difference being the superiority of the Thai materials in terms of germination/ survival ability after planting, plant type and root DM content. Consequently, the percentage of selection from among the Rayong materials is significantly higher than that from the CIAT materials (**Fig. 12.3**). Thus the Thai/CIAT breeding program at Rayong appears to be a major gene pool source for the semiarid lowland tropics.

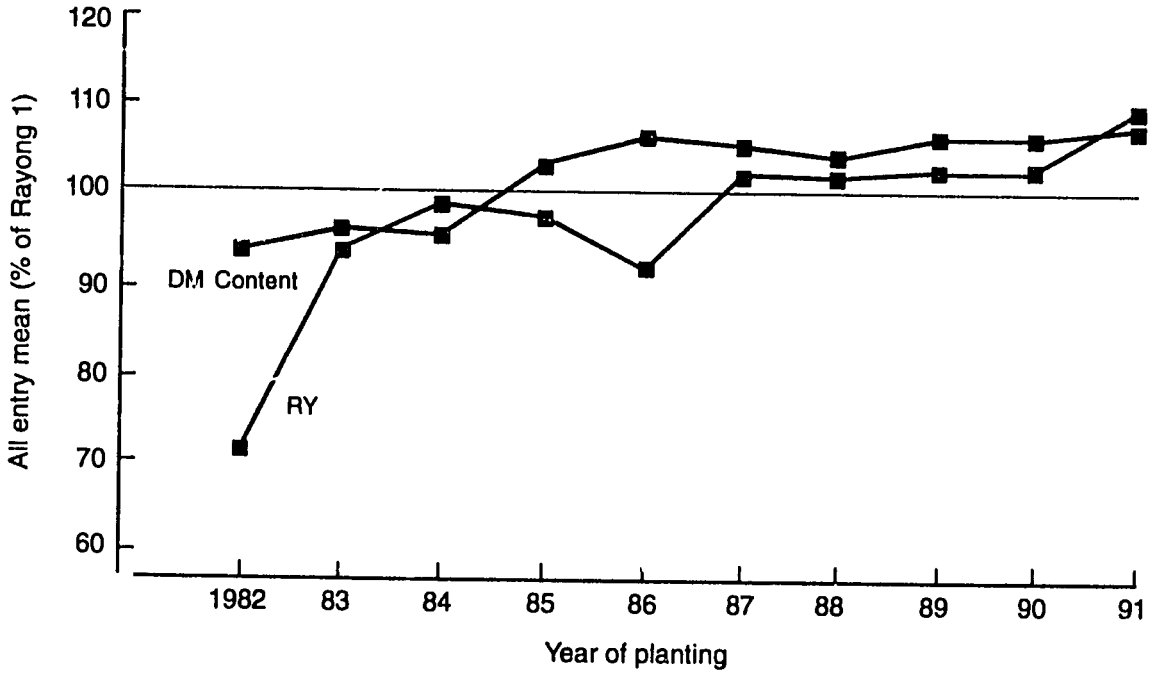

Figure 12.1. Change in mean RY and DM content of yield trial entries (all-entry mean) in Thailand.

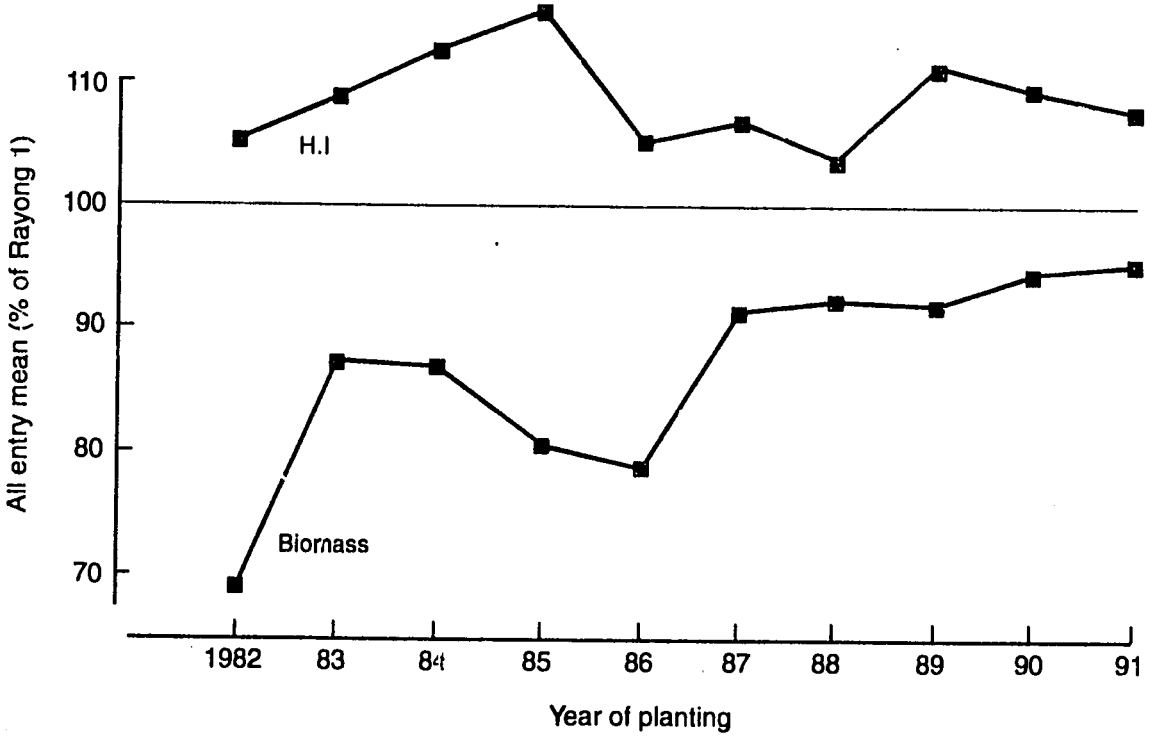

Figure 12.2. Change in mean HI and biomass of yield trial entries (all-entry mean) in Thailand.

Table 12.1. Comparison between CIAT HQ and Thai/CIAT (Rayong) clones in Single-row Trial at Rayong, Thailand.[1]

Character	1986/87 planing Yr			1991/92 planting Yr		
	CIAT HQ clones	Thai/CIAT clones (% of CIAT HQ clones)		CIAT HQ clones	Thai/CIAT clones (% of CIAT HQ clones)	
Dry root yiel (kg/plant)	0.80	1.10	(137)	0.68	0.84	(124)
Fresh root yield (kg plant)	2.44	3.21	(131)	2.19	2.53	(116)
Total plant weight (kg/plant)	4.81	5.71	(119)	4.08	4.20	(103)
Harvest index	0.507	0.562	(111)	0.536	0.603	(113)
Plant type rating[2]	2.87	3.42	(119)	3.35	3.99	(119)
Root dry matter content (%)	32.9	34.3	(104)	30.9	33.1	(107)
Germination/Survival of planting stakes (%)[3]	45.3	72.6	(160)	75.3	83.4	(111)

1 Mean of all entries in single-row trial (735 CIAT HQ and 1228 Thai/CIAT clones for 1986-87 and 621 CIAT HQ and 1696 Thai/CIAT clones for 1991-92).
2 1 = very poor, 5 = very favorable.
3 Data from PYT of following year.

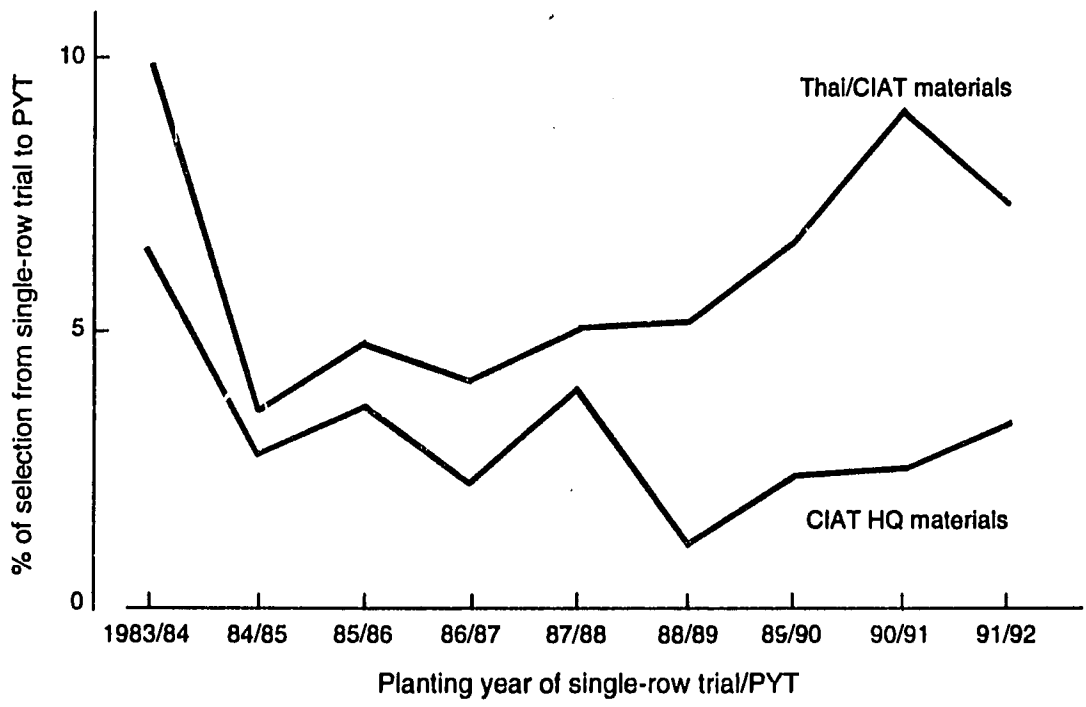

Figure 12.3. Comparison between CIAT HQ and Thai/CIAT (Rayong) materials in percent selection from single-row trial to PYT at Rayong, Thailand over a 10-yr period.

12.1.2 Distribution of advanced breeding materials

Using the selected parents of both local and CIAT origin, thousands of hybrid seeds are produced annually at RFCRC, primarily for selecting advanced genotypes for the Thai conditions but also very importantly for contributing to the selection programs in other Asian countries (**Table 12.2**). Initial data suggest that these are a highly promising source for varietal selection in Vietnam and Indonesia as well.

Table 12.2. Cassava F1 hybrid seeds from CIAT/Thailand distributed to Asian programs.

	No of Seeds			
Country	1985-1990	1991	1992	TOTALS
Indonesia	13,813	1,139	1,393	16,345
China	5,871	741	1,793	8,405
Vietnam	4,700	1,435	2,441	8,576
Philippines	4,634	520		5,154
Malaysia	2,500			2,500
India	2,700			2,700
Myanmar	950			950
Sri Lanka	750			750
Israel	750			750
CIAT HQ	6,721			6,721
TOTALS	43,369	3,835	5,627	52,851

Transfer of advanced clones--mainly in the form of aseptic meristem culture from the Thai/CIAT breeding program to other national programs--has become increasingly important (**Table 12.3**). Initial data clearly indicate that the Thai/CIAT clones thus transferred may be an immediate source of varietal selection in Vietnam and can be so in Indonesia, the Philippines and China as well.

The CIAT HQ breeding program has a long history of contributing hybrid seeds to many Asian national programs (**Table 12.4**). The importance of this function is increasing as the capacity of Asian national programs has been strengthened. Hybrid seeds are a major source of superior varietal selection in Indonesia, China, Vietnam, the Philippines and Malaysia. Important cross parents have been selected from this source for the hybridization programs in Thailand, China and the Philippines.

Table 12.3. Cassava clones transferred from CIAT/Thailand to Asian programs.

Country	No of Clones		
	1987-1990	1991	TOTALS
Indonesia	3	14	17
China	13	10	23
Vietnam	26	10	36
Philippines	16	10	26
Malaysia	16	10	26
India	13	10	23
Laos	17		17
Myanmar	13		13
Sri Lanka	13	10	26
Israel	13		13
Nepal		2	2
CIAT HQ	21		21

Table 12.4. Cassava F1 hybrid seeds from CIAT HQ distributed to Asian programs.

Country	No of Seeds			
	1975-1990	1991	1992	TOTALS
Thailand	109,411	9,583	11,727	130,721
Indonesia	28,800	4,219	9,552	42,571
China	35,999	5,511	6,021	47,531
Vietnam	13,850	3,750	4,500	22,100
Philippines	30,736	7,679	4,297	42,712
Malaysia	11,440	2,918	2,079	16,437
India	10,700		1,200	11,900
Sri Lanka	1,500			1,500
Taiwan	1,700			1,700
TOTALS	244,136	33,660	39,376	317,172

12.1.3 Strengthening national program capacity

CIAT collaboration has been helpful in establishing cassava breeding programs in many Asian countries, and training efforts have been particularly significant in training national

program personnel in the basic understanding of cassava research. Acquiring the skill of genetic selection has been accomplished mostly through working with the actual breeding materials in the field. Actual field selection by national program and CIAT breeders, working side by side, has been and still is an efficient procedure whereby selection skills and the understanding of the cassava situation in each country are effectively and mutually enhanced.

Through this process, the cassava breeding programs in Thailand and China have grown to be comprehensive in conducting every step of the breeding process including hybridization. Similarly, the programs in Malaysia, Indonesia and the Philippines are now capable of every step of clonal evaluation; and the Vietnamese program is rapidly catching up. The usefulness of breeding materials CIAT provides for the national programs is the most crucial factor in convincing and encouraging national program breeders to consolidate their working scheme.

India has been an exception to this procedure in that a fairly comprehensive program had been operating there long before CIAT began cooperating with national programs in the early 1970s.

12.1.4 Selection of superior genotypes

The present status of selection is summarized in the results of 60 on-farm and regional trials comparing the performance of the latest cv. Kasetsart 50 with the local cv. Rayong 1 (**Table 12.5**)--the most successful cv. in Thailand and probably in the world as well. In every important agronomic trait, Kasetsart 50 was superior to Rayong 1. Kasetsart 50 appears to have the potential to be a great cv. for replacing Rayong 1--not only on fertile soils as has been the case for previous cv. released in Thailand (e.g., Rayong 3) but also under less fertile conditions.

Table 12.5. Comparison between Rayong 1 and Kasetsart 50[1].

Character	Rayong 1	Kasetsart 50	Kasetsart 50 in % of Rayong 1
Dry root yield (t/ha)	7.2	9.7	135
Fresh root yield (t/ha)	23.1	28.3	123
Root dry matter content (%)	31.0	34.3	111
Total plant weight (t/ha)	42.3	45.8	108
Harvest index	0.55	0.63	114
Germination and survival (%)	88.7	94.4	106

[1] Mean of 60 on-farm and regional yield trials.

Selection in Indonesia continues to indicate the superior performance of CIAT clones, especially at the Umas Jaya (South Sumatra) selection site (**Table 12.6**); and superior clones have been sent to other selection sites in Indonesia. In China, selections both from crosses made in China between local and selected CIAT clones, and from CIAT hybrid seed populations showed promising results at the South China Academy of Tropical Crops (SCATC), Hainan (**Table 12.7**). Superior clones have been transferred to other institutions in Guangdong and Guangxi. Both in Indonesia and China, CIAT collaboration has been helpful in establishing linkages among different institutions within the country.

Table 12.6. Results of varietal trial in Sumatra, Indonesia[1].

Clone	Origin		Dry root yield (t/ha)	Fresh root yield (t/ha)	RDMC[2] (%)	Total plant weight (t/ha)	HI
	Hybridization	Initial selection					
CM4049-2UJ	CIAT HQ	Indonesia	20.4	53.4	38.2	82.2	.65
CM4031-10UJ	CIAT HQ	Indonesia	19.5	50.0	39.0	80.6	.62
Rayong60	Thailand	Thai-CIAT	17.5	46.7	37.5	70.6	.66
B6-3	Indonesia	Indonesia	17.3	46.6	37.1	74.0	.63
Adira 4	Indonesia	Indonesia	16.9	46.2	36.6	81.1	.57
B16-3	Indonesia	Indonesia	16.2	44.3	36.6	73.8	.60
Rayong3	CIAT HQ	Tahiland	15.5	41.1	37.7	56.3	.73
OMR28-19-3UJ	Thai-CIAT	Indonesia	15.2	41.4	36.7	64.7	.64
OMR28-65-7UJ	Thai-CIAT	Indonesia	15.0	42.0	35.7	73.7	.57
OMR28-82-4UJ	Thai-CIAT	Indonesia	13.5	38.2	35.3	62.6	.61
B18-1	Indonesia	Indonesia	10.9	27.6	39.5	44.5	.62
Kretek	Indonesia	traditional	9.3	27.9	33.3	62.0	.45

1 Means of three replicated yield trials at Umas Jaya Farm, Lampung, Sumatra, 1990-91.
2 Root dry matter content.

The most spectacular selection results have been obtained in Vietnam. Superior Thai clones such as Rayong 60 and Kasetsart 50 continue showing yielding capacity far superior to the local cv. at Hung Loc Research Center, S Vietnam IAS (**Table 12.8**). Clones locally selected from CIAT HQ and Thai/CIAT seed introductions also show highly promising results (**Table 12.9**). Superior Thai/CIAT clones have been tested in many on-farm trials (**Table 12.10**). Initial results from the evaluation at Agricultural College No. 3 in N Vietnam also indicate the promising performance of some Thai/CIAT clones (**Table 12.11**). Collaboration with these Vietnamese institutions has resulted in substantial progress in a short time.

Table 12.7. Result of varietal trials in Hainan, China[1].

Clones	Origin		Dry root yield (t/ha)	Fresh root yield (t/ha)	RDMC[2] (%)
	Hybridization	Initial Selection			
ZM8729	China	China	12.5	32.4	38.6
SM965-3	CIAT HQ	China	11.3	28.9	39.1
SM769-2	CIAT HQ	China	10.8	29.3	36.9
SM582-5	CIAT HQ	China	10.5	27.7	37.9
SM481-1	CIAT HQ	China	9.9	23.9	41.4
ZM8741	China	China	9.9	28.5	34.7
ZM8803	China	China	9.4	27.3	34.4
SM205	(Local Control)		9.3	25.4	36.6
ZM8775	China	China	9.2	26.3	35.0
ZM8816	China	China	9.1	24.3	37.4
SM965-2	CIAT HQ	China	9.1	26.4	34.5
SM8758	China	China	9.1	26.2	34.7
ZM8774	China	China	9.0	23.8	37.8
SM980-1	CIAT HQ	China	9.0	24.9	36.1
SM987-2	CIAT HQ	China	9.0	24.1	37.3
ZM8752	China	China	8.7	25.0	34.8
SM979-2	CIAT HQ	China	8.7	25.2	34.5
SM758-4	CIAT HQ	China	8.4	24.1	34.9
ZM8769	China	China	8.4	23.9	35.1
SM965-5	CIAT HQ	China	8.1	22.0	36.8
ZM8701	China	China	7.3	26.4	27.7
ZM8702	China	China	6.5	22.9	28.4

1 Mean of two advanced yield trials conducted at South China Academy of Tropical Crops in 1990 and 1991.
2 Root dry matter content.

12.2 Outputs

12.2.1 Release and pre-release of cultivars

In Thailand distribution of planting stakes of Rayong 90 [(CMC 76 x V43)21-1], named in 1991 was started in 1992 under the supervision of the RFCRC and the DOA. Hybridization and the initial selection of Kasetsart 50 [KUC28-77-3]--released this year in commemoration of the 50th anniversary of KU--was conducted by the cassava breeding group at KU using the cross parents provided by the DOA and CIAT. The final regional

and on-farm evaluations were conducted jointly by KU and the DOA. Clone CMR25-105-112 is in the pre-release stage.

Table 12.8. Evaluation of clones introduced through CIAT/Thailand and evaluated at Hung Loc Research Center[1].

Clone	Origin		Dry root yield (t/ha)	Fresh root yield (t/ha)	RDMC[2] (%)	Total plant weight (t/ha)	HI
	Hybridization	Initial Selection					
Kasetsart 50	Thai-CIAT	Thai	11.5	30.0	38.3	48.4	.62
Rayong 60	Thailand	Thai-CIAT	10.4	27.4	38.0	44.2	.62
CM6125-125	CIAT HQ	Thai-CIAT	10.0	27.5	36.3	43.7	.63
MKUC28-71-66	Thai-CIAT	Thai-CIAT	9.8	25.4	38.6	40.3	.63
CM4758-29	CIAT HQ	Thai-CIAT	9.3	24.9	37.3	38.9	.64
CM4231-32	CIAT HQ	Thai-CIAT	9.3	24.4	38.1	36.4	.67
CM6125-129	CIAT HQ	Thai-CIAT	9.0	24.4	36.9	42.8	.57
CM6125-117	CIAT HQ	Thai-CIAT	8.3	22.1	37.5	37.5	.59
Rayong 3	CIAT HQ	Thailand	8.1	20.8	38.9	28.9	.72
CM5262-27	CIAT HQ	Thai-CIAT	8.0	21.6	37.1	36.6	.59
CM5257-33	CIAT HQ	Thai-CIAT	7.9	20.9	37.8	30.7	.68
Rayong 1	Thai Traditional		7.8	20.9	37.4	47.5	.44
CM5604-21	CIAT HQ	Thai-CIAT	7.2	19.6	36.8	33.2	.59
HL-24	(Local control)		6.9	19.2	35.9	41.7	.46
HL-23	(Local control)		5.8	15.9	36.4	28.9	.55

1 Mean of three yield trials conducted at Hung Loc Research Center, Dong Nai, Vietnam in 1989-1992.
2 Root dry matter content.

In Indonesia clones CM4031-10UJ and CM4049-2UJ were pre-released and reported to be already planted on hundreds of ha. In China two clones (8002 and 8013) selected from the crosses made between Chinese clones and a clone (CM4031-2) selected from a CIAT HQ seed population at SCATC were pre-released.

In the Philippines, M Col 1684, one of the earliest clonal introductions from CIAT HQ, is now planted on more than 1000 ha in Mindanao. The Philippines Root Crops Research and Training Center (PRCRTC) is in the process of naming and releasing this clone officially for the Mindanao area. In Malaysia MM 90 [CM3906-31] was released as an early-harvestable cv.

Table 12.9. Evaluation at Hung Loc Research Center[1], of clones selected from hybrid seed introductions from CIAT/Colombia and CIAT/Thailand.

Clone	Origin		Dry yield (t/ha)	Fresh yield (t/ha)	RDMC[2] (%)
	Hybridization	Selection			
SM981-2	Colombia	Vietnam	12.4	35.5	35.0
SM1095-7	Colombia	Vietnam	11.8	35.5	33.3
OMR32-02-3	Thailand	Vietnam	11.1	31.7	35.1
SM981-3	Colombia	Vietnam	10.9	29.8	35.8
SM1096-10	Colombia	Vietnam	10.4	26.9	38.6
OMR32-06-3	Thailand	Vietnam	9.8	25.1	38.9
OMR32-13-9	Thailand	Vietnam	9.8	26.3	39.2
SM905-2	Colombia	Vietnam	9.3	25.1	37.2
SM1129-2	Colombia	Vietnam	9.3	24.5	38.1
SM1141-5	Colombia	Vietnam	9.1	24.5	37.1
SM1157-1	Colombia	Vietnam	9.1	24.4	37.3
OMR32-31-9	Thailand	Vietnam	8.7	23.0	37.7
SM1157-3	Colombia	Vietnam	7.9	21.3	37.2
SM1135-8	Colombia	Vietnam	7.1	19.2	41.4
HL 24(Local control)			6.1	17.2	35.5

1 Data from a preliminary yield trial conducted at Hung Loc Research Center in 1991/92. Only selected clones (14 clones selected from a total of 58 clones) are presented.

2 Root dry matter content.

The numbers of CIAT-related cv. and pre-released clones with the background information and their yearly development are presented in **Table 12.12** and **Fig. 12.4**, resp.

12.2.2 Varietal adoption

Rayong 3 in Thailand continues to be planted on the fertile soils where starch and chipping factories pay differential prices for the higher starch content of this cv.; and it is reported to be planted on more than 50,000 ha. A vigorous varietal dissemination program for Rayong 3, Rayong 60, Rayong 90, Sriracha 1 and Kasetsart 50 is being implemented, involving the DOA, the Dept. of Agricultural Extension and KU.

In Indonesia Adira 4--a selection from the country's breeding material and multiplied in a collaborative program involving the national institution, a private corporation and CIAT--continues to be planted in large areas in South Sumatra and is expanding to Central Sumatra and other outer islands (Kalimantan and Sulawesi).

Table 12.10. Results of on-farm trials conducted by Hung Loc Research Center in South Vietnam, 1991/92.

Clone	Fresh Root Yield (t/ha) on the farm of								
	A	B	C	D	E	F	G	H	Mean
Rayong 3	12.3	12.5	13.8	14.2		13.2			13.2
Rayong 60		16.8			17.4		17.2	18.6	17.5
CM5257-33		10.5	12.1	12.1					11.6
CM6125-117	14.7	13.7	16.7	16.4	16.7	15.7			15.7
CM6125-125	17.1	16.2	19.6	18.6	20.0	17.8			18.2
CM6125-129	15.6	13.4	18.4	15.8	15.4	14.6			15.5
MKUC28-71-66	16.4	14.6				16.4			15.8
HL23			12.3	13.7	12.3		18.0	15.3	14.4
HL24	10.6		11.8	14.8	14.5	10.4	13.8	12.2	12.6
Gon		11.0				8.4	8.9		9.4

Farmer A; Mr. Nhuyen Van Lai
B; Mr. Tran Daw
C; Mr. Tran Van Tai
D; Mr. Nguyen Van Thang
E; Mr. Nguyen Diah Van
F; Mr. Troung Van nhuon
G; Ms. Nguyen Thi Sam
H; Mr. To Van Minh

Table 12.11. Evaluation at Agricultural College No.3, Bac Thai, North Vietnam[1] of Clones introduced through CIAT/Thailand.

Clone	Parents	Dry yield (t/ha)	Fresh yield (t/ha)	RDMC[2] (%)	Total plt. wt (t/ha)	HI
Rayong 60	M Col 1684 x RI	14.6	35.0	41.7	66.0	.53
Rayong 1		13.1	37.4	34.9	66.4	.56
Kasetsart 50 (MKUC28-77-3)	R1 x R90	12.6	31.1	40.8	68.5	.45
CM5267-27		11.8	28.7	41.2	67.4	.42
Vinh Phu (Local control)		11.3	30.9	36.5	48.6	.63
Rayong 3	M Mex 55 x M Ven 307	10.1	27.7	36.3	50.7	.54
Hanatee		9.1	27.0	36.7	66.7	.40

1 Result of a replicated yield trial conducted at AC3 in 1991.
2 Root dry matter content.

Table 12.12. Number of CIAT-related cassava cultivars released by national programs as of 1992 in Asia.

Category	No. of Cultivars Officially Released	No. Clones in Prerelease	Country
Selected CIAT clones	3	1	China, Philippines
Selection from local cross of local germplasm	2	2	Indonesia, China
Selection from CIAT cross	5	3	Thailand, Malaysia, Philippines, China, Indonesia
Selection from local cross between CIAT and local parents	4	1	Thailand

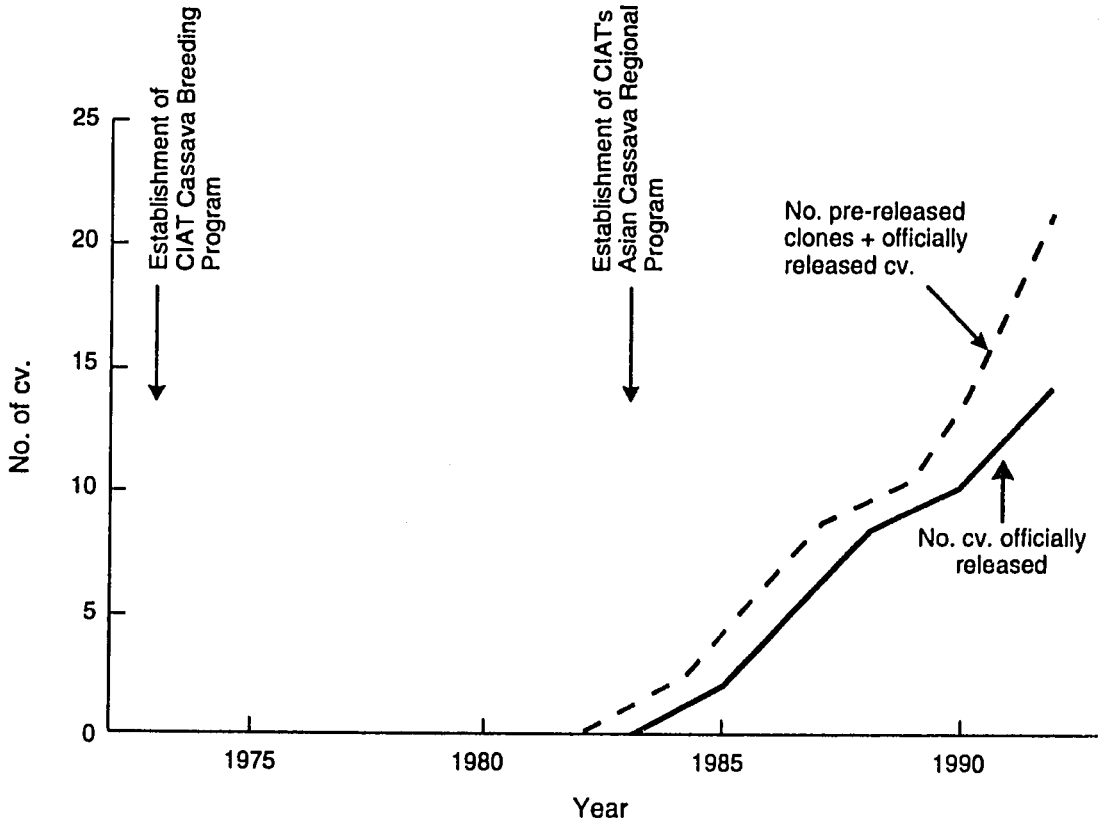

Figure 12.4. Yearly development of no. of CIAT-related cassava cv. officially released and pre-released by national programs in Asia.

In China the first officially released cv. Nanzi 188 [CM321-188] was once reported to have spread to 13,000 ha. As a result of poor stake storage during the winter and most likely its insufficient yield performance in marginal areas, the acreage is reported to be decreasing in Guangdong Province; but it is still increasing in Guangxi Province. South China 124 [E-24] is reported to be spreading well into the northern limit of cassava-growing areas. SC-124--selected from a local cross made at the SCATC in the late 1970s--became a nationally recommended cv. in 1989 through the network of regional evaluations.

In the Philippines two of the earliest CIAT clonal introductions (M Col 1684 & CMC 40, now called VC2) are finally expanding in area (more than 1,000 ha), especially in Mindanao.

Combining these adoption rates, the yearly development of adoption of CIAT-related cv. in Asia is estimated in **Fig. 12.5**. It took 12 yr from the start of the HQ breeding program to the release of the first CIAT-related cv. in Asia and 16 yr before seeing a significant field area planted with CIAT-related cv.

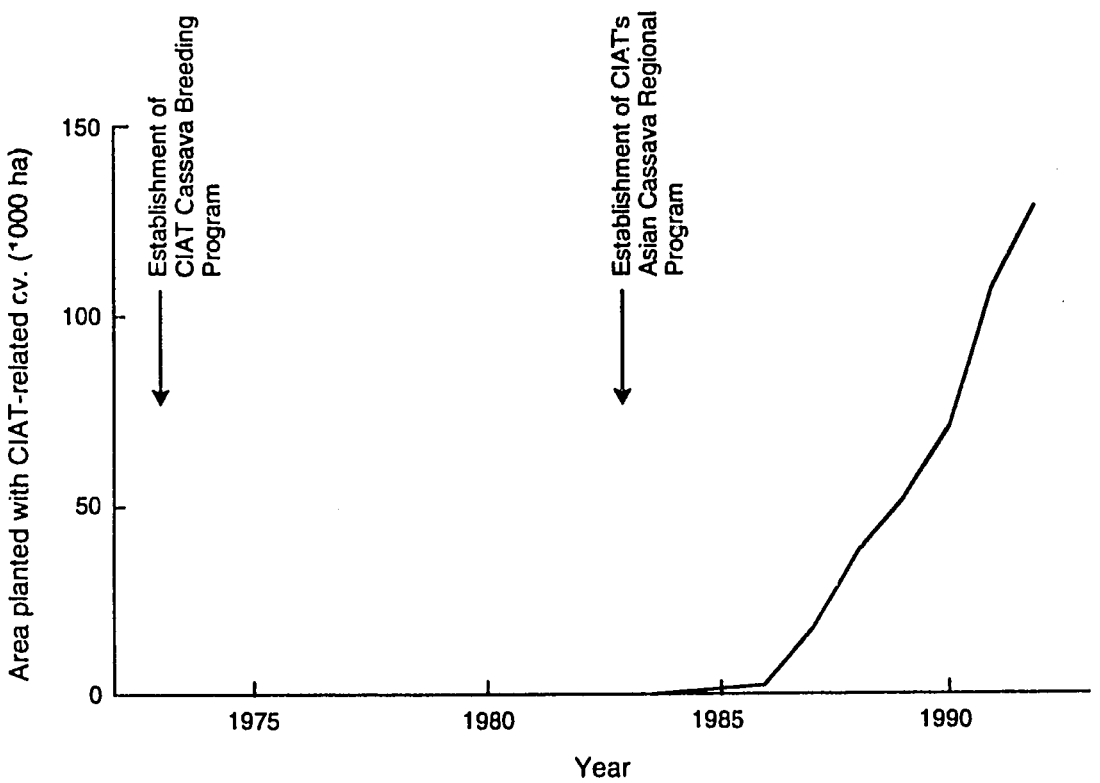

Figure 12.5. Yearly development of area estimated to be planted with CIAT-related cassava cv. in Asia.

13. GENE POOL DEVELOPMENT FOR AFRICA

The development of a broad germplasm base for specific agroecologies of Africa is being done in close collaboration with IITA. The work comprises the introduction of botanical seeds obtained at CIAT by open pollination and controlled hybridizations, using parents adapted to similar ecologies in Latin America. Evaluation of the progenies under semiarid, mid-altitude, humid and subhumid environments are being made on the basis of general performance of seedlings and resulting clones, root and shoot characteristics, and resistance to major pests and diseases.

From the 1990 introductions, 538, 311 and 474 clones were advanced to the clonal evaluation trials at Ibadan, Onne and Kano/Zaria in 1991, with 3 pl/plot and no reps. After 12 mo 9, 17, 38 and 53 clones were selected and established in preliminary yield trials (PYT) (2 reps) at the same locations.

The no. of seedlings/clones evaluated in each step of the selection scheme begun in 1991 is indicated in **Table 13.1**. A much higher selection pressure was imposed at all four sites in the 1991-92 seedling nurseries, with more careful selection for diseases (ACMD and CBB) and pest (CGM) resistance at Ibadan and Onne, and for leaf retention and growth at Kano and Jos.

Table 13.1. No. of seedlings evaluated at four sites in Nigeria in 1991 and resulting clones advanced to PYT in 1992.

Evaluation Site	Seedling Nursery	Clonal Evaluation
Ibadan	5,300	250
Onne	4,174	61
Kano	15,000	194
Zaria	-	233
Jos	10,794	265
TOTAL	35,268	1,003

Table 13.2 compares the seedlings selected in 1991 and 1992 on the basis of their main morphological and agronomic characteristics. In Kano the 1992 selections were taller and branched later than the 1991 selections. This reflects the emphasis being given to high vigor at that site. The avg roots harvested at the three locations were brown, had white pulp and a light cortex pigmentation. Compared to 1991 data, the avg fresh root wt (FRW) of the 1992 selections were higher in Onne, lower at Ibadan and showed no changes at Kano. The reduction of RY at Ibadan was mainly due to the differences in soil

fertility and texture existing between the 1990-91 and 1991-92 seedling nurseries. The avg no. of roots/pl was slightly reduced at all locations.

Table 13.2. Morphological and agronomic characteristics of seedlings selected at three locations in Nigeria in 1990-91 and 1991-92; data are means of all seedlings selected.

	Ibadan		Onne		Kano	
Traits	90-91	91-92	90-91	91-92	90-91	91-92
PH (cm)	213	197	236	248	145	194
Ht 1st branch (cm)	113	142	141	150	97	116
Branch levels	3.4	1.5	3.5	3.8	1.6	2.6
Leaf retention[1]	24	21	15	19	39	24
Root color[2]	2.6	1.9	2.5	2.3	2.5	2.0
Pulp color[3]	1.3	1.4	1.4	1.1	1.5	1.4
Cortex color[4]	0.6	0.3	0.7	0.4	0.8	0.5
Constrictions[5]	1.4	2.1	1.5	1.8	2.0	1.4
RY (kg/pl)	2.8	1.1	2.3	3.0	2.3	2.3
Roots/pl	6.2	5.6	6.0	5.5	6.9	6.0

[2] Percent of total ht with leaves at harvest.
[3] 1 = Dark brown; 2 = light brown; 3 = white.
[4] 1 = White; 2= cream; 3= yellow.
[5] 0 = No pigmentation; 4 = intense purple.
[6] 0 = No constrictions.

In an attempt to quantify the differences between selected seedlings and those harvested but not selected in the 1991-92 seedling nurseries planted at Ibadan, Onne, Kano and Jos, averages for some traits measured at harvest are shown in **Table 13.3**. It is clear that the seedlings selected were taller, branched later and had more branching levels in comparison with the nonselected ones. The data on FRW and no. of roots/pl also show a marked difference in favor of the individuals selected in all four sites. These characteristics--added to those pertinent to reaction to the main pests and diseases in each site, and quality characteristics of the storage roots--are the ones being taken into consideration for identifying the best genotypes to be advanced in IITA's breeding scheme.

13.1 Evaluation of Clones by Agroecological Zone

13.1.1 Ibadan/Onne

The main drawback of seedlings of Latin American origin has been high susceptibility to ACMV, especially at Ibadan, where disease pressure is extremely high during the raining

season (Apr-Nov). Practically 100% of the seedlings evaluated from 1990-92 had the disease 2 MAT.

Table 13.3. Differences in morphological and agronomic characteristics in selected and nonselected seedlings evaluated at four locations in Nigeria during 1991-92; data are means of each group of seedlings.

	Ibadan		Onne		Kano		Jos	
Traits	S	NS	S	NS	S	NS	S	NS
PH	197	139	248	182	194	138	142	100
Ht 1st branch	142	115	150	149	116	96	83	73
Branch levels	1.5	0.6	3.8	1.5	2.6	1.6	2.9	1.5
Leaf retention	21	24	19	28	24	29	41	43
RY	1.1	0.5	3.0	1.0	2.3	0.7	1.2	0.6
Roots/pl	5.7	3.7	5.5	3.7	6.0	3.3	7.7	4.8

S = Selected seedlings
NS = Nonselected seedlings

When compared with two IITA elite clones planted as checks in the 1991-92 seedling nursery, the degree of incidence in the seedlings was comparable to that of TMS 91934, a susceptible clone; but much higher than that of TMS 30001, a highly resistant clone, during the rainy season (**Table 13.4**). The increased incidence observed in TMS 30001 in Mar-Apr coincides with the onset of the 1992 rainy season.

The major difference in the performance of the introduced germplasm and the IITA clones is the degree of disease severity. The data in **Table 13.4** show that severity levels of the seedlings were always higher than those observed in the resistant clone TMS 30001 and slightly higher than those of TMS 91934.

The differences in the pressure of ACMV at Ibadan and Onne can be assessed by the results of evaluating 82 families common to the two sites in the 1991-92 seedling nursery. **Figure 13.1** shows that severity of the disease is higher at Ibadan up to the end of the rainy season (Nov), after which the severity levels were reduced, probably as a result of a dry spell.

Correlations were run between ACMV severity and root fresh wt in both Ibadan and Onne seedling nurseries in order to assess the effects of the high levels of disease incidence and severity at various stages of the growth cycle on yield of the Latin American germplasm.

Table 13.4. Incidence and severity of ACMV in seedlings of Latin American origin and IITA elite clones at Ibadan in 1991-92.

	Incidence (%)			Severity[1]		
Month	SDL[2]	TMS 91934	TMS 30001	SDL[2]	TMS 91934	TMS 30001
July	79.7			2.8		
Aug	99.7			3.6		
Sept	99.7	99.4	64.1	3.7	3.0	1.8
Oct	99.7	100.0	65.3	3.8	3.0	1.7
Nov	99.8	100.0	63.4	3.7	2.9	1.6
Dec	99.7	100.0	89.2	3.1	2.9	1.9
Jan	99.5	100.0	85.7	3.0	2.9	1.9
Feb	66.5	100.0	43.6	2.4	2.8	1.5
Mar	95.3	95.4	95.9	2.6	2.1	1.9
Apr	96.7	92.1	99.5	3.1	2.5	2.0

1 Means of a minimum of 3000 seedlings; scale: 1 = no symptoms; 5 = severe symptoms of ACMV.
2 Seedlings of Latin American origin.

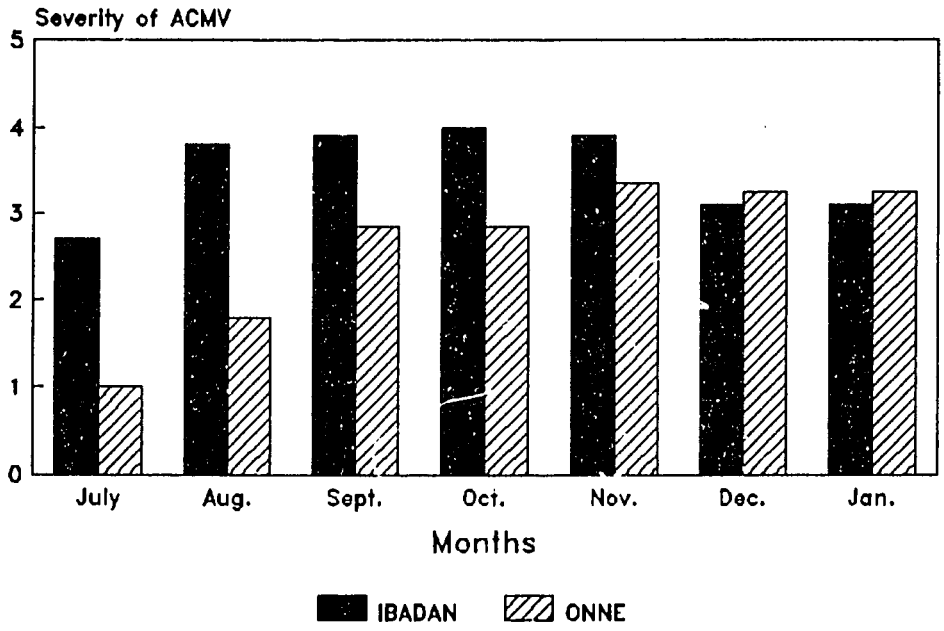

Figure 13.1 Comparison of ACMV disease severity at Ibadan and Onne.

The 1-5 evaluation scale was adopted to assess disease severity, 1 being no symptoms and 5, max. symptom expression. Recent studies at IITA[13.1] show that for genotypes with a systemic type of reaction to ACMV, this methodology can be used rather than the scale based on shoot-tip infection (used to evaluate genotypes with a nonsystemic type of reaction). The results obtained to date show that the majority of the germplasm introduced from Latin America have the systemic type of reaction. The evaluations consider the presence and degree of symptom expression in the younger leaves of the plant at the time of evaluation.

Data from 410 seedlings harvested at Ibadan were used in the correlation analysis. Each pair of data represented severity scores taken at monthly intervals in the same seedlings and the final FRW at 11 MAT. Correlations were also calculated on a family basis, by grouping the different seedlings of the same family (135 different families).

When data from individual seedlings were used, correlation coefficients between disease severity and FRW were always low, but negative (**Table 13.5**). The higher correlation coefficients were obtained when disease severity assessed during the period of max. disease pressure (Oct-Dec) was correlated with FRW. Although statistically significant (given the high number of pairs), correlations are low (**Table 13.5**).

When disease severity on a family basis was compared with mean FRW per family, there was a slight increase in the correlation coefficients. Higher values (near -0.3) were obtained when the disease was scored between Nov and Jan. The increase in *r* is probably due to a higher variation in severity levels obtained when using averages with one decimal point.

The comparison between the avg severity level (mean of 10 evaluations) and final FRW using individual seedlings and families resulted in correlation coefficients of -0.129 and -0.187, both of them lacking significance at the 0.05 level.

The results of similar correlation analyses done at Onne, using data collected from 1012 seedlings, were different. Correlation coefficients higher that -0.6 were found between Sept and Jan, as a result of a gradual increase in the disease levels at that site. Although the levels of disease severity were always lower than those recorded at Ibadan (**Table 13.6**), the larger sample size at Onne may have contributed to a more realistic comparison between disease severity and FRW.

Data collected at Onne also show a broader range of ACMV scores, as shown by the avg severity levels in each, when compared with the narrow range observed at Ibadan (**Table 13.6**). This may have contributed to the higher correlation coefficients obtained at Onne, suggesting that a higher no. of observations is needed at Ibadan.

[13.1] H.W. ROSSEL, virologist, IITA, pers. comm.

Table 13.5. Correlation coefficients between disease severity assessed at various stage of the growth cycle and final FRW of seedlings grown at Ibadan and Onne; correlations calculated on an individual and on a family basis.[1]

	Ibadan		Onne	
Month	Individual	Family	Individual	Family
July	-0.0239	-0.065	-0.0402	-0.1148
Aug	-0.0268	-0.074	-0.1661	-0.3285
Sept	-0.0615	-0.018	-0.3376	-0.6136
Oct	-0.2132	-0.277	-0.2397	-0.6102
Nov	-0.2392	-0.279	-0.4030	-0.6808
Dec	-0.1450	-0.297	-0.3343	-0.5987
Jan	-0.1521	-0.276	-0.3701	-0.5580
Feb	-0.0163	-0.045	-0.2759	-0.4117
Mar	-0.0329	-0.036	-0.3742	-0.6574
Apr	-0.0282	-0.040	-0.2853	-0.4869
Avg	-0.129	-0.1870	-0.2850	-0.4740
No.	410	135	1012	109

[1] Scale: 1-5: 1 = No symptoms.

Disease severity on a family basis was more correlated with FRW than the comparisons on an individual basis. In this case, *r* values up to -0.68 were obtained in Nov, suggesting a higher influence of the disease on yield, compared with the values obtained at Ibadan.

Although these data need further confirmation, they provide preliminary information on the effect of ACMV on yield, both on a single plant and on a family basis, using a large number of observations. Further studies are being carried out at both locations in order to understand better the relationship between ACMV and yield.

3.1.2 Kano/Zaria

The selection of germplasm adapted to the semiarid conditions in Northern Nigeria requires additional information in order to identify parameters that can better assess the tolerance of the germplasm to water stress. In addition to the evaluations for pests and diseases at all sites, in the specific case of Kano (Minjibir) some studies are being conducted in order to observe eventual differences in terms of water consumption and its relation to growth, expressed by PH measured at regular intervals. During 1991-1992 access tubes for measuring soil water content using a neutron gauge were installed both in the seedling nursery (SN) and in the clonal evaluation trial (CET). Two tubes were also installed outside the trials, as controls.

Table 13.6. Frequency of individuals in different severity classes of ACMV at Ibadan and Onne, 1991-92; data are averages of 410 and 1012 seedlings evaluated at Ibadan and Onne, resp.[1]

	Ibadan						Onne					
Month	1	2	3	4	5	Avg	1	2	3	4	5	Avg
July	88	38	186	92	6	2.7	773	31	176	32	0	1.5
Aug	1	36	235	135	3	3.2	773	31	176	32	0	1.5
Sept	3	12	188	202	5	3.5	414	57	269	246	23	2.4
Oct	2	27	173	208	0	3.4	263	86	498	155	8	2.5
Nov	3	37	175	195	0	3.4	190	36	349	421	12	3.0
Dec	3	103	255	47	1	2.9	110	26	654	207	10	3.0
Jan	2	109	249	49	1	2.8	59	49	596	284	20	3.1
Feb	2	102	273	32	0	2.8	25	115	626	231	8	3.1
Mar	12	175	214	8	0	2.5	18	187	590	205	9	3.0
Apr	15	38	280	75	0	3.0	2	27	630	305	44	3.3

[1] Evaluation Scale: 1-5; 1 = no symptoms.

Soil water status in both the SN and in the CET was monitored at 10-day intervals, starting at 140 DAP until 290 DAP. Measurements were taken at 5 different depths (25, 55, 85, 115 and 145 cm). Data for 170, 180 and 190 DAP were not obtained because of problems with the gauge.

Table 13.7 shows that Relative Water Content (RWC) was lower in the CET than in the SN. This suggests a higher ability of the clones to extract water from deeper soil layers, which can be explained by their more profuse root system. The smaller differences found at 25 cm are probably due to the little amount of water available to the plants at that depth from the beginning of the measurements.

Table 13.7. RWC (%) in five soil layers at Minjibir during the dry season and onset of the 1992 rainy season; comparison is made between clones (C) and seedlings (S) of the same age.

	25 cm		55 cm		85 cm		115 cm		145 cm	
DAP	S	C	S	C	S	C	S	C	S	C
140	5.0	4.5	6.6	5.4	9.2	6.9	10.4	9.3	11.1	12.5
150	4.7	4.5	6.3	5.2	8.9	6.5	9.9	8.5	10.6	11.4
160	4.5	4.3	6.1	5.2	8.4	6.4	9.6	7.9	10.1	10.7
200	4.1	4.2	5.7	5.0	7.8	5.9	8.7	7.0	9.0	9.5
210	3.9	4.0	5.7	4.9	7.7	5.9	8.4	6.7	8.7	9.1
220	3.9	4.0	5.5	4.8	7.5	5.9	3.3	6.8	8.7	9.0
230	3.7	4.0	5.4	4.8	7.3	5.6	8.1	6.7	8.5	8.7
240	3.6	3.8	5.3	4.7	7.4	5.6	8.1	6.7	8.3	8.6
250	3.4	3.8	5.3	4.7	7.2	5.8	7.8	6.4	8.0	8.3
260	3.3	3.8	4.9	4.6	7.1	5.7	7.7	6.4	8.2	8.1
270	4.0	4.1	5.0	4.6	7.0	5.6	7.7	6.2	8.1	7.8
280	5.0	4.9	5.2	4.6	7.0	5.4	7.7	6.3	7.9	7.9
290	4.3	4.3	5.1	4.5	7.0	5.5	7.6	6.0	7.8	7.8

RWC measured at 145 cm was slightly higher in the CET than in the SN (**Table 13.7**) given the differences in root architecture existent between clones and seedlings, with the latter having a tap root that can reach deeper layers of the soil profile.

Differences in RWC were also observed across families in the SN and across clones in the CET. **Tables 13.8 and 13.9** show changes in RWC measured in the access tubes installed in the SN and in the CET, resp., from 140 to 290 DAP.

Seedlings of families SM 1278/SM 1279, SM 1128/SM 1129 and, to a lesser extent, SM 948/SM 959 were able to reduce more RWC in the soil from 140 to 290 DAP, indicating a higher capacity for water extraction (**Table 13.8**).

Table 13.8. Changes in RWC in access tubes installed inbetween plants of two adjacent families in the Minjibir SN during the 1991-92 dry season; measurements were taken at 25, 55, 85, 115 and 145 cm.

		DAT												
T[1]	Families	140	150	160	200	210	220	230	240	250	260	270	280	290
12	SM 1287/1288	9.8	9.4	9.0	8.0	7.9	7.8	7.7	7.5	7.5	7.9	9.8	7.6	7.2
6	CM 7543/7576	9.7	9.2	8.7	8.1	8.1	8.0	7.9	7.8	7.8	7.4	7.6	8.1	7.8
9	SM 1128/1129	9.4	8.8	8.3	7.2	6.9	6.7	6.4	6.4	6.3	5.9	6.1	6.3	5.8
8	SM 948/959	9.3	8.9	8.6	7.7	7.3	7.1	6.9	6.7	6.5	6.3	6.4	6.6	6.1
5	SM 1627/1632	9.0	8.5	8.1	7.0	6.8	6.7	6.7	6.6	6.7	6.6	6.6	6.6	6.5
10	SM 1197/1198	8.9	8.5	8.1	7.1	6.8	6.7	6.5	6.5	5.9	6.1	6.2	6.4	6.3
11	SM 1278/1279	8.8	8.2	7.6	6.6	6.3	6.0	5.6	5.5	5.0	5.1	5.2	5.3	5.1
4	SM 1606/1608	8.4	8.0	7.7	7.2	6.9	6.8	6.6	6.6	6.3	6.3	6.4	6.6	6.6
7	CM 7966/7975	7.8	7.0	7.0	6.3	6.1	6.1	5.8	5.6	5.3	5.4	5.3	5.4	5.6
3	SM 1509/1510	7.4	7.2	6.9	6.8	6.9	6.9	6.9	7.0	6.9	6.7	6.9	7.2	6.9
2	SM 1321/1322	6.7	6.7	6.6	6.5	6.4	6.4	6.5	6.5	6.3	6.4	6.4	6.5	6.5
1	SM 1118/1296	6.1	6.1	6.2	6.0	5.9	6.1	5.8	5.9	5.7	5.7	6.0	6.5	6.0
	Average	8.4	8.1	7.7	7.1	6.9	6.8	6.6	6.5	6.3	6.2	6.4	6.6	6.4
	LSD (0.05)	1.2	1.1	1.0	0.8	0.7	0.8	0.7	0.7	0.7	0.8	0.7	0.6	0.7

[1] T = Access tube no.

Changes in RWC measured near families SM 1188/SM 1296, SM 1321/SM 1322 and SM 1509/SM 1510 were minor, suggesting a lower water extraction capacity.

RWC measured near clones SM 1256-7/9, SM 1277-8/22 and SM 1280-21/26 was always higher than measurements taken near the other clones (**Table 13.9**); on the other hand, RWC was very low near clones SM 1250-20/32. This suggests a greater ability of these two clones to extract water from the soil.

Changes in PH measured in 10 plants per family and 3 plants per clone planted near the access tubes are expressed by the slope of linear regressions calculated against time. Two regression lines were calculated for each family/clone using two different periods: a dry period (140-260 DAP) and a recovery period (270-310 DAP), following the onset of the first rains in April 1992. As shown in **Tables 13.10 and 13.11**, the linear approach gave R^2 values of 0.98 or higher, which justifies the use of linear equations.

Growth of seedlings was higher than that of clones during the dry period (**Tables 13.10 and 13.11**). During the recovery period, however, the clones were able to grow at higher rates. It is hypothesized that the more voluminous superficial root system characteristic of vegetatively propagated plants was more efficient in absorbing water from the superficial layers of the soil after the first rains.

The higher growth rates observed in the seedlings during the dry period are probably due to the ability of the tap roots to grow deeper and then, to reach deeper layers of the soil profile, vs. the root systems of the clones.

Differences in growth across families and clones were also detected (**Tables 13.10 and 13.11**). During the dry period families SM 1321, SM 1632, CM 7543 and CM 7576 had higher growth rates than the other seedlings measured. During the recovery phase, however, plants of these families--except those of SM 1632--had a reduction in growth rates, probably due to the exhaustion of the water available in the soil during the dry season.

On the other hand, plants of families SM 1288, Sm 1278, SM 1128 and SM 1129 significantly increased their growth rates during the recovery phase, as compared with rates measured during the dry period. This suggests a greater ability to use the water made available in the topsoil as a result of the first rains. **Table 13.10** also show that these families extracted more water during the whole period of measurement.

Families SM 1606, SM 1608, SM 1627 and, especially, SM 1632 had very high growth rates both in the dry period and in the recovery phase. This shows a very high capacity for extracting water from the soil and can also be related to the genetic background of the seedlings, originated from crosses made between parents adapted to the dry areas of NE Brazil.

Table 13.9. Changes in RWC in access tubes installed inbetween plants of two adjacent clones in the Minjibir CET during the 1991-92 dry season; measurements were taken at 25, 55, 85, 115 and 145 cm.

		DAP												
T[1]	Clone	140	150	160	200	210	220	230	240	250	260	270	280	290
20	SM 1256-7/9	9.7	9.0	8.7	8.0	7.5	7.6	7.4	7.4	7.6	6.6	6.6	6.6	6.3
17	SM 1277-8/22	9.4	8.8	8.4	7.6	7.3	7.1	6.9	6.8	6.7	6.8	6.8	6.7	6.4
18	SM 1280-21/26	8.6	8.1	7.7	7.0	6.9	6.7	6.5	6.3	6.3	6.2	6.4	6.7	6.7
16	SM 1250-7/13	7.7	7.2	6.8	6.0	5.9	5.8	5.7	5.6	5.6	5.4	5.3	5.6	5.4
15	SM 1247-21/26	7.0	6.7	6.5	5.9	5.8	5.8	5.7	5.6	5.6	5.6	5.5	5.8	5.5
13	SM 816-21/25	6.9	6.4	6.0	5.6	5.4	5.5	5.3	5.3	5.3	5.0	5.0	5.2	5.1
14	SM 867-9/12	6.7	6.0	5.8	5.5	5.2	5.2	5.2	5.0	5.0	5.3	5.1	5.1	5.0
19	SM 1250-20/32	5.9	5.5	5.4	5.0	5.0	5.1	4.9	4.9	4.8	4.8	4.8	4.9	4.6
	Avg	7.7	7.2	6.9	6.3	6.1	6.1	6.0	5.9	5.8	5.7	5.7	5.8	5.6
	LSD (0.05)	1.3	1.1	1.1	1.1	1.0	1.0	1.0	0.9	1.0	0.9	0.9	0.9	1.0

[1] Access tube no.

Table 13.10. Coefficients of determination (R^2) and regression line slopes (b) calculated on the basis of PH (Y) and time (X) for cassava seedlings of different families planted at Minjibir; data are avg of 10 seedlings/family.

	140-160 DAT		260-310 DAT	
Family	R^2	Slope	R^2	Slope
SM 1188	0.97	0.258	0.99	0.333
SM 1296	0.99	0.239	0.99	0.310
SM 1321	0.99	0.418	0.98	0.390
SM 1322	0.99	0.299	0.99	0.250
SM 1509	0.97	0.221	1.00	0.200
SM 1510	0.99	0.244	0.99	0.290
SM 1606	0.98	0.368	0.99	0.330
SM 1608	0.99	0.351	0.99	0.450
SM 1627	0.9[illegible]	0.321	0.97	0.410
SM 1632	0.97	0.487	0.99	0.600
CM 7543	0.97	0.424	0.96	0.410
CM 7576	0.97	0.465	0.99	0.320
CM 7966	0.99	0.391	0.99	0.280
CM 7975	0.99	0.333	0.99	0.230
SM 948	0.98	0.252	0.98	0.320
SM 959	0.99	0.335	0.98	0.270
SM 1128	0.97	0.228	0.99	0.310
SM 1129	0.97	0.282	0.99	0.430
SM 1197	0.99	0.302	0.92	0.320
SM 1198	0.98	0.258	0.98	0.280
SM 1278	[illegible]	0.309	0.99	0.380
SM 1279	0.96	0.340	0.99	0.410
SM 1287	0.98	0.159	0.98	0.200
SM 1288	0.99	0.286	0.82	0.370
Avg	0.99	0.328	0.98	0.337

3.2 Ongoing Activities

In 1992 a total of 33,434 seeds were sown in screenhouses at the 4 sites and the resulting seedlings transplanted after careful inspection. The no. of seedlings transplanted in each location was 3514, 2606, 2597 and 668 at Ibadan, Kano, Jos and Onne, resp. Another introduction of 13,863 seeds representing 147 families was done in Mzuzu, Malawi, in coordination with IITA's East and Southern Africa Root Crops Research Network. Families to be tested in Malawi are potentially adapted to semiarid and high-altitude areas of Latin America and will be evaluated under similar conditions in Southern Africa.

Table 13.11. Coefficients of determination (R^2) and regression line slopes calculated on the basis of plant height (Y) and time (X) for cassava clones planted in Mingibir; data are avg of 10 seedlings/family.

	140-160 DAT		260-310 DAT	
Clone	R^2	Slope	R^2	Slope
SM 816-21	0.99	0.192	0.99	0.240
SM 816-25	0.98	0.148	0.99	0.310
SM 867-9	0.98	0.208	0.99	0.430
SM 867-12	0.98	0.185	0.98	0.240
SM 1247-21	0.98	0.289	0.91	0.560
SM 1247-26	0.98	0.143	1.00	0.200
SM 1250-7	0.98	0.447	0.99	0.560
SM 1250-13	0.98	0.231	0.98	0.270
SM 1277-8	0.96	0.334	0.99	0.360
SM 1277-22	0.98	0.200	0.99	0.320
SM 1280-21	0.99	0.192	0.99	0.420
SM 1280-26	0.98	0.196	0.99	0.330
SM 1250-21	0.99	0.317	0.97	0.330
SM 1250-32	0.99	0.258	0.99	0.450
SM 1256-7	0.99	0.298	0.99	0.460
SM 1256-9	0.99	0.171	0.93	0.350
Avg	0.97	0.238	0.97	0.310
SM 1129	0.97	0.282	0.99	0.430
SM 1197	0.99	0.302	0.92	0.320
SM 1198	0.98	0.258	0.98	0.280
SM 1278	0.98	0.309	0.99	0.380
SM 1279	0.98	0.340	0.99	0.410
SM 1287	0.98	0.159	0.98	0.200
SM 1288	0.99	0.286	0.82	0.370
Avg	0.986	0.328	0.98	0.337

14. DISEASE MANAGEMENT

14.1 Control of Root Rots

The risk of root rot epidemics is high in most cassava-growing areas. It probably constitutes the most important biotic problems of the crop in a given region for the following reasons:

i) The pathogens directly attack the roots (the most valuable product), causing a damage that cannot be recovered.

   Several pathogenic bacteria, fungi and phytomonads (35 spp. have been reported as root rot pathogens thus far) can induce root rots, alone or synergetically, making genetic control difficult.

ii) Most cassava root rot causal agents are systemic and are disseminated through the use of stakes taken from affected plants.

iii) Most of these pathogens are facultative saprophytes able to survive in the soil for long time.

Consequently, research on the control of cassava root rots has been organized by establishing a network in 19 different sites: 16 sites in 9 states of N and NE Brazil and 3 sites in Colombia. Where root rots are important, strategies are directed toward integrating cultural practices, genetic resistance, biological control and chemical treatment of cuttings into production packages that can be implemented in edaphoclimatically similar cassava-growing areas. The following is a summary of the results of the trials at the 19 locations.

14.1.1 Cultural practices

Results suggest that cultural practices can be put into two groups according to the extent of control or prevention of one or more root rot diseases.

- Universal. The following cultural practices are recommended to be implemented in all cassava plantations with root rot problems. Their effect relates to the prevention of root rot dissemination and the reduction of the inoculum potential of the pathogens in infested soil.

  - Use of pathogen-free planting material. Stakes should be taken from harvested plants with high yields and healthy root systems.

- Rotation with a crop immune to pathogen(s) affecting cassava in the target region. This control measure should be applied every time that root rot incidence is higher than 3% at harvest.

- Elimination of affected plant debris after harvesting the crop. All affected stems and roots should be removed from the plantation and burned.

- Elimination of excess water. Each plot should be well drained before planting as excess water predisposes plants to root rot infections. In areas with persistent water problems, drainage channels to each plot should be built before planting.

■ Regional. The following cultural practices are recommended for cassava plantations affected by one or more pathogens that can be controlled effectively only by specific means:

- Planting on ridges. This practice is recommended for soils with high water retention and poor drainage capacity or in regions where rainfall is higher than 1200 mm/yr or where prolonged rainfall periods are frequent (more than 2 consecutive days). This planting system is effective for controlling those pathogens favored by high soil water content (*Pythium, Phytophthora, Fusarium* spp.).

- Intercropping cassava with maize or sorghum reduces the spread of those pathogens that are disseminated by water splashing or wind within plantations (e.g., *Xanthomonas campestris* pv *manihotis, Diplodia manihotis*).

- Mulching can enhance root rot problems if soils are infested with root rot pathogens whose incidence and severity are favored by soil water saturation. This practice is not recommended in wet areas with root rot problems.

- Manipulation of planting time has shown to be effective in reducing root rot losses induced by some root rot pathogens (e.g., *X. campestris* pv. *manihotis, Pythium* sp.), but the control measure appears to be location specific, thus requiring validation before its implementation.

- Early harvesting avoids late root rot problems induced by pathogens that appear to prefer swollen starchy root tissues (*Rhizoctonia* sp., *Verticillium dahliae*). Damage induced by these pathogens generally begins 6 to 7 mo after planting. To implement this practice it is necessary to plant precocious clones that accumulate in the roots early.

- Reduced planting distance. It has been observed that the extent of root rot damage is greater in high-density plots (less than 80 x 60 cm between rows and plants). This appears to be due to the effect of the plant canopy on soil water

evaporation, resulting in increased periods of water-logging. A 1.0 m planting distance is recommended in root rot-infested areas.

14.1.2 Genetic control

Root rot damage appears to be higher when susceptible branched clones are planted in affected plots than when unbranched clones are planted in similar plots. This appears to be related to the effect of water from saturated soils. When it is necessary to intercrop cassava with rice or sorghum to control root rot pathogens disseminated by wind or water splash, unbranched types are required.

Clones that are resistant/tolerant to root rot pathogens have been identified in *M. esculenta*. Some clones can become susceptible to the group of root rot pathogens that prefer swollen starchy root tissues 6 or more mo after planting; however, these clones produce steadily when production packages for controlling root rot are implemented. This year, for example, the clone EMBRAPA 8 (IM 186) was released in cooperation with EMBRAPA (the Centro de Pesquisa Agroforestal de la Amazonia, CPAA and CNPMF) for the Amazon varzea region. By following a production package that included spacing, stake size, chemical treatments, planting on ridges and the latest possible harvesting period (at 7 mo), the avg yields obtained on large production plots (more than 1/2 ha) over a 3-yr period were 25 t/ha vs. only 14.5 t/ha without the production package.

Resistant clones selected in a given locality were susceptible or poorly adapted in other regions. The aforementioned clone EMBRAPA 8 showed high susceptibility to *Scytalidium* sp. in Pernambuco. This pathogen is not present in the varzea region, where the clone was selected.

14.1.3 Chemical control

Chemical treatment of stakes has proven effective in protecting them against soil-borne pathogens in infested fields. This is not an effective method for eradicating pathogens from the stake tissues, but can disinfest stakes from secondary infection by fungal propagules of wind-blown pathogens.

14.2 Cultural Control of CBB

The severity of CBB has been increasing progressively on the Atlantic Coast of Colombia for the last three years, mainly as a result of using unselected stakes for planting and the lack of appropriate cultural practices directed to reduce disease incidence in this CBB-endemic region. In a location where plantations were severely affected in 1991, the following cultural practices were used to control CBB: plant debris from previous planting was burned, planting material was taken from healthy-looking plants, and cassava was intercropped with maize. Results (**Table 14.1**) have shown a sharp decrease in CBB severity and incidence. Similarly, SED (a wind-borne disease) severity and incidence were

also significantly reduced. This system, reported in the 1986 Annual Report, was first validated in the state of Santa Catarina (Brazil) in 1988 with similar results. This system should be implemented in CBB-endemic areas in plantations for producing high-quality stakes.

Table 14.1 CBB and SE incidence and severity on plots where heavily CBB-infected plant debris was burned, planting material was selected from CBB-symptomless plants, and cassava was intercropped with maize.

	Disease Incidence (%)		Disease Severity[1]	
Production System	CBB	SE	CBB	SE
Improved system	6	0	1.0	1.0
Traditional system[2]	100	73.5	2.7	3.4

[1] Disease severity: 1 = no symptoms; 5 = dieback and plant death.

[2] Monocropping.

15. PEST MANAGEMENT

15.1 Acarology

15.1.1 Major activities and results

Tetranychid mites are significant pests throughout the African cassava belt and in several seasonally dry to semiarid cassava-growing areas in the Americas. In order to contribute to the Program's crop management objectives, the focus during 1992 was on meeting needs for methodology development, strategic research and training identified by the national agricultural research institutions of Brazil and Ecuador, and by IITA in Africa.

In 1993 a major collaborative project with EMBRAPA will be initiated in Brazil and IITA, focusing on the implementation of integrated pest and disease management in cassava in 3 NE Brazilian states and 4 W African countries. Among the goals of this project are to establish effective exotic natural enemies of the CGM (*Mononychellus tanajoa*) in Africa; select and introduce exotic species and/or strains of natural enemies to Brazil; and develop methods for enhancing and conserving native and introduced biological control agents.

In Ecuador the cassava Caribbean mite (CCM)(*M. caribbeanae*) is thought to be the major pest limiting cassava production in the dry coastal areas of the country. The Instituto Nacional de Investigaciones Agropecuarias (INIAP) has requested support in measuring the impact of CCM and in developing control alternatives. Initially in-service training was provided to an INIAP entomologist, and a document was compiled with basic information on the distribution of CCM and its natural enemies in Ecuador, the biology and ecology of the mite and its antagonists, and basic acarological research methodology.

In the subsequent sections activities in methodology development are described; the strategic research is summarized in Chap. 8.

15.1.2 Phytoseiid release methodology

Between 1984 and 1988 more than 5.5 million phytoseiids (18 strains of 11 spp.) of Colombian origin were released at 348 sites in 10 African countries;[15.1] but establishment was not achieved. From 1988-90, 1.9 million *Neoseiulus idaeus* and *Typhlodromalus limonicus s.l.* from NE Brazil were released at 133 sites in 6 countries, resulting in the

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[15.1] YANINEK, J., A. ONZO & B. OJO. Continent-wide experiences releasing neotropical phytoseiids against the exotic cassava green mite in Africa. (submitted)

establishment of *N. idaeus* in Benin[15.2]. Releases were made in plantations of more than 300 plants of a single clone, and 30 adult female phytoseiids were released on an avg of 35 pl/site. Fields 3-6 mo old at the start of the dry season were chosen as such plantings were young enough to support increasing *M. tanajoa* populations during the dry season, but would not be harvested prior to the following wet season. Other than guaranteeing temporal continuity of cassava, other controls on macro- or microhabitat conditions at the time of release were not reported.[15.3]

The establishment rate in Africa on a per-site basis was low. The specific reasons for establishment failures--particularly of phytoseiids of Colombian origin--are poorly understood; however it is known that they are sensitive to habitat conditions[15.4] (see Sect. 8.1.4). Microhabitat conditions at release sites should be considered in the planning of release strategies in order to improve the probability of establishment.

Many of the phytoseiid mites associated with cassava are generalists that consume acarine and nonacarine foods [e.g., *Typhlodromalus* spp. (see Sect. 8.1.2)[15.5]]. The Mesa-Bellotti rearing method, which provides tetranychid mites on a leaf substrate, was developed in response to difficulties in rearing such species with the standard McMurtry & Scriven method.[15.6] The cassava *Neoseiulus* spp., on the other hand, are specialists, feeding primarily on acarine prey. These differences suggest that release plans for different phytoseiid types should be developed. Acarine specialists may require a high density of prey at release time and may benefit from the presence of other tetranychid-infested plants (e.g., weeds), which can serve as a refuge during periods of low CGM density. Generalist species can be expected to survive periods of low CGM density; however, the presence of alternate foods when the releases are made may be critical to establishment. Factors such as the degree of mite or other damage to the leaves and the presence of high numbers of phytophagous mite exuviae may affect the availability of alternate foods or phytoseiid prey-searching efficiency. Phytoseiid sensitivity to microhabitat and food conditions suggests that a release strategy involving an intensive effort in a limited number of sites and including experimentation with different methods,

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[15.2] YANINEK, J.S., B. MEGEVAND, G.J. DE MORAES, F. BAKKER, A. BRAUN & H. HERREN. 1991. Establishment of the neotropical predator *Amblyseius idaeus* (Acari: Phytoseiidae) in Benin, West Africa. Biocontrol Sci. Tech. 1:323-330.

[15.3] Yaninek et al. (submitted), op cit.

[15.4] BAKKER, F.M., M. KLEIN, N.C. MESA & A.R. BRAUN. Drought tolerance of phytophagous mites and their phytoseiid predators on cassava. (submitted); Yaninek et al., 1991, op cit.

[15.5] BAKKER, F. & M.E. KLEIN. 1992. Transtrophic interactions in cassava. Exp. Appl. Acarol. 14:293-311.

[15.6] McMURTRY, J.S., & G.T. SCRIVEN. 1965. Insectary production of phytoseiid mites. Econ. Entomol. 58:282-284.

may be called for. Once the factors affecting establishment are better understood, a more extensive strategy may be employed.

Preliminary observations were made on the use of field cages for pre-release adaptation of lab-reared *N. idaeus* (Fonseca, Depto. Guajira, Colombia strain) and *T. tenuiscutus* (Quevedo, Ecuador). These species have never been reported at the release site (CIAT). Two field cages of black plastic screening supported on a tubular PVC frame (3 x 3 x 2 m) were placed over 9 six-month-old plants of CMC-40 with a low to moderate population of *Mononychellus* spp. and native phytoseiid fauna associated with the Colombian inter-Andean zone. Approx. 100 individuals/pl of one sp. were liberated per cage. After 5 days the cages were removed and 8 days later, weekly sampling of one upper, intermediate and lower leaf/pl was initiated. All phytoseiid stages were counted under a dissecting microscope, and all adults were collected in lactophenol and identified to species.[15.7]

N. idaeus was recovered over a 2-mo period from all leaf strata (**Fig. 15.1**); numbers dropped after 2 rainy weeks. Subsequently, the disappearance of *N. idaeus* coincided with an increase in *T. limonicus s.l.* numbers, particularly in the upper and lower leaves. *N. anonymus* was observed sporadically in low numbers during the first 2 mo.

As *T. tenuiscutus* was never recovered, the second cage served as a control for the *N. idaeus* cage (**Fig. 15.2**). In the latter cage, *N. anonymus* was displaced by *N. idaeus* (**Figs. 15.1 & 15.2**) and *T. limonicus s.l.* numbers were suppressed, presumably through competition with *N. idaeus*.

The feasibility of multiplying an exotic species under semiprotected conditions in the field was studied in a set of 3 cages identical to those already described, placed over 9 plants of M Mex 59. From 800-1000 individuals of *N. idaeus* (Fonseca) were released in one cage. The same number of *T. tenuiscutus* (Quevedo) were released in another cage. A third containing only the native phytoseiid population served as the control. In the cages inoculated with phytoseiids, 15 leaves from the upper, intermediate and lower foliage were sampled weekly over a period of 3 mo, and 35 leaves were collected from the control cage. All female phytoseiids were counted, and a subsample (n=10/stratum) was identified to species. The population of phytophagous mites dropped drastically in all 3 cages 6 wk after inoculation. The foliage was cut and transferred to an adjacent group of 9 mite-infested plants in order to inoculate the new sites with phytoseiids. Sampling was resumed one week later.

[15.7] CIAT. 1990. Cassava acarology. *In* Annual Report. Cassava Program (Working Document No. 95), pp. 145-171. CIAT, Cali, Colombia.

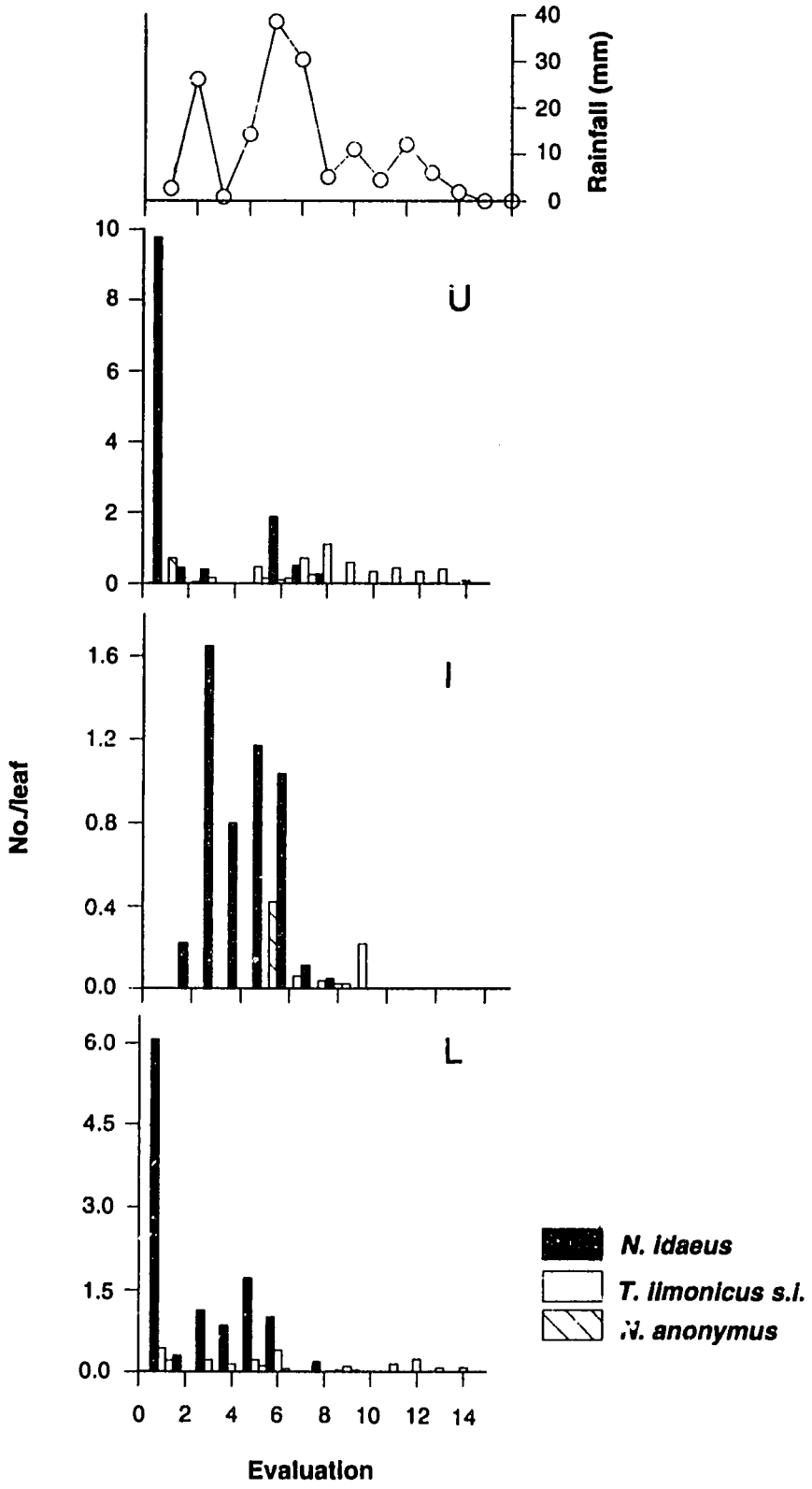


Figure 15.1 Population dynamics of *N. idaeus* and *T. limonicus s.l.* in upper (U), intermediate (I) and lower (L) leaves in plants where *N. idaeus* was released; the upper panel shows total rainfall for the week preceding each sampling date.

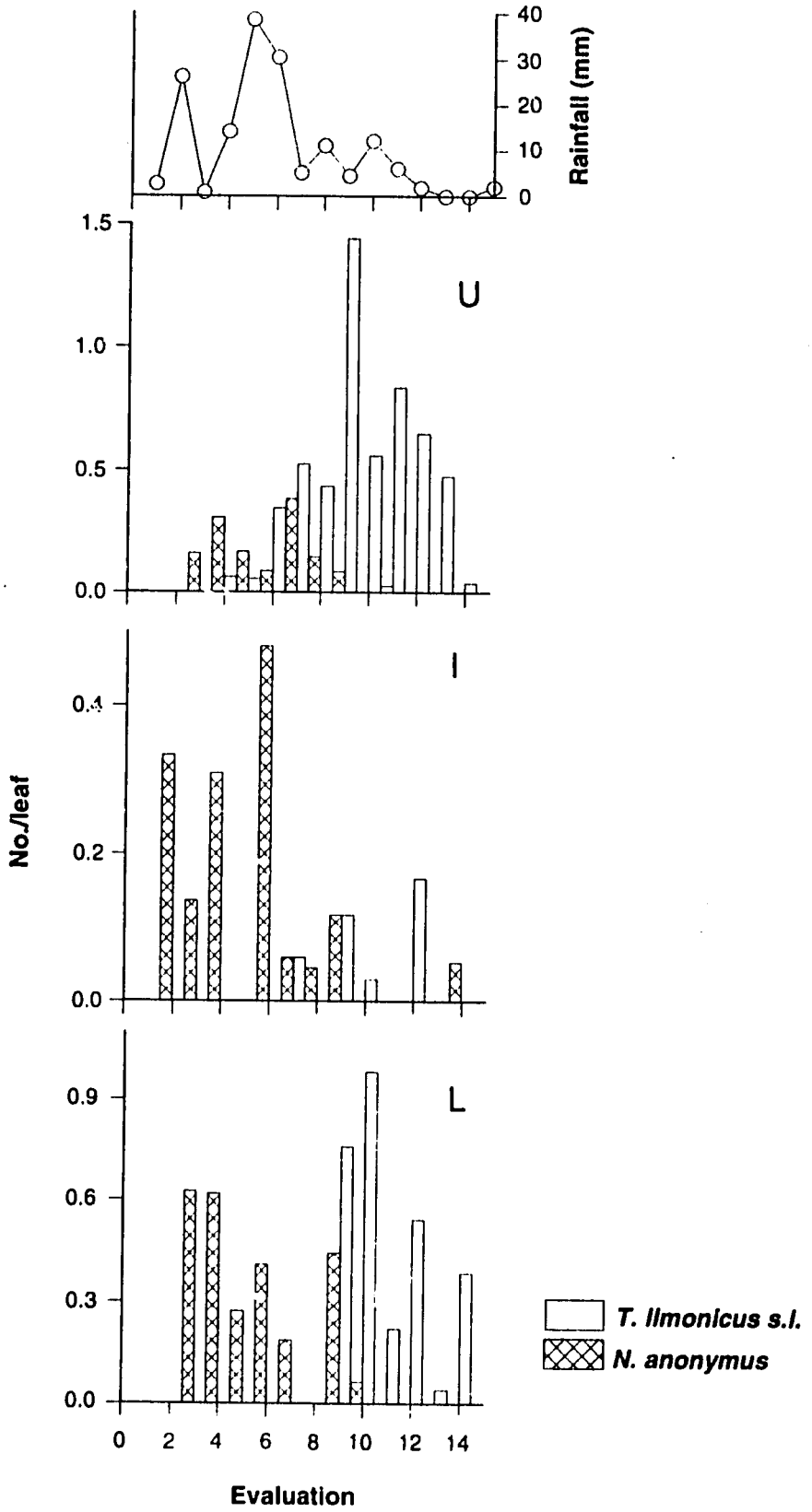


Figure 15.2 Population dynamics of *T. limonicus s.l.* and *N. anonymus* in upper (U), intermediate (I) and lower (L) leaves in plants where *T. tenuiscutus* was released but not recovered; the upper panel shows total rainfall for the week preceding each sampling date.

In the *N. idaeus* cage the exotic population persisted in all leaf strata throughout the 3-mo sampling period (**Fig. 15.3**). The native phytoseiid (*T. limonicus s.l.*) persisted in the control cage throughout the sampling period, but was suppressed by *N. idaeus* in the cage where it was released. *E. ho* and *N. anonymus* were displaced by competition from *N. idaeus* (**Fig. 15.3 & 15.4**), and *N. idaeus* invaded the control cage from the adjacent cage where it had been released. *N. idaeus* densities were higher in the lower leaves and when the field cage was left in place (**Fig. 15.1 & 15.3**).

In contrast to the previous experiment, when the field cage was left in place, low numbers of *T. tenuiscutus* were recovered over a period of ± 6 wk, primarily from the lower and intermediate leaves (**Fig. 15.5**). The native species *T. limonicus s.l.* dominated the phytoseiid fauna in the cage and was not suppressed relative to the control (**Figs. 15.4 & 15.5**).

Field cages that provide shade and a RH above the ambient level may offer a means of gradually adapting lab-reared phytoseiids to field conditions and of increasing their numbers before release. Such methods may also provide greater flexibility in timing releases.

15.1.3 Cassava Caribbean mite sampling

Yaninek et al.[15.8] developed a method for rapid estimation of *M. tanajoa* in the field: 30 leaves/plot are inspected and classified on a scale of 1 to 4 (1 = no mites; 2 = 1-25 mites/leaf; 3 = 26-200 mites/leaf; 4 = >200 mites/leaf). Factors for converting the scale to the mean no. of mites/leaf were based on direct counts of the no. of mites on leaves that had been previously evaluated with the scale method. *M. caribbeanae* can reach significantly higher densities than *M. tanajoa* under field conditions on the Atlantic Coast of Colombia[15.9], suggesting that sampling coefficients determined for *M. tanajoa* should not be assumed to be valid for other species of *Mononychellus*. Braun et al.[15.10] (1989) showed that clone, leaf age and the presence of predators affect the spatial distribution of *M. tanajoa*, suggesting that sampling coefficients for *Mononychellus* spp. should be adjusted for local conditions.

[15.8] YANINEK, J.S., G.J. DE MORAES & R.H. MARKHAM. 1989. Handbook on the cassava green mite (*Mononychellus tanajoa*) in Africa. Rome: Alphabyte Ed.

[15.9] HERRERA, C.J., M.M. GUERRERO & A.R. BRAUN. Impacto de predadores (Acari: Phytoseiidae) asociados al cultivo de la yuca sobre *Mononychellus* spp. en la Costa Atlántica de Colombia. (submitted)

[15.10] BRAUN, A.R., J.M. GUERRERO, A.C. BELLOTTI & L.T. WILSON. 1989. Within-plant distribution of *Mononychellus tanajoa* (Bondar) (Acari: Tetranychidae) on cassava: Effect of clone and predation on aggregation. Bull. Entomol. Res. 79:235-249.

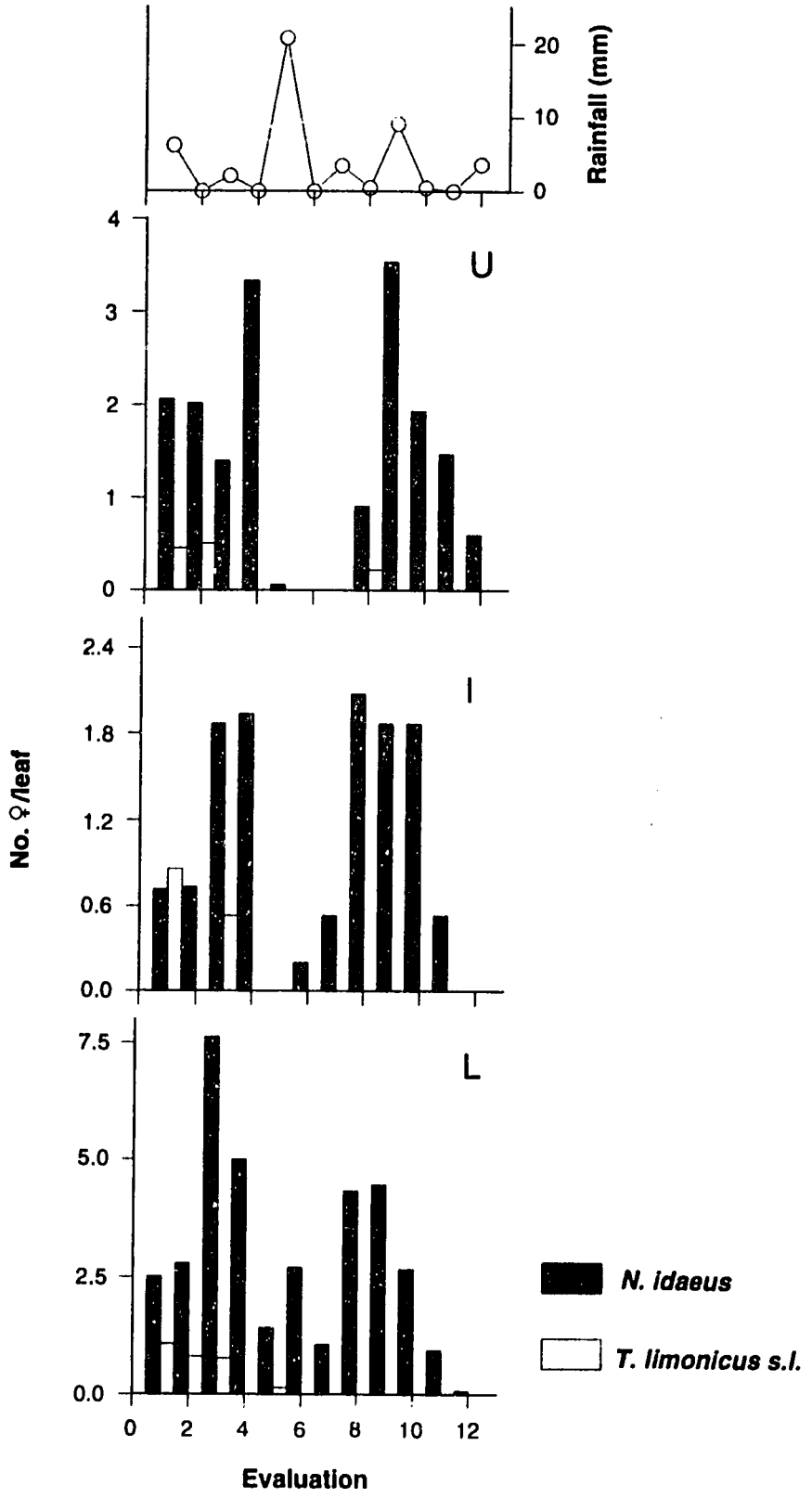


Figure 15.3 Population dynamics of exotic *N. idaeus* and native *T. limonicus s.l.* in the upper (U), intermediate (I) and lower (L) leaves of a field cage.

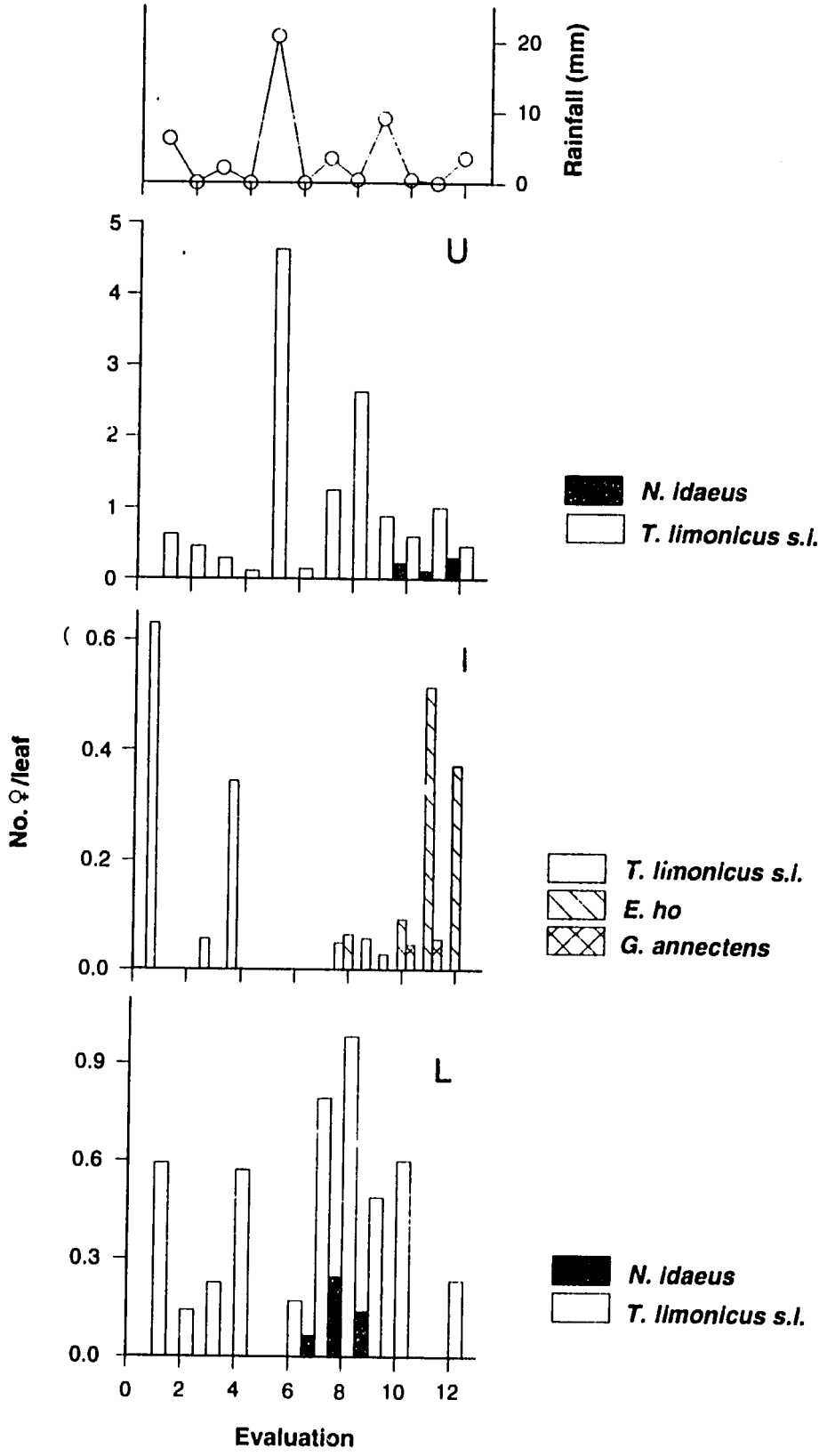


Figure 15.4 Population dynamics of the native phytoseiids *T. limonicus s.l*, *E. ho* and *G. annectens* in the upper (U), intermediate (I) and lower (L) leaves of a field cage.

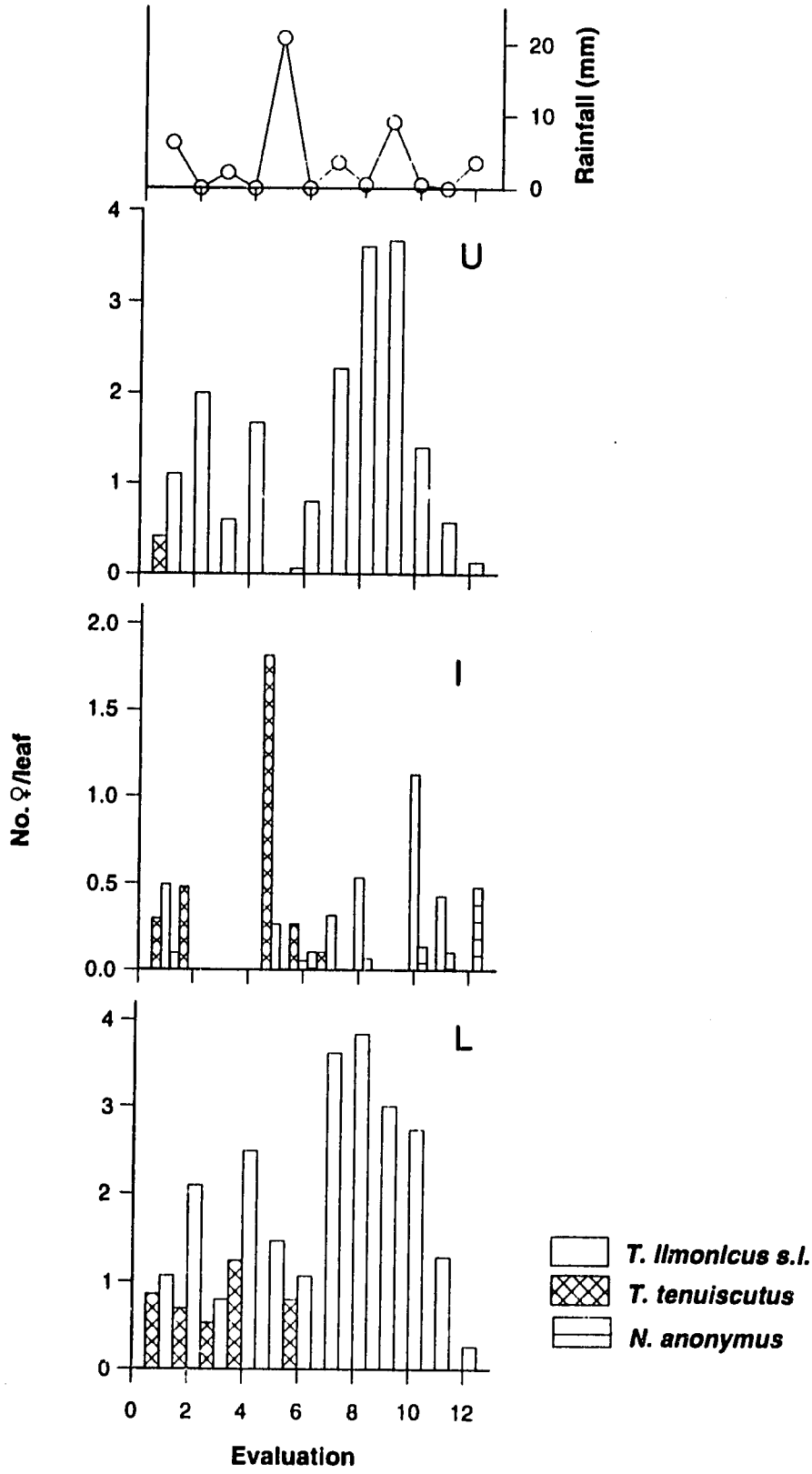


Figure 15.5 Population dynamics of exotic *T. tenuiscutus* and the native species *T. limonicus s.l.* and *N. anonymus* in upper (U), intermediate (I) and lower (L) leaves of a field cage.

Factors for converting scale evaluations of *M. caribbeanae* to mean no./leaf were determined for 4 leaf strata (**Table 15.1**) in Fonseca (Colombia), a site with 5 dry mo and 946 mm rainfall/yr. In upper and middle leaves, samplers consistently underestimated mite numbers. In lower leaves samplers overestimated moderate populations of CCM. The coefficients for levels 1-10 and 11-20 indicate that CCM densities reach similar levels in the upper and middle leaves; few CCM occurred below node 30.

Table 15.1. Factors for converting population scale to no. of *M. caribbeanae*/leaf in 4 leaf strata of cassava.

Stratum[1]	Scale[2]	n	Conversion Factor	SE
1-10	1	29	2.8	1.2
	2	66	61.1	9.6
	3	66	220.0	20.1
	4	34	413.1	53.9
11-20	1	29	5.7	1.6
	2	68	73.9	12.4
	3	57	280.6	36.7
	4	25	405.9	61.9
21-30	1	40	16.6	7.3
	2	56	95.5	18.9
	3	22	90.0	17.7
	4	-	-	-
31-40	1	26	4.6	2.3
	2	12	61.0	25.2
	3	-	-	-
	4	-	-	-

[1] Node position of leaf from growing point down: 1 = first fully opened leaf with petiole at 45° angle to stem.
[2] 1 = no mites; 2 = 1-25 mites/leaf; 3 = 26-200 mites/leaf; 4 = >200 mites/leaf.

15.1.4 Host plant resistance (HPR)

Germplasm from the Germplasm Development Program was evaluated at CIAT HQ, Media Luna and Santo Tomás for cassava mite (*Mononychellus* spp.) damage, using the following scale:

1 = no mite damage
2 = chlorotic spots present on less than 25% of leaf surface
3 = chlorosis severer; present on 25-50% of leaf surface; some leaf size reduction observed
4 = severe chlorosis on more than 50% of leaf surface
5 = leaf necrosis and defoliation

Clones selected for further evaluation have a damage rating below 3 on the scale (**Table 15.2**). Mite population pressure was not high so selected lines will be replanted and evaluated for a second year. Selected materials will also be evaluated in the screenhouse with artificial infestation.

Table 15.2 Preliminar evaluation and selection of progeny from controlled crosses from the cassava Germplasm Development Program at CIAT, Media Luna and Santo Tomás.

Site	Germplasm[1] Stage Evaluated	No. of Lines Evaluated	No. of Lines Selected	No. Evaluations (mo eval.)
CIAT	FYT GY 9172	413	41	2 (5 & 11)
	PYT GY 9108	230	35	1 (7)
	AYT GY 9174	112	65	2 (5 & 10)
	AYT GY 9109	126	20	1 (7)
	AYT GY 9151	221	27	1 (5)
	AYT GY 9175	111	28	2 (5 & 9)
Media Luna	FOT GY 9162	417	50	1 (7)
	RYT GY 9164	53	10	1 (7)
Santo Tomás	FOT GY 9166	135	56	1 (7)
	PYT GY 9167	66	23	1 (7)
CIAT	Wild Spp.	Spp. eval. 23	Spp. select. 1	

[1] OYT = Observational yield trial (F_1, or F_1 C_1)
PYT = Preliminary yield trials
AYT = Replicated yield trial

Whitefly-resistant clones (M Bra 12, M Ecu 72) and 3 selected progeny (CG 489-23, CG 489-31, CG 489-34) were evaluated for mite damage at CIAT. M Bra 12, a tolerant clone, sustains high populations of *Mononychellus* (3.5-4.0 damage rating) without suffering severe yield depression. M Ecu 72 demonstrates high levels of resistance, displaying minimal leaf damage (2.0-2.5 damage rating). The three aforementioned progeny are intermediate between both parents (3.0-3.5 damage rating); CG 489-31 and CG 489-34 behave more like M Ecu 72, which has a lower rating (3.0) than CG 489-23, which is similar to M Bra 12 (3.5 damage rating).

15.2 Entomology

15.2.1 Cassava mealybug

One hundred clones from the core collection were evaluated for mealybug resistance at Carimagua. Three reps of 5- and 2-mo-old plants were artificially infested with mealybug

eggs (one ovisac/pl) to promote uniform population pressure. Plants were evaluated 1 and 2 mo after infestation.

Seven clones were selected as promising for resistance/tolerance (**Table 15.3**). All selected clones were evaluated at less than 5 (1 = no damage, 9 = defoliation and plant distortion); the susceptible check M Ven 77 received a damage rating of 7. M Bra 12--a clone selected as tolerant to whiteflies and mites--received a damage rating of 2 and 4 in the two evaluations, resp. Selected clones will be reevaluated, using yield depression techniques, during a second year cycle.

Table 15.3. Selected cassava clones from a screening of 100 core collection clones for mealybug (*P. herreni*) damage at Carimagua.

	Damage rating[1]	
Clone	1st. Evaluation	2nd. Evaluation
CMC 7270-2	4	5
CM 7232-9	3	4
M Bra. 12	2	4
SM 1045-13	2	2
CM 7255-1	3	4
SM 1146-1	3	3
SM 1044-17	3	4
M Ven 77[2]	5	7

[1] Damage scale: 1 = no damage to 9 = necrosis of leaves and branches.
[2] Susceptible control.

Clones CM 2177-2, SG 106-59 and SG 250-3 were previously selected as promising sources of resistances in yield depression trials.[10,11] Yield reduction was 9.3, 10.1 and 34.2% for CM 2177-2, SG 250-3 and SG 106-59, resp. The developmental time and oviposition rates were studied on these clones plus M Col 1468 (susceptible control) in the lab. In the first trial, first instar mealybug nymphs were placed on excised leaves in petri dishes; in the second they were placed on leaves of potted plants and maintained in the growth chamber. Nymphs feeding on excised leaves of clone SG 106-59 showed a significantly longer developmental time than on the others. Nymphs feeding on leaves of potted plants showed no significant difference in developmental time when compared

[15.11] CIAT. 1991. Cassava entomology. *In* Annual Report 1991. Cassava Program. CIAT, Cali, Colombia.

to the susceptible check (**Table 15.4**). In addition developmental time on excised leaves was considerably longer than on attached leaves, indicating that the former is not an optimal medium for mealybug development. These data indicate that a tolerance mechanism is probably responsible for resistance-like results obtained in the field with the three clones.

Table 15.4. The effect of 4 cassava clones on the developmental time and behavior of *P. herreni* on excised and attached leaves in the lab.

	Developmental time (days)				
		Attached Leaves[2]		Migration from Leaves or Death	
Clone	Excised[1] Leaves	Rep.1	Rep.2	Excised	Attached[3]
CM 2177-2	18	14	14	14	2.5
SG 106-59	24	14	14	26	13.5
SG 250-3	21	15	15	26	3.5
M Col 1468[4]	19	15	14	18	1.5

[1] Leaves placed on wet sponge in petri dishes (25°C; 60% RH).
[2] Leaves on potted plants in growth chamber (28°C; 50% RH).
[3] Avg of 2 reps.
[4] Susceptible control.

Off-leaf migration of nymphs was higher on excised leaves than attached leaves. Highest migration occurred with clone SG 106-59, indicating that this clone may be a nonpreferred host. Oviposition per female was lowest on SG 250-3 (343) and M Col 1468 (353), and highest on SG 106-59 (433) and CM 2177-2 (417). Studies will continue on these and additional selected clones.

15.2.2 Whiteflies

Whiteflies damage cassava by feeding on the phloem of the leaves, resulting in considerable reduction in RY if prolonged feeding occurs. The predominant species in Colombia is *Aleurotrachelus socialis*; in NE Brazil, *Aleurothrixus aepim*. The objectives of whitefly research are to increase the basic knowledge on behavior, identify important natural enemies, and select and develop resistant germplasm. Research efforts on whiteflies have increased in recent years, especially in the search for HPR to *A. socialis*. The key to successful HPR research is the establishment of a clean working colony for a continual supply of whitefly adults and immatures for lab and field studies. A permanent colony of *A. socialis* was established in the greenhouse on 1.5-mo-old potted plants of

clone CMC 40. Production of several thousand adults and immatures monthly is expected.

HPR studies with *A. socialis* have identified several resistant clones over numerous years of field evaluations. At Nataima (Tolima), 200 clones of Peruvian origin were evaluated in 2 reps of 5 plants each. Five evaluations using a combination of a 1-5 population scale (adults, eggs, nymphs and pupae) and a 1-5 leaf damage scale were employed to select promising clones. Infestation by naturally occurring whitefly populations commenced shortly after germination and continued throughout the growing cycle. Numerous plants were lost to poor germination and stealing. High, naturally occurring whitefly populations exerted considerable selection pressure: 166 clones received a damage rating of 3 or above (**Fig. 15.6**); 63% had ratings of 4.0 or 4.5. These selected clones are being evaluated for resistance mechanisms in the lab and greenhouse.

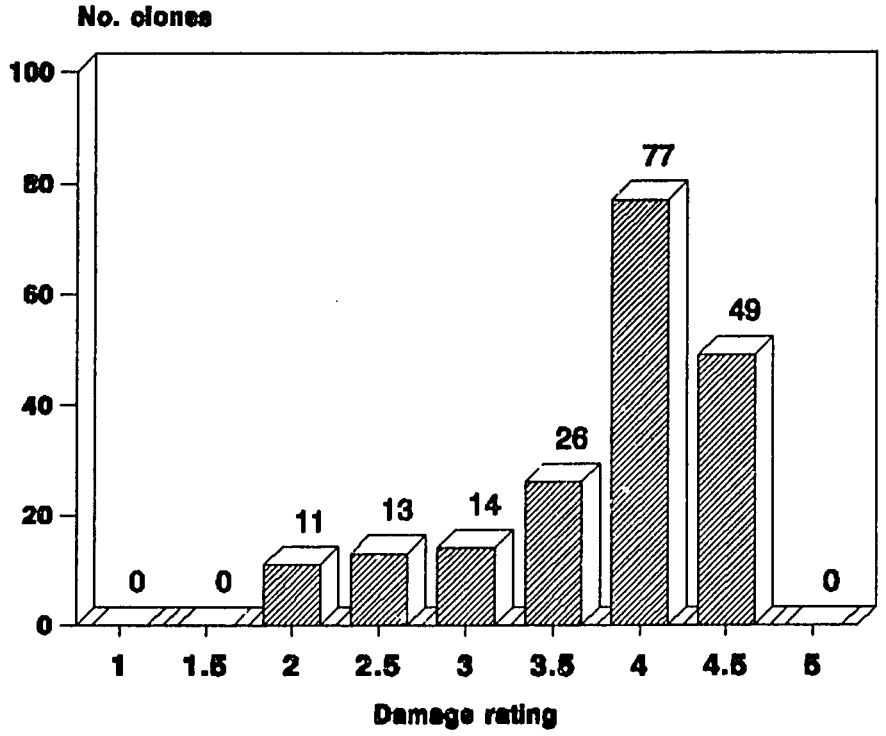


Figure 15.6. Evaluation of 200 cassava clones for leaf damage by *A. socialis* at Nataima (Tolima), 1992.

Seven clones (M Per 216, M Per 353, M Per 266, M Per 321, M Per 342, M Per 224 & M Per 365) with a rating of 3 or below in foliage damage and whitefly pupa populations were selected to enter a yield depression evaluation scheme. (**Table 15.5**). These and other

previously identified promising clones as well as highly susceptible clones will continue to be evaluated.

M Per 321 and M Per 224 have the highest yield potential under whitefly pressure. M Per 266 and M Per 342 had the lowest combined damage ratings (2.0) and pupae populations (2.0-2.5). Culinary ratings indicate that all clones except M Per 224 are hard, fibrous, glassy and sweet; M Per 224 is semihard, slightly fibrous, glassy and sweet. M Per 365 and M Per 224 were highest in DM (30.1%) and starch content (28%).

15.2.2.1 HPR mechanism studies. The parents (M Ecu 72, M Bra 12) and their progeny (CG 489-23, CG 489-31 and CG 489-34), identified as resistant to whitefly (*A. socialis*) attack, were evaluated to determine resistance mechanisms in the field and greenhouse.

Table 15.5. Selected clones (200 evaluated) showing low foliar damage ratings and whitefly (WF) populations in Tolima.

	Damage Evaluations		RY		Root Quality	
	Leaf[1] Damage	WF PPop.(pupae)[2]	No. Plants	kg/pl	% DM	% Starch
M Per 216	2.8	2.5	5	0.2		
M Per 353	3.0	3.0	9	1.08	26.4	24.0
M Per 266	2.0	2.0	6	0.73	21.5	19.5
M Per 321	2.5	2.9	7	2.3	24.6	22.6
M Per 342	2.0	2.5	2	1.13		
M Per 224	3.0	3.0	5	1.15	30.1	28.0
M Per 365	2.0	3.0	76	0.70	30.1	28.0

[1] Highest leaf damage rating (1-5 scale) of 5 evaluations.
[2] Pupal population scale (1 = <500 to 5 = >4000 pupae per leaf).

Five nylon mesh cages (2 x 1 x 1 m) were located in cassava fields in Nataima (Tolima). Potted (15-cm diam X 16-cm ht) plants of the aforementioned clones, as well as CMC 40 and M Col 1505 (susceptible checks), were placed in the cage so that all growing points were at the same ht. Each of 7 clones (8 reps) was randomly deployed in the cage. More than 13,000 field-collected whiteflies were released into the cage and allowed to oviposit during a 48-h period and then removed. Plants were transported to CIAT and placed in growth chambers. Egg counts of the species *A. socialis* and *Trialeurodes variabilis* were done with a stereomicroscope.

Whitefly egg populations consisted of 91.4% *A. socialis* and 8.6% *T. variabilis* and *B. tuberculata*. There were significant differences in oviposition on the different clones. Only those results for *A. socialis* are discussed here. Hybrids CG 489-31 and CG 4898-34 and

the female parent (M Ecu 72) were least preferred for oviposition with 19.0, 20.5 and 40.4 eggs/leaf (**Table 15.6**). CMC 40 and M Bra 12 were highest with 75.2 and 82.1 eggs/leaf, resp. The progeny CG 489-31 and CG 489-34 behave more similarly to the female parent (M Ecu 72), while CG 489-23 is more similar to the male parent (M Bra 12). *A. socialis* prefers to oviposit on the first and second apical leaves, with highest oviposition on the second leaf.

In a second trial the aforementioned clones were evaluated for whitefly mortality. The methodology was similar to that described above except that 5 pl/rep were used and plant exposure was for only 24 h to prevent excessive oviposition. One hundred nymphs were allowed to develop until the pupal stage and adult emergence was measured.

The no. of emerged adults is a direct function of the initial no. of pupae The model Ln (emerged pupae) = a + b [Ln (initial no. of pupae)], where b is the slope. A negative slope indicates antibiosis; a positive slope, tolerance. Hybrids CG 489-23 and CG 489-31, and the female parent (M Ecu 72) gave negative slopes; whereas hybrid CG 489-34 resulted in a positive slope, similar to the male parent (M Bra 12) and the susceptible clones CMC 40 and M Col 1505.

Table 15.6. Ovipositional preference of *A. socialis* and *T. variabilis* on 7 clones in Tolima.

Clone	No. Leaves observed	Avg Eggs/Leaf[1]			
		A. socialis		*T. variabilis*	
CMC 40	57	75.2	a	5.9	ab
CG 489-23	54	69.7	ab	6.8	a
M Ecu 72	75	40.4	b	2.5	bc
M Bra 12	92	81.2	a	8.3	a
M Col 1505	70	59.3	ab	4.0	bc
CG 489-31	77	19.0	c	3.2	c
CG 489-34	102	20.5	c	3.6	c

[1] T-test (0.05) and Ryan test (0.005).
Values with same letter are not significantly different.

The developmental period (egg to adult) of *A. socialis* was determined on the 7 clones. Plant leaves were infested with *A. socialis* eggs as previously described. Five pl/treatment were infested with 10 eggs/pl (total 50 eggs/clone) in Nataima and transferred to growth chambers at CIAT HQ (28±1°C and 55±10% RH).

Differences in development time were small, but significant (**Table 15.7**). On all clones, the developmental period of *A. socialis* averaged between 33.9 (M Col 1505 and CG 489-23) and 37.5 (CG 489-31) days. M Ecu 72 and CG 489-34 had developmental periods of 35.1 and 35.0 days, resp. These results indicate that the resistant progeny (CG 489-31 and CG 489-34) behave similarly to the resistant parent (M Ecu 72). Hybrid CG 489-23 behaves more like the tolerant parent (M Bra 12). These data support previous observations with these parents and progeny.

Studies into the mechanisms of whitefly resistance will be emphasized in the future. Considerable progress has been made in maintaining whitefly colonies and developing methodologies for resistance studies, but further improvements are necessary.

15.2.3 Cassava hornworm

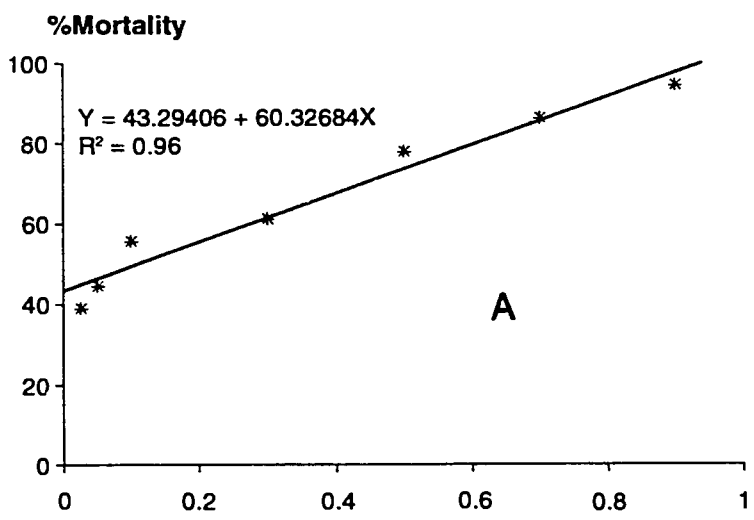
The cassava hornworm *Erinnyis ello* L., a major pest throughout many cassava-growing regions of the Neotropics, is a highly migratory species. It is hypothesized that the migratory capacity of the hornworm adults is a mechanism for escaping from natural enemies, limiting their effectiveness. The major objectives are to develop an effective biological control program for the hornworm and reduce pesticide use. In recent years research activities for biological control have concentrated on a naturally occurring baculovirus--an easily manageable natural enemy, which provides effective control.[15.12]

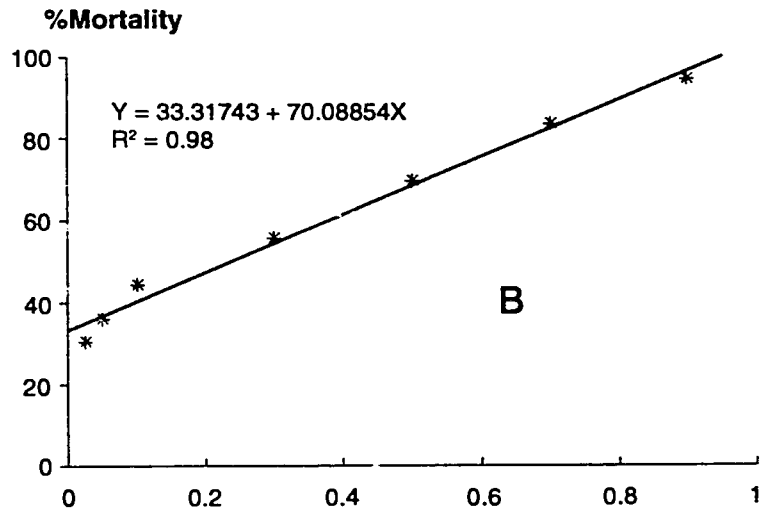
Table 15.7. Developmental time of *A. socialis* on 7 clones in the greenhouse.

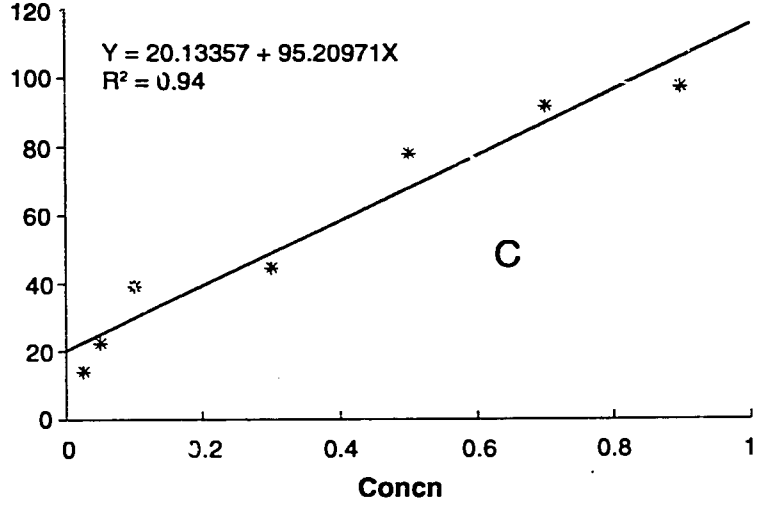
Clones	No. Observations	Developmental Time (days)[1]				
		Minimum	Max.	Avg[2]		SD
CG 489-31	50	33.0	37.0	35.7	A	1.47
M Ecu 72	50	32.0	37.0	35.1	B	1.60
CG 489-34	50	33.0	37.0	35.0	B	1.18
CMC 40	50	32.0	35.0	34.1	C	1.08
M Bra 12	50	32.0	35.0	34.0	C	1.10
CG 489-23	50	32.0	35.0	33.9	C	0.75
M Col 1505	50	32.0	35.0	33.9	C	0.77

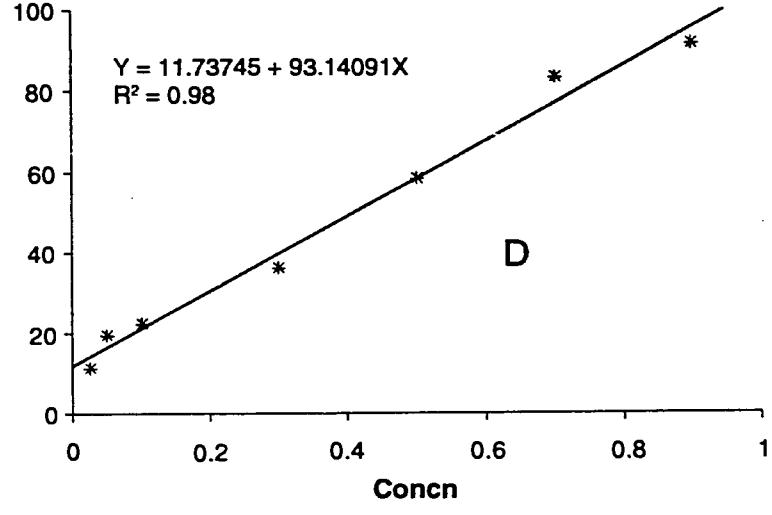
[1] Development time = egg to adult emergence from pupae.
[2] Means followed by the same letter are not significantly different (P = 0.05, Ryan multiple F-test).

[15.12] See CIAT Cassava Program Annual Reports 1980, 1983, 1986, 1988, 1990, 1991.


%Mortality
Y = 43.29406 + 60.32684X
R² = 0.96
A
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1


%Mortality
Y = 33.31743 + 70.08854X
R² = 0.98
B
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1


Y = 20.13357 + 95.20971X
R² = 0.94
C
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Concn


Y = 11.73745 + 93.14091X
R² = 0.98
D
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Concn

Continued studies on the hornworm virus have attempted to determine dose requirements to obtain adequate control under field conditions. Recent research has determined the relationship between concn (ml virus/l H_2O) and LD_{50} for each hornworm instar. From these data linear regressions were developed for instars I-IV (**Fig. 15.7**). To convert each concn determined for the LD_{50} of each instar to the dose required in the field, the following formula was used:

$$\frac{y - a}{b} = X$$

where:

y = LD_{50} (concn causing 50% mortality)
a = natural field mortality
b = % increase in mortality for each unit increase in concn
X = Concn causing desired mortality

Field application results indicate that the virus concn required for effective hornworm control are 22, 48, 62 and 84 cc/200 l H_2O for I, II, III and IV instar larvae, resp. (**Table 15.8**).

Table 15.8. Dose equivalent, concn equivalents and no. of inclusion bodies of baculovirus required for controlling 4 hornworm instars.

Instar	Concn Equiv.	Dose[1] Equiv.	No. Inclusion Bodies
I	22	0.11	2.1×10^5
II	48	0.24	8.7×10^5
III	62	0.31	1.2×10^6
IV	84	0.42	1.8×10^6

[1] cc of viral extract/200 l H_2O.

16. SOIL-CROP MANAGEMENT IN LATIN AMERICA

The Physiology Sect. has conducted research on soil-crop management on infertile acid Inceptisols at Santander de Quilichao and on very poor sandy soils on the Atlantic Coast of Colombia (Media Luna, Depto. Magdalena and Santo Tomás, Depto. Atlántico). Long- and medium-term NPK trials were established to assess the impact of continuous cassava cultivation on soil fertility and on crop productivity. Screening advanced CIAT clones for adaptation to poor sandy soils and for their response to moderate NPK levels were also conducted during the past few years.

The Physiology Sect. has collaborated with scientists from the U. of Hohenheim in conducting research on soil conservation/crop management on Inceptisols of the Andean hillsides of the Depto. of Cauca in SW Colombia (see Chap. 17). Highlights of some research findings are given here.

16.1 Soil-Crop Management Systems on Sandy Soils

A long-term field trial was initiated at Media Luna (Magdalena) in 1988 to study whether productivity could be improved on poor sandy soils with application of fertilizer and/or with plant mulch in combination with tillage system. The soil is very low in OM (≈ 0.2%) and nutrients (**Fig. 16.1**). In addition to these edaphic constraints, the region is characterized by two rainy periods (April-June and Sept-Nov) and a long dry period (Dec-Mar). The local cv. 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 and conventional tillage); two fertilizer levels (i.e., no fertilization and 330 kg/ha) of the compound fertilizer 15:15:15 (50-20-43 kg/ha NPK) in two split applications 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 mulch consisted of weeds, grasses and crop residues. Planting was done after the onset of the rainy season (May), and the harvest was at 11 mo.

Table 16.1 summarizes data averaged over 4 yr for yield, biomass, root DM content and total HCN. Irrespective of tillage system, there were strong responses to fertilizer and to mulch in terms of RY, top and total biomass, and HCN content of the parenchyma of storage roots. The increases in yield and biomass and the reduction in HCN due to fertilizer and mulch application were significant. The effect of mulching was, however, more pronounced in the absence of fertilizer. There was a slight increase in DM content of roots with the combined application of fertilizer and mulch. These data indicate that on this infertile sandy soil, cassava productivity is greatly enhanced by either the application of chemical fertilizer or mulch. Mulch application appears to be beneficial in improving soil fertility (**Fig. 16.1**). Irrespective of tillage system, annual application of mulch in the absence of chemical fertilizer improved soil OM slightly in the fourth year. It is noteworthy that continuous cultivation of cassava on this sandy soil had led to increases in soil OM, irrespective of mulch and fertilizer applications. It is known that

cassava recycles 3 to 6 t/ha dry fallen leaves/growing season, which might explain the buildup of soil OM that was observed in these trials. The level of K was more than doubled in the fourth year due to mulch application, as compared to the initial soil K level, without chemical fertilizer. This effect of mulch is of a paramount importance in this case as cassava removes more than 60% of the absorbed K in the harvested roots. In the absence of mulch and chemical fertilizer, the soil K level tends to decrease with continuous cassava cultivation. In the case of P, there was slight improvement in the fourth year with mulch and no fertilizer application. When mulch was combined with chemical fertilizer, there was a pronounced buildup of P in the soil, particularly with zero tillage. In the presence of mulch, both Mg and Ca levels in the soil were sustained near their initial levels in contrast with the pronounced decline in their levels observed over the years without mulching.

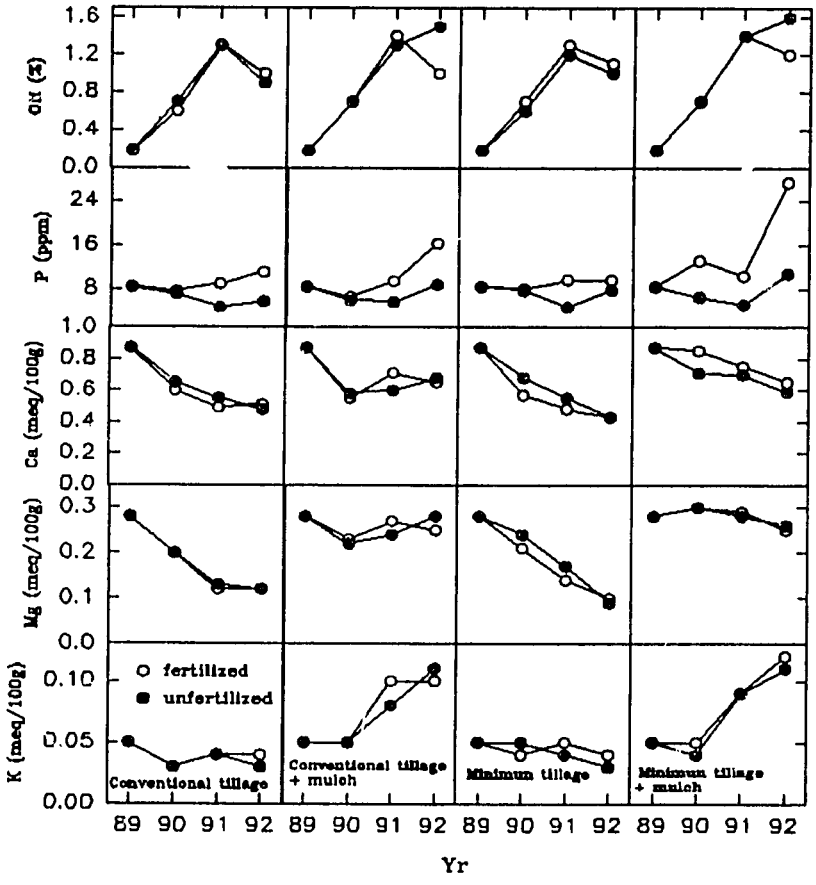


Figure 16.1. Some chemical properties of sandy soil of Media Luna, Magdalena, as affected by surface plant mulch, tillage and fertilizer application. Cassava continuous monocropping system.

Table 16.1. DRY, total harvested biomass, aerial biomass, root DM and total HCN in roots (cv. M Col 1505) at Media Luna, Magdalena; values are avg of 4 yr (1988-92).

Treatment[1]	DRY	Aerial Biomass	Total Biomass	Root DM (%)	HCN (ppm)
		(t DM/ha)			(dry basis)
Tillage + F	5.23	3.43	8.66	28.6	156
Tillage + F + M	6.27	4.45	10.72	31.0	134
Tillage - F	2.71	1.85	4 56	29.9	265
Tillage - F + M	4.92	3.42	8.34	29.8	156
Min.Tillage + F	4.69	3.35	8.04	28.5	154
Min.Tillage + F + M	4.95	3.79	8.74	29.7	126
Min.Tillage - F	2.15	1.73	3.88	27.8	259
Min.Tillage - F + M	3.87	2.68	6.55	28.8	142
LSD 5%	0.96	1.04	1.62	2.0	25

[1] + F = Fertilized with 330 kg/ha 15:15:15 NPK
- F = Unfertilized
+ M = 3 to 4 t/ha of dry crop residues and grasses applied annually as surface mulch at planting.

Moreover, mulch can alleviate water stress in these sandy soils by reducing water evaporation from the surface soil, normally exposed to high temp (**Figs. 16.2 & 16.3**). Mulch dramatically reduced soil temp at midday and afternoon in the top 20 cm during both the rainy (**Fig. 16.2**) and the dry periods (**Fig. 16.3**). Reduction in surface soil temp and, consequently, reduction in water evaporation are of a paramount importance as these sandy soils are characterized by low water-retention capacity.

Alleviating heat and water stress in the surface soil may underlie the notable reduction in HCN content in the roots observed with mulch application (**Table 16.1**). The high midday temp of the exposed surface soil (> 40°C) during the dry period and at near harvest may also affect root quality. More information on the effect of mulch on root quality is reported in Chap. 6 of this report.

16.2 Response of Cassava to NPK Fertilizer on Sandy Soils on the Atlantic Coast of Colombia

In 1991-92 a field trial was established on a private farm in Santo Tomás (Atlántico) to test response of a number of clones to NPK fertilizer. The soil is sandy (> 80% sand) and very low in OM and nutrient contents. Annual rainfall was less than 800 mm with a long dry period from Dec to April. The trial was planted on 4 May 1991 and harvested 7 May 1992. Half the experimental plots (split block design with 4 reps) received no fertilizer; the second half received 50-20-43 kg/ha NPK (330 kg of 15:15:15 compound fertilizer) 30 DAP.

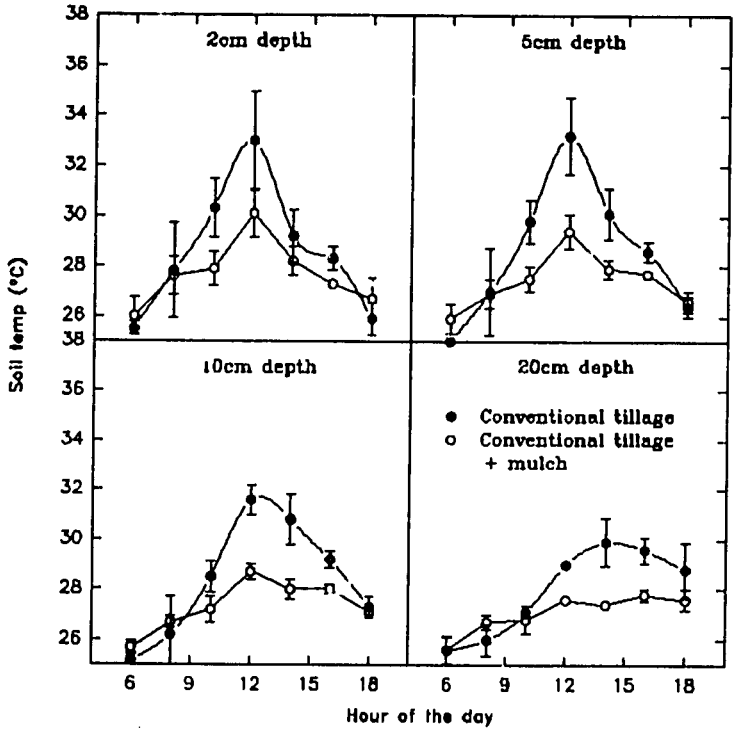


Figure 16.2. Soil temperature of the sandy soil of Media Luna, Magdalena, as affected by surface plant mulch. Measurements were recorded on 10 October, 1991 (125 days after planting). Rainy period.

Table 16.2 summarizes data on DRY, top and total biomass and percent DM in the roots. There were significant responses to fertilizer across all clones. The avg increases due to fertilizer application for all clones were 46%, 92% and 68% for RY, top growth and total biomass, resp. This is a remarkable response considering that the land was under grass fallow for several years before planting cassava. Genotypic differences in response to fertilizer were also observed as indicated by the significant genotype x fertilizer interaction. The highest yielding clones at both fertility levels were CG 1141-1, CM 3306-4 and M Bra 191. Clones CG 1220-2, CM 3555-6, M Col 1505 and M Col 2215 showed either no or slight response. it is noteworthy that two high-yielding clones (CG 1141-1 and CM 3306-4) had relatively high root DM content as compared with the overall avg. CG 1141-1 is a CIAT clone released in 1992 as a commercial cv. (Costeña) for the Atlantic Coast of Colombia.

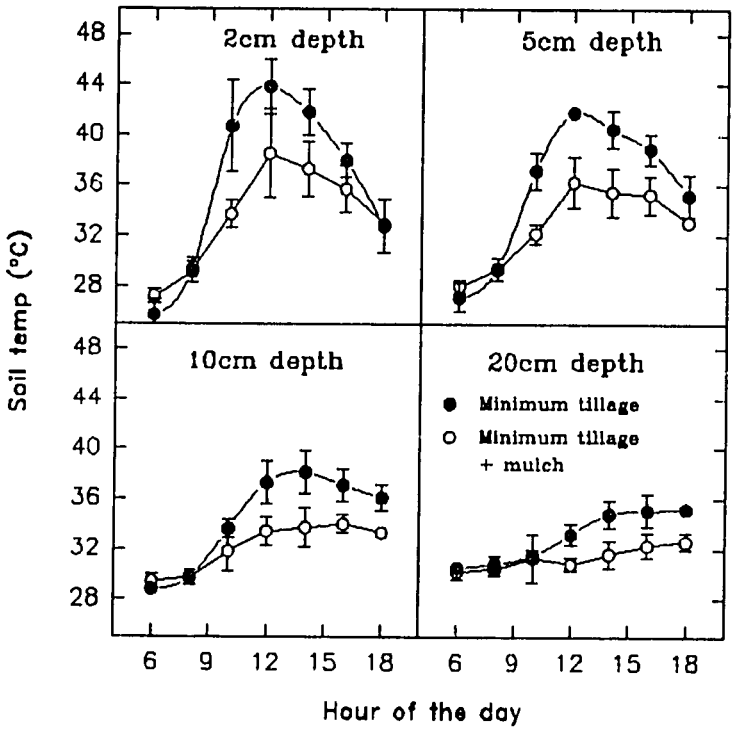


Figure 16.3. Soil temperature of the sandy soil of Media Luna, Magdalena, as affected by surface plant mulch. Measurements were recorded on 27 February, 1992 (275 days after planting). Dry period.

At Media Luna field trials were established in 1988 to evaluate germplasm productivity on infertile sandy soils and to test the response to NPK fertilizer (50-20-43 kg/ha NPK = 330 kg of 15:15:15 compound fertilizer). Cassava had been grown at the same site continuously for 4 yr. **Table 16.3** shows data of DRY, top and total biomass and root DM content for the 1991-92 season. The avg increases due to fertilizer application for all clones were 100%, 68% and 85% for RY, top growth and total biomass, resp. This indicates that by continuously growing cassava on this poor sandy soil, productivity will decline and the need to fertilize the soil will become more crucial. This is substantiated by the greater response to fertilizer application at Media Luna as compared to Santo Tomás (compare data of Table 16.2 vs. Table 16.3). CIAT clones again outyielded local cv. at both sites, with and without fertilizer. Some of these clones were either released as cv. or are currently under further evaluation.

Table 16.2. Response of cassava to NPK fertilizer on the sandy soils of Santo Tomás (Atlántico), 1991-92.

Clones	Fertilized				Unfertilized			
	Roots	Tops	Total	Root DM	Roots	Tops	Total	Root DM
	(t DM/ha)			(%)	(t DM/ha)			(%)
CG 1141-1	7.2	5.9	13.1	31.1	4.8	2.9	7.7	31.5
CG 1220-2	3.5	6.8	10.3	21.8	3.0	4.4	7.4	23.4
CG 1372-5	4.8	8.3	13.1	24.9	3.0	4.1	7.1	25.4
CG 912-9	6.9	5.9	12.8	25.6	3.9	2.4	6.3	27.5
CG 915-1	6.4	6.3	12.7	27.2	3.8	2.6	6.4	23.7
CM 3281-4	3.5	8.6	12.1	18.6	2.4	5.2	7.6	20.1
CM 3306-4	8.8	9.2	18.0	33.3	5.3	3.9	9.2	29.7
CM 3306-9	7.4	5.6	13.0	29.5	3.7	2.9	6.6	28.2
CM 3320-4	5.3	9.3	14.6	25.3	3.5	3.5	7.0	26.0
CM 3372-4	6.9	7.5	14.4	25.2	4.1	3.0	7.1	24.3
CM 3555-6	4.6	8.0	12.6	26.1	4.9	4.6	9.5	28.7
M Bra 191	7.0	8.7	15.7	29.3	5.4	4.9	10.3	29.2
M Col 1505[1]	4.2	4.3	8.5	24.9	3.3	3.2	5.5	27.8
M Col 2215[1]	4.5	4.8	9.3	30.0	4.3	3.5	7.8	30.3
M Col 2216[1]	4.0	3.7	7.7	29.0	2.5	2.8	5.3	27.8
Avg	5.7	6.9	12.6	26.8	3.9	3.6	7.5	26.9
% increase due to fertilizer	46	92	68	-				
LSD 5% (Clone x treatment)	1.3	2.7	2.1	2.3				

[1] Local cv.

16.3 Long-Term Response of Cassava to NPK Fertilizer on Infertile Acid Soils at Santander de Quilichao

For the last 9 yr cassava was grown continuously 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. **Table 16.4** shows the long-term response of cassava to NPK. Irrespective of the initial level of soil fertility, cassava productivity at the 9th year was greatly limited by K. Only in the initially exhausted soil, was there a significant response to N application. In the case of P, there was no significant response to fertilizer on either soil. These results are to be expected as M Col 1684 was less responsive to P application than other cv. (see Chap. 5). Application of high levels of N and P did not enhance yield in the absence of K application, indicating that K is the most limiting nutrient on these soils. It is known that cassava removes large quantities of K in its harvested roots (> 60% of absorbed K) and it recycles 3 to 6 t/ha dry leaves/yr. The lack of response to P and the low response to N could be partially due to maintenance

Table 16.3. Response of cassava to NPK fertilizer on the sandy soils of Media Luna (Magdalena), 1991-92.

Clones	Fertilized				Unfertilized			
	Roots	Tops	Total	Root DM	Roots	Tops	Total	Root DM
	(t DM/ha)			(%)	(t DM/ha)			(%)
CG 1141-1	6.3	5.5	11.8	32.5	3.0	1.9	4.9	32.3
CG 1355-2	9.2	5.5	14.7	26.0	3.3	3.3	6.6	25.8
CG 1372-5	5.1	5.3	10.4	24.6	2.9	4.4	7.3	25.7
CM 3306-4	6.0	4.1	10.1	33.9	3.0	3.0	6.0	35.6
CM 3320-4	4.7	3.0	7.7	22.8	2.4	2.1	4.5	23.4
CM 3372-4	7.8	4.5	12.3	22.2	3.5	2.8	6.3	20.7
CM 4181-1	3.8	2.9	6.7	27.1	1.2	1.6	2.8	27.4
CM 4365-1	4.0	2.9	6.9	34.6	3.3	2.6	5.9	35.0
CM 4733-2	6.1	3.9	10.0	30.3	3.1	2.8	5.9	29.4
CM 4793-1	6.5	3.3	9.8	30.6	3.0	1.7	4.7	27.4
CM 4919-1	6.8	5.8	12.6	30.6	2.8	1.7	4.5	29.2
M Bra 191	6.2	3.5	9.7	28.5	3.8	3.6	7.4	26.1
M Col 1505[1]	3.6	5.5	9.1	29.5	1.7	1.4	3.1	27.6
M Col 2215[1]	3.1	2.5	5.6	34.5	2.1	2.0	4.1	34.3
M Col 2216[1]	4.1	4.1	8.2	31.7	2.5	2.5	5.0	32.5
Avg	5.6	4.2	9.8	29.3	2.8	2.5	5.3	28.8
% increase due to fertilizer	100	68	85	2				
LSD 5% (Clone x treatment)	1.4	1.2	2.3	2.6				

[1] Local cv.

Table 16.4. Long-term response of cv. M Col 1684 to NPK fertilizer on acid Inceptisols at Santander de Quilichao (Cauca); data from the 9th year (1991-92).

Treatment			Exhausted Soil				Fertile Soil (Initially Fertilized)			
N	P	K	Roots	Tops	Total	Root DM	Roots	Tops	Total	Root DM
(kg/ha)			(t DM/ha)			(%)	(t DM/ha)			(%)
0	0	0	5.6	1.7	7.3	31.6	5.3	1.5	6.8	30.5
50	50	50	9.5	2.4	11.9	31.0	9.5	5.2	14.7	31.4
0	100	100	9.1	3.5	12.6	31.4	10.6	4.6	15.2	31.1
50	100	100	11.6	6.4	18.0	31.3	11.6	6.5	18.1	31.4
100	100	100	13.4	6.3	19.7	32.7	11.1	7.0	18.1	32.0
100	0	100	12.4	2.9	15.3	33.0	11.2	5.0	16.2	32.2
100	50	100	12.7	5.6	18.3	32.1	11.6	6.7	18.3	31.1
100	100	0	4.9	1.3	6.2	30.9	4.2	2.0	6.2	29.6
100	100	50	11.2	4.0	15.2	32.8	9.7	4.6	14.3	32.1
Avg			10.0	3.8	13.8	31.9	9.4	4.8	14.2	31.3
LSD 5%			1.6	0.7	1.5	1.4	1.3	0.7	1.2	1.5

of adequate levels of these elements in the soil. Recycling crop residues into the soils appears beneficial in improving soil fertility as shown in these long-term trials as well as in the medium-term plant mulch trials at Media Luna.

In conclusion it can be stated that cassava productivity could be maintained at a reasonable level in acid soils high in OM, provided that an adequate amount of K fertilizer is applied.

16.4 Effect of Soil Fertility Level on Quality of Planting Materials and Crop Yield

A field trial was established in the 1991-92 season at Santander de Quilichao (Cauca) to evaluate the effect of soil fertility level on quality of planting materials and on cassava productivity. Planting materials from the 8th crop cycle of the long-term NPK trials at Quilichao were used (M Col 1684). Trials were established on relatively exhausted soil with no chemical fertilizer. **Table 16.5** contains data on crop establishment and on yield at 11 mo. It is clear that both crop establishment and final RY were affected by the origin of the planting materials as related to soil fertility levels. The lowest yields were obtained when planting materials originated from soils that received no NPK or no PK fertilizer. In contrast with N and P, the lack of K application to original soils resulted in lower percent germination (78%), with apparent response to applied K. These data confirm the importance of K as a limiting factor--not only on productivity but also on subsequent crop establishment and yield when planting materials originate from low-K soils. The soil fertility status is crucial in ensuring high-quality stakes and consequently better crop establishment and higher yield. In farming systems where cassava is grown continuously on poor soils, application of moderate levels of chemical fertilizer or organic and green manures would improve yield as well as the quality of planting materials.

Table 16.5. Effect of original soil fertility level on germination of planting materials and on yield (cv. M Col 1684), Santander de Quilichao, 1991-92.

Origin of Planting Materials (kg/ha)			Germination in the Field	RY	Top Fresh Biomass	HI
N	P	K	(%)	(t/ha)		
0	0	0	86	13.5	4.5	0.75
50	50	50	88	17.9	4.6	0.80
0	100	100	99	17.4	4.2	0.81
50	100	100	96	19.5	4.6	0.81
100	100	100	95	24.1	5.0	0.83
100	0	100	97	14.9	5.0	0.75
100	50	100	96	22.5	5.2	0.81
100	100	0	78	15.6	4.2	0.79
100	100	50	88	21.6	4.4	0.83

17. SOIL CONSERVATION

In the Andean Region, as in other parts of the tropics, soil degradation due to erosion and depletion of nutrients has reached an alarming level. Better management of soil resources is therefore essential to ensure sustainable production and reduce environmental degradation caused by improper land use practices. This is also the case with cassava--a crop that is frequently grown on degraded hillsides because of its resistance to environmental stresses, thus replacing other crops and causing further soil degradation at these sites.

In response to this problem, the Cassava Program has placed special emphasis on soil conservation and fertility management in cassava-based cropping systems since 1979. In 1992 this work was continued by a joint research project between CIAT and the U. of Hohenheim on soil conservation in smallholder hillside farming systems with cassava.

Activities focus on (a) collecting fundamental data on soil erosion and related processes of Andean Inceptisols; (b) evaluating and testing cultural practices and components in relation to soil erosion and productivity; and (c) founding and developing linkages with farmers' groups and institutions working regionally to induce common work on soil conservation.

17.1 Generating Long-Term Soil Erosion Data Related to Soil Properties, Climatic Conditions and Cropping Systems

17.1.1 Trials on soil erosion and runoff measurement plots on Andean Inceptisols in Northern Cauca

The effects of conventional as well as improved cropping systems were examined for both quantity and quality of soil and water losses. The productivity of innovative systems was compared with traditional cultivation of cassava.

17.1.1.1 Research sites. In Santander de Quilichao trials were carried out at the CIAT station: 990 m alt., avg temp 23.7°C; annual rainfall 1608 mm, bimodal in distribution with peaks expected in April/May and Oct/Nov. The potential evaporation is 1573 mm. The soil was classified as an amorphus, isohyperthermic Dystropept.

Mondomo is the second, more mountainous research site, located on a private farm at an elevation of 1450 m. The mean annual temp is 18.2°C; rainfall is at 2133 mm, with peaks similar to those of Santander. The soil was classified as a kaolinitic-amorphous isophyperthermic oxic Humitropept.

17.1.1.2 Methodology. In accordance with the procedures described in the USLE[17.1] and at the same time examining the formula as to its applicability to tropical Andean conditions of South America, an objective of the project was to work out basic information about rainfall characteristics and soil properties of Andean Inceptisols in relation to water erosion. The equation used was

$$A = R*K*L*S*C*P$$

where A is the soil loss (t/ha/yr), R is the erosivity factor for rainfall and runoff, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor, and P is the support practice factor.

Permanent bare fallow plots (22.1 m long x 11 m wide) were established in 1986 to determine the factors of the formula of this empirical soil-loss prediction model. All other plots were 16 m long x 8 m wide. The research plots were established on uniform slopes: 7-13% in Santander and 13-20% in Mondomo. At the lower end of all plots, painted canals of asbestos cement were installed to collect eroded soil material as well as runoff water. At the end of each canal, set at a slight angle, the water flow was directed to a filter, passing a 15-outlet divider, collecting the runoff of one outlet in a 55-gal tin.

17.1.1.3 Treatments. The following cropping systems were established in April/May 1990 and evaluated until April 1992:

- Complete tillage, establishment of parallel contour ridges 1 m apart, planted to cassava
- Tillage as above, traditional planting of cassava on the flat
- Cassava intercropped with kudzu (*Pueraria phaseoloides*) in Santander; *Centrosema acutifolium* in Mondomo
- Cassava intercropped with the legume *Zornia glabra*
- Complete tillage, establishment of contour double rows of vetiver grass (*Vetiveria zizanioides*), 8 m apart
- Complete tillage, with contour strips (2 m) of elephant grass (*Pennisetum purpureum*), 8 m apart
- Cassava intercropped with *Centrosema macrocarpum*

[17.1] Universal Soil Loss Equation by Wischmeier & Smith. 1978. Predicting rainfall erosion losses--A guide to conservation planning (Agricultural Handbook No. 53). USDA, Washington, DC.

In the second year, the plots intercropped with legumes received minimal tillage only (planting holes for cassava). Cassava was always established in the first rainy season.

17.1.1.4 Results

- Rainfall characteristics R and L-S factors. As can be seen in **Table 17.1** rainfall characteristics such as total amount, distribution and intensity--crucial parameters with respect to soil erosion by water--varied considerably at both trial sites. Mean kinetic energy/mm of rain was nearly constant; total kinetic energy of rainfall was closely correlated to its respective amount (r = 0.98 and r = 0.93 in Santander and Mondomo, resp.). Nevertheless, there were markeddifferences with regard to the aggressiveness of the rains. The R factors, expressing the erosivity of rainfall, were quite high for both sites and, in the case of Mondomo, independent of the total amount of rain per year.

Table 17.1. Rainfall in Santander de Quilichao (STQ) and Mondomo (MO) (Cauca Depto.), and mean kinetic energy/mm and m^2 for the years 1987-92.

	Annual Rainfall (mm)		Kinetic Energy ($Jm^{-2}.mm^{-1}$)	
Period	STQ	MO	STQ	MO
5/87 - 4/88	1458	1498		
5/88 - 5/89	2416	2376	21.3	20.4
5/90 - 4/91	1352	1016		
5/91 - 4/92	1788	1330	21.9	21.3

R and L-S factors (characterizing the influence of steepness and length of a slope on soil erosion processes) are shown in **Table 17.2.**

Table 17.2. R and LS factors for Santander de Quilichao (STQ) and Mondomo (MO) (Cauca Dept.).

	E x I30 max (kj*mm)/m2*h	
R Factor (Erosivity)	STQ	MO
1990-91	806	855
1991-92	1063	456
LS Factor (slope & slope length)	0.63 - 1.58	1.55 - 2.99

- Applicability of the USLE and dynamics of K factors in the bare fallow standard plots. In applying the USLE to the conditions of the Andean hillsides in southern Colombia, it was possible to observe changes in major soil parameters over time. The K factor, assumed to be a constant describing the susceptibility of a given soil to erosion, increased for both Inceptisols during the 5-yr period investigated thus far (see **Table 17.3**). Hence the loss or removal of the topsoil layer and the degradation of soil characteristics tend to accelerate erosion processes on these soils. The key factors governing these dynamics are not fully understood as yet, but soil data are being analyzed in detail by an MSc student and a PhD student who finished collecting two years' field data in May 1992 (see Sect. 17.2).

Table 17.3. K factors (soils erodibility factors) as calculated from the USLE and measured values of K in erosion plots at Santander de Quilichao (STQ) and Mondomo (MO).

	STQ	MO
Calculated[1]	0.08	0.08
Determined in the field		
1987-88[2]	0.04	0.03
1988-89	0.13	0.10
1989-90	n.a.	n.a.
1990-91	0.17	0.10
1991-92	0.18	0.13

Source: Ruppenthal, M.; CIAT Soil Conservation Project, unpublished.

[1] Equation: $K = 2.77 * M^{1.14} * 10^{-6} * (12\text{-}OM) + 0.042\,(A\text{-}2) + 0.032(D\text{-}3)$

OM = Organic matter; M = Soil texture index;
A = Aggregate class; D = Permeability class

[2] Plots established in 1986.

- Soil loss and productivity of cassava in different cropping systems. Even on moderate slopes (compared to the steepness of many farmers' fields in the region) high soil loss occurred on the bare fallow plots, indicating a rather high potential for erosion (See **Tables 17.4 & 17.5**). The mean annual losses of topsoil were 1.5 cm in Santander and 1.8 cm in Mondomo.

  Traditional cassava cultivation caused soil erosion above tolerable levels. Cassava on contour ridges or together with contour barriers of elephant and vetiver grasses reduced erosion to acceptable levels of 1.3-5 t/ha/yr in the experimental plots at both sites.

Table 17.4. Mean losses of soil DM (t), cassava RY (t/ha) and forage yields (t DM/ha) for different cassava production systems in Santander de Quilichao (1990-92).

	Soil Loss (t/ha/yr)	Cassava (t/ha)[2]	Forage (t/ha)
Bare fallow	152.5[1]	-	-
Cassava with contour ridges	3.0[1]	29.6 (102)	-
Traditional (flat)[3]	7.8[1]	29.2 (100)	-
Cassava with kudzu	9.7	18.7 (64)	2.4
Cassava with *Zornia*	14.2	19.2 (65)	2.9
Cassava with vetiver barriers[4]	1.3	26.9 (92)	-
Cassava with *C. acutifolium*	7.0	21.5 (73)	3.5
Cassava with *Pennisetum* barriers[4]	3.8	20.0 (69)	5.0
10% slope			

[1] Data for 5 yr.
[2] % control (traditional cultivation).
[3] Plowed, rotary cultivator.
[4] Barriers 8 m apart.

Table 17.5. Mean losses of soil DM (t), cassava RY (t/ha) and forage yields (t DM/ha) of different cassava production systems for Mondomo (1990-92).

	Soil Loss (t/ha/yr)	Cassava (t/ha)[2]	Forage (t DM/ha)
Bare fallow	183.2[1]	-	-
Cassava with contour ridges	2.0[1]	14.5 (92)	-
Traditional (flat)[3]	16.4[1]	15.8 (100)	-
Cassava with *Zornia*	3.8	13.8 (88)	0.6
Cassava + vetiver barriers[4]	2.6	12.8 (82)	-
Cassava + *C. acutifolium*	2.1	12.5 (79)	1.9
Cassava + *Pennisetum* barriers[4]	0.7	13.4 (85)	8.1
Cassava + *C. macrocarpum*	3.2	9.6 (61)	3.1
15% slope			

[1] Data for 5 yr.
[2] % control (traditional cultivation).
[3] Plowed.
[4] Barriers 8 m apart.

Relatively high soil losses were registered with the cassava-legume mixtures during the first growing seasons the result of slow initial development of the legumes and highly erosive rainfall events during that period. Compaction of the upper soil layer

and continuous soil disturbance caused by reseeding operations also contributed to high soil losses in these treatments during the first year.

At the beginning of the second growing season, the legumes were well established; and all treatments associated with legumes reduced soil erosion to acceptable levels (**Tables 17.4 & 17.5**).

With regard to yields for the different cassava cropping systems, contour ridges, traditional flat planting, cassava with grass barriers or intercropped with *C. acutifolium* gave best results. Yield reductions due to associated forage legumes were around 20% in the case of *Z. glabra* and *C. acutifolium*, but were partly compensated by a good forage yield. Yield depressions as in the case of *C. macrocarpum* (≈ 40%) are most likely not acceptable to farmers despite considerable forage production. There is a need to select and identify a number of barrier grasses and/or legumes that can protect soils quickly and effectively, without causing excessive competition.

17.2 Topsoil Characteristics of Andean Inceptisols in Relation to Soil Erosion and Erodibility

As already shown in **Table 17.3**, calculated K values characterizing the erodibility of a soil may differ markedly from measured K values in tropical soils. On the other hand, measuring real soil erodibility with standard erosion plots is a very costly, laborious procedure.

In order to contribute to simplify determining the erodibility of tropical Inceptisols and for a better understanding of soil erosion processes, an MSc thesis, done in collaboration with the Universidad Nacional de Colombia in Palmira, was begun in April 1992.

One of the objectives is the approximation of the soil erodibility factor K by a set of values from easily measurable, mainly physical soil parameters in the topsoil layer (0-10 m), comparing these data with the factor derived from erosion measurement plots. (Parameters evaluated include texture, structural stability, permeability, conductivity, apparent and real density, pore volume, aggregate stability, OM content, etc.).

17.3 Development of Sustainable Cassava Cropping Systems

17.3.1 Cassava cropping systems with undersown forage legumes

As could be demonstrated in the erosion measurement plots, undersowing of cassava with legumes can reduce erosion to acceptable levels once the legume crops are established. In farming systems with an animal component, yield reductions caused by undersown legumes are compensated for by considerable forage yields (2-4 t/ha DM in STQ & MO). Nevertheless, competition between legumes and cassava is a constraint for

adopting the intercropping systems, and in-depth physiological and agronomic research is necessary to understand and minimize competitive effects.

In trials carried out over the last two years, several legumes with good adaptation to poor, acid soils and with good soil cover capacity were identified. **Table 17.6** shows the results of a soil cover-screening trial with forage legumes. Five out of 14 legumes covered the soil by more than 50% within 4 mo, *Centrosema brasilianum* being the most effective.

Table 17.6 Estimated soil cover by herbaceous legumes in Santander de Quilichao 4 mo after sowing (planting density 0.25 x 0.5 m; 2-7 seeds/site)[1].

Legume Species	CIAT No.	% Soil Cover	± SE
Desmodium intortum	13013	2.3	0.3
Desmodium uncinatum	3307	16.0	4.3
Stylosanthes capitata	1315	15.6	3.8
Lablab purpureus	17189	17.0	5.3
Desmodium ovalifolium	13089	21.0	2.8
Zornia latifolia	9199	21.6	3.7
Stylosanthes guianensis	10136	47.3	5.8
Arachis pintoi	17434	39.3	4.6
Stylosanthes guianensis	184	47.3	13.6
Galactia striata	964	52.3	3.2
Centrosema acutifolium	5277	63.3	3.8
Centrosema macrocarpum	5713	75.0	4.9
Centrosema brasilianum (a)[2]	5234	90.0	4.1
Centrosema brasilianum (b)[2]	5234	74.6	14.1

[1] Mean of 3 reps; ± SE of the mean.
[2] Planted with the same sp.

Once the potential of adaptation, forage production and soil cover capacity had been identified and taking into account the growth habit of the legumes, trials were initiated with preselected species to evaluate their characteristics when undersown in cassava. **Table 17.7** shows Year One data of the response of cassava to the association with different legume species, sown in a single row as microbarriers between rows of cassava.

Mean annual soil cover by legumes was poor as a result of slow initial development. Competition caused by legumes with good soil cover capacity was approx. 20-25%. Differences occurred with regard to percent yield reduction per percent soil cover provided, *Galactia* competing nearly twice as strongly as *C. acutifolium*.

Table 17.7. Total RY of cassava and mean soil cover of intercropped legumes when sown simultaneously in Santander de Quilichao, 1991-92.

Treatments	Cassava RY (t/ha)	Mean Soil Cover of Legumes (%)	
Legumes			
Control	37.6 ± 1.6[1]	0	± 0
Phaseolus beans	37.4 ± 1.3	4.3	± 0.3
Galactia striata	25.1 ± 2.0	11.7	± 2.9
Macroptilium gracile	31.3 ± 2.0	5.4	± 1.35
Zornia glabra	27.3 ± 1.9	17.8	± 3.1
Zornia latifolia	33.9 ± 2.3	4.4	± 1.9
Centrosema acutifolium	26.8 ± 2.5	22.3	± 2.2
Stylosanthes capitata	28.3 ± 1.6	6.8	± 1.1
Arachis pintoi	31.2 ± 2.3	2.1	± 0.1
Planting density			
10,000/ha	31.1 ± 0.89	10.5	± 1.23
15,000 ha	30.7 ± 1.19	6.4	± 0.76
Cassava var.			
M Col 1684	30.9 ± 1.1	10.2	± 1.26
M Col 1522	31.0 ± 0.9	6.6	± 0.76

[1] SE = Standard errors of the mean.

17.3.2 Live barriers with grasses as an integrated element of cassava production on hillsides

Live barriers can be very efficient in reducing soil losses; nevertheless, farmers normally hesitate to adopt this simple technology because there is additional labor involved or because of competition caused by the contour- planted barriers. Thus ease of establishment and management, as well as low competition with associated field crops, are considered important criteria for reducing technology adoption constraints.

Comparing 6 grasses for ease of establishment under on-farm conditions, lemon grass (*Cymbopogon citratus*) had the highest survival rates 1 mo after planting; whereas vetiver was somewhat susceptible to dry weather conditions after planting.

With regard to competition caused by barrier grasses, cassava was sown with different grass species at only 50-cm distance to induce high competition. Barrier grasses had been established with irrigation 3 to 4 mo before. As can be seen in **Table 17.8**, all grasses competed with cassava under these extreme conditions; but lemon grass and vetiver reduced yields much less than citronella (*Cymbopogon nardus*) and Guatemala grass (*Tripsacum laxum*). Analysis of the rooting characteristics suggests that differences in the rooting system are the main reason for different degrees of competition.

Table 17.8 Competitive effects of different barrier grasses on the yield of cassava (M Col 1505) on an Inceptisol in Santander de Quilichao[1].

Grass Species	RY (t/ha)	cv.
Cymbopogon nardus (citronella)	12.40 a	0.11
Cymbopogon citratus (lemon grass)	19.20 b	0.13
Vetiveria zizanioides (vetiver)	19.68 b	0.20
Tripsacum laxum (Guatemala grass)	8.13 a	0.23
Test without grasses	28.13 c	0.23

[1] Different letters significant at 0.05 level.

17.3.3 Growth characteristics of cassava related to soil erosion

Soil losses in cassava are especially high when planting coincides with intensive rainy periods, given the fact that cassava canopy development is slow during the first 3-4 mo, especially in cool tropical mid-altitudes. In trials testing germplasm for its adaptation to mid-altitudes carried out in Mondomo (Cauca) (1450 m), it was found that despite this similar growth pattern, there are considerable differences among varieties with regard to early soil cover.

In **Figure 17.1** soil cover percentage of 5 varieties is given for 2-4 mo after planting. Some varieties showed good initial development and intermediate canopy growth afterwards, resulting in a high HI. CG 502-1 was typical in this respect, combining good initial soil cover with high yields. SG 427-87 showed similar behavior; whereas CG 402-11 also gave high yields but poor soil cover in the first 3 mo. At 4 mo after planting, soil cover was from 28% to 68% for the 31 varieties tested, the local var. Algodona (M Col 1522) giving highest soil cover values. These data suggest that soil cover capacity should be considered an additional criterion for varietal recommendations in hilly areas.

17.4 Interinstitutional Collaboration and Contacts with Farmer Groups

In order to ensure that on-station research activities are in line with the possibilities, needs and preferences of farmers in a given region, efforts have been made since 1991 to develop linkages with farmer groups and regionally active institutions working in rural development and natural resources management. Currently the project maintains contact with an Indian group of farmers in Toribio, a black farmer community in Buenos Aires, and mestizo farmers in the area of Mondomo and Pescador (Cauca).

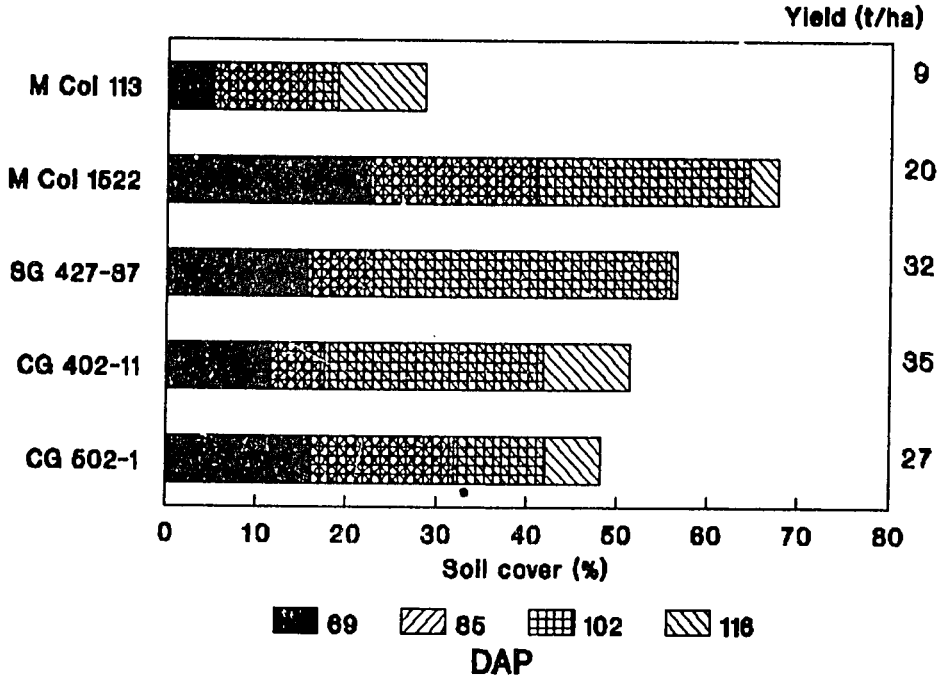


Figure 17.1. Soil cover provided by some cassava varieties 2-4 mo after planting at a site near Mondomo (Cauca) (1450 m); yields are reported in the right column.

Demonstration trials using elements of soil conservation--combined with the transfer of other CIAT technology such as improved varieties, integrated pest management and germplasm testing--are the principle activities carried out with these groups to maintain the ongoing dialogue.

Interinstitutional collaboration with the public and private sector is normally informal. A formal agreement has been signed only with the Corporación Autónoma Regional del Cauca (CVC), the regional natural resources management institution. With the Federación Nacional de Cafeteros (FEDECAFE), multiplication plots for vetiver grass and the legume ground cover *Arachis pintoi* were established on three farms, and trials with innovative diversified, soil-conserving coffee plantations are planned.

CETEC (Corporación para Estudios Interdisciplinarios y Asesoría Técnica), a Colombian NGO is linked to the project with two soil erosion trials on steep degraded hillsides near Santander de Quilichao. Legume intercropping and barriers are tested against the traditional practices of cultivation. FUNDAEC (Fundación para la Aplicación y Enseñanza de las Ciencias), an NGO active in the field of education appropriate for rural areas is cooperating in erosion trials and seed multiplication of CIAT cassava varieties, barrier grasses and legumes. They are also testing germplasm from the CIAT Tropical Forages Program based on their own criteria of adaptation and usefulness as forage and/or for soil fertility management. Recently they received 15,000 rooted seedlings of vetiver grass for multiplication locally in northern Cauca.

Cooperation within CIAT is mainly with the Tropical Forages Program, the GRU and the IPRA project on participatory research with small farmers.

17.5 Training

Martin Ruppenthal from the U. of Hohenheim finished data collection from erosion trials in April and returned to Germany in July in order to finish his PhD thesis on soil erosion in cassava cropping systems on Andean Inceptisols. Wolfgang Felske started a third PhD project in April to ensure continued data collection on soil erosion characteristics of Andean Inceptisols and to monitor long-term dynamics of the development of soil properties, taking a closer look at rainfall characteristics as well as the cropping factor C of the USLE.

Jesús Castillo, project assistant, began his MSc thesis, investigating the influence of soil surface characteristics on soil erosion in March (see 17.2). Another graduate student from Hohenheim, Karen Tscherning, is finishing her thesis on aspects of competition between grass barriers and cassava in Santander de Quilichao and Mondomo. As of September a graduate student is doing research on aspects of competition between intercropped forage legumes and cassava, focusing on interactions below ground.

Two Colombian students from the Universidad del Valle are currently doing their graduate thesis with support from the project. The aim is to reconstruct the history of soil erosion in the region of Suárez (Cauca) and to document the perception of erosion processes by the people living in the area.

18. CROP/SOIL MANAGEMENT IN ASIA

During the triennial Asian regional cassava workshops, research topics on crop and soil management practices were discussed and prioritized by cassava researchers from national programs and CIAT. The priority research is being conducted by the national programs with active participation of CIAT scientists, who help define experimental designs, improve experimental procedures, and analyze and interpret results. Results obtained in one country may be used to orient the research in others. If the need arises, national scientists are trained in specific skills at CIAT HQ. Research results are presented and discussed during the regional workshops and the reports are published in the workshop proceedings for widespread distribution among cassava scientists in the region.

The following strategies are used to attain these objectives:

- Conducting research on crop/soil management under a wide range of soil and climatic conditions

- Strengthening of the research capabilities of national cassava programs through regional activities and collaborative research

As soil and crop management practices tend to be fairly site specific, the research is conducted under a wide range of soil and climatic conditions in various locations in China, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand and Vietnam. The following aspects were studied during 1992:

- Effect of temp and rainfall on cassava yield and starch content by monthly planting of 2 cv. on Hainan Island in China

- Optimum stake planting position and plant bed configuration in S Vietnam and Bohol Island of the Philippines

- Optimum economic returns for cassava grown in monoculture or intercropped with maize, rice and various grain legumes in Indonesia, the Philippines, Vietnam and Thailand

- Response of cassava to application of various levels of NPK in long-term fertility trials conducted at 11 locations in China, the Philippines, Indonesia, Sri Lanka and Vietnam

- Effect of green manures, cover crops or alley crops on cassava yield and soil fertility in Thailand and Indonesia

- Effect of soil and crop management practices on cassava yield and soil erosion at 7 locations in China, the Philippines, Indonesia and Thailand

18.1 Effect of Temperature and Rainfall on RY and Starch Content

In the subtropics the growth and yield of cassava is not only limited by low rainfall but also by low temp during the winter mo. To determine the effect of rainfall and temp, two cassava cv. were planted at monthly intervals at the South China Academy for Tropical Crops (SCATC) on Hainan Island in China. Rate of germination, PH at 100 days, and RY and starch content after 8 and 12 mo were determined.

Figure 18.1 shows the RY of both cv. during the first year cropping cycle when harvested after 8 mo. Fluctuations in temp and rainfall are also shown. For both cv. highest yields were obtained when planted in Feb to May; whereas lowest yields were obtained when planted in Sept and Oct. Surprisingly, the low yields were not obtained when cassava was planted in the driest or coldest mo; low yields, however, were obtained when low rainfall and/or low temp occurred during mo 3-5; i.e., those of most rapid cassava growth. For both cv. there was a highly significant correlation of FRY at 8 mo with PH at 100 days or with either avg mean temp or avg rainfall for 3-5 MAP. For both cv. root DM content was highest when harvested in Feb-Mar and lowest when harvested in July and Aug.

18.2 Stake Length and Planting Position

On Bohol Island in the Philippines, farmers often plant short stakes (only 10-15 cm long), usually in a horizontal position. To determine the effect of stake length and planting position on RY, 2 cv. were planted with stakes 10, 15 or 20 cm in length and in either vertical, inclined or horizontal position. **Figure 18.2** shows the avg results for 3 yr including one when plants were seriously damaged by a typhoon.

Yields of the local cv. Golden Yellow were consistently higher than those of the new cv. VC-1, which is high yielding only under optimal conditions. Under suboptimal conditions, such as drought after planting or during typhoons, or when planted with short stakes, the yield of this cv. was significantly reduced. In contrast, the more vigorous Golden Yellow was little affected by either stake length or planting position. Vertical or inclined planting usually resulted in the highest yield for Golden Yellow, while horizontal planting produced the highest yields for VC-1.

18.3 Intercropping

The effect of intercropping cassava with maize and several grain legumes was studied in Vietnam. In S Vietnam cassava was planted either in single rows with a spacing of 1.0 x 1.0 m (intercropped with 1 row of maize or 2 rows of legumes) or in double rows (2.0 + 0.8 x 0.71 m; with 2 rows of maize or 6 rows of legumes).

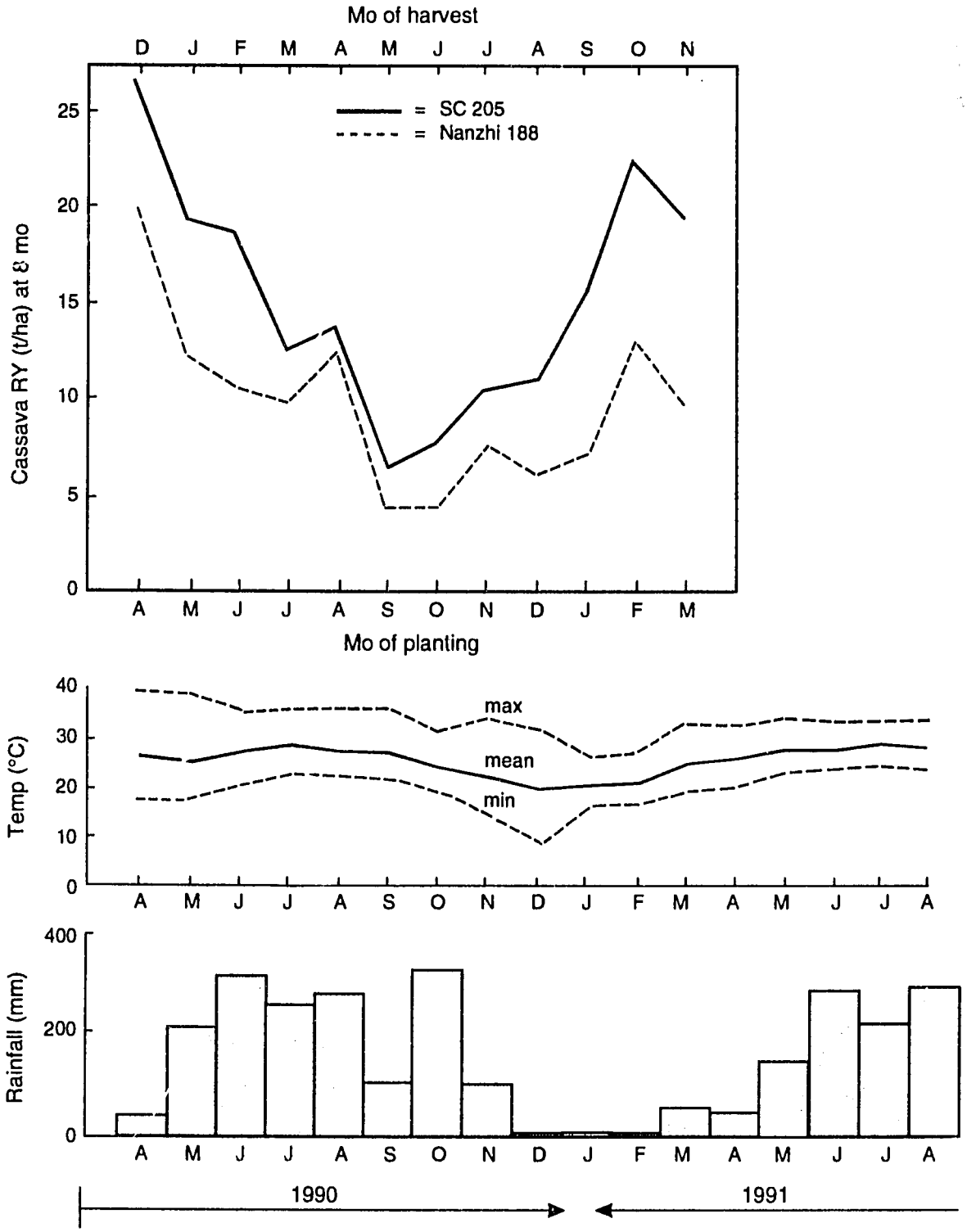


Figure 18.1. Effect of planting date on the RY of two cassava cv. harvested at 8 mo at the SCATC, Hainan, China; below are shown the temp and rainfall during the growth cycle.

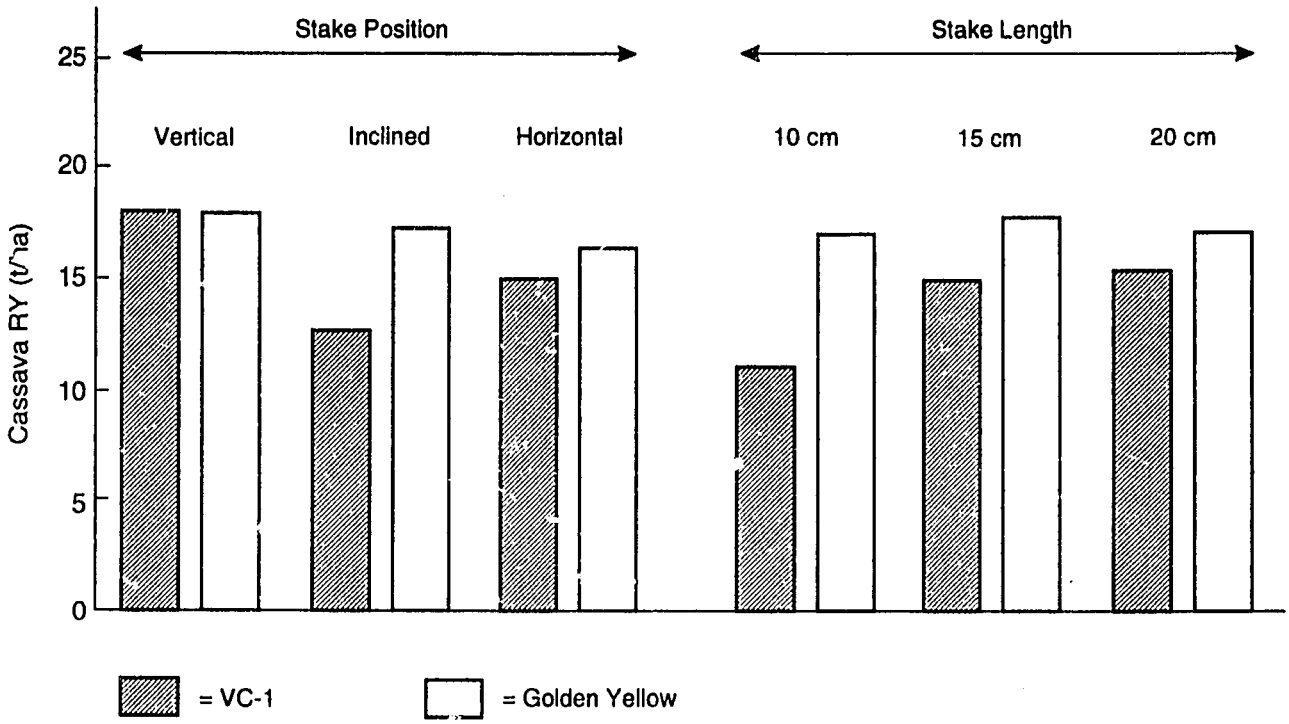


Figure 18.2. Effect of stake planting position and length on the RY of two cassava cv. grown in Ubai, Bohol, Philippines, data are avg for 3 yr.

In N Vietnam there was no significant yield reduction when intercropping cassava with peanuts, mungbeans, soybeans or maize, but there was a 28% yield reduction when intercropping with black beans. In contrast, however, intercropping always caused a yield reduction of cassava in S Vietnam, especially when intercropped with winged beans, sword beans and maize (**Fig. 18.3**). The double-row cassava system always resulted in lower yields than the single-row system, whether cassava was mono- or intercropped. Highest net income was obtained with cassava grown in monoculture or when intercropped with peanuts or soybeans; total net income was always higher for the single- than for the double-row system, except when intercropped with maize.

The effect of cassava row spacing on cassava and intercrop yields was determined in Yogyakarta, Java Island, Indonesia for 2 yr. Two intercropping systems were used: cassava intercropped with rice followed by soybeans and cassava intercropped with peanuts followed by soybeans. The soybeans were planted in the inter-row space after harvesting the first intercrop; i.e., after rice or peanuts. **Figure 18.4** shows that both cassava yield and total crop value (avg of 2 cropping systems over 2 yr) increased as the cassava population increased by decreasing the cassava inter-row space.

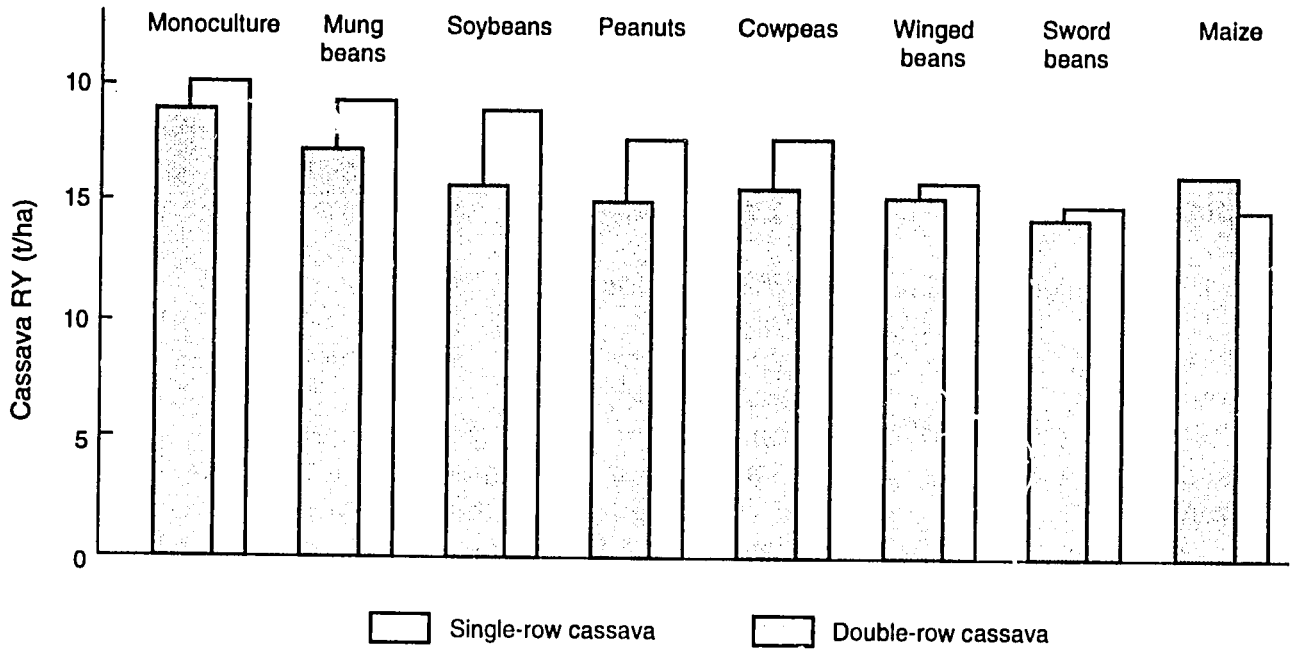


Figure 18.3. Effect of cassava planting arrangement and intercrops on the RY of cassava cv M-23, grown at the Hung Loc Research Center in S. Vietnam, data are avg 3 yr.

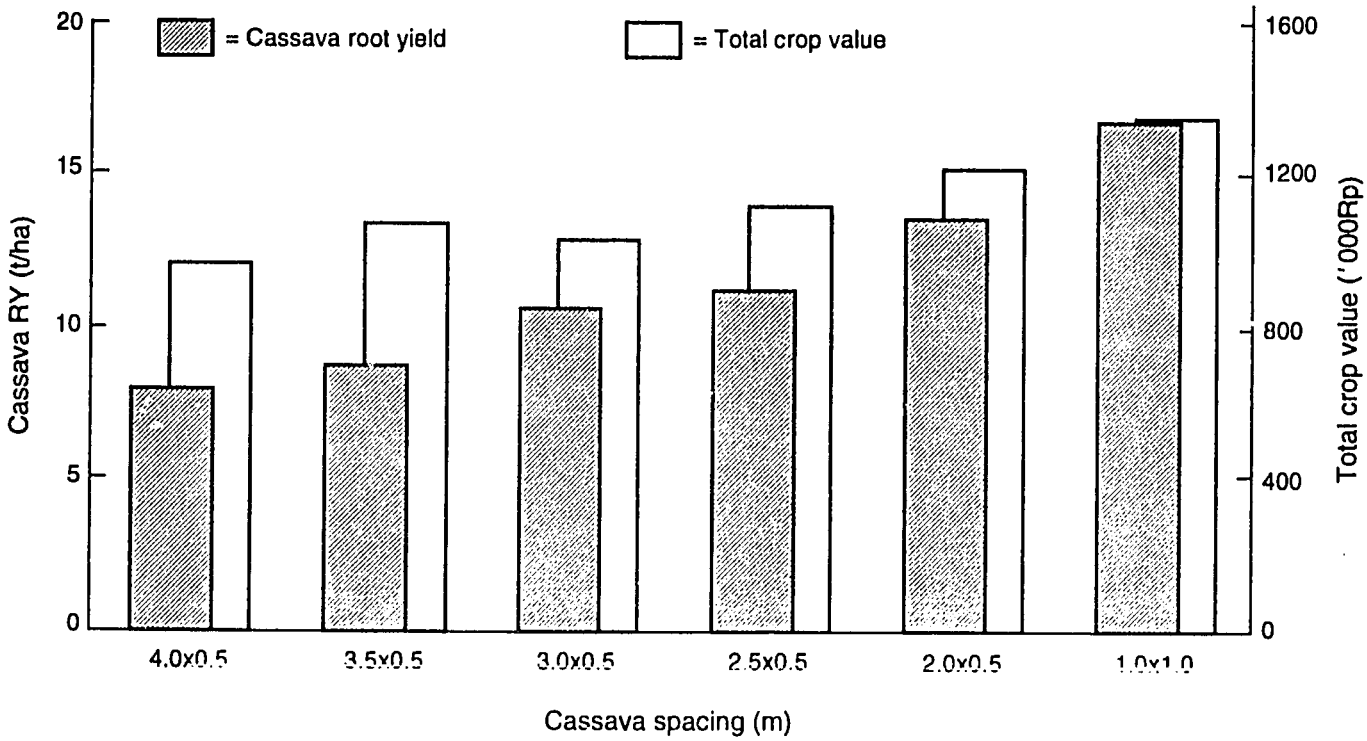


Figure 18.4. Effect of cassava row spacing on avg cassava RY and total crop value in cassava+rice-soybeans and cassava+peanuts-soybean intercropping systems in Yogyakarta, Indonesia, data are avg of two cropping systems and 2 yr.

Highest cassava yields and total crop value were obtained when cassava was grown in a normal square planting arrangement of 1.0 x 1.0 m. However, as the cassava row spacing decreased, so did the yield of the second intercrop (soybeans) due to excessive shading by cassava. To maintain a reasonable yield of the second intercrop, farmers will probably prefer to plant cassava at a spacing of 2.0 x 0.5 m rather than at 1.0 x 1.0 m.

18.4 Long-Term Fertility Maintenance through Fertilizer Application

Trials to determine the short- and long-term nutrient requirements of cassava were continued at 11 locations in 5 countries. With most trials now having completed 2 to 4 yr of continuous cropping, fertilizer responses intensified. There was a significant response to N at 10 sites, to P at 5 and to K at 3 locations. **Figure 18.5** shows the lack of any response in Hung Loc Station in S Vietnam, but a highly significant response to all 3 nutrients at Agricultural College #3 in N Vietnam. At the latter site, both cv. responded mainly to the application of K, which increased yields from ca. 4.5 to 22 t/ha. **Figure 18.6** shows a nearly perfect relation between the K concn of the youngest fully expanded leaf blades at 4 MAP and FRY. A critical K concn, corresponding to 95% of max. yield, was found to be 1.4%, which corresponds well with critical levels previously determined in Colombia. K application increased leaf life at 3 mo from 67 to 89 days and at 6 mo from 38 to 50 days. Without K application the limited K supply was retranslocated to the plant's growing points, resulting in excessive leaf drop during the later stages of plant growth.

18.5 Soil Fertility Maintenance through Green Manuring and Cover Cropping

18.5.1 Green manuring

To study the effect of green manures on cassava yield and soil fertility, a trial using six leguminous green manure species was initiated in Pluak Daeng, Thailand. At 2 1/2 MAP, the green manures were cut and either mulched or incorporated into the soil, after which cassava was planted in early Sept and harvested in July of the following year. Additional plots without green manures but with/without fertilizers were also planted, either in June (early rainy season) or in Sept (late rainy season).

Table 18.1 shows the DM production and nutrient content of the green manures as well as the cassava yields obtained. Incorporation or mulching of green manures did increase cassava yields compared with the nonfertilized check; and some species such as *Crotalaria juncea*, pigeon peas and *Mucuna* increased yields above the fertilized check. Although mulching of the green manures was slightly superior to incorporation, none of the green manure treatments resulted in cassava yields as high as those obtained without green manures when planted in the early rainy season. Thus the planting of green manures in the early rainy season inevitably delays the planting of cassava to the late rainy season, resulting in low yields for lack of adequate soil moisture during much of the growth cycle.

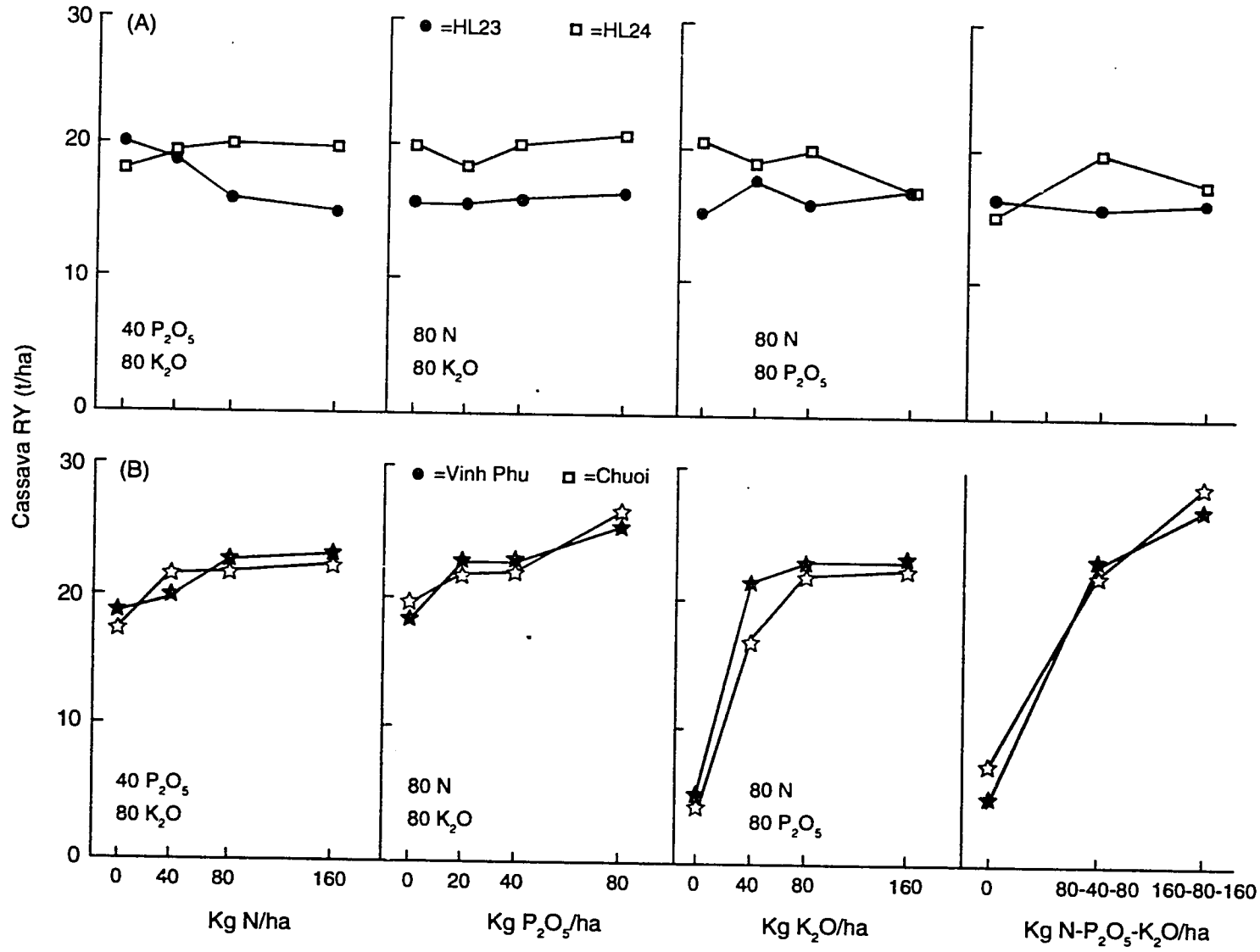


Figure 18.5. Response of two local cassava cv. to the application of various levels of NPK in (A) Hung Loc Center, Dong Nai Province and in (B) Agric. College #3, Bac Thai Province of Vietnam, 1991-92 (2nd yr).

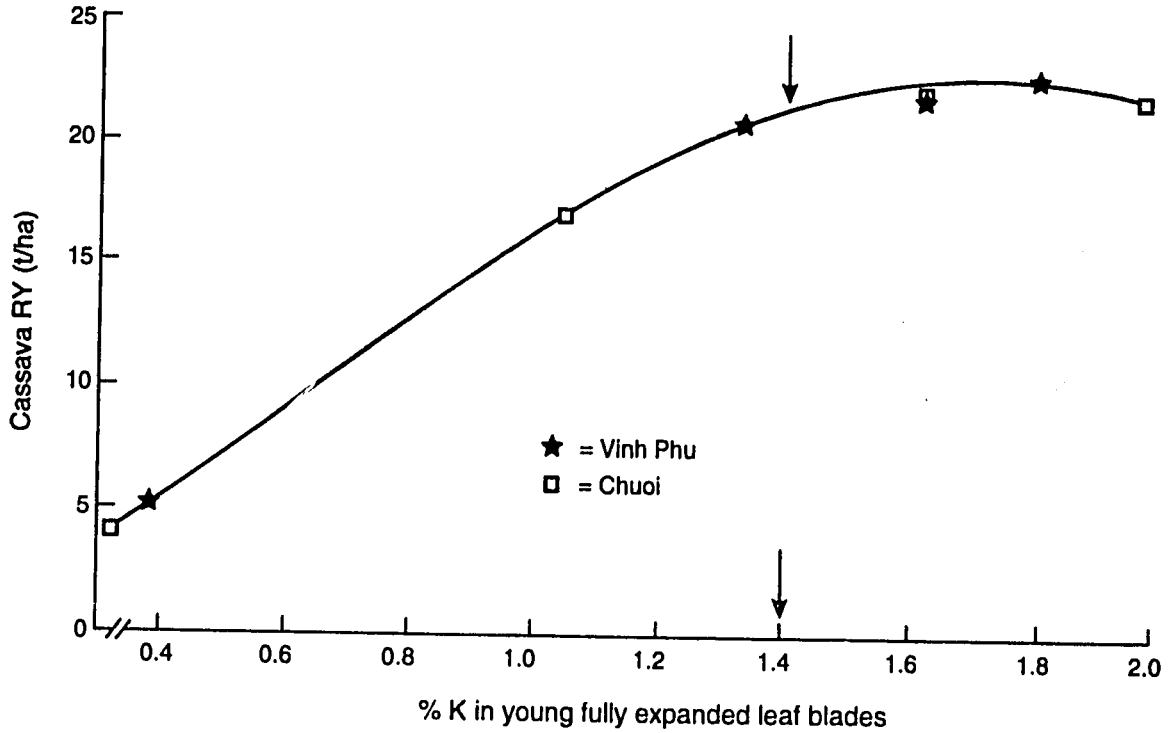


Figure 18.6. Relation between the RY of two cassava cv. and the K concn of the youngest fully expanded leaf blades at 4 MAP at Agric. College No. 3, Bac Thai Province, Vietnam, 1991.

TABLE 18.1. Effect of cassava planting time, fertilization or green manuring[1] on cassava yields in Pluak Daeng, Thailand, 1991/92.

		Green Manures (t/DM/ha)		Nutrient Applic. (t/ha)[2]			Cassava RY (t/ha)	
	Treatments	Incorp.	Mulched	N	P	K	Incorp.	Mulched
1	June planting, no fertilizers	-	-	-	-	-	12.54	9.12
2	June planting, with fertilizers	-	-	94	-	42	13.37	13.25
3	Sept planting, no fertilizers	-	-	-	-	-	3.75	3.46
4	Sept planting, with fertilizers	-	-	94	-	42	5.29	6.12
5	Sept planting, after *Sesbania rostrata*	1.09	1.68	23	4	23	4.21	5.33
6	Sept planting, after *Mucuna fospeaoa*	3.97	5.69	154	11	77	5.96	8.12
7	Sept planting, after *Crotalaria juncea*	7.02	7.59	123	9	61	7.29	8.17
8	Sept planting, after pigeon peas	5.08	5.29	106	13	52	8.33	6.87
9	Sept planting, after cowpeas	2.61	3.04	74	8	51	6.71	5.29
10	Sept planting, after *Canavalia ensiformis*	4.79	5.54	136	9	54	5.54	6.46

1 Green manures were planted in June, cut in late Aug. and either incorporated or mulched before cassava planting in early Sept.; cassava was harvested at 9 1/2-10 mo.

2 Nutrients in the green manures were produced either through N fixation or uptake from the soil.

Under the rainfall distribution pattern of eastern Thailand, with only 5 mo of rainy season (often interrupted by 1-2 mo with little rain), the planting of green manures in the early rainy season followed by cassava in the late rainy season does not seem feasible. Intercropping cassava with green manures and cutting back or pulling up and mulching the green manures after 1-2 mo seems a more practical approach that should be investigated.

18.5.2 Cover crops

In Pluak Daeng another trial was established to study the potential of cover crops to increase cassava yields through improved soil fertility and erosion control. Seven cover crops were planted between cassava rows; cassava was planted either at 1.0 x 1.0 m or with a wider row spacing of 1.5 x 0.66 m to facilitate management of the cover crop. **Table 18.2** indicates that there was no significant difference between cassava planting patterns in terms of FRY. Cassava plant survival rate and top growth was slightly better with the square planting arrangement. Among the leguminous cover crops, indigo and *Mimosa invisa* developed a soil cover rapidly; but they also competed the most with cassava. *Stylosanthes hamata* was intermediate; whereas *Zornia latifolium* and *Z. glabra* were slow to establish and thus had little effect on cassava yield.

TABLE 18.2. Effect of cassava row spacing and leguminous cover crops on cassava RY and dry wt production of cover crops in Pluak Daeng, Thailand in 1991/92.

	Cassava RY (t/ha)			Dry wt Cover Crops (t/ha)		
	Cassava Spacing (m)			Cassava Spacing (m)		
Cover Crops	1.0x1.0	1.5x0.66	Avg	1.0x1.0	1.5x0.66	Avg
Indigo	8.56	8.10	8.33	5.36	7.73	6.55
Zornia latifolium	16.71	15.97	16.34	1.28	0.88	1.08
Zornia glabra	28.35	16.10	22.23	0.21	0.75	0.47
Mimosa envisa	10.73	15.95	12.71	5.03	4.23	4.61
Stylosanthes hamata	12.35	14.87	13.61	2.47	3.96	3.21
Alyslcarpus vaginalis	18.58	15.80	17.19	1.69	1.05	1.37
Arachis pintoi	14.06	17.87	15.97	0.20	0.33	0.26
No cover crop	18.69	18.52	18.61	-	-	-
	16.00	15.24		2.32	2.69	
Cassava spacing (A)		NS			NS	
Cover crop (B)		**			**	
LSD (0.05) cover crop		6.14				
Interaction (AxB)		NS			NS	

As in previous years, all cover crops competed with cassava to a greater a lesser extent, reducing cassava yields; only *Z. glabra* increased yields significantly in the first year of establishment, while *Alysicarpus vaginalis* resulted in only an insignificant reduction in yield. A replanting of the same trial in the already established soil covers in 1992 resulted in a significant loss of cassava stand due to severe competition for water during short periods of drought after planting.

18.6 Erosion Control

18.6.1 Erosion and nutrient removal by different crops

To compare the nutrient extraction and soil erosion caused by cassava with those of other crops, a trial was initiated in mid-1989 on 5-8% slopes in Sri Racha, Thailand. Both cassava for root production (planted at 1.0 x 1.0 m) and for forage production (planted at 0.5 x 0.5 m) were compared with maize, sorghum, peanuts, mungbeans, sugarcane and pineapple. Soil erosion was measured at monthly intervals by collecting the sediment that eroded into plastic-covered ditches below each plot. At harvest each crop was separated into harvested and nonharvested products, and each fraction was analyzed separately for the major and secondary nutrients in order to determine the nutrient offtake in the harvest as well as the nutrients returned to the soil in the crop residues.

Figure 18.7 shows the soil erosion losses of each crop over a 22-mo period, corresponding to 2 crops of cassava for root production, 4 cuts of cassava leaves for forage production, 2 crops of maize, sorghum, peanuts, 3 crops of mungbeans and one of pineapple; sugarcane established very poorly so data are not included. Cassava for root production caused highest levels of erosion (140 t/ha), followed by cassava for forage production and mungbeans (about 70 t/ha); in the case of the other crops, erosion losses varied from 30-45 t/ha. Cassava for root production caused the most serious erosion because of the wide spacing used and the slow rate of initial growth resulting in slow canopy closure; while cassava for forage production caused less erosion as a closer plant spacing was used, and the crop did not have to be replanted the second year. Short-cycle crops such as maize, sorghum and peanuts caused less erosion because of a more rapid canopy closure after planting; after harvest the soil was protected by the growth of weeds and by crop residues left as mulch. Thus it is clear that in areas where rainfall distribution permits the planting of only one short cycle crop per year, erosion losses caused by a long-cycle crop such as cassava can be much higher than those of these short-cycle crops. Nevertheless, as cassava is often the only crop that grows well under conditions of poor soils and irregular rainfall, farmers will continue to grow it. Although erosion cannot be prevented, it can be reduced to a minimum, mainly through the use of better cultural practices.

Table 18.3 shows the DM production and nutrients in the harvested and nonharvested products. Planting cassava for forage production resulted in the highest levels of N and K removal in the cut leaves and young stems.

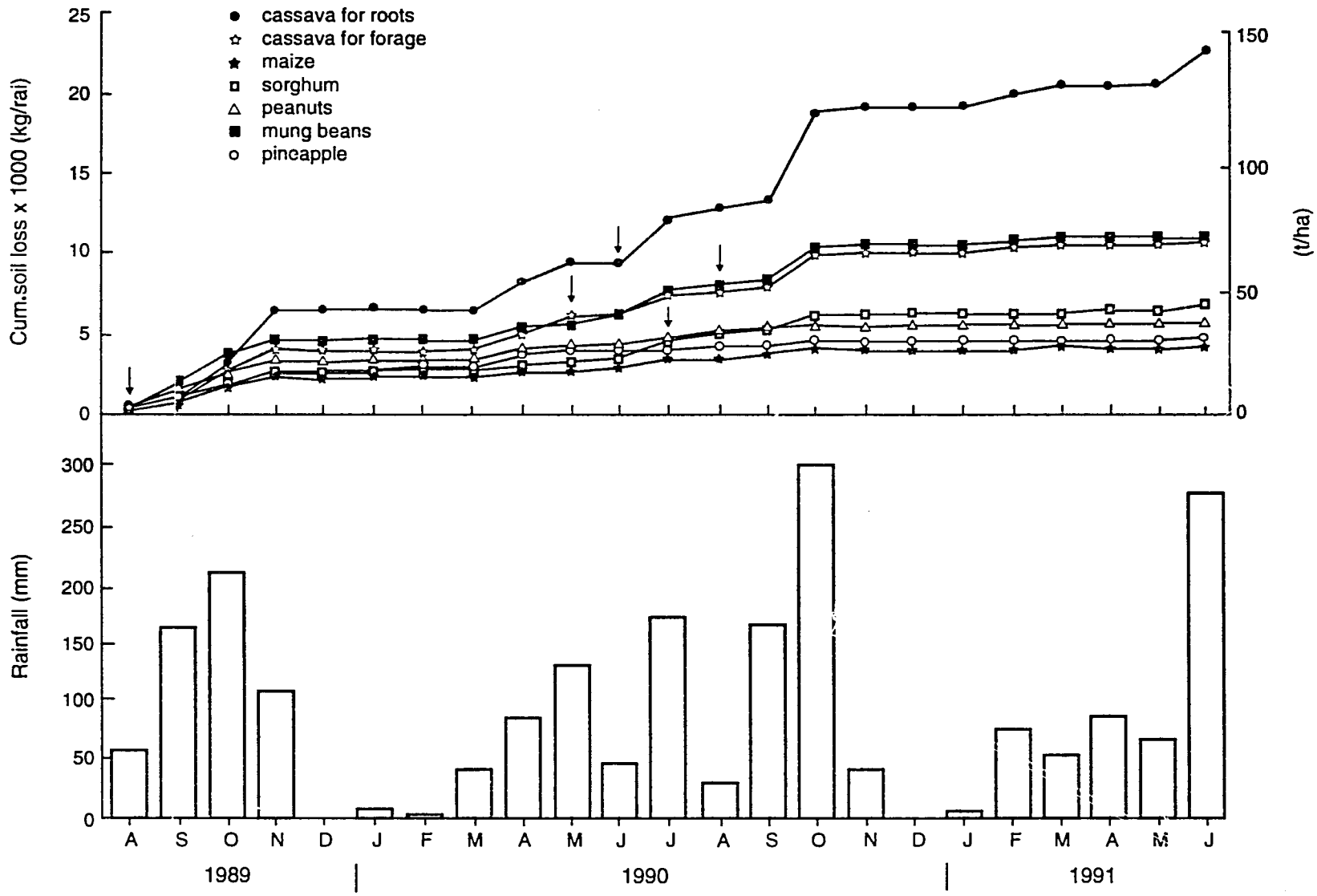


Figure 18.7. Cumulative dry soil losses due to erosion in various crops grown during a 22-mo period on a 7% slope in Sri Racha, Thailand from 1989-91; arrows indicate time of planting; rainfall distribution is shown below.

Cassava for root production removed much less N than peanuts but similar amounts to maize, sorghum, mungbeans and pineapple. P removal was lower than in maize and sorghum, while K removal was lower than pineapple but higher than most other crops. Compared with others crops, cassava removed relatively large amounts of K in the harvested roots, while it returned most of the absorbed N to the soil in the form of leaves and stems.

TABLE 18.3. DM and major nutrients in the harvested and nonharvested products of various crops grown for 22 mo. in Sri Racha, Thailand.

	DM Production (t/ha)		Nutrients Removed (kg/ha)			Nutrients Returned (kg/ha)		
Crop	Harv. Prod.	Nonharv. Prod	N	P	K	N	P	K
Cassava for roots	9.01	5.90	102	19	104	182	20	87
Cassava for forage	11.82	-	329	39	193	-	-	-
Maize	8.78	12.76	118	44	87	101	13	271
Sorghum	5.10	17.18	79	25	51	147	27	305
Peanut	4.90	8.59	213	19	52	133	25	184
Mung beans	2.73	2.99	114	14	59	51	6	64
Pineapple	7.58	19.21	82	15	188	161	31	279

18.6.2 Effect of cultural practices on erosion

The effect of land preparation and other cultural practices on cassava yield and erosion losses were studied on Hainan Island (China). **Figure 18.8A** shows that highest erosion losses were obtained without fertilizer application. Losses were drastically reduced by live barriers of *Brachiaria decumbens* or *Stylosanthes guianensis*, by contour ridging and by applying fertilizers. In the land preparation trial, conducted on 15% slope, the traditional practice of plowing twice followed by harrowing twice with oxen caused extremely high soil losses (250 t/ha). Soil losses were markedly reduced (but still unacceptably high) by contour ridging or by reducing land preparation to only a single plowing or to zero tillage. Planting after a single plowing or after hand preparation of planting holes produced the highest yields, while zero tillage reduced yields only slightly.

The effect on erosion of live barriers of citronella and vetiver grass, intercropping with *Crotalaria juncea* and mulching with dry grass was measured on a 20% slope in Baybay, Leyte, Philippines. **Table 18.4** shows that mulching with dry grass resulted in even higher cassava yields than those obtained with chemical fertilizers, while erosion losses were only about half as high.

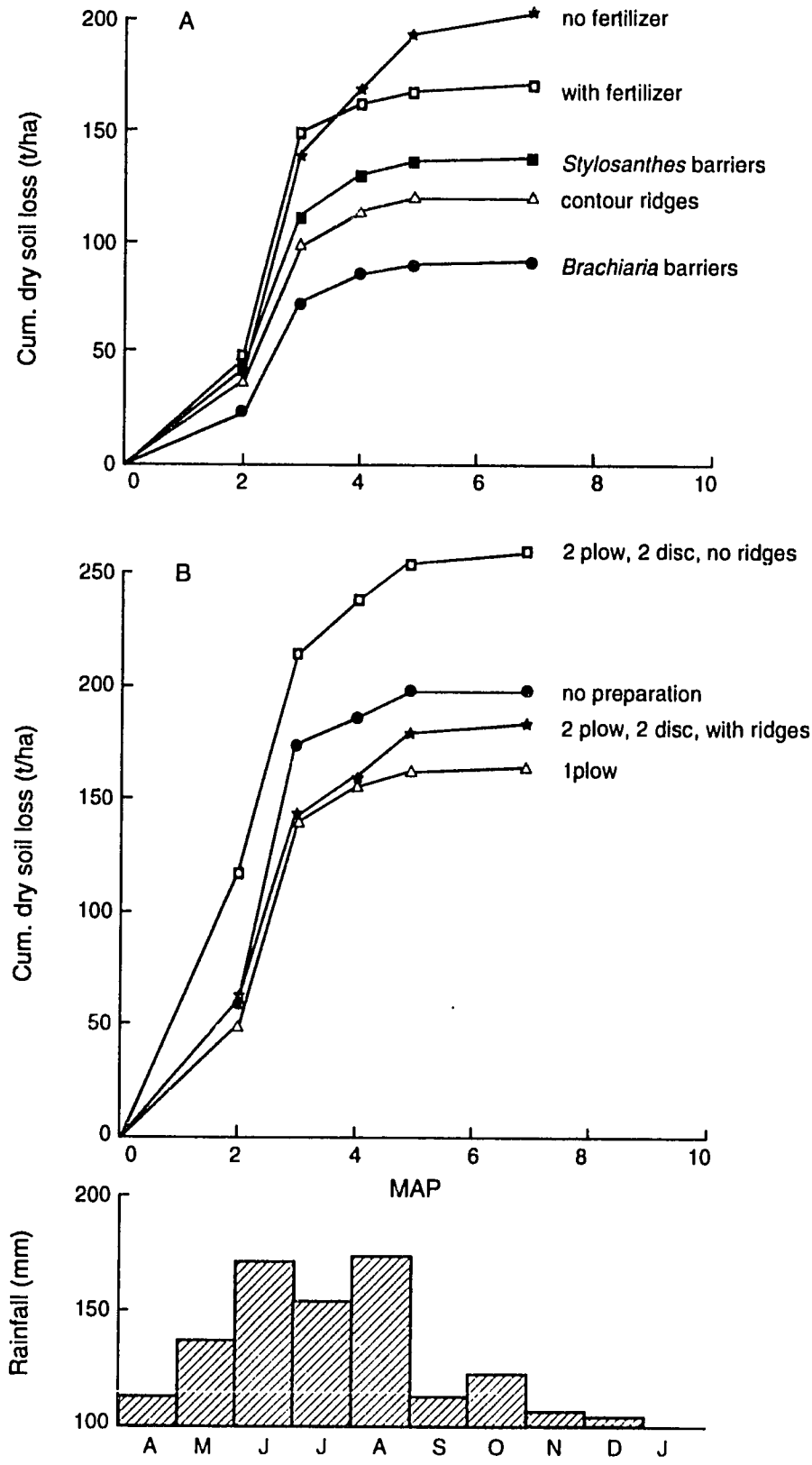


Figure 18.8. Effect of (A) cultural practices or (B) land preparation methods on the cumulative soil loss due to erosion when cassava (SC205) was grown on a 15 and 25% slope, resp., at the SCATC, Hainan, China in 1991; the rainfall during the growth cycle is shown below.

TABLE 18.4. Effect of cultural practices on dry soil loss due to erosion and on RY of cassava growm on 20% slope in Baybay, Leyte Philippines in 1991-92.

Treatments		Soil Loss (t/ha)	Cassava RY (t/ha)
1.	Cassava + fertilizers[1]	52.73	34.72
2.	Cassava + live barrier of citronella	62.89	25.22
3.	Cassava + live barrier of *vetiver g.*	70.82	22.22
4.	Cassava + intercrop of *Crotalaria juncea*	30.98	23.39
5.	Cassava + mulch of dry grass	27.99	37.49

[1] Fertilizers (60 kg/ha each N, P_2O_5, K_2O) applied only in Treatment 1.

Live barriers of citronella or vetiver grass were not effective in reducing erosion during the first year of establishment; similar results were also obtained with lemon grass barriers in Thailand. Once these barriers are established, they can reduce erosion drastically by slowing the downward flow of water and by enhancing natural terrace formation during land preparation along the contour.

18.6.3 Effect of plant type and cultural practices on erosion

Erosion losses are reduced when soil cover increases, which may be achieved either by cultural practices or by changing the plant type. Four cassava cv. with different plant types were planted with 3 different fertilization treatments and planting distances on a 5-8% slope in Pluak Daeng. Rayong 1 and Rayong 90 have a rather erect plant type with late branching; Rayong 3, a more prostrate plant type with profuse branching; Hanatee, a tall erect plant with late branching of 2-3 main stems.

Figure 18.9A shows that the tall erect Hanatee caused less erosion than the other three cv. because of its greater early vigor and more rapid canopy closure. Although this cv is late branching, it generally bifurcates very early, resulting in 2-3 main stems and a rather wide canopy width; in contrast, Rayong 3 is short with profuse branching, but growth is less vigorous and canopy closure is delayed. **Figure 18.9A** also shows that closer plant spacing was not nearly as effective as fertilizer application in controlling erosion. Fertilizer application markedly increased the rate of canopy closure in all cv.; on avg this reduced erosion by 45% and increased yields by 60% (**Fig. 18.9B**). Thus fertilizer application is a practice that can be very effective in increasing yields while decreasing soil erosion.

18.6.4 Erosion trials on farmers' fields

Several years of erosion trials on experiment stations have indicated that certain cultural practices such as fertilizer application, contour ridging, minimum tillage, mulching and closer plant spacing can reduce erosion markedly. In order to determine which of these

practices is most effective in farmers' fields and acceptable to them, 4 preliminary trials were conducted in Rayong Province (Thailand).

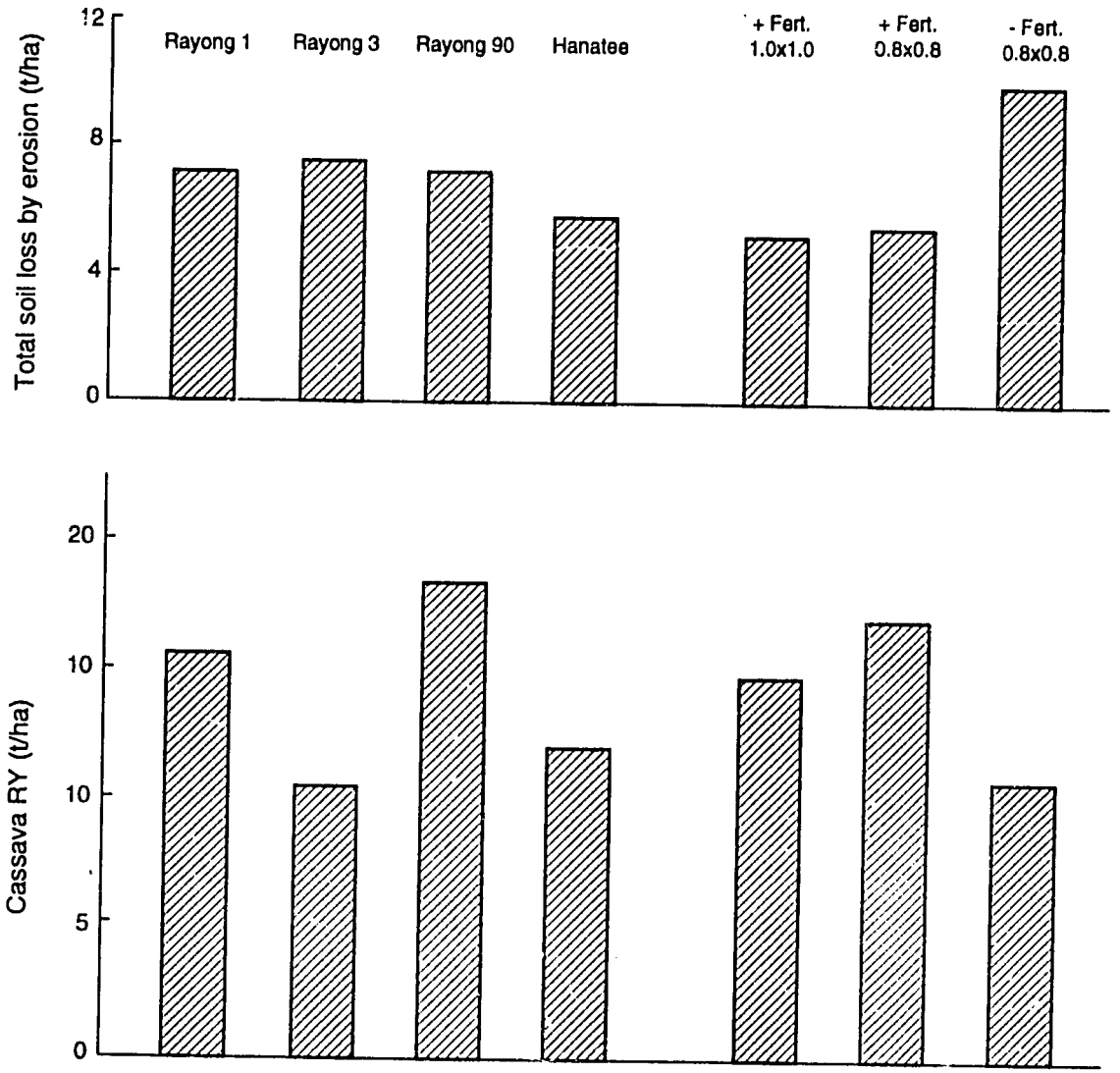


Figure 18.9. Soil erosion losses (top) and cassava RY (bottom) of 4 cv. with different plant architecture and grown at two planting distances, with or without fertilizers in Pluak Daeng, Thailand, 1991-92

In discussions with extension officials, it was decided to test the effect of fertilization, contour ridging and closer plant spacing, using 6 treatments (no reps) on each farm; the use of mulch was considered impractical given the high labor costs. Erosion losses were estimated from the monthly weighing of sediment collected in plastic-covered channels below each plot.

Erosion losses were highest on the rather steep land of Wang Chan (**Table 18.5**). Among the various treatments, lowest levels of erosion were obtained by the farmers' practice. This rather surprising result indicates that farmers in the Rayong area already use many of the recommended practices such as fertilizer application and the use of high plant populations. In fact, a recent survey of 120 cassava farmers in Rayong Province indicates that 90-95% of the farmers use chemical fertilizers, about 80-85% plant more than 10,000 pl/ha, and about 55% plant on ridges, of which 60% are contour ridges and 40% are up-and-down ridges. The recommended practice of closer plant spacing (0.8 x 0.8m), application of a higher fertilizer rate (312 kg 15-15-15/ha) and contour ridging produced the second lowest level of erosion and the highest yield. Again the application of fertilizers was most effective in increasing yield and reducing erosion. From these preliminary on-farm trials, it is clear that farmers in Rayong Province are well aware of and are actively using the recommended practices through close collaboration with a well-organized extension service--not only to reduce erosion losses but also to maintain high yields and economic productivity in a sustainable manner.

TABLE 18.5. Effect of plant spacing, fertilization and contour ridging in total soil losses due to erosion and on cassava RY at four locations of Rayong[1] Province in Thailand in 1991-92.

		Soil Loss (t/ha)					RY (t/ha)				
Treatments		A	B	C	D	Avg	A	B	C	D	Avg
1	1.0x0.8m, no fert.	6.90	12.17	21.62	9.07	12.44	8.89	6.31	20.74	2.92	9.71
2	1.0x0.8m, with fert.	3.45	4.79	27.65	12.33	12.05	13.40	11.60	25.47	4.72	13.80
3	1.0x0.8m, no fert., ridge	3.19	13.27	28.65	11.61	14.18	7.46	5.40	18.79	6.69	9.59
4	0.8x0.8m, no fert.,	7.62	4.31	22.07	6.25	10.06	7.86	6.15	21.14	3.44	9.65
5	0.8x0.8m, with fert., ridge	4.16	9.55	16.14	9.89	9.93	13.87	10.81	27.11	8.16	14.99
6	Farmers' practice	8.41	1.61	15.47	4.90	7.60	11.71	8.84	20.57	8.09	12.30

1 A= Land Development Center, Rayong, 6% slope, 831 mm rainfall
B= Farmer's field Ban Chang, 5.4% slope, 779 mm rainfall
C= Farmer's field Wang Chan, 11,4% slope, 619 mm rainfall
D= Farmer's field Mab Yang Pon, 4.5% slope, 939 mm rainfall

2 Farmers' practices vary slightly among locations, but generally include a planting distance of 0.8 (or 1.0) x 0.7m, no or up - and - down ridging and the application of about 200 kg 15-15-15/ha.

3 With fertilizer = application of 312 kg 15-15-15/ha at 1 mo after planting.

19. CASSAVA FLOUR

Following the implementation of the new strategic plan, all core-funded research activities in cassava utilization were terminated at the end of 1991. Two principal research areas remain, funded by special projects:

- cassava flour for human consumption (funded by IDRC)
- cassava starch (funded by CIRAD)

This chapter covers the research on cassava flour; Chap. 20, that on starch. The projects that facilitated direct involvement in the Atlantic Coast Integrated Project--funded by Colombian government agencies (DRI and PNR)--were not renewed, thereby terminating CIAT's input into the fresh cassava storage pilot project in Barranquilla and marginal involvement in the dried cassava project.

The need for continuing cassava utilization research--addressing problems and opportunities of relevance for the 1990s and beyond--is being met through coordinated product development and related research (see Sect. 19.3).

19.1 Cassava Flour Project: Commercial Expansion Phase

The development of cassava flour for human consumption, which has constituted a major research effort of the Cassava Utilization Section since 1984, received funding from the International Development Research Centre (IDRC) for three phases: research, pilot and commercial expansion. The 1991 Annual Report provided an overview of the development of this project from research through to pilot plant operation and evaluation; the commercial expansion phase started in Jan 1992. Nevertheless, technical problems encountered during the pilot operation of the plant remained to be resolved before the activities related to commercial expansion could be addressed.

19.1.1 Phase 3 objectives

The specific objectives of this project are to:

- Develop and execute a plan for expanding the cassava flour agroindustry in Colombia including site selection methodology, a reduced-cost redesign of the plant, the identification of potential sites, the promotion of the agroindustry, market development, training, and monitoring and evaluation

- Understand the factors affecting cassava flour quality and their relation to end-product quality

- Enhance the financial rate of return (FRR) of the pilot plant by increasing capacity, testing and adapting in-plant, small-scale milling operations and reducing drying costs

- Promote the dissemination of project results in other relevant countries of Latin America and Asia

- Study the effect of free market policies on wheat imports and prices in Latin America

19.1.2 Modifications made to overcome problems

At the end of the pilot phase in 1991, the pilot plant, located in Chinú, Córdoba and operated by a farmer coop, was still producing cassava flour of deficient microbial quality. This impeded its acceptance in potential food industries identified through market research (processed meats, cookies, etc). An in-depth evaluation of the process identified several potential sources of microbial contamination, and a series of trials at CIAT, with the assistance of NRI, were programmed for early 1992 to provide some concrete options for process modifications at the pilot plant.

Four drying trials were conducted to test the effect of chip loading rate, airflow rate and temp on drying time, dried chip microbial quality and total cyanogen content. The results demonstrated that low loading rates decreased drying times and substantially improved the microbiological quality of the chips; however, drying efficiency was adversely affected (costs increased). A second series of trials investigated the effects of the following variables on dried chip quality:

- Time between harvest and process initiation
- Holding roots in sacks or under water before processing
- Use of sodium hypochlorite in wash water

Based on the results of these and previous experiments, the following sequence of operations was recommended for the pilot plant:

- Minimize the time between harvest and initiation of the process (< 24 h)
- Keep roots in sacks before processing, not under water
- Wash for 5-7 min, with Cl concn of 10-20 ppm

A series of modifications were made to the pilot plant to improve the drying system and to prepare the plant for future expansion. The air distribution during drying is improved using a less elongated design; thus the existing drying chamber of 2 x 10 m was reformed to create two chambers of 3 x 7 m each. The entire drying area was enclosed within brick walls to prevent contamination of the chips during drying. An additional coke-fired burner was purchased and coupled in parallel to the existing burner to provide

additional heat for one of the drying chambers. This made it possible to achieve higher drying temp and therefore, shorter drying times and improved microbial quality of the dried chips and flour. The second drying chamber will be used once the market demand is sufficient to justify the purchase of the additional burner required to operate it. A design for a brick-lined coal burner, based on the model in use at CIAT, was prepared, and the potential for gas-fired burner systems will also be evaluated.

19.1.3 Results of pilot plant operation and product quality

The modifications to the pilot plant were finished in May 1992, and the pilot plant began operations in June. The 1991-92 growing season in the Atlantic coast region was characterized by unusually low rainfall and severe outbreaks of CBB, both of which contributed to decreases in cassava yields, adversely affecting the availability and the quality of the raw material for the pilot plant. Specifically, the root DM content was, on avg, exceptionally low (20-25%). In addition, the drought led to rationing electricity for up to 8 h/day from March onward. This obliged the pilot plant to dry cassava overnight, when higher energy consumption was required to reach the desired temp.

Despite these unforseen difficulties, considerable success was achieved. In a series of trials designed to relate loading density, air temp and drying time to the microbial quality of the dried cassava, 13 lots of cassava were processed. Care was taken to select as high a quality cassava as possible and to minimize the time between harvest and processing (10-20 h). From June to July, 19 t of roots (purchased at Col$30/kg) and 5.42 t of high-quality dried chips were produced for a conversion rate of 3.51. This exceptionally high conversion rate was due to the low DM content of the available cassava, as explained above. During 1991 a series of standards for controlling the different process operations was established, including use of labor, fuel, water and time in the different stages of the process, and limits for the amount of reject roots and waste produced. In general the use of labor and other inputs was close to the established norms except for labor used in washing and chipping (50% above limit) and during drying (low root DM content increased drying times)

The two burners coupled in parallel produced a significant increase in the temp of the air entering the drying chamber, but still required 4 h to reach the desired 60°C to ensure a well-dried product. Because of the electricity rationing, drying by day and night was undertaken. The combination of night drying plus the use of cassava with very high moisture contents led to the very high coke consumption reported for most of the lots. Trials were conducted using loading rates from 38-106 kg/m^2 in order to establish an optimal loading rate for chips of acceptable microbial quality. Coke consumption ranged from 1573 kg/t dried cassava for the lowest loading rate used down to 738 kg/t--still well above the 250 kg/t established as a limit in the 1991 trials. Thus the poor DM content of the cassava produced in the area of the pilot plant during 1992 resulted in significantly higher drying costs than in the previous year. The new dimensions of the drying chamber did, however, produce more even drying of the chips. The avg variable costs for

producing flour from Col$145,000 to a high of $203,000/t. The high max. values reflect the low loading rates used in the first few lots. The high conversion rates and coke consumption also contributed significantly to these costs.

The microbiological quality of the chips produced from these lots was significantly better than in 1991. Max. counts of 200,000; 100 and 1000 for total mesophilic bacteria, coliform bacteria and fungi/yeasts, resp., have been set by the Instituto Colombiano de Normas Técnicas (ICONTEC). For wheat flour, the max. total mesophile count permitted is 300,000. Ten of the 13 lots produced total counts below 200,000; the remaining 3 lots, 300,000. Total coliform counts were 0 in all but two cases (9 and 11), and *E. coli* was absent from all lots. In 1991 counts of over 1 million for total mesophilic bacteria, and the presence of *E. coli* had made it impossible to commercialize the flour. The dramatic improvement in chip quality was undoubtedly the result of improvements made in the chip drying system and the stricter control applied to the management of the fresh roots. Some of the lots did, however, show higher-than-permitted levels of fungi and yeasts. As the chips were well dried and no visible contamination ensued in storage, it is likely that this represents contamination of the samples prior to lab analysis (often delayed because of constant power cuts).

Further lots of cassava were processed in Sept-Oct; detailed information is available for the first 3 lots of Sept (**Table 19.1**). The fresh root MC was lower than in the June-July period; hence conversion factors and coke consumption were more acceptable. Total variable costs were as low as Col$132,000/t. These results demonstrate the importance of fresh root quality in total costs--not just in terms of raw material costs but also energy consumption, labor use, etc. These results are reflected in the economic and financial model (Sect. 19.1.5).

The prototype small-scale milling system developed as part of the previous phase of the project was transported to the pilot plant for evaluation under true operational conditions. As a result, several modifications were made to improve throughput and ease of maintenance/cleaning and to ensure a longer life for the finer of the two cylindrical screens used in the milling and screening operations. Initial operation at the pilot plant produced an 85% conversion of chips to high-quality flour, within the target range of 85-90%. A throughput of 95 kg/h was achieved with manual feeding of the flour; when a mechanical feed system was installed, throughput increased to 250 kg/h.

19.1.4 Market development

The previous phase of the project had relied on milling the chips in a wheat flour mill in Medellín; hence market development work had been focused on the major flour-using food industries of that city. The installation of the small-scale mill in the plant made it possible to refocus market development work in the Atlantic Coast region itself. Based on the results of the initial market survey, visits were made to 4 producers of processed meats, 2 bakeries, 3 flour wholesalers and 2 wheat flour mills in the region (Sincelejo,

Cartagena and Barranquilla). As a result, two sales were made, totaling 1.8 t flour--both to processed meat companies, one in Sincelejo and the other in Barranquilla. An introductory price of Col$ 210/kg was fixed. Both firms expressed satisfaction with the quality and the price of the product (wheat flour is currently at Col$ 270-280/kg) and have since become regular clients of the coop. A third processed meat firm in Barranquilla has also purchased cassava flour.

Table 19.1. Results of 3 lots of cassava processed in Sept 1992.

Lot No.	Fresh Cassava (kg)	Chips Produced (kg)	Conversion Factor	Coke Consumed/ t Chips
14	1488	598	2.49	563
15	1354	556	2.43	656
16	1088	349	3.00	945
Mean	3930	1503	2.61	688

Lot No.	Cost Raw Material/t[1]	Labor/t (Person-h)	Total Variable Costs[1]	Fresh Root MC
14	74,700	51	132,240	64.6%
15	72,900	56-7	136,946	64%
16	90,000	67.6	174,748	71%
Mean	78,300	57	144,550	

[1] US$1 = Col.Ps.$; avg. for 1992.

The price of cassava flour was initially fixed on the basis of production costs and maintaining a 15% discount vs. wheat flour. A 5% discount is given for the first purchase and for cash payment, as well as for bulk purchases. After August, the price was increased to Col$ 220/kg in Sincelejo, taking into account the higher cost of wheat flour in this market (cassava flour can have a greater profit margin in this market).

The brand name (YUKARIBE) was selected for this flour and is in the process of being legally registered by the coop. The license permitting the sale of the flour for human consumption is being solicited from the Ministry of Health. A design for a 25-kg sack (0.5 x 0.8 m) was prepared in two colors (red and green) and has been printed onto sufficient polypropylene sacks for 6 mo production.

19.1.5 Economic and financial feasibility

As a result of the technical improvements made and the inclusion of the milling operation at the pilot plant, the economic feasibility of the plant improved considerably.

The latest output of the financial model (**Table 19.2**) used to determine the FRR and other information gives an overall FRR of 26%, compared to the current opportunity cost of capital of about 30%. With further minor improvements and increases in capacity when demand for flour expands, a FRR well above 30% can be expected.

The variable costs for flour production total Col$150,000/t, including Col$84,000 for cassava raw material and $38.000/t for the coke used during the artificial drying process. Fixed costs represent an additional Col.$15/t if capacity utilization averages 80%. Total flour and by-product production costs are therefore Col$164,716/t, with a selling price of Col$220,000/t for flour and $100,000 for the by-product, which is used for animal feed and represents 15% of total vol.

The selling price for the two products provides net and gross margins of 18% and 25%, resp. The current price of wheat flour on the Atlantic Coast of Colombia is Col$270,000-280,000/t on a wholesale basis; thus cassava flour can compete in price with wheat flour and maintain acceptable margins. The possibilities for replicating this pilot experience are now positive.

19.2 Other Activities In Cassava Utilization

As stated previously, all research activities in dried cassava for animal feed and fresh cassava storage technologies were terminated at the end of 1991. The Section has, however, continued to respond to a large number of worldwide requests for detailed information on these topics and remains in close contact with integrated projects where these technologies are being used. This is essential if the Cassava Program is to remain relevant to cassava farmers and processors in Latin America, through feedback on current activities. The integrated projects meeting held in Ceará (Brazil) in Oct 1992 was vital in this respect. Continued interaction with several countries will be essential if they are to develop projects based on these technologies; e.g., fresh cassava storage and dried cassava use in animal feed for Paraguay, dried cassava for Bolivia, and starch extraction for Argentina.

In March a joint mission with the NRI was made to Ghana to assess the feasibility of implementing the fresh cassava storage technology in that country. As a result, substantial information on fresh cassava marketing in Ghana was obtained from primary and secondary sources; and the feasibility of a project, established. This will be executed by Ghanaian institutions and NRI.

Table 19.2. Pilot plant operational costs with FFR, 1992.

Basic Information	Plant production capacity 180 t/yr flour Capacity utilization 80%			
	Inputs	Unit	Unit Cost (Col$)[1]	Units/t
	Fresh cassava	kg	30	2800
	Labor	person-h	180	70
	Sacks	1	175	40
	Electricity	kwh	45	150
	Coke	kg	54	700
	Water	m^3	200	7
Variable Costs			Cost (Col$)/t	% Total Costs
	Fresh cassava		84,000	51
	Coke		37,800	23
	Labor (4 workers)		12,600	7
	Electricity		6,750	4
	Sacks		7,000	4
	Water		1,400	1
		Total	149,550	91
Fixed Costs				
	Salaries		10,083	5
	Maintenance		4,083	3
	Other		1,000	1
		Total	15,166	9
		Total production costs	164,716	100
	Sale price			
	Flour (85% of total)		220,000	
	By-product (15% of total)		100,000	
	Net margin		18%	
	Gross margin		25%	
	FRR		26%	

[1] US$1 = Col$700; avg. for 1992.

20. CASSAVA STARCH

A collaborative project between CIAT and CIRAD-SAR (Systems Agro-alimentation et Ruraux) on "Production and utilization of cassava starch" was initiated in 1989 in order to develop new technologies for the small-scale industry of cassava starch extraction in Latin America and to improve starch quality to strengthen existing markets and create new ones for both "sweet" (native) and "sour" (fermented) starch.

The priority areas of research were established in 1989 in agreement with producers and users of starch. The first results, which were detailed in the last report (Cassava Program 1987-1991), can be summarized as:

- Standardization of analytical methods. The analytical methods used by different labs working on cassava were compiled, evaluated and adapted for cassava starch (Physicochemical analysis, functional properties, structure...)

- Characterization of sour starch. In order to evaluate the expansion power of sour starch, defined as "the ability of a fermented starch to increase the volume of a dough containing that starch, and submitted to a process of baking," a simple test was designed. The protocol has been improved this year to establish good replicability and reproducibility. A study on sensory analysis of products based on sour starch has been also carried out. The expansion power of high-quality sour starch is correlated significantly with lactic (+) and acetic (-) content, color and functional properties of sour starch.

- Equipment improvement. One of the main conclusions of the 1989 technological diagnosis was the very low efficiency of the traditional process. To improve the extraction rate, new equipment was designed using the same principles as the existing machinery (washer/peeler, grater, extractor), and the system of sedimentation in settling channels was proposed. This sedimentation system has already been adopted by some producers in Colombia, and demonstration plants are operating in Ecuador and Paraguay. The new equipment was tested, and the improvements/modifications proposed as a result, evaluated in 1992.

- Influence of raw material. Trials were undertaken to evaluate the suitability of different cv. for sour starch production. Both cv. and harvest period play an important role in extraction yields (17.8-24.4 %). M Col 1522 (called Algodona, long cycle), which gives the best quality sour starch, has functional, structural and physicochemical properties very different from the other cv. (short cycle). Thus a direct relationship between the raw material and the behavior of fermented starch seems likely.

- Mechanisms involved in natural fermentation. Natural fermentation is homolactic, inducing drastic modifications of the:

  - structure of the granules (attack by enzymatic enzymes, which makes some of them pitted and porous)

  - chemical characteristics (production of organic acids and carbonic gas absorbed by starch)

  - functional properties of starch (decrease in max. viscosity during heating and no gelling tendency during cooling of the fermented starch paste)

  - the baking power seems to consist of a competition between the gaseous expansion due to the gases discharged and the viscoelastic properties of the amylaceous network. Hypotheses have been made as to the role of some molecules associated with starch to produce the adequate viscoelastic network (polysaccharides, phenolic compounds...)

These basic studies on the fermentation and the mechanisms involved in determining sour starch baking power were continued this year.

20.1 Improvement of the Starch Extraction Process

20.1.1 Grating

A metallic drum (40 * 22 cm) covered by abrasive layer (silicon carbide, granule size 24, thickness 25 mm) was evaluated. Although the capacity of the grater was reduced to 400 kg/h, the starch extraction from the mash is much improved: more than 90% vs. a mean of 81% for the traditional grater.

20.1.2 Extraction

The improved process consists of two steps:

- Extracting starch in a cylindrical water extractor (0.76 * 0.90 m), similar to the traditional extraction equipment but equipped with four mechanized mixing screws

- Refining the starch milk in a simple vibratory sifter

First, the mixing screw system was evaluated comparing the efficiency of the existing extractor and the new one under the same working conditions (**Fig. 20.1**). Then the working conditions were optimized as follows (**Fig.20.2**):

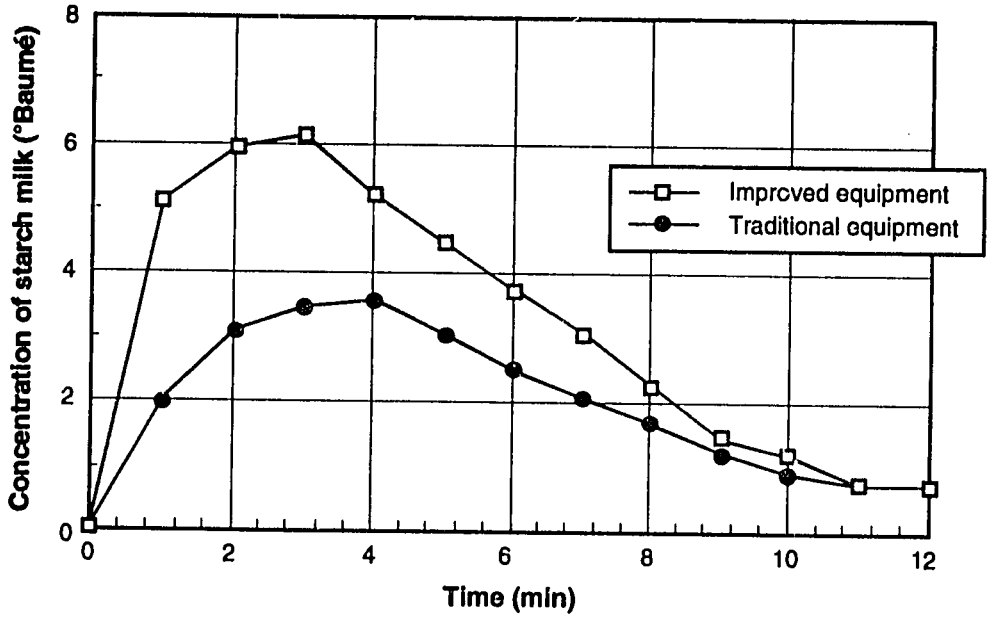


Figure 20.1. Changes in the concentration of starch extraction water with time.

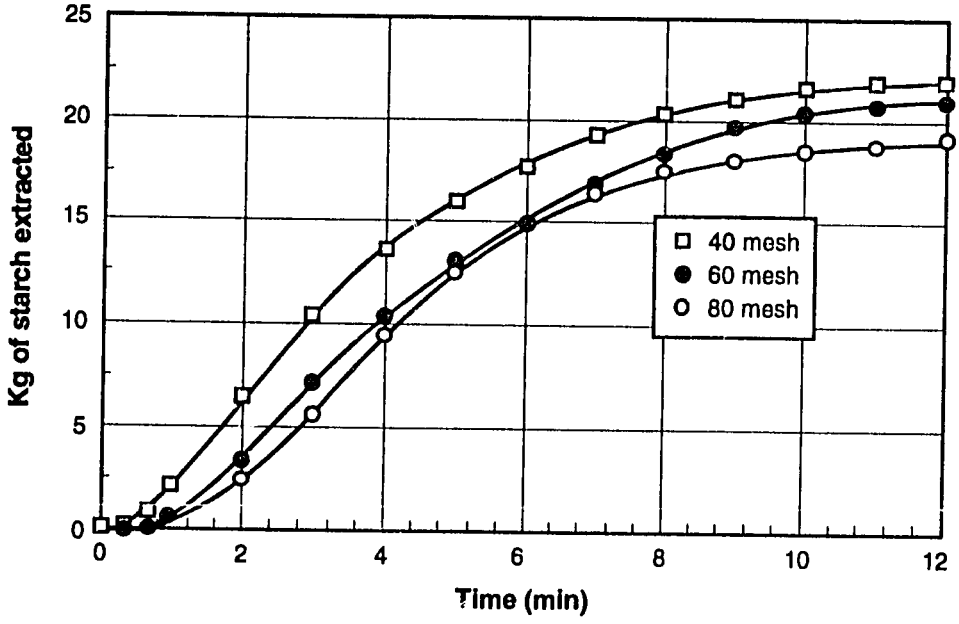


Figure 20.2. Effect of mesh size on starch extraction rates with time.

- Water flow rate of 36 l/min (flow rate generally available in the rallanderías)
- Batch of 80 kg of mash (i.e., a ratio load/useful vol of 57 kg/m^3)
- Sieve of the cylindrical extractor, 40 mesh
- Sieve of the vibratory sifter, 120 mesh

As designed and tested under these conditions, the equipment has an extraction capacity of ca. 280-300 kg fresh roots/h. Thus the bottleneck of the extraction step in the traditional process can be eliminated using this improved equipment. Starch losses in the extraction cake are reduced, and the improvement of the starch extraction rate is ca. 10% (**Table 20.1**). The extracted starch has good quality (fiber content from 0.06-0.19% in accordance with the typical specifications for industrial uses of less than 0.8%).

Table 20.1. Efficiency of the traditional and improved extractor.

	Capacity (kg/h)	Extraction Cake Starch Content (%) (± SD)	Extraction Rate (%) (± SD)
Existing equipment	200-220	16.4 (± 3.4)	20.6 (± 7.6)
Improved equipment	280-300	12.9 (± 1.1)	> 22.0

20.2 Improvement of Sour Starch Quality

20.2.1 Improvement of baking test

The protocol of the baking test was improved with the following steps:

- Manual milling and sieving (70 mesh) of the starch
- Mixing of ingredients (starch/cheese/water) in a Hobart mixer for 1 min and kneading the dough for 2 min
- Making six 30-g breads in ring form (internal diameter, 2 cm)
- Baking in a ventilated oven 280°C, 17 min
- Determination of bread wt and vol (with a seed-displacement bread volumeter, with 2 reps, using cauliflower seeds) after 2 h and the avg specific vol of the 6 breads

This protocol gives good repeatability ($p = 0.40$) and reproducibility ($p = 0.07$ for 5 collaborators trained).

20.2.2 Sensory analysis

A panel with 8 panelists was formed and trained. Then a descriptive test was developed to evaluate "**pandebono**," a typical bread product made with sour starch; 13 sensory

attributes were used with a structured scale from 1 to 9. This descriptive test has shown the influence of the sour starch quality on the acceptability of the pandebono, and an ideal profile was determined (**Fig. 20.3**).

20.2.3 Study of natural fermentation

A screening of the microorganisms during the natural fermentation confirmed that the dominant microflora is a lactic flora with a constant microbial population during the process of about 10^7 to 10^8 cells/g starch DM (**Fig. 20.4**).

Mucous strains are present with a population between 10^3 to 10^6 cells/g. Among these strains, the polysaccharide-producing species *Leuconostoc mesenteroides* ssp. *mesenteroides* et *dextranicum* was identified.

20.2.4 Isolation of lactic amylolytic bacteria

Using the protocol of coloration of lactic bacteria by aniline blue in MRS-starch medium, 75 strains of lactic amylolytic bacteria were isolated and purified; 50% of these strains were isolated during fermentation with clone M Col 1522 (Algodona).

A series of 20 strains were selected in relation to their amylolytic power and growth ability. All are homofermentative with a production of lactic acid between 0.5 and 2.0 g/l supernatant; their growth pH varies between 4.1 and 4.6. Using API 50 systems, they were identified as *Lactobacillus crispatus* (10 strains), *Lactobacillus acidophilus* (3 strains) and *Lactococcus raffinolactis* (4 strains).

The enzymatic biochemistry of these strains was studied (see BRU report).

20.2.5 Solar drying influence

Viscoamylograms of fresh and dried (solar or oven drying) starch show different functional behaviors (**Fig. 20.5**): The decrease in paste viscosity and the disappearance of the first peak of solubilization for dried samples show that modification of functional properties occurs during drying. Furthermore, baking power increased during the solar drying step (**Fig. 20.6**), with the specific vol of the breads increasing from 2.2 to 6.1 cm^3/g). The same sample dried by artificial drying (oven, 40°C) does not expand (specific vol 2.0 cm^3/g). Solar radiation including UV rays seems to play an important role in obtaining good-quality sour starch: this is supported by the sour starch producers themselves. Fermentation may give potential expansion properties to the fermented starch, which are expressed only after a solar drying step. It is possible that phenolic compounds are esterified with polysaccharides, and a complex formed during solar drying by an oxidative reaction catalyzed by UV rays. Further research will be carried out to test this hypothesis.

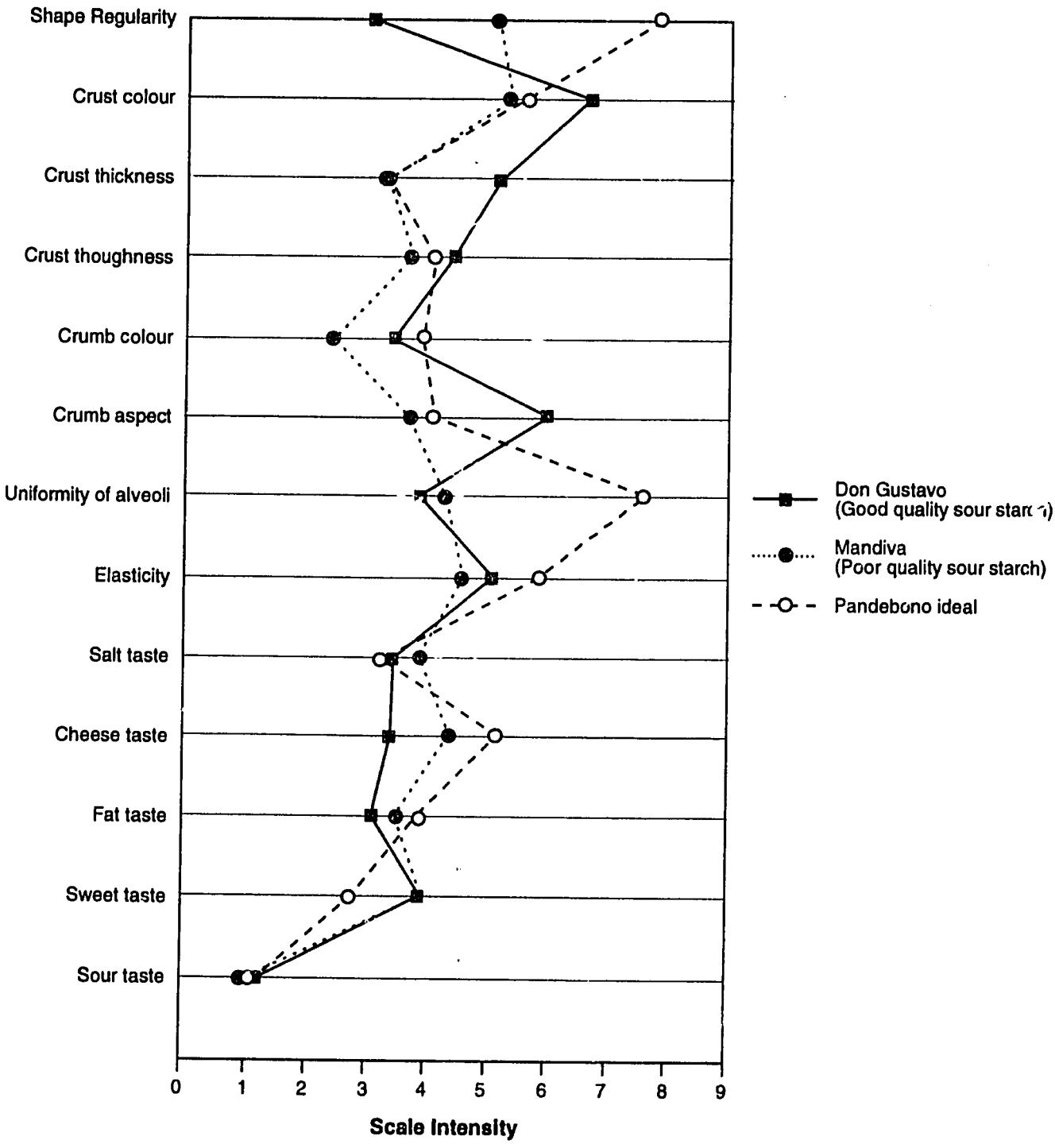


Figura 20.3. Sensory profiles of "pandebono" made with good and poor quality sour starch and ideal profile.

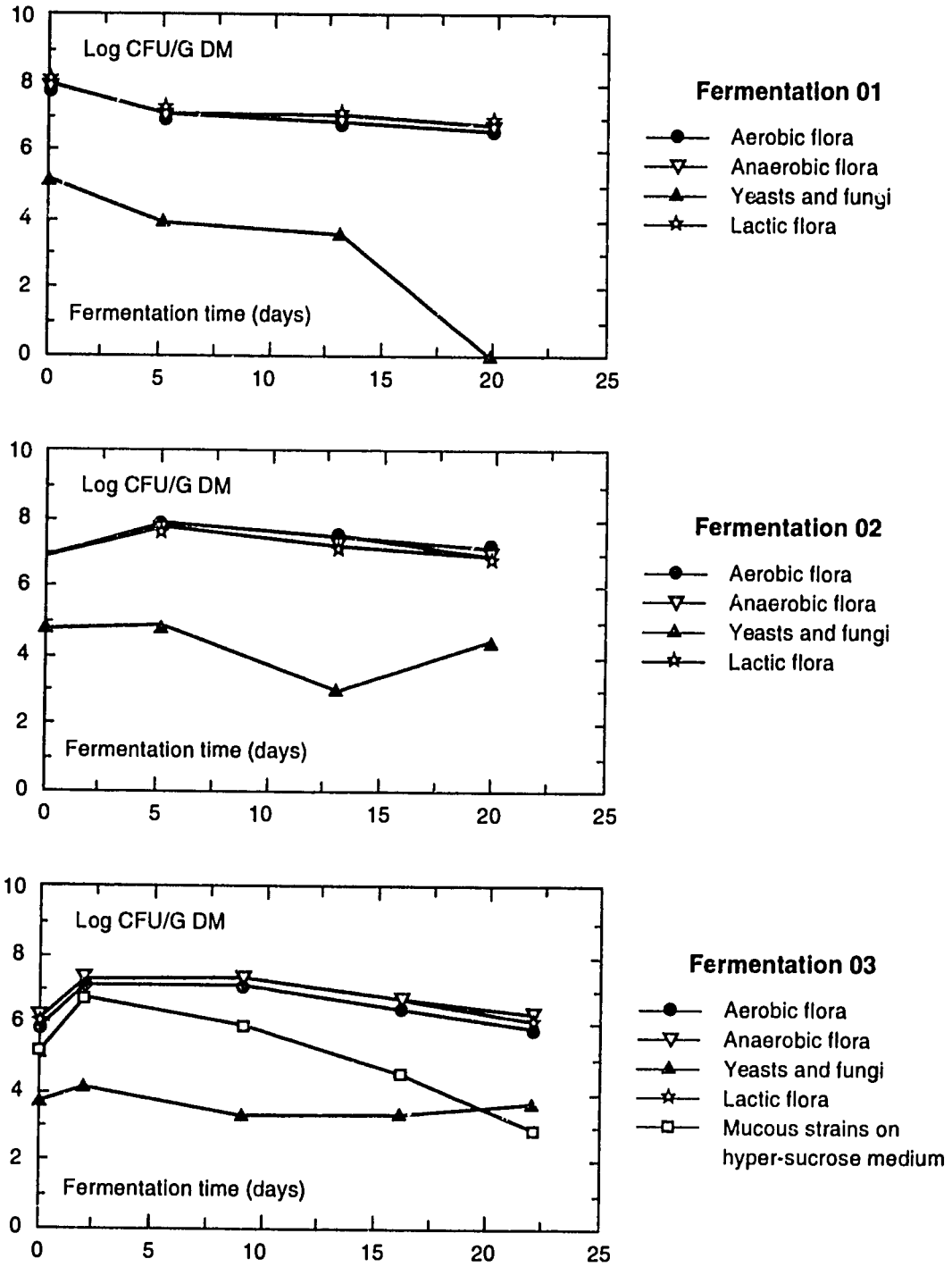


Figure 20.4. Microflora changes during the natural fermentation of cassava starch.

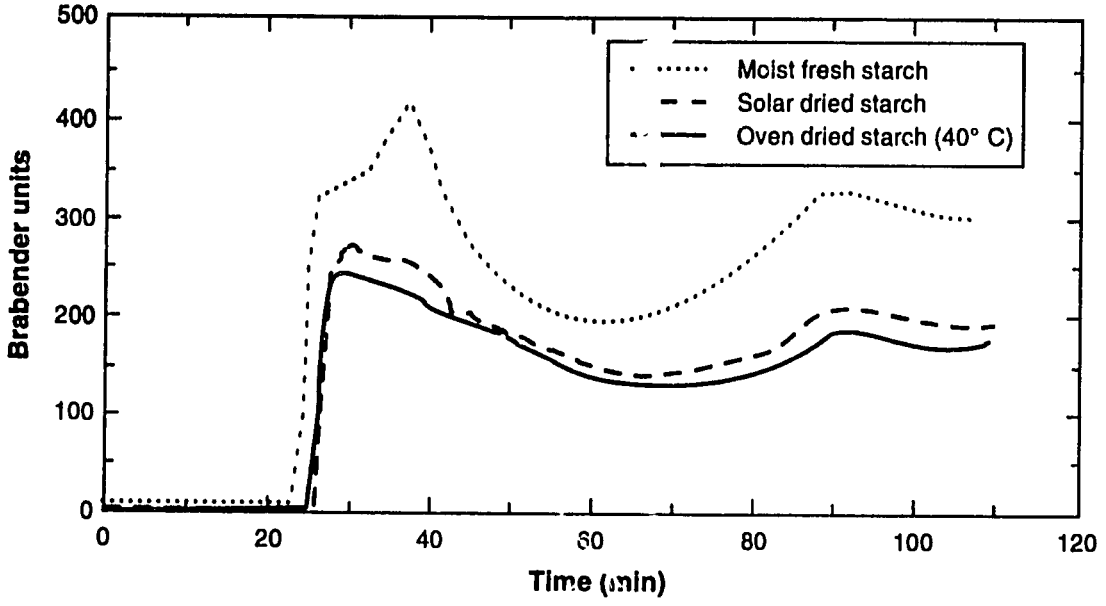


Figure 20.5. Brabender viscogram of moist fresh, solar and oven dried starch in pH 6,5 buffer.

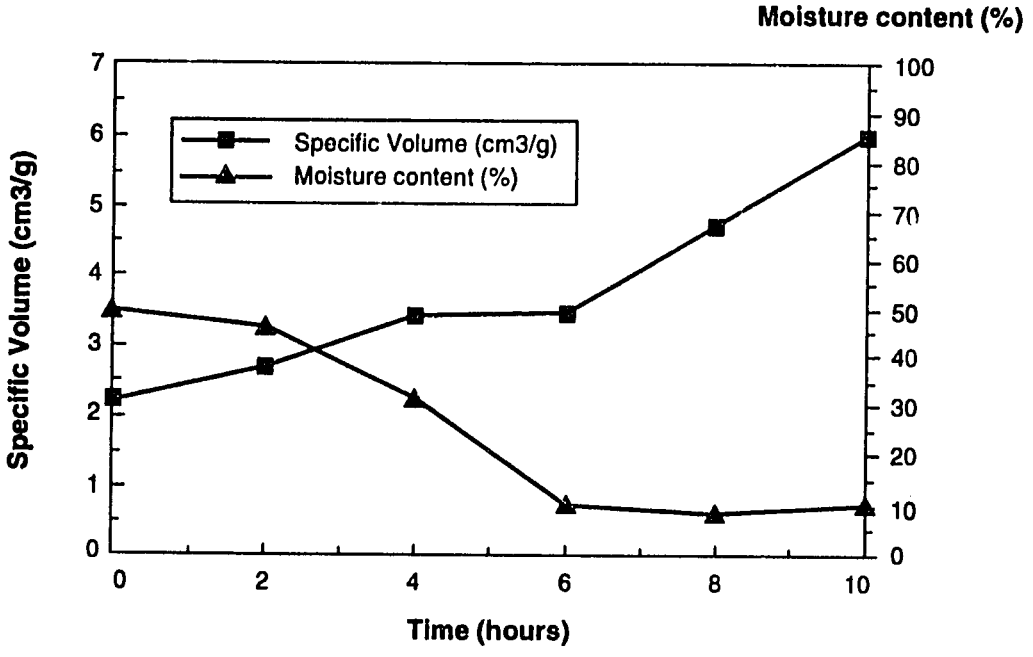


Figure 20.6. Effect of sun=drying cassava sour starch on moisture content and expansion power.

21. DESIGN AND ORGANIZATION OF INTEGRATED CASSAVA PROJECTS

21.1 Integrated Projects Network in Latin America

The informal network of integrated projects held its third meeting in Ceará (Brazil) from 28 Sept-20 Oct, during which more than 50 participants from 8 countries and 12 projects received updates on current projects and discussed several important issues: the production component, project monitoring and farmer organizations. In addition, field visits helped give a good appreciation of the Ceará integrated project.

Discussions on the future of the network led to the identification of individual project needs in terms of methodological, technical, organizational and financial support. The network will be developed to respond efficiently to these needs, taking advantage of the expertise already existing in current projects.

The integrated projects remain a vital research tool--both for adaptive testing and diffusion of new production, processing and marketing technologies and for feedback to basic research. The integrated projects are the Cassava Program's best means for keeping in touch with the beneficiaries' priorities, thereby maintaining the relevance of all basic and applied research.

21.2 Ceará - Northeast Brazil

The pilot phase of the project "Cassava Development: Integrated Production, Processing and Commercialization of Dry Cassava for Animal Consumption in Ceará, Northeast Brazil" ended this year. This special project had been supported by a 3-yr grant (March 1989-June 1992) from the W.K. Kellogg Foundation. The purpose of the grant was to enable CIAT--in partnership with Brazilian agricultural research and technical assistance agencies and farmer organizations at both national and state levels--to introduce improved cassava production and processing technologies and appropriate organizational schemes for institutions and farmer groups throughout the State.

The overall structure of the work plan used for project implementation included the following activities:

- Development of a macroeconomic planning frame
- Selection of an initial site for developing the pilot project
- Identification of local institutions, establishment of a working group and identification of local financial resources

- Design and establishment of the pilot project
- Observation of the operation and in situ modification of the modus operandi to adapt it to local conditions
- Monitoring of project performance and modification of project
- Design of the expansion phase to commercial scale

The macroeconomic planning phase (Activity no. 1) was conducted prior to project initiation through joint studies carried out by CIAT, EMBRAPA, the Empresa Brasileira de Assistencia Técnica e Extensão Rural (EMBRATER), the state-level Empresas de Assistencia Técnica e Extensão Rural (EMATER) and other Brazilian agencies at national and state levels. The production of dry cassava for animal feed in the NE was identified as the most promising enterprise.

The selection of the State of Ceará as the most suitable site for establishing the pilot project (Activity no. 2) was strongly influenced by the prior existence of strong research and extension efforts in cassava, coupled with considerable small-scale production and processing activities.

21.2.1 Project results

21.2.1.1 Development of the pilot project. At the onset of the project in May 1989, there were already 11 farmer groups with dry cassava processing agroindustries. As part of project activities these groups were reorganized and/or reactivated, and another 147 farmer groups were established, for a total of 158 producer groups organized around dry cassava agroindustries by the end of the pilot project. The majority of these groups (75%) were organized during the last year of the project and will be initiating dry cassava processing activities only as of July-Dec. Of the 158 farmer groups established during the last 3 yr, 12 are not considered ready as they are facing serious problems for lack of funds, raw material and, in some cases, consolidation of the groups themselves.

Rapid expansion of the project in terms of the number of farmer groups organized was especially significant during the third year of activities--mainly due to the strong intervention of the Government of Ceará, which through the Secretariat of Industry and Commerce launched a program of grant-type financial aid that permitted 69 rural communities to build dry cassava agroindustries during the period Jan 1991-May 1992. Despite the importance of having additional sources of funding available for farmer groups, the implementation of these programs needs to be coordinated at the central level--preferably through the Ceará Cassava Committee (CCC)--to avoid the types of problems that were already occurring during the last year with the distribution of the grants such as (a) the poor selection of the farmer groups; (b) the lack of institutional presence in some areas, making it very difficult to offer technical assistance to farmers;

and (c) the delay in delivering the economic resources to the farmers. Moreover, these programs have all too often been characterized by the need for rapid action, with minimum time for careful deliberation with farmer groups.

21.2.2 Local support

- Institutional support. Throughout the span of the pilot project, the CCC became a coordinating body for all activities related to the cassava crop in Ceará. The two main counterpart agencies (EMATERCE and EPACE) accepted the CCC as part of the institutional and organizational structure prevailing in the State. Coordination of activities in the areas of project influence was pursued through the establishment of the Regional Cassava Committees (RCC), five of which were operating by the end of the project. Promotion of small-scale production and processing activities during the present project was facilitated by the existence of significant institutional experience on which to draw, coupled with the participation of policy-makers, top-level administrators and technicians from local agencies who had been exposed to similar experiences in other countries and whose participation was fundamental at the onset of the project in defining the organizational and operational strategies.

  The onset of project activities coincided with the process of merging the two local counterpart agencies into a new agency with integrated responsibilities for agricultural research and technical assistance. By the end of the pilot project, this process had not yet been fully defined and seemed to have bogged down, creating uncertainty and instability among staff of both institutions and affecting their operational and organizational capacity. If the overall efficiency and coverage of the technical assistance schemes offered to farmer groups through the pilot project is to be maintained and enhanced, a reorganization of some of the technical teams will be necessary. Of course this will be feasible only when the organizational structure of the two local agencies becomes definitive.

- Financial support. Identification of sources of financial resources aimed at benefiting farmer groups allowed project activities to be carried out within the proposed goals. Total contribution of Brazilian agencies and development programs for project activities during the period 1989-92 reached US$1,002,000, not including the salaries of the technicians who participated in the project at all levels. Of these funds 57% was used to finance the establishment of dry cassava agroindustries, accounting for the rapid expansion of the social basis of the project. These grant-type financial sources are likely to become scarce, and the activities initiated during the last year of the pilot project related to the implementation of loan-type credit programs for establishing agroindustries, cassava production and processing bear special significance and must be carefully monitored and evaluated as they may become the most readily available source of funds for expanding project activities. These credit programs are based on price variation of cassava products such as dry cassava; and given the very high

inflation rates prevailing in Brazil (25-30% monthly), they are thought to represent a less risky credit scheme for farmers as compared with other credit sources available, which include monthly index-linked adjustments for inflation.

21.2.3 Production technology

Two types of activities were implemented to address this component: pre-production trials and planting material production plots.

- Pre-production plots. In 1990, 15 PPPs were established and harvested at 15 mo. Avg yield was 22.4 t/ha, 59% more than the avg yield obtained in farmers' plots. In the 1991-92 cropping season, 41 new trials were added with 28 being set for the first time. Avg yield for the PPPs in 1991 was 19.5 t/ha, representing 116% more than the avg yield obtained in farmers' plots. Initial results obtained with this activity have been very clear in the sense that the adoption of improved technology components makes it feasible to increase currently low productivity levels (8.3 t/ha, statewide avg). However, these results must be considered cautiously as they were obtained in a situation where all expenses were paid by the project. It remains to be assessed to what extent small-scale farmers will be willing to invest scarce economic resources in inputs such as organic fertilizer (10 t/ha) or weed control. Cow manure, for example, has become very expensive in Ceará, and its high transportation costs usually make its use unfeasible. Moreover, increased weed control activities may not be attractive given the farmers' scarce economic resources. Future project activities in this area must continue to evaluate this adoption process as well as assess the use of other alternatives such as green manure and cover crops as a means of maintaining soil productivity and sustaining reasonable yields.

- Planting material production plots. During the 1990-91 cropping season, a total of 15 plant material plots were installed; for the 1991-92 season the no. was increased to 41. Cassava production in Ceará presents a lag period of at least 6 mo between harvesting and planting, and storing of stakes for use as planting material is not feasible. To eliminate this constraint, the project strategy was to introduce the practice of pruning to obtain good-quality planting material at the onset of the rainy season. Results showed that the strategy of farmer-administrated plots for producing planting material combined with pruning practices at planting time is likely to fail. Moreover, the planting material distribution program carried out by the Secretariat of Agriculture (SEARA) is costly and covers only limited areas. This strategy will need to be reformulated in the future including activities such as regional commercial-scale production and distribution of best local cv. and closer integration with the interinstitutional breeding efforts currently being implemented in Ceará, where high yield-potential gene pools are being developed and characterized. Improved planting material production and

distribution is perhaps the best short-term strategy for increasing production and productivity levels in Ceará.

- Other activities. The project gave economic and logistic support to research and extension activities carried out by the two local counterpart agencies related to two problems identified as the major prevailing production constraints in Ceará: WB disease and the cassava hornworm (*Erinnyis ello*).

  - Cassava hornworm. Activities supported economically and logistically by the Kellogg Foundation funded-project have been oriented toward adapting and implementing--under the conditions of Ceará--a biological control technology for the hornworm: Baculovirus, already available on a commercial scale in other cassava-producing regions of Brazil. Project staff have already mastered the production of hornworm eggs and larvae of known ages for experimental purposes, as well as the production and testing of the virus under controlled conditions. Future activities will be oriented toward testing the efficiency of the virus in hornworm-infested fields and developing storage and application techniques.

  - WB disease. Research efforts to control WB were initiated in 1986 with the participation of EMBRAPA/CNPMF and CIAT and financial support from SEARA. Since its inception in 1989, the pilot project has supported the implamentation of these research efforts. Thus far control practices have been identified for WB and in general significant reduction in WB incidence and increases in RY have been obtained in those locations where farmers followed the recommendations.

21.2.4 Processing technology

Total amount of roots processed during the pilot project was 7094 t, with a total output of 2677 t of dry cassava. This production was obtained with 12 farmer groups functioning during the first year, 33 in the second and 45 during the last year. Total and avg annual output for the agroindustries varied considerably throughout the project, showing that an assured supply of roots for the drying plants depends on several factors including (a) strong competition from local and regional markets (e.g., **farinha**, animal feeds); (b) lack of working capital to purchase the roots--a constraint that remained unsolved during the three processing seasons; and (c) insufficient cassava production in several regions due to climatic factors. On the other hand, farmers appear to be adapting easily to the new processing technology, given its simplicity and especially the fact that cassava processing activities in the region have been carried out historically by farmer groups who produce **farinha de mandioca**, a traditional staple in NE Brazil.

The relationship between **farinha** and dry cassava chips as two commercialization options for farmers will be the main factor determining the financial success of the dry cassava-

based agroindustries that are being installed in Ceará. When market prices for the **farinha** are low, the agroindustries become important commercialization outlets for cassava production statewide; conversely, when the **farinha** markets offer prices attractive to farmers, it becomes difficult for producers to find sufficient root supply to maintain the agroindustries operating efficiently. Farmer groups' performance is further affected by factors such as skewed land and farm size distribution and a semiarid climate, which have a strong influence on the seasonal availability of roots.

21.2.5 Commercialization

Total dry cassava output during the pilot project was 2604 t purchased by a total of 975 consumers of whom 92.6% were low-vol consumers (less than 5 t of dry cassava/yr) and only 4.6% were large-vol consumers (more than 10 t/yr). In relation to volumes purchased during these 3 years, the situation was reversed, with the large-vol consumers accounting for 58.7% of the total production of dry cassava and the low-vol consumers purchasing 32.4% of the total output. Almost 65% of the total annual production in Ceará is processed in the form of **farinha**, mainly in communally owned small-scale processing units found in just about every single farming community of the state. **Farinha** demand statewide is quite high, and it is estimated that nearly 40% of total consumption is imported from nearby states. Despite this high demand, **farinha** prices are highly variable, and farmers usually get paid low prices. Among the reasons for this vulnerability are the small size of their operations, the low quality of the **farinha**, lack of transportation and their poor organizational levels. Farmers participating in the project are faced with two options: to process their crop individually in the form of **farinha** or sell the roots to the dry cassava agroindustry, where there will be a collective processing in which they will also participate. The important fact is these farmers now have two options for commercializing their crop and that the technicians have been trained to offer advice to farmers so as to improve the rationality of the economic decisions they have to make.

21.2.6 Organization

The considerable government attention that resulted in the creation of the CCC greatly favored the implementation of the pilot project. Despite the fact that the CCC is now fully established as the coordinating body for all activities related to the cassava crop, its work has been done mainly within the context of an internationally financed rural development project, in which the central coordination of activities has been closely shared with CIAT. From now on both the CCC and the RCCs will have to be given the legal status necessary to act as legitimate agencies within the prevailing agricultural institutional setting of the state; plans are now under way to transform the CCC into a technical assistance unit under the administrative responsibility of SEARA.

A central strategy for implementing the pilot project was the organization of farmer groups around dry cassava-based agroindustries. Defining the organizational structure most appropriate for Ceará's cassava producer groups has not been easy. Most of the 146

groups that participated during pilot project activities originated in larger communal-type organizations although in some cases parallel groups were organized, often with overlapping leadership. Efforts were made throughout the project to maintain the degree of social cohesion that already existed in these rural communities. Another strategy implemented to enhance farmer organization was to stimulate the creation of second-order producers' groups at the regional level, with the specific objective of increasing their bargaining power and their participation in planning and implementation of all project and cassava-related activities, with initial emphasis on the commercialization of cassava products. By the end of the pilot project, three second order-type coop organizations were finishing the red tape required to obtain their legal status. Another long-term objective envisaged initially--the formation of a statewide third-order group, a Federation--was not pursued, given the slow progress made in the setting up of the farmers' organizational component.

In general the no. of farmer groups participating in the project grew rapidly during the pilot project, mainly due to the fact that these groups were organized around specific income-generating activities--to improve their cassava production, processing and commercialization system. The reasonable degree of success they have had with this initial objective is enhancing the potential for these farmer organizations to consolidate and expand into other activities. The transition toward achieving a broader, more permanent status will not be a quick process and will demand a strong commitment from local agencies to support these organizational efforts.

21.2.7 Training

The pilot project training strategy included four types of events: courses, seminars, field trips and special days. A total of 108 training events were held with the participation of 832 technicians and 2123 farmers. Activities were mainly oriented toward building capacity among local agency staff members rather than toward farmers, given the class structure and organizational profile of the local environment in which project activities are being implemented--especially the fact that illiteracy rates among project beneficiaries are very high (> 50%). Throughout the pilot project phase, avg participation in training activities for the cadre of field-level extension agents and researchers engaged in project activities was 9 events per technician.

Educational and organizational needs of project beneficiaries are much greater than those of project staff. High rates of illiteracy and lack of organizational skills--particularly those related to handling funds, keeping records, organizing meetings--are cited among the major constraints affecting greater farmer participation in project activities. Current training strategies used by local agencies and technicians include nonformal training and mass communication activities and are basically centered upon the extension of technological services. As such, these training methodologies tend to be useful only for those farmers with the needed skills and thus end up segregating the people chosen for training from the rest of the community, making it more difficult to develop a broader

leadership base at the community level. An innovative approach to farmer education was initiated during the last year aimed at providing 50 farmer groups with basic reading and writing skills. The program is also benefiting members of the larger community within which each agroindustry operates. Initial results have been very encouraging; but given the limited coverage of this program, the rapid expansion of the social basis of the pilot project and the very high rates of illiteracy among the beneficiaries, it becomes extremely important for local agencies to find the means of creating institutional arrangements that can guarantee the continuity and the expansion of this Kellogg Foundation-supported educational effort.

21.2.8 Monitoring and evaluation (M&E)

From the onset of the pilot project, M&E activities were considered an integral part of the implementation strategy. An M&E model was structured in which monitoring activities were carried out at three different levels, differentiated on the basis of project specific objectives, target population and methodologies. By the end of the pilot project, the **first level**--a baseline data bank--already included information on 133 dry cassava-based farmer organizations[21.1] with a total of 2962 farmers. The **second level**--an annual survey--was conducted twice: in 1989 with 160 farmers and in 1991 with 932 cassava producers. The **third level** --an intensive monitoring of a smaller subsample of selected farmers--was conducted throughout the PPPs.

Data generation and collection for the three levels of the M&E were done mainly by farmer managers of the dry cassava processing organizations and the extension agents, under the coordination of the RCCs. This information has been centralized and analyzed by the CCC and reported back to beneficiaries and project staff through monthly reports and to donors and decision-makers by means of annual reports. By the end of the pilot project, two aspects of the M&E model were especially well covered: the baseline data bank and the series of monthly processing, financial and technical reports on the performance of the farmer groups. Implementation of the M&E systems has thus far been a responsibility mainly of the CCC and the RCCs. The fact that these working groups do not yet have a legal status within the local institutional landscape will certainly affect their short- and long-term sustainability. Furthermore, second-order farmer organizations, which have the potential to assume responsibilities for monitoring activities, are just being organized. The extent to which ongoing changes in the larger local institutional environment will affect local agencies in charge of project implementation, the rapid definition of a legal status for the CCC and the RCCs and their integration with second-order farmer groups will be some of the more critical factors for strengthening and consolidating the M&E system.

21.1. 25 additional farmer groups were still facing organizational and/or institutional problems, and information on their social basis was not yet available by the end of the pilot project.

Areas in which the M&E system was currently providing information by the end of the pilot project were as follows:

- Characteristics of the beneficiaries

  - Land tenure. A total of 133 farmer groups (2962 members) were actively engaged in project activities. The land tenure system under which these farmers operate their holdings includes three forms distributed as follows: owners (58.6%), leasers (28.9&) and sharecroppers (12.5%). Of the owners, 21% belong to land reform settlements.

  - Age of the participants. 70% of project beneficiaries are between the ages of 30 to 60, 17% are younger than 30, and only 13% are older than 60.

  - Gender. 97% of project beneficiaries are men, and only 36 groups include women among their members.

  - Literacy. 55% of the current beneficiaries are illiterate, and 45% do not have any basic reading and writing skills. Of the literate farmers, 90% have had from 1 to 3 years of schooling.

- Size of cassava farmers' organizations. By 1992, the pilot project was already covering 11 regions with a total of 133 farmer groups and 2962 direct beneficiaries. The overall avg size for these producers groups was 22 farmers although the social basis has been changing from year to year, mainly due to the fact that these organizations are still facing a transition process from larger **casas de farinha**-based groups to generally smaller, dry cassava-based agroindustries.

- Cassava production. To test the validity of the assumption that as a consequence of the opening up of an alternative, more profitable marketing channel, cassava plantings among beneficiaries would be expanded, two factors were monitored during the pilot project: cassava plot size and (2) the relationship between the farmers' land tenure system and the size of their cassava plots.

  - **Size of cassava plots, 1988-91**. Information collected over a four-year period indicates that the size of cassava plantings among project beneficiaries has remained fairly constant during this period, with ca. 56% of the farmers planting areas smaller than 1 ha, and with nearly 85% of the entire population planting plots of no more than 2.0 ha in size. Conversely, fewer than 15% of the total no. of farmers have been planting plots larger than 2.0 ha.

  - **Cassava plot size and land tenure systems, 1988-91**. During the last four years the owners have generally been planting larger cassava areas

than leasers and sharecroppers. By the end of the project, the avg size of cassava plots for the entire population presents a slight decline (8%) in relation to avg size of plots at the beginning of the project (1989). This decline appears to refer primarily to the smallholders, whose avg cassava plantings are now 13% smaller than 2 years ago. Among the factors that may explain this slight decline in production by project beneficiaries, it is worth mentioning that 75% of total project population belong to farmer organizations that joined the project only during the last year as well as the fact that throughout the pilot project the farmers had no credit available for cassava production.

- Results of the processing seasons, 1988-91. Farmers participating in the pilot project received three types of benefits: a new market for their roots; additional employment opportunities in the dry cassava agroindustries; and the annual share of profits generated by the cassava-based processing units. The first two benefits are open to any member of the larger community within which the agroindustry operates; whereas the last (profit-sharing) is available only to organization members. Information gathered on the results and benefits obtained by farmer groups during pilot project processing activities is described below:

  - **Cassava sales, 1989-92**. During the pilot project, a total of 7094 t of roots were processed, of which only an avg 38.3% came from members of the processing units. Additional information collected indicates that during the last year of the pilot project, 51.2% of the total membership sold roots to the agroindustries, representing an increment of 51% and 70% resp., in relation to the first and the second processing seasons. Avg participation of project beneficiaries as roots suppliers during the pilot project was 39.6%.

  - **Total annual incomes, 1989-92**. The total annual incomes received by farmer members of the dry cassava agroindustries was monitored during the pilot project. Total annual incomes includes cassava sales[21.2] processing wages and the sharing among members of the annual profits obtained from the sale of the dry cassava. During the three years covered by the project, the total incomes gained by the farmers reached US$163,689, of which 37.3% corresponded to cassava sales, 10% to processing wages and 52.7% to sharing of annual profits. According to the land tenure system of the beneficiaries, the distribution of these total incomes indicates that 58.9% went to smallholders and 32.45% to leasers, but sharecroppers received only 8.7%.

[21.2] It is assumed that cassava production costs have been already covered and that the actual amount of cassava roots sold to the agroindustries represents a net profit for farmers.

The relationship between the total annual incomes gained by project beneficiaries and the size of their cassava plots was another parameter monitored during the pilot project. Data collected indicate that the greatest part of the benefits went to the farmers with the fewest resources. Of total incomes generated, 77% went to those farmers planting cassava areas no larger than 2.0 ha; and only 14% of the total income generated during the three processing seasons went to farmers planting areas larger than 3.0 ha. The pattern of distribution of total project incomes among farmers remained practically the same during the pilot project, except for the beneficiaries planting larger plots (> 3.0 ha), whose share of the total incomes by the end of the project presented a significant increase of 115% in relation to the situation at the onset.

21.2.9 Adoption and impact

As the pilot project was initiated only three years ago, it is not possible to conduct a complete ex-post evaluation, but the project has been under a continuous M&E (see 21.2.8). Output of the M&E model utilized in the pilot project--especially the data bank--can be utilized to assess the rapid adoption of dry cassava processing technologies in the Kellogg Foundation-funded pilot project in Ceará as follows:

- From the start of the project, the no. of dry cassava-based agroindustries increased from 11 to 138 and the no. of regions of influence from 4 to 11, indicating the rapid spread of the dry cassava processing technology into new regions and rural communities.

- Despite the fact that buyers of the dry chips have been mainly livestock producers near the processing plants, the actual no. of clients has been increasing continuously; and during the last year of the pilot project, a total of 4 .3 different clients were purchasing the product.

- The organizational structure implemented during the pilot project included by the end of the third year the CCC, 5 RCCs, 146 farmer organizations and 3 regional-level farmer coops in process of formation. In addition, a total of 43 farmer groups were exposed to improved production technologies by means of the pre-production plots.

Although the aforementioned data bank outputs can be analyzed to assess rapid diffusion and adoption in time and space, there is still a lack of quantified data on project impact at the farm level and aggregate.

During pilot project implementation, two surveys were developed and tested. The first one in 1989 included 160 farmers; the second in 1992 surveyed 932 cassava producers and was meant to become a benchmark type of study for future adoption and impact

analysis. The 1989 survey included some farmer groups that were dissolved during the pilot project, and the membership of other groups decreased considerably. Thus the sample size of farmers who participated in both surveys was reduced to only 86. A brief analysis of some of the results allows some preliminary conclusions regarding impacts due to project activities:

- Changes in on-farm cassava consumption and utilization. It has been argued that newly created demand for dried chips will have an immediate effect on on-farm consumption and sales. Farmers are currently selling 53% of their production to the drying agroindustries in contrast with the situation at the onset of the project when the share of total production used for dry cassava processing was only 4.8%.

  Additionally, the production of **farinha** for human consumption now accounts for ca. 38% of total production: whereas in 1989 it represented a 64.5% share of the total production.

  The utilization of cassava for on-farm feeding of animals has remained about the same. Furthermore, the selling of roots to other markets such as dairy and cattle producers--which in 1989 represented a 25% share of the total production--is now insignificant.

  The farmers participating in the project are starting to adopt the new processing technology and the new market has stimulated them to transform their cassava utilization patterns, becoming more market oriented.

- Changes in cassava area. Survey results indicate that the mean area plot for the farmers has increased from 1.44 to 1.89 ha in the littoral region and from 1.63 to 1.68 ha in the three regions covered by the survey. A quick response to this kind of project-induced stimulus depends on several factors, among which the availability of production credit is crucial. The fact that this type of financial support has been absent throughout the pilot project has indeed affected farmer groups' possibilities of increasing their cassava areas.

- Cassava household consumption. In relation to cassava consumption at the household level, results from the surveys indicate that total consumption of **farinha** increased from 5.5 to 6.8 kg/household in the coastal region, one of the most important areas of project influence. When considering the three regions covered by the survey, the same tendency is observed with an increase from 4.6 to 6.2 kg/household/wk. This increased consumption of **farinha** could be explained by the fact that farmers are now able to rationalize the destiny of their production, getting better prices for the roots, and are not forced to utilize their production exclusively in the production of **farinha**. With the extra income generated from selling roots to the dry cassava agroindustries, their cash availability is increasing

and the supplies of **farinha** are probably being used for additional household-level consumption.

The aforementioned measures of project impact have been relatively easy to quantify based on the information available from the M&E system and the two surveys. Additional project impact on community welfare, institutional support and the general environment can be described only qualitatively at this stage. Analysis of the 1992 survey regarding farmers' view of impact of the project indicates that the project has served as a vehicle for increasing community development in general (organization, knowledge, employment opportunities, incomes) and that the promotion of cassava-based farmer organizations has strengthened local institutional support (technical assistance, availability of working capital). It also indicates that the adoption of improved production technology and consequently the increases in productivity are taking place slowly among project beneficiaries with very low use of inputs and selected seeds. Additionally, the lack of opportunities for farmers to purchase or lease additional land has limited significant increases in cassava area planted by project beneficiaries.

21.2.10 Conclusions and recommendations

Based on the foregoing description of the activities carried out during the pilot project and the principal accomplishments, the overall conclusion to be drawn is that the project design proved to be flexible, takes advantage of existing resources and facilitates effective decentralization and participation within the current institutional landscape of the agricultural sector in Ceará, despite the adverse economic situations that have prevailed in Brazil for the last three years. Moreover, the linkage of an international agricultural research center with local agencies has proven to be a viable approach to promoting cassava-based development activities for small-scale, poor-resource farmers and has made it possible to strengthen the institutional capacity of local agencies as well as enhance their work methodologies, resulting in improved technical assistance and support systems for farmers.

Despite the significant advances made in the achievement of the expected project benefits--mainly agroindustrial development, institution building and improved welfare--there are some constraints that need to be addressed in order to consolidate and expand the cassava-based development activities to a commercial scale.

- There is a need to validate the organizational structure adopted during the pilot project for local agencies and farmer groups, as legal components of the prevailing institutional framework

- The income-generating potential of the project is located at the level of the producer; however, the principal gains in income come from yield-increasing technology--an activity pursued only partially during the project. Moreover, the

very long growth period for the crop in Ceará (15-18 mo) requires an approach with a longer time horizon.

- Development of a market alternative for the farmers in Ceará--i.e., through the production of dry cassava chips for animal feeding-- was initiated; but its consolidation will depend upon whether the product can be offered at prices that are competitive with alternative products and in sufficient quantities to meet increasing demand. At the same time, research activities must be initiated to identify additional cassava-based products and markets that could contribute to transforming production in Ceará into a more profitable, less risky activity.

Given the foregoing, it is recommended that a second phase of this project be executed, with the purpose of consolidating the activities and results obtained during the pilot project. This second commercial-level phase should emphasize actions aimed at:

- Strengthening local agency and farmer groups' organizational and operational capacities

- Consolidating marketing channels for dry cassava and identifying additional market opportunities for the crop

- Designing sustainable production systems

At the same time, operational strategies should be aimed at transferring full control and administration of the project to local agencies within the short term (6 mo) and total withdrawal of foreign donor-sponsored financial support for project activities in an intermediate term (3 yr).

21.3 Ecuador Integrated Cassava Project

The Ecuador Integrated Cassava Project is a collaborative effort between CIAT and several Ecuadorean organizations begun in 1985. The 1991 Annual Report (Chap. 15) summarized the development and results of the project from 1985 through Oct 1991. This report will highlight some of the activities and results of the project since then.

21.3.1 Changes in the institutional environment

Some important shifts occurred within and among the key institutional partners in the project that auger well for the health and future of the project.

21.3.1.1 Instituto Nacional de Investigaciones Agropecuarias (INIAP). In late 1991, an agronomist returned from a 2-yr leave in Puerto Rico, where she completed her MS, bringing the no. of professionals in the INIAP Portoviejo Tropical Roots and Tubers Program to four. She is responsible for coordinating many of the activities involving other

institutional partners, such as the annual cassava seminar and the field days for release of new cv. and the annual harvesting competition. While her return was not directly responsible, it did seem to set in motion a series of other changes.

The annual cassava seminar--normally held in November in the midst of harvesting, processing and end-of-year planning activities--was held in April. Though there is still some confusion over whether it is a training course or a seminar to present research results, the organization and attendance improved.

A planning meeting to develop a preliminary plan for future research was held in conjunction with the seminar, and three CIAT HQ scientists attended. While the initial results of this meeting were disappointing, they set in motion a planning process within INIAP, coordinated by the Fundación Ecuatoriana de Investigaciones Agropecuarias (FUNDAGRO), which is now leading to the final version of a long-term plan.

The plan, which contemplates both cassava and sweet potatoes, has involved input from a broad range of departments and sets future research within a systems context. It expands the limits of research beyond the Manabí province and calls for diagnostic efforts in the other cassava-producing regions of the country in order to identify problems and set priorities for research. Furthermore, the plan clearly identifies research mandates for non-INIAP entities, including the postharvest research roles that farmer organizations such as the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY) must play.

Following the seminar, the Program was moved to a new location in the station with two offices, providing a larger space for the team to work. The physical improvements seem to have had a positive effect on both morale and the quality of the Program's outputs.

Other INIAP departments have increased their collaboration in research this year. The leader of the Soils Dept. supervised an MS agronomy student from the U. of Florida doing field work on fertilizer use in maize-cassava systems in flat and hillside sites (see 21.3.4). An entomologist spent 3 wk at CIAT gaining in-service training in the management of cassava mites and is planning research to determine economic losses from mites in 1993. One of the program agronomists has been assigned responsibility for postharvest activities, especially involving quality research. Rather than continuing to wait for the creation of a specific lab to do her work, she is now collaborating with the INIAP station near Quito (Sta. Catalina), conducting analyses of cassava products in their labs and sharing her training in analytical techniques with the other technicians.

One of the most important changes in INIAP this year, which has undoubtedly conditioned these other shifts, was Congress' approval for INIAP to separate from the Ministry of Agriculture (MAG). This, plus the change in the Govt. of Ecuador in September, has altered favorably the public opinion of INIAP and appears to have improved the morale. A new director was appointed to the Portoviejo station (also the director when the

integrated project was initiated). He is moving quickly to improve external collaboration, improve efficiency and leadership within programs, enhance the station's budgetary resources, and develop long-range plans for each program. The former director has been named head of the technology validation and transfer unit (UVTT) and will be leading multilocational validation and demonstration trials with maize-cassava production recommendations.

While the above description provides a positive outlook, the biggest problem facing the Program's future will be budgetary. FUNDAGRO has funded the majority of the cassava research since 1988 and all of it during the past 2 yr through its USAID research, extension and training (IEE) project; but this will terminate at the end of 1993. PROTECA (IDB-funded extension project within the MAG) will resume funding some of the on-farm work in 1993; however, the Program will have to complete its long-term plan soon in order to begin the more difficult task of developing successful proposals for funding to implement it.

21.3.1.2 UATAPPY-Manabí. After more than 2 yr and substantial pressure, the union of cassava producers and processors finally received approval from the MAG in May to include associations of rural workers in the union. The name was changed accordingly to UATAPPY. This change is significant because it allows the legal affiliation of associations of farmers without title to their land or who are landless. In Manabí, where land parcels are highly fragmented, the majority of the farmers do not have title to the land they work, and women spouses are not usually given joint property rights, forming a rural workers association is the only organizational mechanism that provides assess to certain kinds of agricultural development support.

Prior to May, however, the MAG did not permit unions to include both producer and rural worker associations. For the former UAPPY, this meant that 8 of its 17 associations (including the three women's groups) were participating in the union illegally. More important to these "nonmembers" was that they could not hold office nor vote although they contributed to the annual profits and participated in credit. The change broadened considerably the leadership potential in the Union and enhanced the participation of these members, especially the women. The election of two women as union officers this year--one as president--is evidence of this change.

The Union has had to make adjustments to this change. Accommodation of now legal members has brought to the surface tensions between older "founders" and the newer associations. Fund-raising efforts to assist the newer associations to expand their processing capabilities up to the levels of the older associations has created jealousies.

A great deal of effort has gone into modifying outdated regulations in line with the revised statutes. Members are calling for more control of the Union's property, greater oversight on spending, and tighter credit regulations. A tension has been created between the members' demand to be involved in (and often to have rights of approval) over greater

parts of UATAPPY business and the danger that too much control will limit the commercial flexibility of the UATAPPY administration, particularly that of the administrator. Concern over who uses the Union vehicles and for what has become pronounced. These tensions seem to be evidence of a maturing organization. The challenge facing the Union in the immediate future will be how to maintain the fine line between encouraging participation of members--coop style-- while continuing to develop the organization as an efficient, profit-making business.

21.3.1.3 FUNDAGRO. The Foundation has not only been the major source of funding but it has also been the "glue" for the Program since 1988. Through the supervision of funds for research, strengthening the farmer organizations, and education and training, FUNDAGRO has fortified the capacities of the participating institutions to conduct their parts of the Program. But more importantly for the integrative aspects of the project, by providing a full-time coordinator, FUNDAGRO has assured that the respective sections of the Program collaborate and communicate.

Success can have a negative impact. Unfortunately, FUNDAGRO and USAID management have recognized the success of the program and would therefore like it to "graduate" out of their funding. Program participants have been advised that 1993 will be the last year for FUNDAGRO funding. While none of the participating organizations will collapse without FUNDAGRO support, it seems likely that the current collaboration among the organizations will diminish, without a specified coordinator. This role is essential to the success of an integrated project and FUNDAGRO will need to be replaced if they decide not to continue their involvement.

21.3.2 Ecuador's first new cv.

In 1987 clone M Col 2215 was first introduced into Ecuador via CIAT. By 1989 farmers observing INIAP trials had become interested in the cv. and wanted planting material. By the end of 1991, pressure from the UATAPPY and institutional collaborators in the project encouraged INIAP to initiate procedures to release M Col 2215 as "Portoviejo 650" (P650), the first new cv. in Ecuador. To prepare for the release, INIAP multiplied 1 ha of material for distribution as planting material. The team also prepared a technical bulletin on the new cv.. On Aug 29 the release took place at the Teodomiro sub-station, where the P650 material was located. It was an extremely well-organized event with 765 participants (642 men and 123 women). Of the total, 520 were farmers, 144 students, 77 technicians and 26 other individuals. INIAP organized participants into small groups to tour the fields and listen to technical presentations on the new cv.. A small refreshment and a bundle of 5 stakes of the new cv. completed each tour. Ten percent of the farmer participants were interviewed to evaluate the event, and a separate discussion and luncheon was held for invited institutional guests.

A number of articles came out in the local and national media concerning the event and drew attention not only to the new cv. but also to the Program itself. It has had a very

positive impact on the Program and on the station as a whole. The release of the cv. seems to have stimulated the self-confidence of the INIAP cassava team. They are now discussing other promising materials for release.

21.3.3 A survey of pre-release adopters

Prior to the P650 release, a survey was conducted of the farmers in Manabí who were already growing the cv.. The purpose of the survey was to find out who were the farmers that had the cv., how they had obtained the planting material, how the P650 was performing, and under what kind of production system they were growing it. A brief questionnaire was designed and administered by the U. of Florida student, two recent Universidad Técnica de Manabí (UTM) graduates and a student doing his thesis on the P650. All were quite familiar with the cv.

Interviews were conducted with 64 farmers who have P650. Of the total no. of farmers with the new cv., 33% were UATAPPY members and the avg age was 43. Of the UATAPPY members, 3% were women; of the nonmembers, 7% were women. Most (74%) of the farmers were growing the cv. for the first time in 1992. Only 13% planted the cv. in plowed land; ca. 50% on hillsides; the rest on the flat. Most planted the cv. near their home, in what thay called a "test"; in effect, "an experiment" with it. Whether it was on the hill or flat depended more on the location of the home rather than any specific intent regarding slope. Only 27% of the farmers planted the cv. in monoculture; the remainder planted it with maize (41%), peanuts (17%) or with other crops (15%) such as rice, beans, plantains or cotton.

According to the farmers, the three most important advantages of P650 over other commonly grown cv. were that it is easier to harvest, has higher DM content and yields are higher. The major disadvantage was the lack of available planting material.

The survey pursued in detail the source of planting material for these early adopters in order to learn how the cv. was being disseminated prior to release. Farmers were identified from lists of collaborators in prior INIAP trials with P650 and from lists of farmers present at field days where the cv. was presented. **Table 21.1** shows that among UATAPPY members, INIAP was the predominant source; but for 48% of the farmer adopters, the sources were other farmers including relatives. Among nonmembers, INIAP played a smaller role and other farmers were the main sources (74%) of the planting material. One farmer in Bellavista, Freddy Garcia, was the source of planting material for over a third of the nonmembers. In the interview, he explained that he had collaborated in one of the early trials and observed advantages in the new cv., known then as "La Colombiana." A member of the Siete de Mayo processing association, he tried chipping some of the roots and saw that the conversion rate was quite low. He saw that they could increase their profits considerably if he could multiply the cv. and convince his neighbors to grow it for sale to the association so he began to multiply and distribute samples of the cv. to farmers in the area. The result is that this year his association is

processing a measurable quantity of the cv., has established differential prices according to DM content and has obtained conversion rates as low as 2.17.

Table 21.1 Sources of planting material for the cv. Portoviejo 650 (P650) among pre-release farmer adopters.

	Source of Material (% of Farmers)			
Type of Farmer	INIAP	Family Member	Freddy Garcia[1]	Other Farmers
UATAPPY members	52	14	10	24
Nonmembers	26	26	37	12
TOTAL	34	22	28	15

Source: M Col Pre-release Survey, UATAPPY/CIAT, 1992.

1 Freddy Garcia is a farmer and UATAPPY member from the Bellavista parish of Manabí.

The UATAPPY hopes to duplicate the success of Siete de Mayo among the other associations in the 1993-94 processing year. The Union continued its seed multiplication project (initiated in 1991) and currently has about 6 ha of the new material for distribution to member associations in Jan. With funds from FUNDAGRO, they hired an agronomist to supervise the seed project and leased a single piece of land for the bulk of the multiplication. They re-multiplied all the material produced in 1991 and planted it in several members' lots early in 1992; in July this material was harvested for stakes and planted under irrigation in the leased lot. The main problem has been low sunlight conditions, which has slowed growth. The UATAPPY anticipates that they will have sufficient material to plant about 60-70 ha of P650 in Jan. It should be possible to begin measuring the economic impact of the new cv. within the next couple of years.

21.3.4 Cassava production system research

INIAP continued on-farm testing of P650 intercropped with maize. Results from 1991[21.3] indicated that the best yields and rates of return were obtained in a maize-cassava system where cassava was planted at 5000 pl/ha (2.0 x 1.0 m) and maize at 25,000 pl/ha (2.0 x 0.6 m, 3 seeds/hill). This work was carried out on farms in four locations representing low, medium and high rainfall zones within the central region of Manabí Province. Avg cassava yield under mixed cultivation across the sites and treatments was 7495 kg/ha (range, 1097-13,070 kg/ha). Avg maize yield across sites and treatments was 2300 kg/ha (range, 1105-3739 kg/ha). Variation across sites was as high as between

[21.3] INIAP, 1991. Programa de Raíces y Tubérculos Tropicales, Informe Anual Técnico.

treatments and should be analyzed in more detail. The experiment was repeated in 1992 at the same sites and will be harvested in Nov.

Work on fertilization in maize-cassava intercrops was initiated in 1991 and expanded in 1992. Work of the MS agronomy student (U. of Florida) on maize-cassava intercrops compares P650 with the most common local cv. Tres Meses under varying population densities with maize. Trials were implemented at 4 sites, 3 of which included comparisons between flat land and hillsides. The trial also combined different N fertilizer rates. Sites were selected in 1991 to allow for measuring the different response of P650 to varying rainfall; however, the unusually high rainfall caused by the "Niño" phenomenon skewed the normal rainfall patterns. Thus she incorporated 3 additional harvest times in order to provide information to farmers and INIAP on earliness of P650. Her results will be presented in her thesis in 1993.

Although the agronomy student's work focused on specific agronomic comparisons, her collaboration with INIAP researchers helped identify some areas where the Program could benefit from training in alternative methods for conducting on-farm research and improved analytical methods for interpreting results. These are being considered by the station director, who hopes to sponsor training workshops on these themes in 1993.

The student's work also highlighted the problem of erosion in the region, especially in years with higher rainfall. As there is very little information available on the extent of the problem in the province, a small, fairly simple diagnostic activity is being planned in collaboration with a group of UATAPPY members to get a rough measure of erosion on selected slopes under different cropping systems in 1993. This work is intended to open a dialogue among researchers, local agricultural policy-makers and farmers in order to determine whether the problem should be addressed more extensively in the future and how.

Other work on cassava cropping systems was conducted by two UTM students, one looking at cassava-peanut systems under lowland irrigation and the other at P and K fertilization using P650. These results will also be available in 1993.

21.3.5 Monitoring and the UATAPPY promotor program

Discussion and analysis of the production and management of the individual UATAPPY associations at the close of the 1991-92 processing year revealed serious problems in several of them. Excessively high production costs and overdue debts were identified in four associations. The women's groups showed deficiencies in calculating costs and high labor expenditures. All the associations complained that there was not enough communication with UATAPPY management and administration. The administrator complained that he did not know during the course of the year how much was being processed and whether scarce funds for operating costs were really going to their proper destinations. In general the existing monitoring system was not working, and results of

the analysis provided by the INIAP economists came too late after the season to be useful in identifying processing problems.

To address these problems, the UATAPPY decided to reinstate its activities with promoters, experienced farmer-processors who are selected to provide farmer-to-farmer training and technical experience to other groups. In the early years of the UATAPPY, promoters were used to establish new groups. After the original four associations, all new groups were organized with the assistance of a promotor. When the UATAPPY stopped forming groups, the promotor function decreased and eventually stopped, and greater attention was placed on value-added transformation of products and marketing. As the UATAPPY grew in size of production and number of products, it became increasingly difficult for both the monitoring and accounting systems, designed for just one product (chips) to handle all of the products, their different costs and prices, and their different markets. The UATAPPY decided that new promoters could be identified and assigned full time to those associations with more serious problems. Associations with relatively good management would be visited by a promotor once a week to check on costs and production, carry messages from the UATAPPY office, and collect processing data to take back to the UATAPPY. Credit disbursements were tied to turning in the weekly summaries of processed products and costs.

Ten promoters were selected and assigned to associations. As a group they redesigned the processing data collection forms, streamlined the information and set up an information management system at the UATAPPY, which although not perfect now allows the administrator to keep better on-going accounts of how much is being processed and how much can be committed for sales. Although the data are currently handled manually, the UATAPPY is hiring a consultant to revamp their entire administration and will be transferring these and other data to a computerized system in Jan.

The new promotor system is greatly improving the communication between the Union and the associations. Promoters already report much lower production costs in several of the "problem" groups. The San Miguel women's association was able to calculate mid-season profits of over S/.2,000,000 due to better management of labor and processing. With this information they were able to calculate how much of their existing debt they will be able to pay back this year and decided to take out a new loan to build a new processing plant on a larger site, incorporating the San Vicente starch technology. The UATAPPY plans to continue the promoters as part of their regular monitoring system in the future.

Concerning monitoring and production survey data collected in the past, work was completed to create a single data base with all the previous years' processing data in order to examine trends and progress over the years of the project. The maize-cassava production systems survey data were merged with the U. of Kentucky's consumption survey data, and a preliminary report was produced by Kentucky consultants, the CIAT advisor and FUNDAGRO. This is being reviewed and will be used as the baseline for a

comparison survey that will be conducted by FUNDAGRO and USAID as part of the end-of-project evaluation in 1993.

21.3.6 Processing results, 1991-92

Table 21.2 shows total amounts of cassava products produced by the UATAPPY from 1985-92. The total amount decreased in 1991-92 from the previous year by 41% for several reasons. First of all, credit for processing was very limited. Although a loan for increasing the UATAPPY revolving credit fund from FODERUMA--a Central Bank fund for development projects in marginal areas--had been approved by mid-July, funds did not arrive until early 1992, after processing was ended. So for the third year in a row, UATAPPY production was seriously limited by a shortage of credit. The only positive aspect was that at least it arrived in time for the 1992-93 processing year.

A second reason was the low availability of fresh cassava in the drier areas of the UATAPPY region. This was the second year of drought, and rainfall in several association areas was less than 500 mm/yr. Low rainfall reduced the production; and as it was the second year in a row, farmers were not able to fall back on the crop left in the ground in hopes of a good rainy season. Yields for 20-mo cassava were low. Unlike the previous processing year, the UATAPPY associations lacking fresh material were unable to buy cassava from the humid region near Sto. Domingo because production was lower there as well and prices for the fresh market in Guayaquil and Quito stayed fairly high--too high to warrant transport to Portoviejo.

A third reason for low output was the low prices at the balanced feed factories. It simply was not profitable to produce white flour (peeled roots) at the price the factories were willing to pay. Availability of cheaper alternatives for pellet agglutinants hurt the market for cassava flour.

A final reason for low production was the early beginning of the rainy season in December, caused by the arrival of the "niño." Normally processing continues into December, but most groups stopped by mid-month. The rains were very heavy throughout the coastal area; areas with 400 mm in 1991 received over 1000 mm in 1992. Much of the flat area flooded and many crops--especially maize, peanuts and cotton--were lost. The rains continued longer than normal, well into June, delaying the start-up of processing activities for the 1992-93 season until late Aug-Sept for most groups. As an after-effect of the "niño," the Manabí Province has been mostly cloudy all of the supposed dry season, making it difficult for the association to dry chips or starch. Normally the drying time for chips is 2 days and 1 day for starch. This year it is taking on avg 3-4 days to dry chips and 2 days for starch. This has greatly reduced the amount of material that can be processed weekly and has affected the Union's total production. By mid-Nov the Union had produced only 700 t of chips and 100 t of starch. It is ironic that this year, the UATAPPY was poised for a substantial increase in production. Rainfall

Table 21.2. Total cassava processed (t) by the UATAPPY-Manabí, 1985-92[1].

			Flour					Starch					
Year[2]	No. of Associations	RY	Whole Industrial	White Industrial	Whole Sifted Industrial	White Sifted Human Consumpt.	Bran	Industrial	Human Consumpt.	Bagazo	Purchased Industrial	Purchased Human Consumpt.	Annual Production
85-86	2		50										50
86-87	4	19	96										115
87-88	10	28	500					11	4				543
88-89	16		1100						5				1105
89-90	16		304	574		33		70	10	24			1015
90-91	17		258	982	200	6	52	119	2	51	69	4	1743
91-92	17		464	304	170		17	20	4	12	37	5	1033
Total	17	47	2772	1860	370	39	69	220	25	87	106	9	5804

1 Values rounded to nearest ton.
2 Production is calculated on an annual basis from July 1 through June 30.

had assured good availability of fresh material. Credit was assured for processing; drying and storage area had been increased; and Colombian dealers were anxious to contract large purchases. But there was little sun. In 1993 the Program will move toward diversification of the production and processing base, adding maize and possibly peanut and cotton commercialization, as well as placing greater emphasis on starch and higher quality flour products. It remains to be seen whether this strategy will be able to compensate for the unpredictable shifts that have limited production and profits in the past.

21.3.7 Applied research on cassava starch

The pilot starch processing plant built at the new San Vicente women's association in 1991--based on an adaptation by UATAPPY technicians of the technology used by the starch plants in the Cauca Valley, Colombia--went into full production in Sept. By mid-Nov San Vicente had produced over 10 t of high-quality starch for human consumption. The women members, along with a UATAPPY starch paratechnician and a UTM student conducting his thesis on the efficiency of the new plant, have been working to improve plant management and control quality. Analyses of the starch indicate that the quality meets the requirements of Ecuador's food industry. Several food industries are experimenting with starch from San Vicente, including Latinreco, Nestle's Latin American research institute in Quito. They have informed the UATAPPY that two new products will be tested on the Ecuador market in 1993 using San Vicente starch. Prices for the new starch are very good and demand is growing.

The success of San Vicente has encouraged the UATAPPY to invest in building several new plants at other associations or adapting existing facilities to accommodate starch processing. The San Miguel plant is under construction and five others will be constructed in 1993.

Not all problems have been resolved, however. Processors are still trying to solve contamination problems during solar drying. The starch for human consumption--dried on raised, plastic-covered bamboo benches--is not so much a problem because its higher value covers the additional costs of the labor involved. There is a huge market for industrial starch, but at a lower price, so the drying costs must be lowered. To do so, it must be dried on cement platforms; however, abrasion lifts sand from the cement and contaminates the starch for use by the cardboard box factories. Two possible solutions have been identified. One is to seal the platforms with an epoxy paint and improve the turning process so as not to contaminate the starch; however, the paint is very expensive and may eventually flake with the handling of the starch. A second alternative was identified by the UATAPPY processing projects leader and a collaborator from the Fundación Adelanto Comunitario Ecuatoriano (FACE, a vocational-oriented NGO that prepares machinists) during a trip to southern Brazil in Aug in search of processing technology. A flour-separating machine was identified and the team was able to use it to experiment with separating sand from starch. The results were very positive and the

company cooperated by sharing the plans for building the machinery. In 1993 UATAPPY will build part of the machinery and purchase the rest in hopes of once again entering the potentially lucrative cardboard box industry.

The biggest outstanding problem in starch processing remains the management of the waste water. No immediate solutions look promising. At present the water is simply allowed to evaporate or is used to keep the dust down around the plants. Hopefully, further collaboration with the CIAT/IEE project will identify a better alternative because with expansion of processing, the problem is only going to get worse.

21.3.8 Changes in UATAPPY markets and the new markets study

In 1991-92, the major market sector for UATAPPY products continued to be the balanced feeds industries producing pellets for shrimp pond production. However, this market has continued to be problematic and many of the industries are moving to the use of artificial agglutinants. Demand for cassava flour was decreasing; thus when agents for a Colombian industry approached the UATAPPY in July to negotiate a contract for export sales, UATAPPY was interested. A contract for 600 t was finally negotiated and shipments were completed in mid-Nov; a second contract is being negotiated. Handling large volumes of sales simultaneously with production was difficult initially; but over the course of the various shipments, the group worked out a system. With this experience, UATAPPY is exporting directly, without going through the local intermediary. Results of these shipments, the decrease in demand for shrimp feed, and the increasing sales to wood and food industries is dramatically reshaping the market for the UATAPPY.

Also influencing this are the results from the ongoing New Markets Study--
an adaptation of the one conducted by CIAT in Colombia to determine market acceptance for cassava flour for human consumption. Although a year late in start-up, due to contracting problems in FUNDAGRO, a national marketing research institute (CENDES) initiated the study in August. Over 200 industries from a range of sectors have been surveyed, and more than 80% are requesting samples for tests. The UATAPPY is literally scrambling to prepare and deliver samples so that the next phase of the interviews can begin. Several industries have bypassed the experiment phase and have initiated contracts for larger purchases. The largest ice cream cone factory is now using cassava flour as a substitute for wheat flour with very good results. A paint company is using industrial starch in some of its wall paints. A military explosives company is trying out starch in ammunition. Several meat processors are interested in cassava flour and starch. Somewhat to our consternation as consumers, at least one of these prefers the poorest quality starch ("corriente" or "industrial de segunda") for its products. The final results of the study will be available in early 1993. The program is planning formal presentations of the results to industrialists and others in both Quito and Guayaquil.

21.3.9 From farmer union to agroindustrial business

As mentioned, funding via the FUNDAGRO/USAID-IEE project will terminate at the end of 1993. In view of this, the UATAPPY and its institutional partners began working on a strategy for the future and funding to support new initiatives. Help for this came from ATI, an alternative technology institution in Washington, DC, where the former CIAT Ecuador advisor currently works. ATI provided a grant of US$10,000 for UATAPPY to conduct feasibility studies to determine areas for possible diversification of production, processing and marketing. These funds were used to hire consultants to conduct a study of the potential market expansion for maize and cassava products and a second study on the possibilities for expanding and reorganizing the processing capability of the UATAPPY's Demonstration Center. Initially, the study team thought that maize starch processing would be a feasible alternative and a way to provide a better market for the region's maize production. However, the study identified several technical problems with this and the price tag was too high for the immediate future. Instead, UATAPPY settled on a strategy to improve cassava products, implement artificial drying technologies to extend the processing season, and incorporate the commercialization of other nonprocessed products including maize and peanuts.

The results of the studies were used to develop two proposals for funding. Both have as a common goal to carry the UATAPPY forward to becoming a diversified, efficient farmer-owned and managed agroindustrial business. The first proposal to the Fondo Ecuatoriano-Canadiense de Desarrollo (FECD) was approved for nearly US$250,000 in Aug. It is being used primarily for processing and marketing credit and for investing in starch processing equipment and infrastructure. All credit through the project operates at near-to-commercial rates of interest. A small nonreimbursable fund from the project is for technical assistance, credit and some equipment purchases. The UATAPPY proposal is being used by FECD as a model in training workshops for other potential recipient organizations.

The second proposal to the IDB small project fund is for roughly US$700,000 and will build on the FECD project to complete the transition of the UATAPPY to an agroindustrial business. The proposal includes an international technical assistance component provided by ATI and will provide funds for UATAPPY to continue its activities in applied postharvest technology testing and adaptation. Prospects for the proposal appear to be quite good.

22. GLOBAL CASSAVA RESEARCH AND DEVELOPMENT NETWORKS

22.1 Cassava Biotechnology Network

The CBN concentrates on uses of biotechnology to enhance the nutritional and economic value of cassava for those who depend on this crop. The CBN Coordinator is based at CIAT HQ, where close contact with biotechnology and cassava research is possible. CBN activities include cassava biotechnology research in developed and developing countries; services to research; promotion of cassava biotechnology research; and diagnostic work and interaction to provide broad input into the CBN research agenda.

Current research services include biannual scientific meetings and exchange of information and materials. To these will be added publication of a brochure and newsletter. In developing and prioritizing its research agenda, CBN is gradually moving to greater involvement with other networks concerned with cassava and with biotechnology for development; and with farmer/processor organizations, women's groups, and NGOs. When possible, interaction with farmer and women's groups proceeds through collaboration with national agricultural R&D programs.

Promotion of cassava biotechnology research and priority setting are responsibilities of a Steering Committee (SC) supported by the Coordinator, who is also responsible for network communication. Biotechnology research takes place in flexible subnetworks of collaborating scientists in developing countries and in centers of excellence for biotechnology applications of relevance to cassava. CBN objectives and membership are dynamic, changing as experience refines network priorities and as scientific progress is achieved.

22.1.1 Background

The CBN, originally known as the Cassava Advanced Research Network, was founded in an international workshop convened at CIAT in Sept 1988. The network was formed to link capabilities of leading laboratories to the needs of national programs in developing countries. Participants in the founding workshop developed a combined priority list from discussion of Latin American, Asian and African constraints.

Cassava advanced research was divided into three categories:

- Areas where emerging technological solutions were feasible
- Areas where there was a current role for biotechnology, but additional basic biochemical knowledge was also needed

- Areas where basic biochemical research was needed to identify areas for new technology approaches

The joint recommendation divided specific objectives into:

- Priority Level 1: TCS (implications for virus disease control); cyanogen content; virus resistance; cassava transgenesis methodology; starch quality; arthropod resistance

- Priority Level 2 (less critical or no research approaches ready at that time): hornworm resistance, nutritional quality, photosynthesis under stress, postharvest deterioration, biomass partitioning

Workshop participants agreed that the network would develop according to funding availability, scientific progress and degree of cooperation; and that periodic review and flexibility would be essential for success. The first CBN SC--which included representatives from CIAT, IITA, the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM), NRI and three individual scientists--was assigned responsibility for the structural features of the network.

Two additional meetings have been of major importance in the evolution of the CBN:

- DGIS (Directorate General for International Cooperation, The Netherlands) Workshop, Cassava and Biotechnology, Amsterdam, March 1990

- BIOTASK (the biotechnology task force of the CGIAR), a follow-up to the DGIS meeting, Oct 1990

At the DGIS Workshop on Cassava and Biotechnology, donor agencies and CGIAR centers exchanged information on biotechnology and cassava and developed joint criteria for cassava biotechnology research. Two levels of priority setting were agreed upon:[22.1]

- Technologies requiring improvement/development:

  - Plant regeneration for genetic engineering

  - Genome studies for mapping, phylogeny, genotype ID

  - Processing/fermentation

  - Germplasm: core collections and wild species

[22.1] DGIS. 1991. Cassava and Biotechnology. Proceedings of a workshop, Amsterdam, 21-23 March 1990. The Hague: Directorate General for International Cooperation.

- Toxicity (breeding)
- New breeding techniques
- Genetic transformation

- Biotechnology research focused on specific constraints:
  - Acid soil tolerance
  - Drought tolerance
  - Soil fertility
  - Diseases/pests
  - Root quality (cyanogens/starch)
  - Processing (cyanogens)

Postharvest deterioration and biocontrol were considered to need more basic research before approaches for improvement could be identified. Biosafety, patents, and export-substitution were identified as requiring particular attention.

BIOTASK considered the DGIS inventory on cassava activities and endorsed the CBN's plan to hold a first scientific meeting in which leading laboratories, national agricultural research institutions and donors would discuss progress of the network, continue the dynamic process of formulating research priorities, and examine future needs of the network.

By 1991 the CBN had grown to more than 20 funded projects (see Table 22.1). The SC proposed appointment of a full-time coordinator to coordinate research; evaluate biological and socioeconomic constraints and research priorities of developing countries with regard to cassava biotechnology research; promote research interaction among scientists from developing and developed countries; develop a newsletter, annual reports and a brochure; organize SC meetings and biannual CBN scientific meetings; and manage training exchange.

22.1.2 The CBN in 1992

The CBN Coordinator--a plant breeder with experience in biotechnology and national program research--was appointed in Aug. Coordination activities, supported by the DGIS, are headquartered at CIAT, in close contact with both the CIAT BRU and the Cassava Program.

Table 22.1 Research projects under way in cassava biotechnology.

Subject	Institutions	Funding
Cyanogenesis	U. of Newcastle upon Tyne, UK	RF/EC/ODA
	Royal Vet. & Agric. U., Denmark	RF/EC
	Mahidol U., Thailand	RF/EC
	Ohio State U., Columbus/CIAT	USAID
	Free U., Amsterdam	-
	Royal Vet. & Agric. U., Denmark/IITA	DANIDA
Virus resistance	ILTAB/The Scripps Res. Institute, La Jolla, USA	ORSTOM/ RF/USAID/GTZ DGIS
	Free U., Amsterdam/U. Zimbabwe	RF
Insect resistance	Washington State U., Pullman/CIAT	
Photosynthesis	Australian Nat. U., Canberra	AIDAB
	U. of Georgia, Athens	USAID
Plant regeneration	U. de Paris, Orsay	EC
	U. of Bath, UK	ODA
	U. of Zimbabwe	DGIS
	CIAT	Core
	South China Inst. of Botany, Guangzhou	RF
	Agricultural U. Wageningen	DGIS
	IITA	Core
Genetic transformation	U. Nottingham, UK	RF
	U. of Guelph, Canada	RF
	CIAT	Core
	CENARGEN, Brazil	-
	IITA	Core
DNA fingerprinting & molecular mapping	Washington U., St. Louis	RF
	U. of Georgia	RF
	CIAT, IITA	RF
New products & utilization of by-products and waste	CIRAD/SAR, ORSTOM, CIAT, NRI, UNIVALLE, UNESP, U. of Buenos Aires	EC
Cryopreservation	CIAT	Core
CBN Coordination	CIAT	DGIS
Other activities	CIAT, IITA	Core

RF (Rockefeller Foundation); EC (European Community); ODA (Overseas Development Administration); USAID (US Agency for International Development); DANIDA (Danish International Development Agency); ILTAB (International Laboratory for Tropical Biotechnology); ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer, France); GTZ (Gesellschaft für Technische Zussamenarbeit); AIDAB (Australian International Development Assistance Bureau); CAF (Corporacion Andina de Fomento, Venezuela); NRI (Natural Resources Institute, UK); CIRAD/SAR (Centre de Coopération International en Recherche Agronomique pour le Développement/Systems Agro-alimentation et Ruraux); UNIVALLE (Universidad del Valle, Columbia); UNESP (U. Estadual Paulista, Brazil).

22.1.2.1 CBN international scientific meeting. The first scientific meeting, sponsored by DGIS and the Rockefeller Foundation, took place in Cartagena, Colombia, in August. Over 70 presentations included contributions from biochemistry, physiology, germplasm resources, medicine, economics and sociology, as well as biotechnology. Advances were reported in several CBN priority areas including methods to reduce costs and increase effectiveness of germplasm conservation and use; construction of a molecular map for efficient crop improvement; and important steps toward a repeatable protocol for genetic engineering of cassava. Animated discussions showed that the CBN is successfully fostering interdisciplinary exchange.

22.1.2.2 Evolution of the CBN. At the 1992 scientific meeting, the SC formulated the following revised CBN objectives:

- The CBN is a forum for cassava biotechnology issues and exchange of information and genetic materials

- The CBN aims to:

  - Stimulate biotechnology research for enhancing the advantages of cassava, lessening its disadvantages, and opening new opportunities for the crop

  - Promote cassava biotechnology research toward developing country priorities; involve developing countries in network activities, and facilitate integration of end-user input in the cassava biotechnology research agenda
  - Promote biotechnology research on cassava in research institutes and the donor community, and foster interaction among researchers and policy-makers

  - Develop a communications system for cassava biotechnology-related activities throughout the world

The SC also restructured its composition to reflect a growing emphasis on integration of national agricultural research and development institutions and end-user perspectives. The SC now includes regional representatives from Latin America, Asia and Africa; representatives from a donor (DGIS), CIAT and IITA; a socioeconomist (position vacant); two biological scientists representing leading labs in the international scientific community, and, ex-officio, the Coordinator. A Technical Subcommittee of four individual scientists will advise the SC and Coordinator on current biotechnology.

23. ADOPTION AND IMPACT STUDIES

Since 1990 the Cassava Program has prioritized studies focusing on technology adoption and impact. Last year studies were undertaken to determine the level and degree of adoption of cassava production technologies on the Colombian Atlantic Coast. Based on preliminary results of these studies, the following sections elaborate on the adoption patterns and aggregate impact of the integrated projects in the region.

23.1 Analysis of Adoption of Production Technology

The purpose of this analysis is to understand better the pattern of adoption of different technological components in cassava production on the Atlantic Coast of Colombia and to identify the factors that influence cassava farmers' response to new technology. Insights with respect to the correlation between technology adoption and the importance of markets, government programs and farm household characteristics are important for researchers and policy-makers to develop and diffuse better new technologies. If the factors that characterize nonadopters can be identified, it is possible that modifications to research, extension or input supply systems can be made so that this segment of the population can be reached better. On the other hand, if the differences between adopters and nonadopters can be distinguished, the effects of technology on income distribution and employment can be determined more effectively.

If we consider that cassava farmers are (a) income-seeking individuals, (b) with some level of risk aversion behavior, (c) sensitive to changes in their environment, and (d) generally effective in their decision making, we can expect to find a correlation between the adoption of technological components and the following factors:

- Importance of markets: distance from the farm to the nearest fresh market (urban area) and to the nearest drying plant
- Characteristics of government programs: access to credit and information (technical assistance)
- Characteristics of the farm: relative crop importance, farm size, topography and cropping system
- Characteristics of the farmer: membership in farmer associations, education, experience, land tenure (% of land owned), age, family size and family labor

In order to understand these relationships, a logit econometric model was developed and estimated with the "logistic" procedure in the SAS package with cross-sectional data obtained through a Cassava Producer Survey conducted on the Atlantic Coast in 1991. The results of this analysis are reported in **Tables 23.1** and **23.2**.

Table 23.1 The effect of farm household characteristics on the probability of adoption of different production technology components on the Atlantic Coast of Colombia.

	Technology Component						
Farm Household Characteristics	Machine	Herbicide	Fertilizer	Seed Treatment	Cv. Venezolana	Cv. MP12	Increased Planting Density
% farmers who adopted technology	39.6	45.1	6.5	6.3	78.1	4.4	45.8
	Probability of Adoption						
Avg farmer[1]	0.36	0.33	0.05	0.03	0.83	0.01	0.43
Coop member	0.71***	0.54***	0.05	0.12***	-[2]	0.02**	0.48
Farm on rolling land	0.20**	0.43***	0.03**	0.03	0.87*	0.00***	0.48
Access to credit	0.51***	0.48***	0.05	0.04	0.85	0.05***	0.42
Monoculture	0.41	0.35	0.13***	0.02	0.68***	0.00*	0.45

1 The avg cassava farmer on the Atlantic Coast has the following characteristics: 3 yr formal education, 21 yr experience as a cassava farmer, owns 69% of his land, the distance to the nearest fresh market is 16 km, the distance to the nearest drying plant is 43 km, farm size of 11 ha, 79% of the farmed land is planted with cassava, received 2 yr of technical assistance, is 50 yr old with a 7-member family 3 of whom worked on the farm. He does not belong to a cassava drying coop (93.3 %), does not receive credit for cassava planting (57%), plants cassava intercropped (62%) and on flat land (58%).

2 The adoption of Venezolana could not be estimated with the dummy variable for coop member because of multicolinearity problems.

* The probability of adoption is significantly different from the avg farmer at a significance level between 0.10-0.25.

** The probability of adoption is significantly different from the avg farmer at a significance level between 0.05-0.10.

*** The probability of adoption is significantly different from the avg farmer at a significance level of less than 0.05.

Table 23.1 shows the probability that an avg cassava farmer on the Atlantic Coast of Colombia would adopt different technological components and how this probability changes if the farmer is a member of a cassava drying plant coop, receives credit, has a farm on rolling instead of flat land, or plants cassava in a monoculture system rather than intercropped. The elasticities of adoption with respect to changes in the distance to fresh and dry markets, relative importance of cassava on the farm, years receiving technical assistance, farm size, years of formal education and experience as cassava grower, % land owned, age, family size and family labor are reported in **Table 23.2**. These elasticities give the percentage change in the probability of technology adoption when the respective factor affecting adoption increases by 1%.

Table 23.2 The effect of changes in farm household characteristics on the probability of adoption of different production technology components on the Atlantic Coast of Colombia.

Factors Affecting Adoption	Technology Component						
	Machine	Herbicide	Fertilizer	Seed Treatment	Cv. Venezolana	Cv. MP12	Increased Planting Density
	% Change in Adoption for a 1% Increase in the Factor (Adoption Elasticities)						
1. Importance of markets							
Distance to fresh market (km)	-0.35***	0.14*	-0.04	0.46**	-0.02	-0.28	0.57***
Distance to drying plant (km)	-0.22***	-0.03	-0.07	-0.73***	-0.07***	-1.38***	-0.16***
2. Characteristics of Government programs							
Technical assistance (no. years)	0.08***	0.20***	0.21***	0.22***	0.02*	0.05***	0.11***
3. Characteristics of the farm							
Relative crop importance (% of cropping area with cassava)	-0.31**	0.04	0.45	0.05	0.07*	-0.33	0.26**
Farm size (ha)	0.06*	0.03	0.24***	-0.21	-0.004	-0.11	0.01
4. Characteristics of the farmer							
Education (no. yr)	-0.02	0.13***	0.19*	0.06	-0.01	-0.21	0.04
Experience (no. yr)	-0.02	-0.11	-0.12	0.21	0.06*	0.39	-0.01
Land tenure (% land owned)	0.22***	-0.005	0.16	-0.12	-0.002	-0.61*	0.09
Age (no. yr)	-0.34	-0.34	0.33	-0.03	0.08	-1.12	0.27
Family size (no. of members)	0.05	0.10	0.35	-0.59	0.12***	0.60	-0.21*
Family labor (no. of members who worked on the farm)	0.07	0.04	-0.04	0.20	-0.10***	0.35	-0.09

* Significance level between 0.10-0.25.

** Significance level between 0.05-0.10.

*** Significance level less than 0.05.

23.1.1 Machinery adoption

In 1991, 40% of the cassava farmers in the region were using machinery for land preparation. While the avg cassava farmer has a 0.36 probability of adopting machinery for land preparation, this probability increases significantly to 0.71 and 0.51, resp., for a farmer who is member of a coop or receives credit. The probability of using machinery significantly decreases to 0.20, however, if cassava is planted on rolling land (probably related to the difficulty of using machinery on rolling land and the problems of erosion); but does not change if cassava is planted in monoculture. Access to markets increases the probability of adoption of machinery considerably. A decrease in the distance to the nearest urban area or cassava drying plant of 10% (e.g., from 16 to 14.4 km and from 43 to 38.7 km, resp.) would increase the probability of machinery adoption by 3.5 and 2.2%, resp. Similarly, a 10% increase in the percentage of land owned, (e.g., from 69 to 76%), the no. of years receiving technical assistance (e.g., from 0.34 to 0.37 yr), and in farm size (e.g., from 10.6 to 12.2 ha) would increase the probability of adoption by 2.2, 0.8 and 0.6%, resp. Machinery adoption, on the other hand, is inversely related to the importance of cassava. A 10% increase in the percentage of total land under crops planted with cassava (e.g., from 77.6 to 85.4%) decreases the probability of using machinery by 3.1%.

23.1.2 Herbicide adoption

According to the 1991 cassava farmer survey, 45% of the farmers were using herbicides for weed control. The probability of using herbicides for the avg cassava farmer is 0.33, increasing significantly for coop members (0.54) and farmers who receive credit (0.48); however, contrary to the case of machinery adoption, the probability would increase significantly on rolling land (0.43). The higher probability of herbicide use on rolling land could be related to the lower use of machinery and therefore the higher incidence of weeds on this type of land. The adoption of herbicides is positively related to the distance to fresh markets (urban areas). This means that if the distance to the nearest urban area increases by 1%, the probability of using herbicides also increases by 0.14%. This positive relationship could be related to the supply of labor, which decreases as the farm is located at a higher distance from urban areas. The increase of 1% in the no. of years of technical assistance and years of formal education would also increase the adoption of herbicides by 0.20 and 0.13%, resp.

23.1.3 Fertilizer adoption

The adoption of fertilizers in cassava production on the Atlantic Coast has been relatively low. In 1991 only 6.5% of the farmers were using fertilizers, and the probability of adoption was only 0.05. This probability becomes significantly higher when cassava is grown in monoculture (0.13) and significantly lower when it is grown on rolling land (0.03). The probability of farmers' adopting fertilizer would increase by 0.24, 0.21 and 0.19% as farm size, years receiving technical assistance, and years of formal education increase by 1%, resp.

23.1.4 Seed treatment adoption

As in the case of the adoption of fertilizers, the practice of treating the seed before planting was adopted by only 6.3% of the farmers. This lower adoption rate could be caused by the extra labor requirements for fertilization and seed treatment, which may be a scarce factor, especially during the planting and weeding seasons. The probability that the avg cassava farmer would treat the seed before planting is only 0.03, but this figure increases to 0.12 if the farmer is member of a cassava drying coop. The presence of drying plants also increases the probability of adoption; a 1% decrease in the distance to the nearest drying plant increases the probability of adoption by 0.73%. On the other hand, proximity to the nearest urban area decreases the probability of adoption; a 1% decrease in the distance to urban areas decreases the probability of treating seeds by 0.46%. This relationship may be related to the fact that farms located closer to urban areas have easier access to high-quality seed, which reduces the need for treating the seed. The no. of years of technical assistance also influences the adoption of seed treatment; a 1% increase in years of assistance increases the probability of adoption by 0.22%.

23.1.5 Adoption of new cassava cv.

This study analyzes the adoption of two new cv. on the Atlantic Coast of Colombia: Venezolana and MP12. According to the producer survey, 78% of the farmers planted cv. Venezolana in 1991, while only 4.4% of them planted MP12, making the probability that the avg farmer plant Venezolana significantly higher than the probability of planting MP12 (0.83 vs. 0.01). The adoption of both cv. decreases if cassava is planted in monoculture rather than intercropped; but increases if the farmer has access to credit. Topography has the opposite effect on Venezolana than for MP12: the probability of adopting Venezolana is higher on rolling land; whereas that of MP12 is higher on flat land. The probability of adopting MP12 also increases if the farmer is a member of a cassava drying coop.

The adoption of both cv. is related to the distance to drying plants, but the effect of drying plants on adoption is higher for MP12 than for Venezolana. A 1% decrease in the distance to the nearest drying plant increases the probability of adopting Venezolana and MP12 by 0.07 and 1.38%, resp. Moreover, the probability of adopting Venezolana increases as cassava represents a higher percentage of the land under crops, but adopting MP12 is not affected by the importance of cassava on the farm. A 1% increase in the percentage of land under crops planted with cassava increases the probability of adopting Venezolana by 0.07%.

Furthermore, as with most of the technological components, the adoption of new cv. is also affected by the no. of years that the farmer has been receiving technical assistance; but this effect is higher and more significant for MP12 than for Venezolana. A 1% increase in the no. of years of technical assistance increases the probability of adopting

Venezolana and MP12 by 0.02 and 0.05%, resp. However, the adoption of Venezolana is also related to experience, family size and family labor, while the adoption of MP12 is not. A 1% increase in the no. of years of experience with cassava and the no. of family members increases the probability of adopting Venezolana by 0.06% and 0.12, resp; yet a 1% increase in the no. of family members who work on the farm, decreases the probability of adopting Venezolana by 0.10%.

23.1.6 Adoption of increased planting density

In the 1991 cassava producers survey, 46% of the farmers on the Atlantic Coast reported to have increased their planting density in order to increase yields. The probability that the avg farmer in the region would increase planting density is relatively high (0.43), a probability that is not affected by coop membership status, access to credit, topography or planting system. The decision of whether to increase the planting density or not is primarily affected by access to markets. Farmers who are near urban areas and who sell their cassava primarily to the fresh market have a lower probability of increasing their planting density than cassava farmers who are near drying plants and who sell their cassava primarily to the cassava drying market.

The relationship between adopting increased planting density and access to markets may be related to the fact that the fresh market demands bigger roots, which can only be obtained if the planting density is lower; whereas the dry market has no restrictions on root size. A 1% decrease in the distance to a fresh market would decrease the adoption of increased planting density by 0.57%, while a 1% decrease in the distance to the nearest drying plant would increase it by 0.16%. Adopting increased planting density would also increase if cassava is relatively more important and if the farmer has been receiving technical assistance for a longer period of time. A 1% increase in the percentage of the land under crops planted with cassava and the no. of years of technical assistance increases the probability of increasing planting density by 0.26 and 0.11%, resp.

23.1.7 Conclusions

This study shows that, except for fertilizer adoption, the adoption of technology on the Atlantic Coast of Colombia was significantly affected by access to markets. Moreover, the study shows the importance of the introduction of cassava drying technology in light of the results regarding "distance to drying plant" and "coop member." The introduction of cassava drying has not only had a significant effect on the stabilization of root prices but has had a further positive effect on cassava production technology; hence these results provide further evidence that cassava drying associations can well serve as vehicles for technology diffusion.

In summary, the foregoing confirms the importance of integrating cassava production, processing and marketing research activities. It is apparent that government programs

that influence the access of cassava farmers to information and credit are of great significance in technology adoption and that technical assistance has a positive and meaningful effect on the adoption of all the technological components analyzed in this study. Access to credit also had an important effect on technology adoption, except for fertilizer, seed treatment and increased planting density. The characteristics of the farm household were of relatively lesser importance in adopting technology, and their effect varied considerably among the different technology components.

23.2 Economic Impact of Integrated Cassava Projects on the Atlantic Coast

Research institutions and funding agencies are interested in effective, efficient research that can provide them with sufficient feedback on the size and distribution of the returns to agricultural R&D. Accordingly, the objective of this study is to quantify the economic benefits of the integrated cassava project on the Atlantic Coast, briefly analyzing the development of the cassava drying industry and the evolution of cassava production and consumption in the area.

For the quantitative analysis, total economic benefits are distributed among the cassava producers, processors, market agents and consumers. Additionally, total benefits are differentiated according to direct and indirect benefits. The former refer to the impact of the cassava utilization technology on the incomes in the region; the latter to the adoption of production technology and the increase in area planted as a production response to the new market, which enhanced the income generation potential of the technology.

Following this analysis, a descriptive model of the Atlantic Coast cassava system--which incorporates cassava production, processing, marketing and consumption--was used to simulate exogenous supply and demand shifts resulting from the adoption of the cassava utilization and production technologies. The estimated changes in equilibrium prices and quantities resulting from adopting each technology are then used to estimate the benefits received by the different groups in society for the period 1984-91.

In the case of the impact of integrated cassava projects on the Atlantic Coast of Colombia, it is of interest to analyze the change in benefits for the following groups: (a) fresh cassava urban consumers; (b) dried cassava purchasers, mainly the feed industry and integrated poultry and swine producers; (c) dried cassava processors, which for the period of analysis (1984-91) were mainly associations of small cassava producers with private enterprises entering the market during the last three years; (d) fresh cassava market agents; and (e) cassava producers. It is also of interest to study the implications of technology for poor vs. rich fresh cassava consumers and for producers who adopt the technology vs. nonadopters.

23.2.1 Development of the cassava drying industry

In 1981 the Colombian Government-sponsored program for Integrated Rural Development (DRI) started a project to promote the development of a dry cassava industry with associations of small cassava producers on the Atlantic Coast and the collaboration of various national and international institutions including CIAT. This project incorporated a methodology to develop, test and validate various production and processing technologies, fully integrating research on cassava production, processing and marketing.[23.1] Subsequently, the first cassava drying pilot plant started to produce dried cassava chips in 1982; but it was not until 1984 that the project began its replication or commercial phase.

Of the 142 drying plants presently operating in the region, 97 are owned by small cassava producer associations; the remaining 45, by private entrepreneurs. During 1991 these drying plants produced around 25,000 t of chips, which implied a demand of 62,500 t fresh roots, representing 6.6% of the total cassava produced in the region in 1991 and 8.6% of the cassava commercialized. Processing costs (1991) for some of the drying plants show that the raw material (the roots) accounted for an avg of 91% of the total variable costs; the remaining 9% was mainly for labor.

23.2.2 Evolution of cassava production

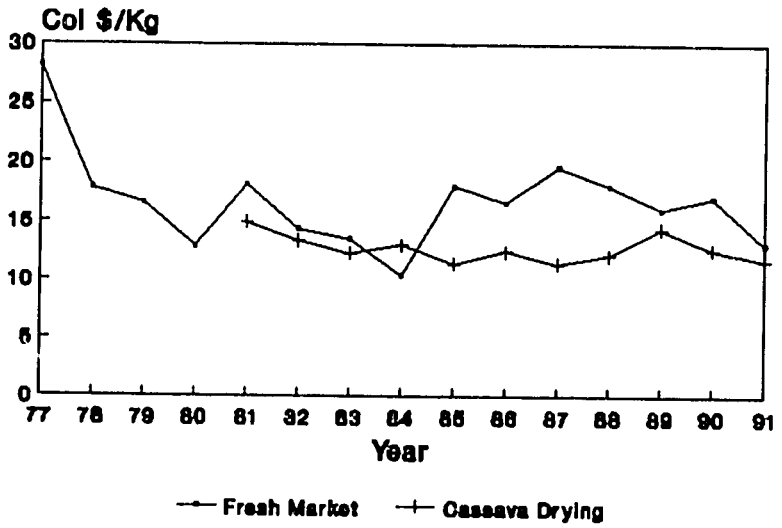
According to the Ministry of Agriculture data base, the total area planted with cassava on the Atlantic Coast from 1980-84 decreased at an avg annual rate of 7.6% (66,100 ha to 55,000 ha). One of the major causes for this decrease in production was the fall in prices caused by the high cassava production during 1981. Many farmers could not find buyers for their crop so they plowed the land without harvesting; and since that time they have been afraid to grow more cassava. This is an example of the instability that normally characterizes fresh cassava markets.

After 1984, when cassava drying plants entered their commercial phase, the reduction in area dedicated to cassava area was reversed. From 1984-91 cassava cultivation in the region increased in area at an avg annual rate of 11.4%, from 55,000 ha to 110,377 ha. The main cause for this marked increase during the period was the decrease in the risk of marketing cassava, brought about by such variables as the price stabilization effect of the cassava drying industry, the land reform program which defined the land situation of many small farmers, the increased availability of credit for cassava production, and the substitution of yam production area with cassava as a result of the adverse effect of anthracnose disease on yam production.

[23.1] For an extensive review of this approach, see C. PEREZ-CARRESPO. 1991. Integrated cassava projects: A methodology for rural development. In Integrated Cassava Projects, pp. 26-43. Cali, Colombia, CIAT Cassava Program.

The decrease in marketing risk--through the stabilization of producer prices--can be seen in **Figure 23.1**. Prices paid to the producer by the drying plants did not vary much from year to year, and an avg floor price of Col$12,859/t (constant Col$1988) was established. The fluctuation in producer prices until 1984 (when the drying plants began to be replicated) was 18%; yet after 1984, this fluctuation in prices decreased to 10% for cassava sold to the fresh market and only 4% for cassava sold to the drying plants.

In terms of the land reform program, data from the Instituto Colombiano de Reforma Agraria (INCORA) shows that 184,134 ha of land were adjudicated to small farmers on the Atlantic Coast of Colombia between 1986-91 (62.3% of the land adjudicated in the last 20 yr). On the other hand, the no. of hectares of cassava planted with credit increased from 11,572 ha (18% of the total area planted with cassava) in 1980, to 40,716 ha (55% of the total area planted with cassava) in 1987 (Ministry of Agriculture).



Source: Annual Reports, Central de Cooperativas de la Reforma Agraria (CECORA) and DRI-CIAT cooperative project on agroindustrial development of cassava on the Atlantic Coast of Colombia.

Figure 23.1 Cassava producer prices on the Atlantic Coast of Colombia in 1988; constant prices, 1977-91.

In terms of productivity, data from cassava producer surveys conducted by the CIAT Cassava Economics Section show that avg yields in the region increased from 7.35 t/ha in 1982 to 9.75 t/ha in 1991. This 32.65% increase in productivity was mainly the result of adopting cassava production technology (see Section on *"Adoption of Cassava Production Technology"*. Using this data on cassava area and yield, a production growth

of 163.8% was calculated for the period 1984-91; cassava production on the Atlantic Coast of Colombia increased from 407,925 t in 1984 to 1,076,176 t in 1991.

The evolution of cassava production on the Atlantic Coast suggests that the high increase in area of cassava cultivation, the productivity of the late 1980s, and the partial stabilization of prices benefitted cassava producers in terms of income increase and employment generation. The calculation and analysis of these benefits are presented in section 23.2.4.

23.2.3 Evolution of fresh cassava consumption

During the early 1980s, the role of cassava on the Atlantic Coast of Colombia diminished due to the high (absolute) price of cassava in urban areas. The urbanization process and the improvement of infrastructure facilitated the importation of cassava substitutes grown outside the region, which increased the price of cassava relative to the substitutes. Janssen (1986) found that fresh cassava consumption fell sharply especially in the more urbanized areas. It became apparent that marketing problems of the crop caused unfavorable retail prices in urban areas and were responsible for the decreased consumption. According to the Fresh Cassava Consumption Survey conducted in 1983 by Janssen, fresh cassava consumption fell in urban areas by 45% between 1980 and 1983. Moreover, data from the DANE (Depto. Administrativo Nacional de Estadísticas) Household Survey of 1985, reflected an additional decrease of 2% between 1983 and 1985.

Socioeconomic studies conducted as part of the Integrated Cassava Project developed by CIAT suggested that efforts to promote cassava production coupled with efforts to improve and open new cassava markets would decrease and stabilize prices. This would subsequently increase production and therefore exert downward pressure on retail prices, thereby increasing fresh cassava consumption. In order to measure and analyze the present fresh cassava consumption and compare it with consumption figures for the 1980s, a household survey was conducted in three representative cities of the Atlantic Coast of Colombia (Barranquilla, Santa Marta and Sincelejo).

Table 23.3 shows the evolution of cassava consumption in Barranquilla, the main urban area of the Atlantic Coast. Cassava consumption in Barranquilla reached its lowest level of 30.5 kg per capita in 1983, a decrease of 46% from its 1980 level. This decrease in consumption can be partly explained by the increase in cassava prices of 22% from 1980 to 1983. After 1983 cassava consumption in Barranquilla began to increase again, reaching a level of 40.9 kg per capita in 1991--a 34% increase from 1983. Again, price fluctuations may be partly accountable for this increase in consumption given that there was a price decline of 50% from 1983 to 1991.

Given the foregoing, there are three important conclusions to be made in terms of fresh cassava consumption in the last decade:

Table 23.3. Fresh Cassava Consumption and Price Evolution in Barranquilla.

Year	Fresh Cassava Consumption (kg per capita/yr)	% Change	Fresh Cassava Consumer Price 1988 Constant Prices ($/kg)	% Change
1980	56.3[a]		80.92[c]	
1983	30.5[a]	-45.83	98.32	21.50
1987	39.5[b]	29.51	70.92	-27.87
1991	40.9[b]	3.54	52.54	-25.92

[1] **Source:** Cassava consumption survey among purchasers and producers, CIAT, 1893.
[2] **Source:** Fresh cassava consumption survey, Cassava Economics, CIAT, 1991.
[3] **Source:** DANE, Boletín de Estadística.

- Fresh cassava consumption per capita increased, especially for low-income people, after a decrease during the early 1980s.
- There was a significant decrease in fresh cassava prices and in their fluctuation.
- The price of cassava substitutes--primarily potato and plantain--increased, thereby reducing the relative price of cassava even more with respect to that of its substitutes.

These changes in fresh cassava consumption suggest that cassava has renewed its importance as a caloric source in the nutrition of the urban population of the Atlantic Coast of Colombia, especially for the poor urban consumers, who utilize more and are more vulnerable to price fluctuations. Therefore, fresh cassava consumers benefit from the Integrated Cassava Project, which allows for an increase in cassava consumption at a lower cost. The extent of these benefits is estimated in the following section.

23.2.4 Analysis of benefits

In order to calculate the total economic benefits of the Integrated Cassava Project on the Atlantic Coast, a model of the cassava system in the region was simulated. This model made it possible to calculate the impact of these benefits among the different social groups involved and to distinguish between the benefits generated directly by the cassava utilization technology and the indirect benefits reflected by the production response. Demand, supply and substitution elasticities for cassava production, marketing, processing and consumption--estimated in previous studies conducted by the Cassava Economics Section this year--were used for this simulation. Preliminary results on total ex-post estimated benefits for society from the Integrated Cassava Project on the Atlantic

Coast of Colombia are shown in **Table 23.4**. These results are then compared with the ex-ante estimation of benefits made by Janssen in 1983 and the total benefits observed in the region.

Table 23.4. Economic benefits of the Integrated Cassava Project on the Atlantic Coast of Colombia.

Social Group	Ex-post Benefits Estimated from Cassava Utilization Technology	Ex-post Benefits Estimated from Cassava Production Response	Total Ex-post Benefits Estimated from Technology	Total Ex-ante Benefits Estimated from Technology[1]	Total Benefits Observed[2]
Fresh cassava consumers	233[3]	1,806	2,039	-5,700	5,211
	(3.35)[4]	(12.10)	(9.32)	(-16.38)	(17.49)
Dried cassava consumers	4,334	0	4,334	7,200	5,279
	(62.40)	(0.00)	(19.81)	(20.69)	(17.72)
Cassava market agents	-78	-584	-662	-	-7,087
	(-1.12)	(-3.91)	(-3.03)	-	(-23.79)
Dried cassava processors	1,150	0	1,150	-	3,323
	(16.56)	(0.00)	(5.26)	-	(11.15)
Cassava producers	1,307	13,706	15,013	33,300	23,066
	(18.82)	(91.81)	(68.63)	(95.69)	(77.42)
Net benefits to society	6,946	14,928	21,874	34,800	29,792

1 Ex-ante benefits estimated from technology by Janssen in 1986 (Market impact on cassava's development potential in the Atlantic Coast region of Colombia. CIAT, Cali, Colombia).

2 Total observed benefits--calculated from observed changes in quantities and prices--include not only the net gains from cassava utilization and production technology, but also gains from the land reform program, improved credit availability and other exogenous factors.

3 The values are changes in economic surplus in thousands of 1991 US$.

4 Values in parentheses are the percent gains for each group in society with respect to the total change in economic surplus.

Cassava producers were the most benefitted by the project, gaining US$15 million between 1984 and 1991. Moreover, producers with fewer production constraints, who were able to adopt improved production technology and react faster to price changes, benefitted the most from technological change. Based on the analysis of cassava production technology adoption (see Sect. 23.1), it can be argued that producers with better access to markets and to government programs were the major adopters of

technology; therefore, cassava farmers who are members of drying coops, have an easier access to fresh markets, are near the drying plants and were beneficiaries of government programs for technical assistance and credit were the ones who received most of the benefits from the Project. Only to a lesser extent were benefits dependent on other farm household characteristics such as farm size, land tenure, education and experience.

The second group benefitting widely from the Integrated Cassava Project was that of the purchasers of dried cassava--primarily animal feed plants and integrated poultry and swine producers. This group gained US$4.3 million from the introduction of the cassava drying plants in the region. Although this group was not targeted as one of the main beneficiaries at the onset of the Project, it is important to realize that the magnitude of these benefits is a driving force behind the strong, continuing demand for dried cassava. Without this demand for the product, the introduction of the cassava drying technology in the region would not have been feasible.

Although cassava producers were the major beneficiaries from the technological changes, urban consumers of fresh cassava also benefitted from the adoption of cassava drying and production technology, obtaining benefits estimated at US$2 million. Poor urban consumers, who consume higher absolute levels of fresh cassava and show a lower price elasticity of demand, are the ones who gained most.

The group with the smallest total gain from the Integrated Cassava Project in the region was the dry cassava processors, who gained only US$1.1 million. However, it must be noted that the majority of the small-scale processors are also cassava producers and they therefore benefit in two ways. From 1984-91, approx. 55,318 t of dried cassava were produced, 84% produced by small cassava farmer associations, which had a total net gain of US$924,000 from the adoption of dry cassava technology during the period in mention. The remainder of the benefits received by this group (US$ 176,000) went to private processors.

Fresh cassava market agents were the only group that lost as a consequence of the Integrated Cassava Project on the Atlantic Coast. The loss of benefits to this group is mainly an effect of the inefficiency of the fresh cassava market. Any attempt to make the marketing of fresh cassava more efficient, approximating perfectly competitive conditions, will decrease the losses to market agents and increase the gains to fresh cassava consumers.

Hence the introduction of cassava utilization technology on the Atlantic Coast benefitted dry cassava purchasers and processors the most; nonetheless, of heightened importance is the indirect effect of creating an incentive to increase the area planted with cassava and to increase yields through the adoption of improved production technology. The production response to this incentive of the new market reaped benefits primarily for cassava producers and fresh cassava urban consumers.

Furthermore, the estimated net benefits to society from the Integrated Cassava Project are estimated at US$22 million. As the total project costs were US$ 252,332, the total return on the investment was approx. US$87 per dollar invested. As show in **Table 23.4**, the net benefits from technology are smaller than the total observed benefits of US$27 million. The difference of US$5 million between the total benefits and the benefits from technology are due to other exogenous factors. Some of the factors that have shifted the supply of on-farm cassava further were the land reform policy, the increased credit availability to small cassava farmers, and the substitution of yam production area with cassava due to the increasing incidence of anthracnose on yams.

These results enforce the significance of this research approach to integrate production, processing and marketing aspects. In the absence of the broadened cassava market, production technology adoption would have been significantly less. Moreover, the principal beneficiaries would have been the consumers of fresh cassava, not the small producers to which the technology is targeted. On the other hand, in the absence of production technology with only processing and marketing innovations, absolute total benefits would have been significantly less and the principal recipients would have been the animal feed factories and, to a lesser extent, processors. The integration of the research has been the prirne factor in optimizing both absolute benefits and their distribution. As such, the research objective of targeting benefits to small producers was realized.

ACRONYMS

AIDAB	Australian International Development Assistance Bureau (Australia)
ATI	Alternative Technologies International (US)
BIOTASK	Biotechnology Task Force (CGIAR)
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit (Germany)
BRU	Biotechnology Research Unit (CIAT)
CAF	Corporacion Andina de Fomento ()
CBN	Cassava Biotechnology Network (CIAT)
CCC	Comite de Mandioca do Ceará (Brazil)
CECORA	Central de Cooperativas de la Reforma Agraria Ltda. (Colombia)
CENARGEN	Centro Nacional de Recursos Genéticos (EMPASC-Brazil)
CENDES	Centro Nacional de Desarrollo (Ecuador)
CETEC	Corporación para Estudios Interdisciplinarios y Asesoría Técnica (Colombia)
CGPRT	Regional Centre for Research and Development of Coarse Grain, Pulses, Roots and Tubers (Indonesia)
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
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)
CPAA	Centro de Pesquisa Agroforestal de la Amazonia (Brazil)
CVC	Corporación Autónoma Regional del Cauca (Colombia)
DANE	Departamento Administrativo Nacional de Estadísticas (Colombia)
DANIDA	Danish International Development Agency
DGIS	Directorate General for International Cooperation (Netherlands)
DOA	Department of Agriculture (Thailand)
DRI	Fondo de Desarrollo Rural Integrado (Colombia)
EC	European Community
EMATER	Empresa de Assistencia Técnica e Extensão Rural (Brazil)
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)
EPACE	Empresa de Pesquisa Agropecuária do Ceará (Brazil)
EPAGRI	Empresa de Pesquisa Agropecuária e Difusao de Tecnologia de Santa Catarina (Brazil)
FACE	Fundación para el Adelanto Comunitario Ecuménico (Ecuador)
FCRI	Field Crops Research Institute (Thailand); Food Crops Research Institute (Vietnam)
FECD	Fondo Ecuatoriano-Canadiense de Desarrollo (Ecuador)

FEDECAFE	Federación Nacional de Cafeteros (Colombia)
FODERUMA	Fondo de Desarrollo Rural Marginado (Ecuador)
FUNDAEC	Fundación para la Educación y la Ciencia (Colombia)
FUNDAGRO	Fundación Ecuatoriana de Investigaciones Agropecuarias (Ecuador)
GRU	Germplasm Resources Unit (CIAT)
GTTPM	Grupo de Trabalho em Tecnologia Pos/colheita de Mandioca (Brazil)
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
IAS	Institute of Agriculture Sciences (Vietnam)
ICA	Instituto Colombiano Agropecuario (Colombia)
ICONTEC	Instituto Colombiano de Normas Técnicas
IDB	Inter-American Development Bank
IEE	(FUNDAGRO-Ecuador)
IDRC	International Development Research Centre (Canada)
IFAD	International Fund for Agricultural Development (Italy)
IITA	International Institute of Tropical Agriculture (Nigeria)
ILTAB	International Laboratory for Tropical Biotechnology
INCORA	Instituto Nacional de la Reforma Agraria (Colombia)
INIAP	Instituto Nacional de Investigaciones Agropecuarias (Ecuador)
INSA	National Institute of Agricultural Sciences (Vietnam)
IPRA	Investigación Participativa en Agricultura (CIAT)
ISNAR	International Service for National Agricultural Research (Netherlands)
KF	W.K. Kellogg Foundation (USA)
KU	Kasetsart University (Thailand)
MAFI	Ministry of Agriculture and Food Industry (Vietnam)
MAG	Ministerio de Agricultura y Ganadería (Ecuador)
NRI	Natural Resources Institute (UK)
NRTRP	National Root and Tuber Research Program (Vietnam)
ODA	Overseas Development Administration (UK)
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer (France)
PNR	Plan Nacional de Rehabilitación (Colombia)
PRCRTC	Philippine Root Crop Research and Training Centre
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)
SAR	Systems Agro-alimentation et Ruraux (CIRAD)
SCATC	South China Academy of Tropical Crops
SCRI	Scottish Crop Research Institute
SEARA	Secretaria de Agricultura y Reforma Agrária (Brazil)

UA#3	University of Agriculture-Bac Thai (Vietnam)
UAF#4	University of Agriculture and Forestry (Vietnam)
UATPPY	Union de Asociaciones de Trabajadores Agricolas, Productores y Procesadores de Yuca (Ecuador)
UNDP	United Nations Development Programme (USA)
UNESP	Universidade Estadual Paulista (Brazil)
UNIVALLE	Universidad del Valle (Colombia)
USAID	United States Agency for International Development
UTM	Universidad Técnica de Manabí (Ecuador)
UVTT	Unidad de Validación y Transferencia de Tecnología (Ecuador)
VRU	Virology Research Unit (CIAT)

ABBREVIATIONS

ACMV	African cassava mosaic geminivirus
ACP	acid phosphatase
alt.	altitude
ANOVA	analysis of variance
API	Appareils et Procédés d'Identification (Biomérieux, France)
approx.	approximately
avg	average
BI	branching index
B'	coefficient of sensitivity
BU	Brabender Unit(s)
C	Centigrade
ca.	circa
CALV	cassava American latent virus
CBB	cassava bacterial blight
CCM	cassava Caribbean mite
CCMV	cassava common mosaic virus
CCSpV	cassava Colombian symptomless virus
cDNA	complementary DNA
CET	clonal evaluation trial
cfb	colony fluid bacteria
CGM	cassava green mite
Chap.	chapter
chl	chlorophyll
Cl	chlorine
cm	centimeter(s)
CMD	Caribbean mosaic disease
CN	cyanide
CO_2	carbon dioxide
concn.	concentration(s)
coop	cooperative(s)
CR	commercial roots
CsXV	cassava X virus
cv.	cultivar(s)
CV	coefficient of variance
CVMV	cassava vein mosaic virus
DAP	days after planting
Dept.	Department
Depto.	**Departmento** (Col. political division equivalent to state)
DI	defective interfering
diam	diameter

DM	dry matter
DMRT	Duncan's Multiple Range Test
DNA	deoxyribonucleic acid
DNase	deoxyribonuclease
dsDNA	double-stranded deoxyribonucleic acid
dsRNA	double-stranded ribonucleic acid
ECZ	edaphoclimatic zone
ELISA	enzyme-linked immunosorbent assay
EM	electron microscope(y)
EPR	preliminary yield trials
ER	advanced yield trials
EU	enzyme unit(s)
fc	foot-candle(s)
FFR	financial rate of return
FRY	fresh root yield
FSD	frogskin disease
g	gram(s)
gal	gallon(s)
GOT	glutamate oxaloacetate
h	hour(s)
ha	hectare(s)
HCN	hydrocyanic acid
HI	harvest index
H_2O	water
HPLC	high-pressure liquid chromatography
HPR	host plant resistance
HQ	headquarters
ht	height
ICMV	Indian cassava mosaic geminivirus
IPM	integrated pest management
J	joule(s)
K	equilibrium constant
Kb	kilo base(s)
KB	King's B medium
kD	kilodalton(s)
kg	kilogram(s)
kj	kilojoule(s)
kw	kilowatt(s)
l	liter(s)
lab	laboratory
LAI	leaf area index
LBA	lima bean agar
LD_{50}	median lethal dose
LM	light microscope

LS	length of stem
LSD	least significant difference
m	meter(s)
MAT	months after transplanting
max.	maximum
MC	moisture content
MCD	meristem-culture derived
M&E	monitoring and evaluation
meq	milliequivalent
mg	milligram(s)
min	minute(s)
ml	milliliter(s)
MLO	mycoplasmlike organism(s)
mm	millimeter(s)
mM	millimolar
mo	month(s)
mol	molecular
M_r	relative molecular weight
MRS	Man Rogosa Sharp
N	nitrogen
n.a.	no data available
NAD-ME	nicotinamide adenine dinucleotide-malic enzyme
NADP-ME	nicotinamide adenine dinucleotide phosphate-malic enzyme
nd	not determined
NGO	nongovernment organization
nm	nanometer(s)
NMV	narcissus mosaic virus
no.	number
NS	not significant
OFR	on-farm research
OM	organic matter
P	phosphorus
PCNB	pentachloronitrobenzene
PCR	polymerase chain reaction
PDA	potato-dextrose-agar
PEPC	phosphoenolpyruvic acid carboxylase
pers.com.	personal communication
pers.obs.	personal observation
PH	plant height
PHD	physiological deterioration
pl	plant(s)
Pn	net photosynthesis
PNCB	pentachloronitrobenzene
ppm	parts per million

PPP	pre-production plot
PUE	phosphorus-use efficiency
pv.	pathovar
PVX	potato virus X
R&D	research and development
RAPD	random amplified polymorphic DNA
reps	replications
resp.	respectively
RF	rapid freezing
RFLP	restriction fragment length polymorphism
RH	relative humidity
RNA	ribonucleic acid
RNase	ribonuclease
RT	rapid thawing
RuBPC	ribulose bisphosphate carboxylase
RWC	relative water content
RY	root yield
SC	steering committee
SD	standard deviation
SDL	seedlings from Latin Ameria
SE	standard error
sec	second(s)
Sect.	section
SED	superelongation disease
SF	slow freezing
SN	seedling nursery
sp./spp.	species
ssp.	subspecies
ss-RNA	single-stranded ribonucleic acid
SSS	seed supply systems
ST	slow thawing
t	metric ton(s)
TCS	true cassava seed
TEM	transmission electron microscope(y)
temp	temperature(s)
U.	University
USLE	universal soil loss equation
UV	ultraviolet
V	viscosity
VAM	vesicular-arbuscular mycorrhiza
var.	variety
vs.	versus
vol.	volume
WB	witches'-broom

WF	whitefly(ies)
wk	week(s)
wt	weight
WTV	wound tumor virus
WUE	water-use efficiency
yr	year(s)

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CASSAVA PROGRAM PERSONNEL (as of December 1992)

Office of the Leader and Networking	**Rupert Best**	Leader	HQ
	Luis Alfredo Hernández	Research Associate	HQ
	Miguel Angel Chaux M.	Research Assistant	HQ
Entomology Section	**Anthony Bellotti**	Entomologist	HQ
	Bernardo Arias	Professional Specialist	HQ
	María del Pilar Hernández	Research Assistant	HQ
	José Castillo	Research Assistant	HQ
Acarology	**Ann Braun**	Entomologist	HQ
	Nora Cristina Mesa*	Research Associate	HQ
	Carlos Julio Herrera	Research Assistant	Sincelejo, Colombia
	Juan Manuel Alvarez	Research Assistant	HQ
Physiology Section	**Mabrouk El-Sharkawy**	Physiologist	HQ
	Didier Pellet*	Junior Research Fellow	HQ
	Luis Fernando Cadavid	Research Assistant	Quilichao, Colombia
	Sara María Mejía de Tafur	Research Assistant	HQ
	Alvaro Acosta	Research Assistant	Pivijay, Colombia
Economics Section	**Guy Henry**	Economist	HQ
	Verónica Gottret	Research Associate	HQ
	Diego Alberto Izquierdo	Research Assistant	HQ
	Carolina Correa*	Research Assistant	HQ
Genetics Section	**Merideth Bonierbale**	Plant Breeder	HQ
	Jairo Alfonso Bedoya	Research Assistant	HQ
	José Luis Claros	Research Assistant	HQ
Genotype by Environment Interaction Section	**Carlos Iglesias**	Plant Breeder	HQ
	Fernando Calle	Research Assistant	HQ
	Gustavo Jaramillo	Research Assistant	HQ
	Jorge Iván Lenis	Research Assistant	Pivijay, Colombia
	Nelson Morante	Research Assistant	HQ
	Javier López M.	Research Assistant	HQ
Pathology Section	**J. Carlos Lozano**	Pathologist	HQ
	Rafael Laberry	Research Associate	HQ
	Carlos A. Bejarano	Research Assistant	HQ
Quality/Utilization Section	**Christopher Wheatley**	Physiologist	HQ
	Gerard Chuzel*	Food Technologist	HQ
	Gerard O'Brien	Food Technologist	HQ
	Dominique Dufour	Bioindustrial Engineer	HQ
	Carlos Ostertag	Research Associate	HQ
	Lisímaco Alonso	Research Assistant	HQ
	Jorge Iván Orrego	Research Assistant	HQ
	Teresa de Salcedo	Research Assistant	HQ
CIAT/DRI Cassava Flour	Miguel Angel Viera	Research Assistant	Sincelejo, Colombia
CIAT/DRI Cassava Storage	Francisco Figueroa*	Research Assistant	Barranquilla, Colombia
Agronomy Section	**Raúl Moreno**	Agronomist	HQ
	Jaime Sánchez	Research Associate	HQ
CIAT/DRI Cassava Production	José Manuel Martelo	Research Assistant	Sincelejo, Colombia
Asian Regional Cassava Program	**Kazuo Kawano**	Plant Breeder	Bangkok, Thailand
	Reinhardt Howeler	Soil Scientist	Bangkok, Thailand
CIAT/IITA Scientist	**Marcio Porto**	Physiologist/Breeder	Ibadan, Nigeria
	Emmanuel Okogbenin	Research Assistant	Ibadan, Nigeria
	Michael Edet	Research Assistant	Ibadan, Nigeria
Cassava Development Project	**Bernardo Ospina**	Agricultural Engineer	Fortaleza, Brasil
CIAT/FUNDAGRO Project	**Susan Poats**	Anthropologist	Quito, Ecuador
CIAT/University of Hohenheim Soil Conservation Project	**Karl Mueller-Saemann**	Postdoctoral Fellow	HQ
	Martin Ruppenthal*	Junior Research Fellow	HQ
	Wolfgang Felske	Junior Research Fellow	HQ
	Jesús Antonio Castillo	Research Assistant	HQ
Cassava Biotechnology Network	**Ann M. Thro**	Plant Breeder	HQ

* Left during 1992