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Annual Report 1990

Cassava Program

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TABLE OF CONTENTS

Page

Page

CASSAVA PROGRAM ANNUAL REPORT 1990
HIGHLIGHTS

An in-depth analysis of the potential of 18 agricultural crops as alternatives for research at CIAT--which were evaluated on the basis of growth, equity, natural resource conservation and institutional criteria--indicated that cassava can contribute substantially to achieving the overall CIAT goal of sustainable agricultural growth with equity. It has therefore been proposed that cassava remain part of the CIAT commodity portfolio in the 1990s.

The current value of cassava production in Latin America and Asia is US$1.46 and 1.76 billion, respectively. The Net Present Value (NPV) of research benefits from improved technology could amount to US$738 million and 1.978 billion, respectively, in Latin America and Asia, with poor consumers accruing benefits to the value of US$460 and 280 million. In addition, cassava development activities can generate 60,000 and 111,000 man-years of labor, respectively, on these continents.

Research Highlights

A first lot of 87,615 botanical seeds obtained at CIAT HQ by controlled hybridization and open pollination was introduced to the International Institute of Tropical Agriculture (IITA) as part of these two institutions' collaboration on cassava germplasm improvement in Africa. Half of these seeds were sown in three different ecologies of Nigeria, representing humid, subhumid and semiarid areas of Africa. The materials will be evaluated and selected on the basis of yield, growth habit and reaction to biotic constraints, particularly African cassava mosaic disease (ACMD) and cassava bacterial blight (CBB).

CIAT-generated technology reaches farmers and consumers largely through the efforts of national research programs. CIAT has made a major effort to adjust its mode of collaboration to suit individual needs and capabilities. In Asia, for example, these programs are highly diverse. The establishment of CIAT's regional office in Asia in 1983 has allowed a close working relationship to develop with many programs. This in turn has contributed to an evident progression of programs through developmental stages. In more advanced programs such as those of Thailand and Indonesia, this has reached the level of socioeconomic impact through adoption of new varieties. The Philippines, China, Thailand, Malaysia and Indonesia have all released varieties based on CIAT germplasm. Countries with recently established breeding programs, such as those of China and Vietnam, are systematically establishing the foundations for similar future impact.

Over the past four years, the Cassava Program has collaborated with the Colombian Agricultural Institute (ICA) and local institutions in Cauca, Meta and six states ("Departamentos" on the North Coast of Colombia on the development of a methodology for farmers' participation in variety selection. This has directly resulted in the release of two clones, ICA Catumare and ICA Cebucán, in 1990, and the preparation of two more for release in 1991. The implementation of the methodology has led to a clearer definition of farmers' criteria for adoption and institutional strengthening via extensive interaction within the framework of the project. This methodology is now beginning to be used in other Latin American countries.

Root rots constitute a major source of yield loss in cassava, and their incidence appears to be increasing in Latin America. In the "várzea" (holm) of the Amazon, more than 80,000 ha are affected by Phytophthora drechsleri and Fusarium solani. Following nine years of research conducted with the Center for Agricultural Research in the Amazon (CPAA), two resistant clones (Mae Joana and Zolhudinha) were released this year.

For the Pivijay area of Colombia, where Diplodia manihotis is endemic, a technology package has been developed. Cassava growers obtained yield increases of 208% for the resistant clone and 300% for the susceptible clone. The resistant clone yielded more than the susceptible clone with or without the associated improved cultural practices. Very high host plant resistance has been identified to Phytophthora nicotianae var. nicotianae, one of the most important causal agents of cassava root rot in poorly drained plantations. This will make it possible to initiate a genetic program to control this pathogen.

The development of integrated pest management for the cassava mealybug remains a high-priority research area because of the seriousness of this pest in Africa. Further important natural enemies of the mealybug have been identified, including the parasitoids Aenasius vexans and Acerophagus coccois collected in Venezuela. In addition, three varieties resistant to Phenacoccus herreni have been identified.

Cassava whiteflies, apart from feeding on the crop, are known to be vectors that transmit a number of viruses that cause extensive yield reduction in certain cassava-growing regions. This year four clones with good resistance to cassava whiteflies were developed.

The Cassava Green Mite (CGM) is a serious cassava pest in NE Brazil as well as in Africa. Based on taxonomic analysis, electrophoresis, differences in distribution and abundance patterns, the low diversity of parasitoid natural enemies and the relatively high frequency of CGM outbreaks in Brazil compared to northern South America, its area of origin is probably Colombia or Venezuela. The introduction of CGM into Brazil is not recent, but it appears that the Brazilian population of CGM has remained relatively isolated. There is evidence for physiological, morphological and ecological divergence from the parent population, suggesting the presence of a distinct strain or biotype in Brazil.

Differences in survival and fecundity on different acarine prey types have been demonstrated between geographical subpopulations of parasitoid predators of CGM. These findings corroborate earlier work which showed that reproductive incompatibility exists between geographical subpopulations of certain parasitoid species. Both types of evidence suggest strain differences between geographical subpopulations. Electrophoretic methods for distinguishing strains were successfully developed. Selection of effective strains will be essential for successful biological control in Africa and NE Brazil.

The feasibility of deploying the fungal pathogen Neozygites sp. against CGM was investigated. No evidence was found for the pathogenicity of this fungus in phytoseiids. Although high relative humidity (> 65% RH) favors development of the fungus on CGM, it inhibits the formation of the anadhesive conidia, responsible for its dissemination.

New fundamental information on the mechanisms responsible for cassava's tolerance to prolonged water stress was obtained, strengthening the views that cassava has a greater comparative advantage than other food crops in semiarid regions such as sub-Sahelian Africa and NE Brazil. Varietal differences in response to water stress were found. Yield reductions due to stress were minimal in some clones with low hydrocyanic acid (HCN) levels.

Several germplasm accessions and new advanced breeding lines were identified for their high tolerance to acid soils with low phosphorus. Tolerance to low-P soils is mainly related to phosphorus use efficiency in terms of yield and biomass production, not to phosphorus acquisition.

The Program is dedicating increased attention to soil fertility maintenance and erosion control through research at two sites in Colombia (Santander de Quilichao and Pivijay) and through a series of trials set up in several Asian countries in collaboration with national programs. In Colombia, the long-term response of cassava to fertilizer application indicated that reasonable sustainable yields could be obtained on infertile soil with moderate levels of K fertilizer but no N and P applications, provided that organic matter (OM) is high. In sandy soils with low OM, sustainable cassava production requires application of NPK fertilizer.

These results are being corroborated in Asia, where soils are low in organic matter and nutrients. In short-term trials, cassava has shown a marked response to N application but little or no response to either K or P.

Research on both continents has shown that soil erosion in cassava-based cropping systems on hilly lands can be greatly minimized by cultivating cassava in contour ridges, with grass barriers, or by using mulch and live ground cover of forage legumes. Agronomic practices that result in rapid canopy closure, such as fertilizer application in poor soils and closer spacing, also reduce soil loss.

In smallholder agriculture cassava is frequently intercropped with other species, especially maize. On-farm research (OFR) on the Atlantic Coast region of Colombia, carried out in cooperation with ICA, continues to increase our knowledge on the interaction of cassava with maize. Results this year show that cassava responds positively to fertilizer applications designed for and applied to the maize intercrop. Furthermore, nutrient balances reveal that cassava is more efficient than maize in the use of nutrients, especially P and K, per unit of dry matter (DM) produced.

The trials also illustrate the important role that cassava plays in reducing risk and sustaining a minimum level of production for the small-scale farmer. In monocropping, the stability of cassava production over time is much greater than for maize. Finally, under the biotic and abiotic conditions prevailing in the region under study over a four-year period, no yield reduction was observed when planting material was selected from plants that had always been intercropped with maize as compared with planting material taken from monocrop plantations. This suggests that intercropping cassava with maize has no effect on the quality of the planting material produced.

In the area of cassava utilization research, the highlights include the construction and initial operation of the first pilot plant for producing high-quality cassava flour. This plant is operated and managed by a small farmer cooperative in Córdoba, Colombia with funding from the International Development Research Centre, IDRC. A recently completed national market survey for cassava flour has identified a potential of 30,000 t/yr for the meat processing and biscuit industries.

Improvements in the traditional starch extraction and fermentation industry processes in Colombia have been designed, and studies relating sour starch functional properties to physicochemical characteristics, initiated. Initial results showed the "expansion power" on baking, a characteristic of the starch. Improvement of small-scale indigenous starch (unfermented) processing is being Hcarried out by national programs in Ecuador and Paraguay with CIAT's assistance.

Experiments have shown that the chemical treatment of the fresh roots to prevent microbial deterioration can be delayed for 24 h after harvest, provided the roots are immediately packed into polyethylene or polypropylene sacks. This permits centralized treatment and repacking of the roots, which has improved product quality control in the Barranquilla pilot project.

With respect to quality research, improved methodologies for starch and cyanide analysis were instituted during 1990. Results from soil fertility and water stress experiments of the Physiology Section clearly show the importance of the preharvest environment in determining root quality. Adequate levels of K are essential for obtaining roots with good eating quality while excessive application of P may have an adverse effect.

During the second year of the Kellogg Foundation-financed project in the State of Ceará, Brazil, 20 new farmer groups were organized, and there are 35 cassava agroindustries functioning. The total output for this second year is approximately 1200 t of dry cassava chips.

Institution strengthening has been actively maintained through the consolidation of the Ceará State Cassava Committee and the formation of five Regional Cassava Committees in each of the main areas covered by the project. These committees have started to play important roles in implementing the project, especially in areas such as training, selection and organization of new farmer groups, technical assistance for farmers, commercialization, and monitoring and evaluation of the project.

CIAT HQ staff have been providing backup support for the State research and extension agencies in establishing technology validation trials (pre-production plots) and in developing methods for controlling the mycoplasmlike witches' broom disease, which is causing serious yield losses.

After a difficult year in 1989, the cassava development project in Manabí Province, Ecuador has consolidated; and with the reactivation of the shrimp industry, it should have a record year in terms of cassava flour and starch production. The 18 farmers associations have projected a total of 1800 t of cassava products, principally flour (88%) for balanced shrimp feed and starch (12%) for the cardboard box industry. A high DM clone introduced from Colombia has proved to be well adapted to the prevailing edaphoclimatic conditions, and its widespread adoption could result in considerable benefits for cassava producers and processors.

Research Networks and Workshops

Existing regional research networks in Latin America and Asia were consolidated, and the first steps were taken toward the formation of a network for the subtropical region of Latin America. The II Latin American Cassava Breeders Network Meeting was held in Cruz das Almas, Brazil from 21-24 May with representatives from 9 countries. Important decisions were taken regarding future collaborative activities: (1) the systematic study of cassava ecosystems according to varietal performance; (2) the exchange of elite clones among countries; (3) the preparation of a uniform list of characteristics for evaluation in breeding and for communicating results; and (4) the establishment of informal communication mechanisms among members of the network.

The III Asian Cassava Research Workshop was held in Malang, Indonesia from 22 to 27 October. Researchers from 12 Asian countries presented 30 papers on varietal improvement, crop management, processing and utilization of cassava. It was agreed that the scope of the regional network should be extended to include socioeconomic and utilization aspects of cassava, with emphasis being put on technology transfer and improved information exchange.

A two-day meeting (15-16 October) was held in Asunción, Paraguay with representatives from Southern Brazil, Paraguay and Northern Argentina to discuss the convenience of promoting horizontal cooperation among these countries with respect to cassava research and development for subtropical environments. Support for this initiative was unanimous: areas of cooperation were outlined, research priorities delineated, and a plan of action drawn up.

Training

1990 saw a radical change in the type of course offered by the Cassava Program at CIAT HQ. The traditional 5-week intensive multidisciplinary course for new cassava researchers and extension leaders was dropped in favor of a two-week introductory course organized around the production/processing/marketing/utilization cycle of the crop in which the interdisciplinary nature of cassava research and development was stressed. Participants then either pursued a period of disciplinary specialization or participated in a three-week course on integrated cassava development projects. This arrangement appears to meet better the actual needs of Latin American cassava workers.

Members of the Program participated in a very successful course organized by the Seed Unit on cassava stake production and distribution systems held from 27 to 31 August for participants from Panama, Colombia and Ecuador. It is envisaged that the demand for this type of training will increase as further integrated cassava projects get under way.

Program Developments

Rupert Best, formerly Head of the Cassava Utilization Section, was appointed Leader of the Program as of 1 May 1990. He replaced Anthony Bellotti, who accepted the additional responsibility of Acting Leader during the interim period between the departure of James Cock in July 1989 and the appointment of Rupert Best. Christopher Wheatley was subsequently appointed Head of the Utilization Section. Guy Henry, Economist, joined the Program on 1 January 1990; and Susan Poats, Anthropologist, replaced Stephen Romanoff in the cassava development project, Manabí, Ecuador as of 1 April.

1. CASSAVA GERMPLASM RESOURCES DEVELOPMENT

1.1 Introduction

1.1.1 Objectives of cassava germplasm development

Genotype-based technology is one of the principal components of CIAT's strategy aimed at improving cassava's contribution to human welfare in the tropics. Through a range of activities in germplasm resources management and development, the CIAT Cassava Program supports national and international institutions by providing components for improving cassava varieties and for promoting these varieties to farmers. Within this mandate, the central activities are stewardship of the world germplasm collection, building the knowledge base upon which genetic improvement depends, genetic improvement for national program needs, and institutional support and strengthening. These activities necessarily involve a multidisciplinary effort within the Program and with other units in CIAT, and close linkages with collaborating national and international institutions.

Specific objectives of germplasm development are to:

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

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

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

-- Provide training to national program personnel

-- Create mechanisms for networking among national programs

-- Develop a production technology based on true cassava seed

1.1.2 Regional priorities

The Cassava Program has a world mandate. Priorities and modus operandi among regions are determined by a combination of factors including importance of cassava production, characteristics of national programs, available genetic diversity, presence of IITA with regional responsibility in Africa, and funding opportunities.

The Program divides responsibilities for germplasm development into three sections: the HQ program, which responds to regional program needs and has principal responsibility for Latin America; an Asia regional program based in Bangkok; and an Africa regional program based at IITA HQ in Nigeria.

Germplasm collection, conservation and evaluation, as well as gene pool development, are given emphasis in Latin America--center of diversity for cassava, its wild relatives and the pests and diseases affecting the crop. For Asia and Africa, the emphasis is on increasing genetic diversity and on introducing genes for resolving specific problems. A CIAT breeder is posted in each of these last two regions. In the case of Asia, the breeder coordinates activities directly with national programs; and considerable emphasis is given to institutional strengthening and networking activities. In Africa the breeder works within IITA's ongoing cassava improvement efforts to assure the effective two-way flow of information and germplasm between the two centers.

The following sections summarize the main activities and results of cassava breeding in the three regions.

1.2 HQ Research/Latin America

1.2.1 Germplasm management

1.2.1.1 **Management objectives and strategies.** Germplasm management includes the activities of collection, conservation, characterization and documentation of cassava and wild Manihot species. CIAT has assumed world responsibility for conservation of cultivated cassava, but no formal arrangements have yet been made at the international level to coordinate the management of the wild species. Nevertheless, CIAT intends to begin a major effort in wild species conservation, evaluation and utilization as part of a long-term strategy for exploiting these potentially valuable genetic resources. The main responsibility for managing the wild species will reside with the Genetic Resources Unit (GRU), working closely with the Cassava Program, especially with respect to evaluation and utilization.

CIAT works toward management strategies that are cost-effective yet provide high assurance of long-term germplasm conservation at low levels of risk of loss, contamination by pests or pathogens, or genetic modification. These strategies at present include the conservation of the collection both in vitro and in the field. The latter is a working collection for providing planting material for experimental purposes and for direct evaluations. The in vitro collection, while not technically a base collection, serves as a more secure means of conservation and as a form for international germplasm exchange.

1.2.1.2 **In vitro management of cassava (Manihot spp.) germplasm.** In February a new tissue culture laboratory was established in the Germplasm Resources Unit (GRU). Subsequently, the responsibility of in vitro cassava germplasm management was transferred from the Biotechnology Research Unit (BRU) to the GRU. This responsibility includes three aspects of in vitro germplasm management:

- Germplasm conservation
- Germplasm exchange
- Production of disease-free clones in collaboration with the Virology Research Unit (VRU)

-- Germplasm conservation. As a valuable complementary method to back up cassava germplasm conservation in the field, in vitro conservation provides a means for maintaining large collections in small spaces, free of pests and diseases, and without risk of loss to climatic changes or soil problems. Cassava pathogen-tested clones are maintained in vitro to allow the propagation of new disease-free plants at any time.

Cassava clones in the in vitro active genebank are maintained under the following slow growth conditions:

- 23-24 °C, constant throughout day (12 h) and night (12 h)
- 1000-1500 lx illumination
- In a slightly modified culture medium
- Test tubes (20 x 150 mm) capped with aluminum foil
- Five test tubes per clone

Materials need to be subcultured every 12 to 18 months, depending on the genotype. The number of in vitro-maintained clones this year was 4354 from 23 countries (Table 1.1); thus, 94% of clones of the field genebank is already conserved.

-- Germplasm exchange. Up to 1980 the principal form of germplasm transfer was via lignified stem pieces (stakes). With the development of in vitro techniques, shipment of vegetative material has been almost exclusively by this method. Recently there has been renewed interest in introducing vegetative material--either elite hybrids or basic germplasm. As many programs have developed a capability for producing their own hybrids, they are looking for specific traits from CIAT to incorporate into their breeding populations. In 1988

CIAT began to make available, for distribution within Latin America, a few elite clones as stakes derived from virus-indexed mother plants. This method provides nearly the same level of phytosanitary security as meristems, but with greater ease of management.

Table 1.1 Number of cassava clones by source country maintained in CIAT's field active genebank and in vitro active genebank as of October 1990.

Source	CIAT Code	Field	In Vitro
Argentina	M Arg	16	16
Bolivia	M Bol	3	3
Brazil	M Bra	833	834
Colombia	M Col	1898	1892
China	M Chn	2	1
Costa Rica	M Cr	147	148
Cuba	M Cub	74	74
Dominican Republic	M Dom	5	5
Ecuador	M Ecu	117	109
Fiji	M Fji	6	0
Guatemala	M Gua	90	88
Indonesia	M Ind	51	51
Malaysia	M Mal	67	67
Mexico	M Mex	101	80
Nigeria	M Nga	19	19
Panama	M Pan	42	31
Paraguay	M Par	194	171
Peru	M Per	406	340
Philippines	M Phi	6	6
Puerto Rico	M Ptr	15	7
Thailand	M Tai	8	21
USA	M USA	9	10
Venezuela	M Ven	241	103
CIAT hybrids	---	327	278
TOTAL	23 countries	4677	4354

A total of 270 elite cassava clones were shipped in vitro to 15 countries (Table 1.2), and 13 clones were introduced from Thailand. In several instances the same hybrid or variety was sent to more than one country. The materials were accompanied by a Colombian

Phytosanitary Certificate and a CIAT Phytosanitary Statement, which describes the procedures, treatments and pathogen testing carried out on the material in preparation for shipment, together with a list of clones being sent and a recommended handling procedure.

Table 1.2 CIAT's international exchange of cassava clones, involving in vitro techniques, by country and institution, 1990.

		Clones (No.)[1]	
Country	Institution	Distributed from CIAT	Introduced to CIAT
Austria	IAEA-Laboratories	7	-
Bolivia	IBTA	1	-
Brazil	CENARGEN (EMPASC)	140	-
Costa Rica	Univ. of Costa Rica	11	-
Ecuador	INIAP	2	-
Fiji	Plant health of SPC/UNDP	10	-
France	ORSTOM	2	-
Guatemala	Mayacrops S.A.	13	-
England	University of Bath	5	-
	Cell biology, Unilever Research	5	-
	The John Innes Institute	1	-
Japan	Japan Association of the Intern. Garden & Greenery Exposition	8	-
Philippines	Philippines Root Crop Research & Training Center (PRCRTC)	18	-
Peru	INIIA	19	-
Thailand	Field Crops, Research Institute	3	13
Tonga	Taufa'a hau-Road Nuku'a lofa	15	-
USA	Washington State University	2	-
	USDA Plant Germplasm Quarantine Center	1	-
	University of Georgia/USAID	7	-
TOTAL	20	270	13

1 Five to ten test tubes per clone were shipped; often the same clone was distributed to several countries.

Under the agreement of the IFAD-supported CIAT-EMPASC collaborative project, shipments to EMPASC (Santa

Catarina, Brazil) were begun of 434 clones that originate from subtropical environments as pathogen-tested, in vitro clones.

In vitro techniques, associated with extensive pathogen testing, have been used for distributing and introducing cassava germplasm in the last ten years. During this period, 2292 clones were distributed to 46 countries and 2010 clones were introduced to CIAT from 15 countries (Table 1.3). Those figures demonstrate the scale and efficiency of the world in vitro germplasm exchange system, which has been developed in collaboration with national and international agencies.

Table 1.3 Number of cassava clones distributed from or introduced to CIAT, using in vitro techniques, 1980-90.

Region	Distributed from CIAT		Introduced to CIAT	
	Countries (No.)	Clones[1] (No.)	Countries (No.)	Clones[1] (No.)
America				
North	1	20	1	10
South	8	967	4	1,540
Central	15	787	3	267
Caribbean	2	27	-	-
Asia	8	324	5	168
Africa	1	51	1	19
Europe	3	14	-	-
Oceania	4	84	1	6
Other (Far East)	4	18	-	-
TOTAL	46	2,292	15	2,010

[1] Usually 5 to 10 test tubes per clone were shipped; often the same clones were distributed to several countries.

Table 1.4 summarizes seed shipments by region over the last five years (1986-90). In the late 1970s, CIAT began to give relatively more emphasis to sending segregating populations rather than finished varieties as national programs developed increasing capabilities for managing the full range of breeding activities.

-- Disease elimination. Whenever possible only cassava plants that show no evidence of viral diseases are selected for the in vitro collection. To ensure disease-free in vitro plantlets, a disease elimination technique was developed in the BRU for cleaning pathogens from clones. Small (0.2-0.3 mm) meristem tips are cultured from apical buds of newly sprouted shoots at 40°C day and 35°C night temp for 3 to 4 weeks. In cases where no stakes are available--i.e., the germplasm was introduced to CIAT as in vitro plantlets--then in vitro thermotherapy is applied. Rates of virus elimination depend, to a large extent, on the size of the explant used for culture and on whether thermotherapy was applied or not, as well as on the virus strain.

Table 1.4 Summary of cassava seed shipments, 1986-90.

Region	No. of Shipments	No. of Crosses	No. of Seeds	No. of Clones
Africa	11	722	108372	
Asia	37	1978	125586	189
Middle East	1			6
Caribbean	8	325	20259	136
Meso-America	15	709	39045	146
South America	11	656	35665	863
North America	7	39	5700	20
Europe	13	70	37450	34
TOTAL:	102	4499	372077	

The disease-free status of the plants is validated through indexing. Viruses and viruslike diseases of major concern for elimination at CIAT are cassava common mosaic virus (CCMV), cassava Colombian symptomless virus (CCSPV), cassava X virus (CsXV), Caribbean mosaic disease (CMD), frog-skin disease (FSD) and some latent agents. Thermotherapy before or during meristem tip culture has been applied at CIAT to some 4300 cassava clones in the last ten years.

The development of sensitive virus diagnostic techniques by the VRU has facilitated producing pathogen-tested cassava clones. Tests to detect viruses are carried out on in vitro plantlets and on plants that have been moved to the greenhouse. A total of 1377 clones have been cleaned and indexed by using diagnostic techniques (ELISA) for at least CCMV and CsXV; and 140 clones have been indexed for the frogskin disease by grafting onto an indicator clone.

The disease elimination technique continued to provide healthy material for:

- Distribution of elite clones to national programs
- Recovery of pest-infested, diseased or damaged clones from the field collection
- Provision of clean seed stocks for regional variety trials and eventual cleanup of the whole collection

1.2.1.4 **Wild Manihot species.** The wild relatives of M. esculenta are receiving increasing attention for their potential as sources of useful traits for improving cassava. Genes for characters such as apomixis (form of asexual reproduction by seed), virus resistance and low HCN are thought to be present in wild Manihot germplasm. Table 1.5 shows the present status of wild Manihot germplasm conserved in the in vitro genebank. In vitro micropropagation techniques of cultivated cassava are not readily extrapolated to wild species. The BRU developed in vitro culture techniques for wild Manihot spp., whereby embryos from seeds are extracted and cultured in sterile media. A student thesis was initiated to study further improvement of the in vitro management of wild germplasm.

1.2.1.5 **Isozyme characterization.** In 1988 the GRU began characterizing the entire cassava collection for banding patterns resulting from electrophoresis on polyacrylimide gels of **alpha-beta** esterase extracts of root tip tissue. This system was the one that demonstrated the highest degree of polymorphism (22 bands tentatively defined). The objectives of this analysis are to:

Table 1.5 Wild *Manihot* species maintained in vitro at CIAT.

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

-- Characterize the cassava germplasm with environmentally stable descriptors

-- Apply these descriptors to the identification of duplicates in the collection, thereby streamlining both field and in vitro conservation

-- Utilize these co-dominant markers in better elucidating the genetics of cassava

-- Apply results to study of genetic diversity in cassava

In the last two years, 3238 cassava clones from 20 countries, as well as hybrid materials from ICA-Colombia and CIAT, have been fingerprinted. This represents about 75% of the entire collection assembled at CIAT (Table 1.6). Every

Table 1.6 Status of cassava germplasm collection at end of 1990.

Country of Origin	No. Clones Analyzed for $\alpha\beta$-Esterase
Argentina	0
Bolivia	0
Brazil	785
China	1
Colombia	912
Costa Rica	137
Cuba	74
Dominican Republic	5
Ecuador	114
Fiji	6
Guatemala	85
Indonesia	51
Malaysia	66
Mexico	81
Nigeria	16
Panama	40
Paraguay	130
Peru	240
Philippines	6
Puerto Rico	15
Thailand	8
United States	8
Venezuela	236
CIAT Hybrids	223
TOTAL	3239

electrophoretic isozyme pattern is analyzed quantitatively by means of a laser densitometer and qualitatively by codifying the presence/absence of each of the 22 bands. Thus far, 1719 different electrophoretic patterns have been identified, with about two-thirds (1167) being represented by a single clone in the collection. The highest number of identical patterns was 39 (Table 1.7).

Table 1.7 Description of banding patterns resulting from electrophoretic analysis of **alpha-beta** esterase in 3288 germplasm accessions.

No. of Distinct Esterase Patterns	No. of Clones for Each Pattern	Total No. Clones
1167	1	1167
291	2	582
96	3	288
55	4	220
29	5	145
19	6	114
13	7	91
8	8	64
9	9	81
8	10	80
2	11	22
5	12	60
2	13	26
3	14	42
2	15	30
2	17	34
1	19	19
1	20	20
2	23	46
1	24	24
1	26	26
1	29	29
2	39	78
1719		3288

Preliminary studies were carried out on the genetics of esterase isozymes. Understanding the inheritance is essential for interpreting genetic variability in cassava properly; aiding in the definition of gene pools; determining relationships between cultivated and wild relatives; and constructing linkage maps. Ideally, the study of isozyme inheritance in cassava would involve selecting polymorphic parental material and characterizing F_1, F_2, reciprocal and backcross populations. Because of the difficulty of obtaining seed in cassava, it is often not possible to meet the normal requirements for complete genetic studies. Nevertheless, some useful preliminary information was obtained.

Four crosses were analyzed using both a hypothetical diploid and a tetraploid model. The esterase 1 locus (EST-1) comprises 4 active alleles (A_1, A_2, A_3 and A_4), thus presenting a possible total of 11 phenotypes and 15 genotypes for the locus. EST-1 presents a maximum of four bands (alleles) for the locus and two for each individual. EST-1 was defined as monomeric, with a disomic inheritance.

1.2.1.6 **Methodology for duplicate identification.** Germplasm conservation for vegetatively propagated species is generally costly compared to seed conservation. Thus it is critical to continue seeking ways of making the process more efficient. One obvious contribution would be to eliminate duplicate accessions in the collection. While there have been no studies to date to quantify potential levels of duplication, simple observation indicates this to be on the order of 20%. Most of the collection has been classified for the basic morphological descriptors defined by the International Board for Plant Genetic Resources (IBPGR). However, these alone do not provide a high enough level of confidence to make a definitive identification of duplicates. The additional biochemical descriptor, **alpha-beta** esterase, whose analysis has nearly been completed for the germplasm collection, provides an additional powerful tool to raise the level of confidence in clonal characterization.

During 1990, alternative procedures were studied for identifying duplicates. To develop a model that could be applied to the entire collection, a group of 175 clones from the North Coast of Colombia, in which a high degree of duplication was suspected, were studied. Grouping of clones was based individually on morphological and/or biochemical traits (**alpha-beta** esterase banding). The final criteria to select the best procedure included empirical analysis of which descriptors should be given greater/lesser weight, depending upon the degree of environmental influence on their expression.

The procedure that appeared to work most satisfactorily consisted of two stages: The first stage involved the grouping of clones on the basis of eight descriptors showing very little influence of the environment; i.e., those for which level of confidence was highest (Table 1.8). In the second stage, cluster analysis was applied to another group of descriptors (9 morphological, 10 biochemical) that were of a somewhat lesser degree of confidence, but that nevertheless helped separate different clones formed by the first level of grouping.

Table 1.8 Descriptors used for primary and secondary levels of classification to identify duplicates in the cassava germplasm collection.

Primary Classification/ Descriptor States	Secondary Classification
Color of stem collenchyma Light green, dark green	Height to first branching cm
Color of stem epidermis Cream, light brown, dark brown	Color of apical leaves Green to purple (1-9)
Electrophoretic bands for $\alpha\beta$-esterase Presence or absence (Bands 9, 10, 19, 20, 21, 22)	Leaf vein color Green to purple (1-9)
	Leaf lobe form 8 shapes
	Leaf lobe width cm
	Leaf petiole color Green to purple (1-9)
	Root surface color White, light brown, dark brown
	Root cortex color White to purple (1-5)
	Root flesh color White or cream, light yellow, deep yellow
	Electrophoretic bands for $\alpha\beta$-esterase (Bands 2, 3, 4, 6, 8, 12, 13, 15, 18) Presence or absence

The model will now be applied to the entire collection. After defining potential duplicates via statistical analysis, these groups will be planted together in the field for a further comparison of morphological traits. If no differences are observed in these two stages of comparison, they will be assumed to be genetically identical (i.e., duplicates). These duplicates will be eliminated from the field collection but will be maintained in the in vitro collection until a further level of testing can be applied to confirm genetic identity, such as other isozyme systems or restriction fragment length polymorphisms (RFLPs).

1.2.2 Gene pool development

1.2.2.1 **General objectives and strategy.** Definition of gene pools on the basis of adaptation to climate and soil conditions, and biological constraints, has been a core concept of cassava varietal improvement at CIAT over the past decade (see past annual reports). During 1990, two basic modifications were made to the gene pool descriptions. First, based on the recognition of the growing importance of semiarid regions for expanding cassava production--especially in Africa and NE Brazil--this edaphoclimatic zone (ECZ) was added as a new objective for gene pool development.

Secondly, the growing concern about effects of HCN on human health--especially in Africa but also in other regions--motivated the subdivision of each gene pool into a low HCN pool and one for which HCN was not considered. As high HCN is preferred for certain industrial processes, the generalized selection for low HCN cannot be justified. Two exceptions are the mid-altitude areas (ECZ IV) and the highlands (ECZ V), corresponding to the Andean zone and the mid- and high-altitude areas of Africa, where only low HCN clones are required. A summary of the new classification is presented in Table 1.9.

To date, the strategy with regard to root surface color has been to maintain variability within gene pools, so that national programs can select according to their own preferences. This strategy may result in some instances of a high proportion of unsuitable root color and therefore a narrower than desirable genetic diversity available for selecting. Nevertheless, it is not felt that separating gene pools by root color is justified. As Program emphasis shifts toward providing parental genotypes rather than germplasm for direct variety selection and with increased emphasis on Africa, a reassessment of the strategy for selecting for root surface color may be necessary. The proportion of white-rooted materials appears to be highest in the gene pool for ECZ I, due in large part to the extensive use of white-rooted materials as parents in the past decade. For

Table 1.9 Revised description of gene pools for defining cassava germplasm development.[1]

No.	Description	Representative Countries/Regions
1	Subhumid tropics	Mexico (Yucatan Peninsula); NE Brazil; NE Thailand; Dominican Rep.; N. Venezuela
1LC	Subhumid tropics; low HCN	Colombia (N. Coast & Santanderes); Panama (Cocle); subhumid belt of Africa (N Nigeria, Benin, Tanzania), Ecuador (NW Coast)
2	Acid-soil savannas	Mexico (Tabasco); Llanos of Colombia & Venezuela; Brazil (Cerrado)
2LC	Acid-soil savannas; low HCN	Cuba; W. Africa savannas; Philippines; Panama (Ocú)
3	Humid tropical lowlands	Amazon Basin (Brazil, Colombia, Peru); West Java & Sumatra; Malaysia; S. Vietnam
3LC	Humid tropical lowlands; low HCN	Equatorial West Africa
4LC	Mid-altitude tropics; low HCN	Andean zone; central Brazilian highlands; mid-altitude areas of Nigeria, Cameroon, E. Africa
5LC	High altitude tropics; low HCN	Andean zone; Rwanda; Burundi
6	Subtropics	S. Brazil; N. Argentina; China; N. Vietnam
6LC	Subtropics; low HCN	Cuba; Paraguay; S. Africa
7	Semiarid	NE Brazil
7LC	Semiarid; low HCN	NE Colombia; (Guajira) semiarid belt of West Africa; Tanzania; Mozambique; Rwanda, Burundi

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

For the immediate future the following gene pools or gene pool combinations are contemplated, with possible disaggregation in the future: 1LC and 4LC; 1; 2 and 3; 2LC and 3LC; 5LC; 6; 6LC; 7; 7LC.

example, M Col 22, M Col 1684 and M Bra 12 participated as parents in 27.9, 21.0 and 7.7%, resp., of elite clones.

1.2.2.2 **Studies on efficiency of selection.** Each harvest season a breeder faces the challenge of selecting genotypes within each gene pool that will be kept for next season and that can be used as new parents. Those rejected (the large majority) are generally lost permanently. Selection usually takes into account information about the performance of a particular genotype in previous years, other locations and early stages of development (especially with respect to disease and pest reactions). For optimal genetic progress, selection criteria need to be based on solid, well-analyzed data.

Data from yield trials involving different sets of genotypes at four environments (2 locations, 2 seasons) were used to estimate the expected response to selection (% improvement over the experimental mean when selecting the top 30%). Four characters were considered: root yield (RY) (t/ha), harvest index (HI), dry matter (% DM), and DM yield (t/ha). Direct and indirect response to selection was estimated considering selection for each individual trait; simple index selection [($I = H_1P_1 + H_2P_2 + \ldots + H_nP_n$), where H_n = broad sense heritability of trait n, and P_n = the phenotypic value of trait n]; and rank summation index.

For this particular set of data (Table 1.10), using DM yield as the main selection criterion seems to be the most effective in terms of improving crop productivity. In two cases, using DM yield gave no expected improvement in % DM, but in those cases % DM is already high (> 32%). Using simple selection indices does not seem to improve the efficiency of selection.

Considerable emphasis has been given in the past to HI as one of the principal selection criteria because of its high positive correlation with yield and its high heritability. At the levels observed in this experiment, however, other traits--possibly including duration of leaf area index (LAI), photosynthetic efficiency, and the capacity of a clone to take full advantage of the whole growing cycle--seem to contribute more to final yield.

Even though the above yield components constitute high priority for selection, many other traits need to be considered as well, including HCN content and cooking quality, which seem to have little or no relation to yield.

1.2.2.3 **Heritability estimates.** Since the beginning of the 80s, cassava breeding at CIAT has been oriented toward specific ECZ adaptation. In order to compare estimated and realized genetic progress in cassava breeding during this

Table 1.10 Efficiency of selection in cassava using individual trait selection, simple selection index, and rank summation index.

Trial:	GY8918 - ECZ I-Season A				GY8958 - ECZ I-Season B				GY8925 - ECZ II-Season A				GY8962 - ECZ II-Season B			
Response in:	RY	HI	% DM	DMY	RY	HI	% DM	DMY	RY	HI	% DM	DMY	RY	HI	% DM	DMY
Selection for Individual Traits																
RY	0.22	0.07	0.02	0.26	0.13	0.12	-0.01	0.14	0.12	0.15	0.00	0.11	0.22	0.12	-0.03	0.22
HI	0.11	0.13	0.00	0.12	0.10	0.13	-0.01	0.11	0.25	0.10	-0.02	0.21	0.17	0.14	-0.02	0.17
% DM	0.07	0.00	0.06	0.14	-0.02	-0.01	0.05	0.01	-0.09	-0.04	0.06	-0.02	-0.02	-0.04	0.07	0.04
DMY	0.20	0.07	0.04	0.27	0.12	0.12	0.00	0.14	0.23	0.10	0.00	0.22	0.20	0.08	0.02	0.25
Simple Selection Index																
RY + HI	0.21	0.11	0.01	0.24	0.12	0.13	-0.01	0.13	0.24	0.11	-0.02	0.20	0.21	0.13	-0.03	0.21
RY + % DM	0.21	0.07	0.03	0.26	0.12	0.11	0.00	0.14	0.24	0.01	0.00	0.21	0.20	0.08	0.02	0.25
HI + % DM	0.13	0.11	0.02	0.16	0.08	0.12	0.01	0.11	0.10	0.14	0.02	0.10	0.16	0.14	-0.01	0.18
Rank Summation Index																
RY + HI	0.21	0.11	0.01	0.24	0.12	0.13	-0.01	0.13	0.23	0.12	-0.02	0.19	0.21	0.13	-0.03	0.21
RY + % DM	0.19	0.06	0.04	0.26	0.06	0.05	0.03	0.09	0.15	0.05	0.03	0.17	0.11	0.02	0.04	0.17
HI + % DM	0.12	0.09	0.04	0.17	0.04	0.08	0.04	0.07	0.04	0.10	0.04	0.08	0.07	0.08	0.03	0.12
Mean for the Trait	17.0	0.55	28.6	4.90	23.7	0.50	36.0	8.53	23.7	0.57	32.0	7.56	19.1	0.50	30.8	5.80
Heritability	0.64	0.76	0.69	0.72	0.46	0.82	0.84	0.54	0.83	0.79	0.65	0.76	0.56	0.74	0.75	0.65

period, as well as to assess present and future breeding strategies, a systematic evaluation of genetic variability was undertaken. Broad sense heritability estimates (H) were obtained by regression analysis using information from the performance of sets of clones in consecutive years from 1981 to 1989. Estimates were obtained for the two main selection sites (Media Luna - ECZ I and Carimagua or La Libertad - ECZ II); two growing seasons (A and B); and two stages of selection (CO, single-row, nonreplicated observation trials; and EPR, multiple-row, nonreplicated yield trials) (Table 1.11).

Pooled estimates showed high H values (0.40-0.60) for HI, % root DM, HCN content, and reaction to superelongation disease (SED); intermediate values (0.20-0.40) for RY, and visual evaluation of foliage; and low values (<0.20) for visual evaluation of roots and reaction to CBB.

Estimates based on EPR tended to be higher for those traits with low and intermediate pooled-H estimates as compared to those from CO. Higher values were obtained for ECZ I and season B, for RY and % DM. A negative association between overall performance for a trait and H estimate was observed.

1.2.2.4 **Progress in gene pool development**

-- ECZ I (Lowland tropics with low to intermediate rainfall and long dry season). Media Luna (Magdalena) and ICA-El Carmen (Bolivar) are the principal and secondary selection sites, resp., for this zone. They are characterized by poor soils (especially low P), and severe water deficits during the latter part of the growing season. In 1990 there was a low incidence of the most relevant pests for the region (thrips and mites) in both seasons. Selection was based primarily on productivity, plant type and quality.

   During **Season A,** the pre-released clones (CG 1141-1 and CM 3306-4), together with clone CM 4777-2 had excellent % DM (Table 1.12). There were many clones with higher productivity (DM yield) than the checks and the pre-released clones; however, few of those had cooking quality as good as the local checks. These are of potential interest for industry. Four introductions from Brazil have demonstrated good adaptation and productivity under Media Luna conditions; and they will broaden the genetic base available for ECZ I.

Table 1.11 Pooled heritability estimates for different locations, seasons and selection stages.[1]

		Root Yield		Harvest Index		% Dry Matter		HCN	
ECZ	Season	CO/EPR	EPR/ER	CO/EPR	EPR/ER	CO/EPR	EPR/ER	CO/EPR	EPR/ER
I	A	0.29	0.26	0.59	0.52	0.68	0.47	0.61	0.44
I	B	0.29	0.48	0.71	0.68	0.67	0.31	0.48	0.52
II	A	0.08	0.51	0.35	0.44	0.08	0.51	0.18	0.63
II	B	0.59	0.37	0.63	0.57	0.59	0.37	0.62	0.60
Overall		0.28		0.56		0.46		0.50	

Table 1.11 cont.

		Foliage Eval.		Root Eval.		CBB		SED	
ECZ	Season	CO/EPR	EPR/ER	CO/EPR	EPR/ER	CO/EPR	EPR/ER	CO/EPR	EPR/ER
I	A	0.22	0.30	0.13	0.08	—	—	—	—
I	B	0.24	0.55	0.10	0.31	—	—	—	—
II	A	0.17	0.28	0.36	0.26	0.00	0.33	0.57	0.30
II	B	0.15	0.19	0.00	0.14	0.15	0.17	0.35	0.48
Overall		0.26		0.17		0.15		0.42	

[1] CO = single-row, nonreplicated observation trials; EPR = multiple-row, nonreplicated yield trials; ER = advanced yield trials.

Table 1.12 Means for selected entries for the yield trial (GY8925) at Media Luna (ECZ I), Season A.

HCN Clone	Female Parent	Male Parent	RY (t/ha)	HI	% DM	DM Yield (t/ha)	(1-9)
M Bra 191			21.5	0.46	33.4	7.2	4.5
M Bra 383			27.1	0.62	31.7	8.6	7.5
M Bra 390			21.8	0.53	35.8	7.8	9.0
M Bra 589			26.3	0.51	33.3	8.8	8.5
CG 915-1	M Bra 12	M Col 1643	25.8	0.58	32.2	8.3	7.0
CG 1141-1	M Mex 1	M Col 65	21.6	0.56	36.9	8.0	7.0
CG 1320-10	M Mex 1	M Pan 51	21.4	0.57	32.5	7.0	6.0
CG 1355-2	CM 922-2	M Mal 3	34.5	0.61	32.8	11.3	7.5
CG 1372-5	M Bra 12	M Mal 3	25.5	0.60	31.6	8.0	7.0
CM 3299-4	CM 849-1	M Col 22	17.9	0.55	33.0	5.9	5.0
CM 3306-4	M Col 22	CM 523-7	17.9	0.55	37.1	6.6	6.0
CM 3306-9	M Col 22	CM 523-7	27.0	0.67	35.7	9.6	6.0
CM 3372-4	CM 517-1	CM 840-31	24.0	0.58	30.9	7.4	7.0
CM 3555-6	CM 841-106	M Col 22	22.4	0.52	31.4	7.0	6.0
CM 3992-9	CM 681-2	M Col 1468	25.5	0.63	33.9	8.6	6.5
CM 4365-1	CM 976-15	M Col 2207	24.4	0.58	35.4	8.6	5.5
CM 4542-4	CM 681-2	M Col 1916	25.8	0.60	31.6	8.1	7.0
CM 4733-2	M Bra 12	M Col 72	25.2	0.57	33.5	8.4	7.5
CM 4772-4	M Col 22	M Mal 3	23.3	0.52	32.7	7.6	5.5
CM 4777-2	M Col 72	CM 523-7	24.1	0.63	38.5	9.3	6.5
CM 4793-1	M Col 72	M Ven 77	26.6	0.54	35.1	9.3	5.5
CM 4843-1	M Col 1468	M Ven 25	26.6	0.60	32.9	8.7	9.0
CM 4919-1	M Col 2207	SM 303-3	29.2	0.75	31.5	9.2	9.0
CM 5461-5	M Col 72	M Pan 12B	21.1	0.52	33.1	7.0	7.0
CM 5577-1	CG 22-7	M Cub 74	25.0	0.57	31.8	7.9	8.5
CM 5586-1	CM 681-2	M Col 2215	20.1	0.57	34.8	7.0	6.5
CM 5644-2	CM 976-15	M Col 2215	21.1	0.69	35.0	7.4	8.0
CM 5830-4	M Mal 2	CG 1-37	25.6	0.50	32.9	8.4	8.5
Avg			24.2	0.58	33.6	8.1	6.9
LSD (0.05)			5.66	0.06	3.73	2.0	
M Col 1505 (ICA P-13)			17.8	0.50	33.1	5.9	7.0
M Col 2215 (Venezolana)			13.4	0.61	36.4	4.9	6.0

During **Season B**, selected entries presented similar percentages of superiority with respect to the checks as in Season A (Table 1.13). Changes in weed control resulted in better cooking quality than previous seasons. Weeds were controlled early in the season with a machete and left as mulch in the plots. No weed control was performed during the last part of the crop cycle. It is suspected that high soil temperatures negatively affect root quality. No clear relationship between % DM and cooking quality was found. Clones such as CG 959-1 and CM 4042-4, with less than 30% DM, were among the best for quality.

Given the difficulty of testing a large number of entries, the cooking of samples is left for the final stages of selection (yield trials) when only preselected materials are tested. There is usually a low frequency of good-quality clones; for that reason clones that do not seem exceptional for other traits may be selected when showing excellent cooking quality. Many medium-productivity, high-quality clones may be lost at intermediate stages of selection, highlighting the importance of improved rapid methods for evaluating root quality.

-- **ECZ II** (Lowland tropics with acid-soil savannas and high rainfall). Previous years showed a steady increment in the incidence of CBB and SED at ICA-La Libertad near Villavicencio, Meta--the main selection site for ECZ II. It seemed that disease pressure conditions similar to Carimagua could be developed. This year, however, the level of disease incidence was low, especially for SED.

It will probably be necessary to enhance disease pressure, possibly through artificial inoculation, in order to have adequate selection pressure. Otherwise "elite" clones that were never checked under heavy disease pressure will be accumulated, or conversely, clones of average productivity that could be valuable for their high disease resistance might be eliminated.

During the last two months of growing **Season A**, there was a severe mealybug attack, leaving little foliar area. Subsequent heavy regrowth prior to harvest resulted in low % DM. ICA-Catumare showed medium RY and high % DM, while ICA-Cebucán had low % DM. All tested entries had glassy roots when cooked, as a consequence of the regrowth (Table 1.14). Two introductions from subtropical Argentina (ECZ VI) performed well in the Llanos Orientales. This provides some support for the utilization of ECZ II materials in crossing blocks aimed at ECZ VI.

Table 1.13 Means for selected entries for the yield trial (GY8962) at Media Luna (ECZ I), Season B.

Clone	Female Parent	Male Parent	Yield (t/ha)	HI	% DM	DM Yield (t/ha)	HCN (1-9)
M Bra 99			21.9	0.52	32.1	7.0	7.5
CG 959-1	M Col 948C	M Col 1643	29.7	0.64	29.2	8.6	4.0
CG 1457-2	M Col 1740	CM 507-37	20.0	0.58	29.7	5.9	8.5
CM 1442-204	M Col 1684	M Bra 12	25.2	0.62	30.4	7.7	7.5
CM 1785-6	CM 507-13	CM 326-407	27.3	0.68	29.2	8.0	5.5
CM 2976-1	CM 1252-12	CM 840-31	26.0	0.62	26.3	6.8	7.5
CM 3997-1	CM 681-2	CM 849-1	18.4	0.48	32.1	5.9	5.5
CM 4013-1	CM 922-2	CM 728-2	28.1	0.64	32.7	9.2	7.0
CM 4042-4	CM 1015-13	CM 180-5	24.8	0.65	29.6	7.3	6.5
CM 4063-6	CM 1015-42	CM 849-1	33.0	0.68	30.4	10.0	7.5
SG 536-1	M Col 948C		17.7	0.48	33.3	5.9	4.0
SG 555-10	M Col 1807		11.7	0.31	37.2	4.3	3.0
SG 756-7	M Col 71		17.6	0.60	32.2	5.7	6.5
SG 761-4	M Col 976		21.1	0.50	30.0	6.3	7.0
SG 787-10	CM 681-2		25.1	0.46	32.9	8.2	8.0
SM 328-1	M Ven 45A		21.6	0.53	33.8	7.3	7.5
Avg			23.1	0.56	31.3	7.1	6.4
LSD (0.05)			7.12	0.07	2.11	2.0	
M Col 1505 (ICA P-13)			13.4	0.42	31.3	4.2	6.0
M Col 2215 (Venezolana)			14.7	0.53	32.9	4.8	5.0

Table 1.14 Means for selected entries for the yield trial (GY8918) at La Libertad (ECZ II), Season A.

Clone	Female Parent	Male Parent	Yield (t/ha)	HI	% DM	DM Yield (t/ha)	HCN (1-9
M Arg 7			29.7	0.71	27.1	8.0	6.5
M Arg 13			23.0	0.64	31.6	7.2	6.0
CG 165-7	M Col 1495	M Pan 90	20.6	0.57	29.4	6.1	9.0
CG 1139-2	M Bra 5	M Ecu 82	22.0	0.71	28.9	6.4	6.0
CG 1450-4	M Col 1505	M Col 1940	19.3	0.64	31.6	6.1	6.0
CM 523-7	M Col 655A	M Col 1515	18.3	0.52	33.6	6.1	7.0
CM 2166-6	CM 430-37	M Ven 218	23.3	0.66	29.8	6.9	3.5
CM 2177-2	CM 430-37	CM 840-138	21.8	0.64	26.3	5.7	4.5
CM 2600-2	CM 523-7	M Ven 77	17.1	0.44	29.6	5.1	6.0
CM 2766-5	CM 723-3	CM 523-7	18.6	0.56	27.1	5.0	3.0
CM 2772-3	CM 727-14	M Pan 12B	12.5	0.51	25.2	3.1	5.5
CM 2952-3	CM 1145-1	M Pan 12B	16.5	0.50	27.1	4.5	5.5
CM 3311-3	M Col 1468	CM 523-7	26.0	0.57	31.4	8.1	8.0
CM 3380-7	CM 586-1	CM 523-7	20.6	0.55	30.5	6.2	7.5
CM 4402-4	CM 1335-4	M Ven 77	23.2	0.56	30.3	7.0	5.0
CM 4574-7	CM 976-15	SM 301-3	21.0	0.41	33.0	6.9	8.5
CM 4729-4	M Bra 5	M Cub 31	11.1	0.52	32.3	3.6	6.0
CM 4793-1	M Col 72	M Ven 77	13.2	0.58	31.0	4.0	5.5
CM 5286-3	CM 1335-4	CM 1223-1	20.5	0.60	29.8	6.1	6.5
SG 104-264	VAR 2		20.7	0.56	29.9	6.1	9.0
SG 804-5	CM 523-7		17.6	0.52	31.5	5.5	9.0
Avg			19.8	0.57	29.9	5.9	6.4
LSD (0.05)			6.89	0.06	3.16	2.2	
Chiroza Morada			7.4	0.35	24.3	1.8	5.5
Chiroza Blanca			18.1	0.50	29.5	5.3	4.0
M Ven 77			18.7	0.56	28.3	5.3	6.0

Contrary to Season A, Season B was almost ideal, with excellent % DM and productivity (Table 1.15). Most of the tested entries had good to excellent cooking quality. Clone CM 4793-1 was simultaneously selected at ECZ I and II, showing broad adaptation.

-- ECZ IV (Mid-altitude tropics). CIAT HQ serves as the selection site for ECZ IV. Although a relatively less important ecosystem than others, it provides a generally consistent possibility of selecting for thrips resistance and for ability of clones to respond favorably to fertile soil conditions. For these reasons, all materials selected in other ECZs are also evaluated at the Palmira station. There is not a particular genetic base built each season for the mid-altitude tropics. The genetic variability generated for ECZs I and II is used as the starting point (Tables 1.16 & 1.17). The high potential for thrips damage in this environment was again confirmed by high levels of damage in susceptible spreader rows. In recent years virtually all clones that arrive at the advanced yield trial stage of selection for any ecosystem are resistant to thrips. Mite resistance, however, still needs to be increased.

  HMC 1, used as the local check, seems to set a high standard for comparison. Just a few clones could significantly outyield HMC 1 this year in terms of DM yield. When cooking quality is considered HMC 1 is hardly equalled. In most years, however, many clones will outyield HMC 1.

-- ECZ V (High-altitude tropics). The high-altitude tropics (1600-2200 masl) are mainly important in the Andean zone of Latin America and in East Africa. In Colombia, CIAT's Santa Rosa experiment station near Popayán, Cauca (1800 masl), has been the main site for selecting highland-adapted materials.

  Two major changes are being introduced to the selection methodology for the highlands. First, in view of the potential importance of CBB in this ecosystem, greater efforts are being given to incorporating resistance. After outbreaks of CBB in Popayán over the last two years, attempts are being made to eradicate the pathogen from the experiment station, which implied a break in selection activities this past year. Whether or not the station can be kept CBB-free is still uncertain; in any case a major effort is under way to incorporate resistance from the ECZ II gene pool. In the East Africa highlands, CBB can also be of moderate importance. Two existing elite clones for ECZ V (M Col 262 and CG 402-11) have shown good CBB resistance. These are being

Table 1.15 Means for selected entries for the yield trial (GY8958) at La Libertad (ECZ II), Season B.

Clone	Female Parent	Male Parent	Yield (t/ha)	HI	% DM	DM Yield (t/ha)	HCN (1-9)
M Bra 97			27.7	0.51	35.1	9.7	6.0
CG 165-7	M Col 1495	M Pan 90	31.9	0.55	35.2	11.2	8.5
CG 1139-2	M Ecu 82	M Bra 5	32.4	0.61	33.6	10.9	5.5
CG 1367-1	M Bra 5	M Pan 90	29.9	0.53	33.6	10.0	6.5
CG 1450-4	M Col 1505	M Col 1940	28.1	0.62	40.1	11.2	6.0
CM 523-7	M Col 655A	M Col 1515	20.3	0.50	40.5	8.2	5.0
CM 2166-6	CM 430-37	M Ven 218	35.3	0.64	34.2	12.1	4.0
CM 2177-2	CM 430-37	CM 840-138	21.0	0.50	37.8	7.9	3.5
CM 2766-3	CM 723-3	CM 523-7	33.2	0.60	37.2	12.3	5.5
CM 2766-5	CM 723-3	CM 523-7	18.1	0.46	36.9	6.7	6.0
CM 3320-8	M Bra 12	CM 523-7	24.7	0.47	34.7	8.6	6.5
CM 4484-2	M Col 1468	M Cub 74	25.0	0.50	35.3	8.8	6.0
CM 5253-1	CM 1223-11	CM 523-7	29.2	0.58	38.5	11.2	5.0
CM 5620-3	CM 955-2	CM 523-7	30.3	0.64	36.6	11.1	7.5
CM 5667-1	CM 2087-101	M Bra 12	24.9	0.51	32.6	8.1	6.0
CM 5789-1	M Col 1823	CM 2175-1	26.2	0.49	36.6	9.6	3.0
CM 5847-1	CG 1-3	CM 1335-4	23.7	0.54	36.2	8.6	6.5
CM 5898-1	CG 32-22	CM 430-37	30.7	0.54	33.9	10.4	3.5
CM 5898-2	CG 32-22	CM 430-37	29.4	0.53	37.0	10.9	5.5
CM 5902-2	CG 32-22	M Col 638	26.3	0.46	37.7	9.9	4.0
CM 5948-1	CM 1335-4	SG 107-35	25.2	0.55	36.5	9.2	5.0
CM 5958-1	CM 1585-13	SG 625-18	31.9	0.64	32.2	10.3	4.0
CM 5962-3	CM 1851-4	CM 1335-4	23.7	0.56	36.3	8.6	7.0
CM 5990-1	CM 2087-101	CM 2298-3	28.0	0.59	35.6	10.0	6.0
CM 5995-2	CM 2088-1	SG 107-35	23.0	0.47	35.8	8.3	6.5
CM 6009-1	CM 2144-1	M Pan 51	30.2	0.59	34.0	10.3	6.0
CM 6031-2	CM 2882-1	CG 32-22	25.4	0.50	36.1	9.2	5.0
CM 6049-1	CM 2882-1	M Ven 77	24.4	0.46	34.1	8.3	5.5
CM 6061-1	SG 105-11	CM 91-3	21.4	0.45	37.8	8.1	6.0
CM 6068-3	SG 591-3	CM 2174-7	29.5	0.57	37.3	11.0	6.0
CM 6070-1	SG 591-3	SG 618-3	30.8	0.52	35.9	11.0	4.0
CM 6082-1	M Bra 5	CG 32-22	30.1	0.57	36.5	11.0	4.5
CM 6094-5	M Bra 12	SG 625-18	26.6	0.61	37.8	10.0	6.0
CM 6103-1	M Bra 35	SG 107-35	19.6	0.48	37.1	7.3	4.5
SG 104-74	VAR 2		28.3	0.49	37.3	10.5	7.5
SM 344-8	CM 523-7		23.3	0.57	38.6	9.0	7.5
SM 494-2	M Per 245		30.6	0.63	34.3	10.5	6.0
SM 667-1	CM 723-3		24.9	0.47	36.1	9.0	6.0
SM 673-1	CM 2448-201		22.1	0.48	36.8	8.2	3.5
SM 673-3	CM 2448-201		25.8	0.52	38.4	9.9	4.5
Avg			26.8	0.54	36.2	9.7	5.5
LSD (0.05)			5.3	0.04	1.2	1.6	
Chiroza Morada			15.3	0.42	32.6	5.0	3.5
Chiroza Blanca			13.1	0.32	35.1	4.6	4.5
M Ven 77			21.5	0.41	35.0	7.5	6.5

Table 1.16 Means for selected entries for the yield trial (GY8914) at Palmira (ECZ IV), Seasón A.

Clone	Female Parent	Male Parent	Yield (t/ha)	HI	% DM	DM Yield (t/ha)	HCN (1-9)
M Cub 32			39.3	0.59	38.8	15.2	4.0
CG 996-6	M Col 1413	M Ptr 19	37.5	0.67	36.9	13.8	2.5
CG 1320-14	M Mex 1	M Pan 51	32.9	0.52	39.0	12.8	3.0
CG 1374-2	M Bra 12	M Ven 156	45.6	0.56	33.3	15.2	5.5
CM 305-41	M Col 113	M Col 22	31.8	0.64	35.7	11.3	4.5
CM 3750-5	CM 1117-3	M Col 22	32.3	0.60	37.3	12.0	6.0
CM 4169-1	CM 845-91	M Bra 12	36.9	0.52	34.5	12.7	4.0
CM 4344-1	CM 922-2	CM 1191-12	38.0	0.63	39.9	15.2	4.5
CM 5307-1	CM 1559-5	M Pan 51	30.8	0.57	35.0	10.8	4.0
CM 5458-4	M Col 22	M Pan 12B	32.4	0.59	35.3	11.4	6.0
CM 5541-1	CG 1-37	M Col 2215	34.3	0.65	40.0	13.7	4.0
CM 5655-2	CM 1203-13	CM 91-3	45.6	0.57	38.0	17.3	5.5
CM 5655-4	CM 1203-13	CM 91-3	42.6	0.64	36.6	15.6	5.5
CM 5656-1	CM 1203-13	M Bra 12	41.4	0.68	33.6	13.9	6.5
CM 5656-2	CM 1203-13	M Bra 12	37.3	0.69	36.2	13.5	6.5
CM 5729-1	M Bra 12	M Col 1818	39.1	0.54	39.3	15.4	6.0
SM 394-2	CM 955-2		36.2	0.56	38.8	14.0	2.5
SM 414-1	M Per 245		34.7	0.66	34.1	11.8	5.0
Avg			37.0	0.61	36.7	13.6	4.8
LSD (0.05)			9.05	0.10	2.86	3.4	
HMC 1			38.0	0.58	35.8	13.6	5.0

Table 1.17 Means for selected entries for the yield trial (GY8955) at Palmira (ECZ IV), season B.

Clone	Female Parent	Male Parent	Yield (t/ha)	HI	% DM	DM Yield (t/ha)	HCN (1-9)
CG 1-37	M Bra 12	M Col 22	22.6	0.55	35.3	8.0	6.0
CG 913-4	M Bra 12	M Col 1112A	19.4	0.65	29.8	5.8	8.5
CG 1286-3	M Col 2207	M Bra 12	20.8	0.48	34.2	7.1	7.0
CG 1287-5	M Bra 12	M Ven 185	33.6	0.51	36.0	12.1	8.0
CG 1370-5	M Bra 12	M Col 1505	35.6	0.56	33.5	11.9	6.5
CG 1403-6	M Col 948C	M Col 1505	15.7	0.57	34.6	5.4	4.0
CG 1413-3	M Col 976	CM 507-37	18.4	0.64	31.2	5.7	7.0
CM 523-7	M Col 655A	M Col 1515	20.4	0.48	35.3	7.2	5.5
CM 1203-13	CM 321-252	CM 477-3	21.8	0.67	32.6	7.1	5.0
CM 1286-7	CM 409-2	CM 477-3	18.9	0.65	36.4	6.9	3.0
CM 3306-19	M Col 22	CM 523-7	15.1	0.55	34.0	5.1	5.5
CM 3997-1	CM 681-2	CM 849-1	19.1	0.57	34.4	6.6	6.0
CM 4063-6	CM 1015-42	CM 849-1	21.3	0.70	32.7	7.0	9.0
CM 4157-34	CM 849-1	CM 723-3	25.0	0.50	34.3	8.6	4.0
CM 4313-2	CM 342-170	M Ven 25	17.7	0.47	35.8	6.3	9.0
CM 4388-1	CM 1195-2	M Col 1828A	15.0	0.64	32.8	4.9	5.0
CM 4420-1	CM 1559-5	M Bra 12	26.7	0.43	35.2	9.4	6.0
CM 4744-7	M Bra 12	M Ven 25	19.5	0.57	31.8	6.1	5.5
CM 5071-1	CM 942-14	CM 723-3	17.0	0.58	34.8	5.9	7.5
CM 5431-2	M Bra 12	CM 1014-2	22.8	0.57	35.2	8.0	5.0
CM 5854-2	CG 1-3	M Col 1818	20.0	0.56	33.9	6.8	8.5
CM 5935-2	CM 922-2	CM 91-3	22.0	0.46	35.6	7.8	4.5
CM 5940-1	CM 1015-6	M Bra 12	22.0	0.55	34.8	7.6	5.0
CM 6068-3	SG 591-3	CM 2174-7	25.7	0.55	32.8	8.4	4.0
CM 6129-2	M Col 72	M Ven 185	20.8	0.53	35.8	7.4	5.0
SG 731-4	CM 922-2		18.1	0.67	39.2	7.1	3.0
SM 540-5	M Bra 12		18.9	0.37	37.2	7.0	4.0
SM 554-8	CM 681-2		20.3	0.58	32.0	6.5	8.5
Avg			21.2	0.56	34.31	7.3	5.9
LSD (0.05)			9.67	0.08	3.93	3.2	
HMC 1			20.2	0.44	34.3	6.9	2.5

multiplied for commercial use in the Popayán region and are also being used extensively in crossing.

The second modification in selection was introduced in an attempt to broaden the range of adaptation of this gene pool. As selection over the past years has been in a single region, there is some evidence of a fairly narrow range of adaptation of the resulting advanced lines. For example, in trials at altitudes of about 1550 masl, neither the ECZ IV nor the ECZ V materials performed very well. As of 1990, all materials beginning with F_1C_1 are being planted and evaluated at both Popayán and CIAT HQ (1000 masl). In order to be selected for the ECZ V gene pool, a clone most show good performance in Popayán and at last reasonable adaptation to Palmira. In the first across-site selection this year, it has been shown that this type of broader adaptation is feasible. In the medium term, this strategy should result in the ECZ V gene pool having a much broader relevance than at present.

1.2.3 Project for developing semiarid- and subtropical-adapted germplasm

1.2.3.1 **General objectives and strategy.** The International Fund for Agricultural Development (IFAD) agreed in mid-1990 to fund a five-year project to develop cassava germplasm for semiarid and subtropical regions. The overall objective of this project is to enhance food security in the drier tropical and subtropical areas of the world, with emphasis on Africa, through the introduction of preselected cassava germplasm from Brazil. This project will provide the means for the Brazilian National Cassava Research Center (CNPMF/EMBRAPA) and other institutions in Brazil, under agreement with CIAT, to expand and accelerate the collection, evaluation and selection of cassava germplasm adapted to the drier and subtropical conditions of Africa, Asia and Latin America. Brazil has special comparative advantages in that it has a wide diversity of cassava-growing environments (including the subtropical and semiarid zones); a broad germplasm base; and an institutional base and experienced personnel for managing cassava breeding activities.

Although external funding will not be available until 1991, several project-related activities were begun in 1990. The subprojects for the subtropics and semiarid regions are essentially independent, except for certain administrative aspects. Some of the activities for each ecosystem are reported, as well as additional related activities for the subtropics, undertaken at CIAT and in Paraguay.

1.2.3.2 **Semiarid region.** A planning meeting was held at CNPMF in May 1990, with the participation of representatives from several state and regional programs, CNPMF and CIAT. The main objective was to introduce the project idea and establish a preliminary basis for interinstitutional collaboration.

Based on suitability of climate and soil conditions (including similarity to target regions in Africa), and institutional interest and capability, four sites were selected for preliminary germplasm evaluation (Fig. 1.1). The first year 500 accessions from the CNPMF germplasm collection (about 1200) will be evaluated at all sites as a basis for selecting parents, the seed of which will be sent to IITA for incorporation into their breeding program for Africa.

1.2.3.3 **Subtropical region**

-- **Southern Brazil.** In order to plan activities for the first year of the IFAD project (subtropics), a meeting was held in July involving representatives from the four southern states (RS, SC, PR, and SP) (Fig. 1.1). The main activities for 1990/91 are in vitro introduction from CIAT of all relevant accessions (particularly those from Paraguay); introduction to EMPASC-SC of germplasm collections from neighboring states; germplasm collection in the state of SC; establishment of regional trials with the most commonly grown clones in the region; establishment of crossing blocks with parental clones selected among the most common varieties and elite genotypes from regional programs; and evaluation of an F_1 nursery under high CBB pressure (inoculation) with seeds introduced from CIAT.

-- **Paraguay.** For the first time the national cassava collection (235 clones) was agronomically evaluated at IAN in Caacupe. Table 1.18 presents results from clones preselected for plant type. There is a high proportion of good clones (approx. 40%) that were selected to be advanced to preliminary trials. The Paraguayan collection represents an excellent germplasm source for cassava breeding in the subtropics.

Introduction of sexual seed to southern Paraguay has resulted in few genotypes being selected at early stages (4 out of about 300), reflecting a need for better defining parental genotypes for this ecosystem. Three local clones are being multiplied and have been distributed to regional cooperatives for promotion in a field day early next year.

-- **Genotype-by-photoperiod interaction.** The main breeding support activity developed at CIAT for the subtropics has been recombination among accessions originating from areas in the subtropics, or between them and clones

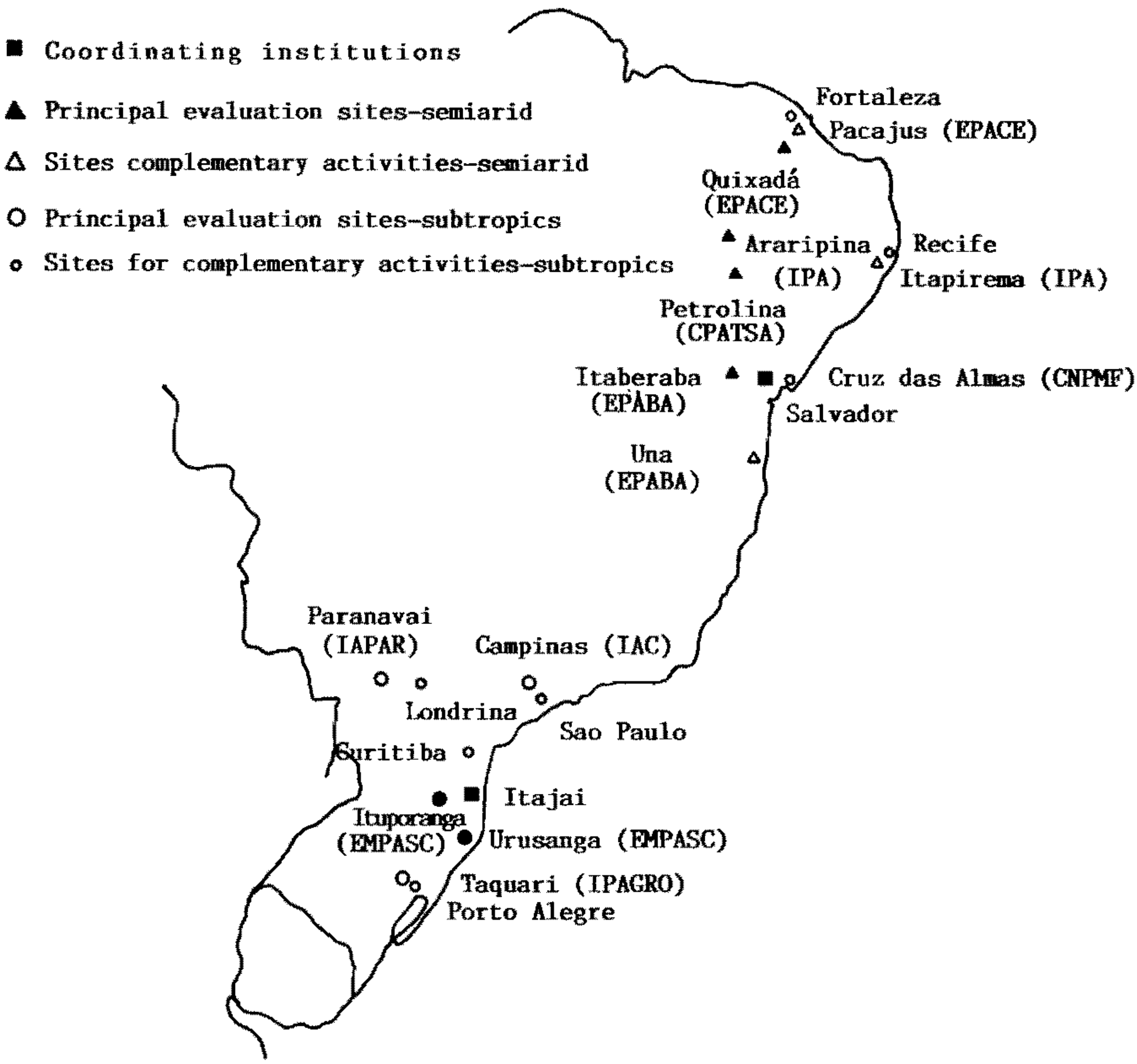


Figure 1.1 Principal evaluation sites and participating Brazilian institutions in collaborative project for developing cassava germplasm adapted to semiarid and subtropical ecosystems.

Table 1.18 Means for preselected entries from the Paraguayan germplasm collection.

Clone	Commer. Roots (t/ha)	Total Roots (t/ha)	Foliage Weight (t/ha)	% DM	HCN	HI
M Par 001	23.0	30.8	18.6	33.8	3	0.62
M Par 005	38.8	44.0	21.4	36.6	4	0.67
M Par 019	38.8	48.0	25.1	37.1	3	0.66
M Par 030	38.0	48.4	39.4	36.6	2	0.55
M Par 032	18.6	32.8	29.4	36.8	5	0.53
M Par 036	28.0	35.4	29.8	38.6	2	0.54
M Par 037	24.8	30.2	20.8	32.9	4	0.59
M Par 040	12.2	16.4	20.6	36.3	3	0.44
M Par 047	28.8	38.6	34.6	34.1	4	0.53
M Par 049	30.4	36.6	29.6	35.4	4	0.55
M Par 051	24.2	29.4	20.2	36.2	3	0.59
M Par 067	15.6	23.0	20.0	34.1	6	0.53
M Par 068	18.8	32.8	42.4	37.9	3	0.44
M Par 073	19.6	24.8	32.4	33.4	7	0.43
M Par 075	24.8	29.4	42.4	35.2	6	0.41
M Par 088	27.2	32.1	32.6	34.6	3	0.50
M Par 090	14.2	18.2	15.0	37.1	3	0.55
M Par 106	14.8	20.8	26.6	36.7	2	0.44
M Par 108	33.2	38.2	26.4	35.3	4	0.59
M Par 109	54.2	58.0	39.5	38.8	3	0.59
M Par 110	52.0	53.4	40.0	35.8	5	0.57
M Par 121	31.2	38.0	30.2	37.3	6	0.56
M Par 126	46.6	49.0	37.6	38.7	4	0.57
M Par 131	18.8	23.0	14.4	38.8	5	0.61
M Par 132	11.5	18.5	20.0	39.8	3	0.48
M Par 139	14.0	21.0	17.0	34.9	4	0.55
M Par 146	46.8	55.2	18.9	31.6	5	0.74
M Par 157	15.0	18.6	17.6	35.2	4	0.51
M Par 160	41.0	45.4	39.2	30.4	6	0.54
M Par 171	32.8	36.0	28.0	36.5	4	0.56
M Par 172	39.0	47.4	36.4	39.8	2	0.57
M Par 173	12.2	17.4	15.4	38.2	6	0.53
M Par 185	28.6	32.8	11.2	32.7	6	0.75
M Par 186	26.2	33.2	37.6	27.6	6	0.47
M Par 188	30.6	38.2	29.6	35.1	4	0.56
M Par 190	28.8	39.6	30.2	32.7	6	0.57
M Par 193	53.6	61.6	41.6	38.2	5	0.60
M Par 195	41.6	52.2	45.8	32.7	4	0.53
M Par 196	44.0	47.4	50.8	35.2	4	0.48
M Par 212	42.8	47.2	24.6	34.6	2	0.66
M Par 213	41.4	45.2	25.0	36.2	6	0.64
M Par 218	41.4	43.0	17.0	34.1	6	0.72
M Par 220	38.2	51.4	39.6	35.4	2	0.56
M Par 228	21.4	25.6	16.8	37.8	2	0.60
M Par 229	36.6	42.0	32.2	35.5	5	0.57
M Par 231	15.6	28.8	30.0	34.1	6	0.49
M Par 234	11.4	21.4	14.8	40.3	6	0.59
M Par 236	35.0	38.6	20.9	37.3	6	0.65
M Par 237	24.4	32.2	21.8	36.7	1	0.60
M Par 238	9.6	14.2	13.4	37.5	3	0.51
M Par 242	20.4	23.6	23.6	30.5	6	0.50
M Par 244	24.6	31.2	24.4	37.3	1	0.56
M Par 247	42.8	52.4	34.6	37.5	2	0.60
M Par 248	33.6	39.0	29.0	36.7	5	0.57
M Par 249	49.0	56.0	53.8	30.8	6	0.51
M Par 251	23.4	27.8	19.8	34.9	5	0.58
M Par 252	20.6	31.6	20.1	40.7	6	0.61
M Par 253	33.2	35.8	29.6	40.4	6	0.55
M Par 255	22.0	27.5	37.6	39.0	4	0.42
M Par 256	10.6	17.6	26.0	36.0	3	0.40
M Par 261	34.6	36.8	25.2	35.5	6	0.59
M Par 263	28.4	31.8	22.4	37.0	5	0.59
M Par 264	25.8	32.4	23.8	38.4	2	0.58
M Par 267	43.4	51.0	49.2	29.2	3	0.51
M Par 268	31.8	35.8	16.2	40.9	3	0.69
M Par 269	31.6	39.4	47.0	35.1	4	0.46
M Par 274	47.4	50.4	77.8	34.4	6	0.39
M Par 275	18.8	24.0	23.8	40.4	3	0.50
M Par 278	10.6	19.0	34.8	33.3	3	0.35
M Par 283	45.8	54.0	32.0	35.6	6	0.63
M Par 283	26.5	37.5	38.5	34.4	5	0.49
M Par 285	14.4	20.4	33.2	36.3	4	0.38

contributing resistance to CBB and SED (from ECZ II). As a result of work done in the Colombian Llanos, there are a wide range of genotypes that may contribute resistance or tolerance to those diseases. Their use represents the introduction of valuable exotic germplasm to subtropical regions.

The reaction of a set of 25 genotypes to photoperiod is being studied to determine the possibility of identifying characteristics as indicators for potential adaptation to the subtropics. The genotypes were planted under two photoperiod regimes: normal photoperiod at CIAT (NPP) (12 h 20'); and an extended photoperiod (EPP) (15 h of light). An early harvest was done at 5 mo and a normal harvest at 10 mo. Preliminary analysis of data showed that EPP resulted in an overall reduction of RY and HI, and an increased production of aerial part (Table 1.19). Sensitivity to EPP $[(\text{Yield}_{NPP} - \text{Yield}_{EPP})/\text{Yield}_{NPP}]$, for RY at 10 mo was considered as the main reference trait. Nonsensitive clones will have values around 0; those stimulated by EPP, negative values; and those whose yield is reduced by EPP, positive values. Correlation of sensitivity with RY involves certain autocorrelation and must therefore be interpreted cautiously. Clones with profuse development of the aerial part tend to be the most affected. EPP tended to stimulate foliage production, translocating fewer carbohydrates to the roots than under NPP. That is also reflected in a close negative correlation with HI under EPP. Clones with the highest HI were less affected or even stimulated by EPP compared to those with a lower HI.

1.2.4 Participatory research with farmers for variety selection

1.2.4.1 **Objectives and strategy.** Since 1986 the Germplasm Development Section has been engaged in developing methodologies to involve farmers in the process of defining and refining selection criteria. This work has concentrated in the Atlantic Coast region of Colombia, to take advantage of several key factors present there: (a) Cassava is a basic traditional crop of the region, and farmers generally have well-formed opinions concerning cassava production technology, including varieties; (b) with the expanding cassava drying industry of the region, an increased demand for improved production technology has been noted, thereby making farmers more receptive to receiving and evaluating new genetic material; and (c) a well-established cassava working group exists in the region, with capability for managing trials in a network fashion.

Table 1.19 Avg sensitivity to extended photoperiod treatment for the main agronomic traits and correlation coefficients between RY (at 10 mo), sensitivity and other traits.

Treatment	% DM	% RY	Foliage Yield	HI
	Average Sensitivity[1]			
Harvest I (5 mo)	0.04	0.32	-0.44	0.40
Harvest II (10 mo)	0.03	0.19	-0.42	0.26
	Correlation Coefficient			
Normal Photoperiod				
Harvest I	0.30	0.49*	0.63**	0.09
Harvest II	0.14	0.76 **	0.64**	0.04
Extended Photoperiod				
Harvest I	0.26	0.04	0.35	0.03
Harvest II	0.22	0.37	0.31	0.47*

1 (Normal photoperiod - Extended photoperiod)/Normal photoperiod.

Based on successes and failures over the past four years, a strategy has evolved for participatory research, involving the following basic stages

-- Preselection of a set of about ten experimental clones, based on breeder evaluations over several sites and growing seasons

-- Selection of regions for on-farm trials

-- Selection of farmers and explanation to them of trial objectives and methodology

-- Planting by farmers with their own management practices

-- Researcher-farmer interaction during various phases of the crop cycle, especially at harvest

-- Data analysis

-- Feedback of results to breeders to refine selection criteria

In 1989-90, experimental clones were planted on 22 farms in five states of the Atlantic Coast region. At harvest, 138 farmers participated, giving their opinions about a wide range of traits of these clones, as well as the local ones.

1.2.4.2 **Analysis and interpretation of results.** Overall, the experimental clones received an acceptance rating above that of the local clones (Tables 1.20 & 1.21). In a multiple regression analysis, three characters stand out as apparently key to acceptance by farmers: number of commercial-sized roots; root thickness; and root surface color (Table 1.22). It is significant that all these characters are closely tied to requirements for the fresh market. This indicates that even though farmers in the region may have access to the drying plants to sell their cassava, they want to maintain dual-purpose varieties that can also enter the higher priced fresh market.

These traits should not necessarily be seen as the only important ones for farmer acceptance of a new variety. Within this group of clones, many traits had already been highly selected such as root flesh color and starch content; therefore, there was little discrimination by farmers among clones for these traits.

Of several experimental clones evaluated on-farm for three years, CG 1141-1 and CM 3306-4 stood out for their superiority in nearly all traits and generalized acceptance by farmers in the region--both being rated considerably higher than the local checks. ICA is in the process of multiplying these clones and preparing one or both for release.

1.2.5 True cassava seed

The Cassava Program will study the feasibility of developing a true-seed alternative for commercial-scale production. Vegetative propagation entails several constraints including virus accumulation, inefficient photosynthate partitioning, and difficulties in storage and management of planting material. Two well-recognized constraints to developing a true-seed technology are seed production and germination. Preliminary studies of these two areas are reported here.

1.2.5.1 **Seed production enhancement.** Assuming there is an internal competition for available photosynthates between the aerial part and the roots, and between seeds and the rest of the foliage, girdling (i.e., removal of a band of phloem near the base of the stem) was proposed as a means of enhancing seed production. Two clones were observed for flowering and seed production, with and without girdling,

Table 1.20 Ratings of acceptability by farmers for ten clones evaluated at 16 sites of the Atlantic Coast region of Colombia, 1990.

Criteria	Level of Acceptability (%)[1]			Total No. of Observations
	High	Intermediate	Low	
Preharvest				
Stake production	61	26	13	92
Branching habit	59	27	15	82
General foliage eval.	69	21	10	89
Postharvest				
Ease of harvest	62	24	14	80
No. commercial roots	78	17	5	77
Starch content	62	23	15	84
Root form	70	20	10	87
Root flesh color	58	26	16	119
Root surface color	63	24	13	95
Root thickness	83	14	3	64
Maturity	67	23	10	88

[1] Percent evaluations of all experimental clones in given categories of acceptability.

Table 1.21 Regression analysis to define the most important criteria for farmer acceptance of new cassava varieties.

Source of Variation	DF	SS	MS	F	Prob >F
Model	10	555.0	55.5	19.7	0.0001
Error	110	309.7	2.8		
Total	120	864.2			

$r^2 = 0.64$; CV = 37.2%

Variable	SD	Probability > T
No. of commercial roots	0.14	0.0001**
Root thickness	0.20	0.0001**
Root surface color	0.23	0.0001**
Root size	0.39	0.0218*
Root flesh color	0.52	0.0695
Preharvest foliage evaluation	0.58	0.0687

Table 1.22 Comparison among experimental and local clones for farmer acceptance in trials at 16 sites on the Atlantic Coast region of Colombia, 1990.

	Farmer Evaluation Criteria/ Overall Evaluation[1]							Researcher Evaluations	
Clone	No. Commerc. Roots/Plant	Root Thickness	Root Surf. Color	Root Size	Starch Content	Stake Production	General Acceptability[2]	% DM	Yield (t/ha)
CG 1141-1	G	G	G	G	G	G	1.1	37	23
CM 3306-4	G	G	G	G	G	G	1.1	38	21
CM 3306-19	G	I	G	I	I	G	1.4	33	25
CG 1355-2	G	I	G	I	I	G	1.6	33	24
CM 3555-6	G	G	I	G	G	G	1.7	35	22
CM 3372-4	G	I	G	G	G	G	1.7	35	24
CM 523-7	I	I	G	I	G	I	1.8	37	21
CM 3306-9	G	I	P	I	G	G	1.9	36	20
Local clones									
M Col 1505	I	I	G	I	G	G	1.8	36	17
M Col 2215	I	I	G	G	G	G	2.0	36	16

1 G = good; I = intermediate; P = poor.

2 Mean of all sites, where I = good; 2 = intermediate; 3 = poor.

and with and without removal of flowers. The girdled plants looked stressed one month after the treatment as a result of restricted carbohydrate flow to the roots, limiting active absorption of nutrients. This nutrient stress resulted in increased flowering and seed production for one of the varieties (Table 1.23); and the increased availability of carbohydrates in the aerial part seems to have increased seed production.

Table 1.23 Means for main traits evaluated in the study of girdling effects on two cassava clones.

Clone	Treatment	Seeds/ Plant	100-Seed Wt (g)	Root Wt (t/ha)	Foliage Wt (t/ha)	HI
CG 915-1						
	Girdled	44	13.8	11.1	15.2	0.42
	100% flower	32	12.0	35.7	24.3	0.60
	0% flower[1]	—	—	34.2	19.6	0.64
CM 3372-4						
	Girdled	390	12.6	8.1	13.4	0.38
	100% flower	125	11.9	27.7	24.0	0.54
	0% flower	—	—	28.9	16.1	0.64

[1] Flowers manually removed.

1.2.5.2 **Pregermination seed treatment.** Cassava seeds germinate well under favorable soil conditions (good moisture and temp around 35°C). Field conditions are usually far from optimal, however, resulting in low percentages of establishment when seed is planted directly in the field. Treating the seed before planting seemed a logical technique for enhancing germination. As many factors can potentially be included in pretreatment studies, combining them in one factorial experiment is difficult. Thus two separate factorial experiments were designed: (a) variety, temp and soaking effects; and (b) variety and red-light effects.

-- Open-pollinated seeds from two clones previously detected to have different germination rates were subjected to a high temp (45°C) for different periods (0, 24, 48 and

72 h), and soaking using a solution with PEG (0.5% osmotic pressure), for the same periods, resulting in a factorial of 16 treatments. Seeds were germinated under two temp: optimal (35°C) and suboptimal (25°C).

From the ANOVA (Table 1.24) it could be observed that except for a slight increase in germination at the intermediate period of temp pretreatment (Table 1.25), there were no differential effects due to other pre-treatments. The significant effects of variety and variety-by-germination temp were a result of seeds from clone 2 having lower percentage germination under optimal conditions than clone 1. Thus varietal or pre-germination treatment effects did not result in much improvement of germination at suboptimal temp.

Table 1.24 ANOVA for maximum germination (%) and germination rate for study involving two varieties and sixteen pregermination treatments (temp. x soaking).

		Max. Germination		Germination Rate	
Source of Variation	DF	MS	PR>F	MS	PR>F
Reps	1	309.72	0.1200	63.39	0.0040
Treatments	63	1844.83	0.0001	34.56	0.0001
Germination temp (GT)	1	95141.23	0.0001	974.79	0.0001
Variety (V)	1	4085.06	0.0001	322.95	0.0001
GT x V	1	6819.51	0.0001	353.38	0.0001
Soaking (S)	3	244.99	0.1290	0.44	0.9800
GT x S	3	327.41	0.0580	3.11	0.7290
V x S	3	355.38	0.0450	8.13	0.3430
GT x V x S	3	181.70	0.2350	9.92	0.2570
Pregerm. temp (PT)	3	359.24	0.0430	27.30	0.0140
GT x PT	3	46.15	0.7750	10.76	0.2230
V x PT	3	5.31	0.9880	3.84	0.6590
GT x V x PT	3	171.50	0.2590	13.28	0.1470
S x PT	9	175.57	0.2050	5.95	0.5920
GT x S X PT	9	111.26	0.5380	8.73	0.3020
V x S x PT	9	111.84	0.5340	5.50	0.6470
GT x V x S x PT	9	133.93	0.3950	5.67	0.6530
Error	63	126.73		9.44	

Table 1.25 Means for combination varieties and pregermination treatment temp under two germination temperatures.

Germination Temp (°C)	Variety	Pregerm. Temp (°C)	Germ. Rate[1]	Varietal Mean	Max. Germ.	Varietal Mean
25	1	0	3.4		15.5	
25	1	24	2.5	2.9	18.2	14.9
25	1	48	3.6		15.5	
25	1	72	2.0		10.2	
25	2	0	2.5		13.9	
25	2	24	3.7	3.0	20.6	18.2
25	2	48	3.4		20.1	
25	2	72	2.5		18.0	
35	1	0	10.4		80.2	
35	1	24	14.8	11.7	88.0	84.0
35	1	48	11.5		86.7	
35	1	72	10.1		81.0	
35	2	0	4.3		61.4	
35	2	24	5.6	5.2	62.1	58.1
35	2	48	6.7		59.8	
35	2	72	4.3		49.1	

[1] Percent per day until maximum germination achieved.

-- In the second experiment, normal visible and red light were applied to seeds from other varieties for 72 h. The seeds were germinated under the same temp conditions as the previous experiment (35° and 25°C). No effect on germination was observed due to variety or red light (Table 1.26).

Low soil temperatures represent a common stressful condition for germination of cassava seeds. The treatments studied seem to offer little advantage for increasing poor levels of germination at 25°C. Other pretreatments need to be studied, as well as screening of the available genetic diversity for seed germination under suboptimal conditions.

Table 1.26 ANOVA for maximum germination (%) and germination rate for study involving two varieties and red light pretreatment.

		Max. Germination		Germination Rate	
Source of Variation	DF	MS	PR>F	MS	PR>F
Model	9	37.73	0.050	3122.25	0.0001
Germination temp (GT)	1	290.11	0.001**	27722.25	0.0001
Rep (GT)	2	0.64	0.930	21.25	0.6800
Variety (V)	1	0.01	0.980	42.25	0.4000
Light (L)	1	31.18	0.110	42.25	0.4000
V x L	1	10.23	0.330	12.25	0.5400
GT x V	1	0.01	0.980	110.25	0.1900
GT x L	1	5.84	0.450	56.25	0.3400
GT x V x L	1	0.94	0.760	72.26	0.2800
Error	6	9.07		51.25	

1.3 **Germplasm: Africa**

For many years the CIAT Cassava Program has collaborated with IITA in germplasm and information exchange in line with CIAT's world mandate for cassava research. The effectiveness of this interchange was limited, however, by the difficulties inherent in long-distance communication and coordination. Thus in 1989 CIAT placed a physiologist/breeder at IITA headquarters in Ibadan, Nigeria, in order to:

-- Facilitate information exchange between CIAT and IITA, especially with regard to areas where the activities and expertise of the two centers are complementary, particularly the area of utilization research.

-- Transfer germplasm between Africa and Latin America, and follow through with evaluation and selection of promising materials primarily for the drier and the highland areas, considering the relatively narrower germplasm base for these ecologies in Africa.

-- Contribute to a better understanding of the cassava production systems in use or with potential to be developed, in the drier areas of Africa, where food deficits are especially acute.

1.3.1 Germplasm exchange

Three basic sources of germplasm were identified for emphasis in the early stages of the new collaborative arrangement between CIAT and IITA, with a view toward complementing the existing germplasm base in Africa.

1.3.1.1 **Brazilian germplasm.** The IFAD-funded project for developing germplasm adapted to semiarid and subtropical ecosystems (see 1.2) has as a major objective the introduction into Africa of improved, drought-tolerant and pest-resistant materials. This project got under way in late 1990, and the first seed shipments are expected during 1991.

1.3.1.2 **CIAT elite germplasm.** The edaphoclimatically oriented gene pools developed by CIAT will be a principal source of germplasm to be introduced into Africa for evaluation under similar ecologies. IITA has requested that special emphasis be given to materials showing the following characteristics: high RY and high DM; low HCN and good cooking quality; high carotene content (yellow root flesh); resistance to CGM and cassava mealybug; adaptation to dry conditions; and adaptation to low temp. A shipment of seeds was sent from CIAT to IITA in early 1990. Their management and evaluation are described in detail in the following sections.

1.3.1.3 **IITA elite germplasm.** CIAT has established 19 of IITA's elite, African Cassava Mosaic Disease (ACMD)-resistant clones within its germplasm collection. These are being used to combine resistance with the specific traits outlined above. Preliminary results in Nigeria indicate the efficacy of this strategy, especially in the more humid regions where ACMD is severest. Therefore, more emphasis will be given in the future to these Africa X Latin American crosses.

1.3.2 Evaluation of introduced germplasm in Nigeria

A total of 87,615 botanical seeds obtained by controlled hybridization and open pollination at CIAT-Palmira were sent to IITA in 1990. This was the first seed lot introduced as part of the IITA-CIAT collaboration on cassava germplasm improvement in Africa.

Seeds were collected from crossing blocks and open pollination fields established at CIAT on the basis of adaptation of parents to specific agroecological zones. Prior to shipment, seeds were tested for Cassava American Latent Virus by the CIAT Virology Unit and inspected for general phytosanitary status by ICA quarantine authorities. Seeds sown in Nigeria in 1990 (40,000) were processed according to recommendations of IITA's Phytosanitary Committee. This included treatment in hot water before sowing in screenhouses. Samples of each cross were tested for presence of bacterial and fungal diseases. The resulting seedlings were inspected by IITA virologists and pathologists to ensure that the introduced material was free of viruses and other pathogens.

The seeds were sown in three different areas of Nigeria representing the humid, subhumid and semiarid ecologies of Africa. Locations were chosen on the basis of similarity to the different target agroecologies, availability of infrastructure, and similarity to zones of adaptation in Latin America where the parents had been selected. Seeds potentially adapted to mid-altitude areas were not sown for lack of basic infrastructure.

Progenies being evaluated at Ibadan (subhumid) and Onne (humid) represent 149 and 78 families, resp. The genetic base of the materials planted at both locations is similar as 94% of the families being evaluated at Onne are also planted at Ibadan. The 62 families at Kano (semiarid) are of different origin as the seeds were obtained from parents adapted to CIAT's ECZ I (lowland tropics with low to intermediate rainfall and long dry season).

Evaluations are being done on both an individual and family basis. Data on plant height, branching height and leaf retention, as well as scoring for the main pests and diseases, are being taken at monthly intervals. Plants will be harvested at 12 mo from planting and selected on the basis of yield, growth habit and reaction to biotic constraints.

Data presented on the reaction to ACMD and CBB refer to the first 5 and 4 mo of the growth cycle at Ibadan and Onne, resp.

1.3.2.1 **Reaction to ACMD.** As this viral disease is not found in South America, the progenies introduced from CIAT were expected to show a high degree of susceptibility at Ibadan, a hot spot of the disease in Nigeria. On the other hand, as some of the introduced families were hybrids between IITA elite clones existing at CIAT and South American materials, a higher level of tolerance was expected for those cases. Table 1.27 gives the results of monthly evaluations being done at Ibadan and Onne since June 1990. Individuals that fall into classes 1 and 2 of the standard evaluation scale (1 = no symptoms to 5) were considered tolerant. The number of individuals classified as tolerant sharply decreased at Ibadan after the first evaluation. As expected, a low average level of tolerance is being observed at that location as a result of the high ACMD pressure.

Table 1.27 Reaction of Latin American germplasm to ACMD at Ibadan and Onne, Nigeria (values are in % of the total seedlings evaluated at each location.

DAT	Total Seedlings Evaluated	Reaction to ACMD[1]	
		Tolerant	Susceptible
Ibadan			
30	4187	60.64	39.36
60	3164	4.92	95.18
90	3014	5.29	94.71
120	3066	2.79	92.21
150	3049	3.39	96.63
Onne			
30	3512	99.04	0.56
60	3249	94.82	5.18
90	3151	89.79	10.03
120	3133	80.81	19.19

1 Tolerant = plants within classes 1 and 2 of the standard evaluation scale (1-5); Susceptible = plants within classes 3-5 of the same scale.

ACMD pressure has been much lower at Onne, the humid ecology (Table 1.27). The percentage of individuals with no or light disease symptoms was always higher than in Ibadan, as was the vector (Bemisia tabaci) population (data not shown). However, symptom expression is still increasing over time at Onne although not so fast as was observed at Ibadan.

These preliminary results confirm the usefulness of Ibadan as the best site for selecting for ACMD resistance in Nigeria as already recognized by IITA's cassava breeding program in its long-term improvement research.

Progenies planted at Ibadan and Onne are also being compared on the basis of the origin of progenitors. Progenies obtained by controlled hybridization at CIAT were divided into three different groups: those that have M Nga 1 (TMS 30001) as one of the parents; those that have M Nga 2 (TMS 30572) as one of the parents, and; those of pure Latin American origin, usually originated from crosses involving CIAT's elite germplasm. TMS 30001 and TMS 30572 are among

IITA's most ACMD-resistant elite clones and were introduced to CIAT in 1986 as sources of ACMD resistance.

Figure 1.2 shows that progenies derived from crosses between IITA clones and CIAT/Latin American materials have a higher percentage of tolerant individuals compared with those of pure Latin American origin. These observations, although preliminary, suggest that resistance to ACMD was incorporated in the crosses with Latin American germplasm and opens up the possibility of combining the beneficial traits present in South America and resistance to ACMD.

In the first 4 mo of the cycle, a few individuals of pure Latin American origin also showed no symptoms of ACMD in the field at Ibadan despite the high incidence of the disease (Table 1.28). Although the possibility of escape cannot be ruled out, this suggests that some Latin American materials may have the potential to express certain levels of tolerance, at least during part of their growth cycle. Five months from transplanting, light symptoms of ACMD developed in those seedlings, but they are still maintaining a low level of symptom expression when compared with the great majority of the germplasm under evaluation.

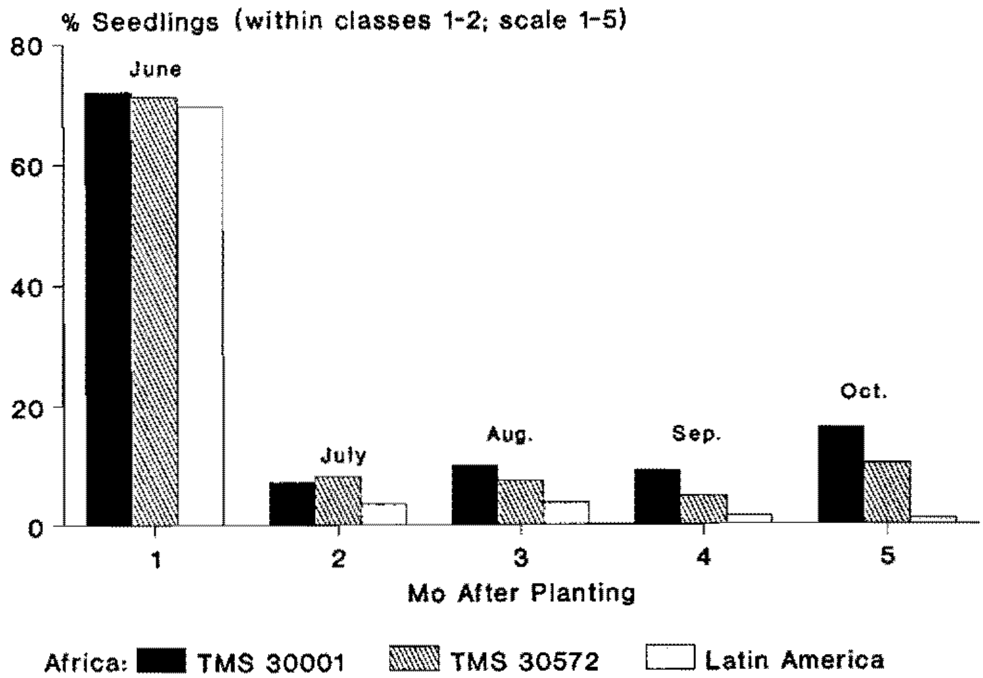


Figure 1.2 Tolerance to ACMD in cassava progenies of African and Latin American origin.

Table 1.28 Reaction of progenies from CIAT and CIAT x IITA sources to ACMD at Ibadan, Nigeria (values represent total numbers of individuals in classes 1 and 2 (tolerant) and 3-5 (susceptible) on each evaluation date.[1]

DAT	No. Seedlings Evaluated[2]	Origin of Parents			
		CIAT		IITA	
		T	S	T	S
30	1244	261	113	623	247
60	842	7	245	34	614
90	858	7	149	63	609
120	893	3	194	46	650
150	879	2	192	88	597

1 Evaluation scale: 1-5 (1 = no symptoms).

2 Increases in no. of seedlings from 60 to 120 DAP are due to sprouting of seedlings previously wilted as a result of CBB infection.

Among the families obtained from open pollination, those originated from M Nga 1 and M Nga 2 also show a higher percentage of individuals with no or light symptoms of ACMD, confirming the tendency observed in the families obtained by controlled hybridization. Families SM 1275 and SM 1276, which have as respective female parents IITA clones TMS 30001 (M Nga 1) and TMS 30572 (M Nga 2), were the ones with the highest percent tolerant individuals (38 and 18%, resp.) at Ibadan between the second and fifth months after transplanting. When all the families under evaluation are considered, 4.1% of the individuals were classified as tolerant in the same period.

Three months after transplanting, no symptoms of ACMD were observed at Kano (semiarid zone). Although no information exists on the degree of ACMD severity at Kano, it seems it is not a serious constraint in semiarid areas. Previous studies show that population buildup of *B. tabaci* is favored by high rainfall (150-280 mm/mo), temp of 27-32°C, and solar radiation of 400 g cal/cm^2. Climatic conditions at Kano are characterized by a unimodal pattern of rainfall distribution with a dry season of 6-8 mo. The seedlings being evaluated were planted late and received only 423 mm of rainfall (mid-Aug.-Sept.). However, further data are needed to confirm the potential pressure of ACMD at Kano, especially in plants established at the onset of the rainy season.

1.3.2.2 **Reaction to CBB.** A major objective of both CIAT's and IITA's cassava breeding programs is resistance to CBB. Both Centers now have elite clones that combine resistance to the disease with high RY and other desirable traits.

Selection pressure for CBB resistance was increased by CIAT in the mid-seventies when evaluation of germplasm started in the Colombian Llanos (CIAT's ECZ 2, representing the lowland tropics with acid-soil savannas and high rainfall), where environmental conditions are ideal for the expression of CBB. The recent release of var. Catumare and Cebucán by ICA reflects the work done by the two institutions in the Llanos to combine resistance to CBB and high yield.

IITA's efforts to select cassava germplasm for resistance to CBB in the past two decades have also been successful. Highly resistant, high-yielding clones have been obtained and are now being used as sources of resistance to that disease by the Root Tuber and Plantain Improvement Program (TRIPP) at IITA. The combination of both CIAT and IITA sources is expected to improve resistance to CBB in the progenies derived from crosses involving African and Latin American germplasm.

A high percentage of CIAT's families under evaluation at Ibadan and Onne were obtained from parents adapted to ECZ 2. The crosses involving both IITA and CIAT materials also have a considerable potential for CBB resistance as the IITA sources used as parents (M Nga 1 and M Nga 2) are also resistant to CBB under the conditions of Nigeria.

Results obtained after 5 and 4 mo of field evaluations at Ibadan and Onne, resp., cannot be considered conclusive. A higher incidence of CBB was observed at Ibadan compared to that at Onne, even causing the death of several young seedlings at 50 and 90 days after transplanting (DAT).

The reaction of the germplasm to CBB at the two locations is shown in Table 1.29 and Figure 1.3. Symptom expression at Ibadan was high at 50 days from transplanting and then decreased. It should be noted that the reduction in the proportion of susceptible material (classes 3-5) after the second month was partially due to the death of susceptible individuals. CBB incidence at Onne was low in 1990 although the environmental conditions (high rainfall, temp and RH) were highly suitable for pathogen development. Further evaluation of the resulting clones and new seed introductions are needed in order to assess the potential of CIAT germplasm for resistance to CBB at that location.

Table 1.29 Reaction of Latin American germplasm to CBB at Ibadan and Onne, Nigeria (values are % total seedlings evaluated at each location).

DAT	Total Seedlings Evaluated	Reaction to CBB[1]	
		Tolerant	Susceptible
Ibadan			
50	3164	78.09	21.92
90	3014	88.60	11.40
120	3066	85.22	14.78
150	3049	95.69	4.31
Onne			
30	3512	99.25	0.75
60	3249	99.71	0.29
90	3151	99.46	0.54
120	3133	99.22	0.77

1 Tolerant = plants within classes 1 and 2 of the standard evaluation scale (1-5); Susceptible = plants within classes 3-5 in the same scale.

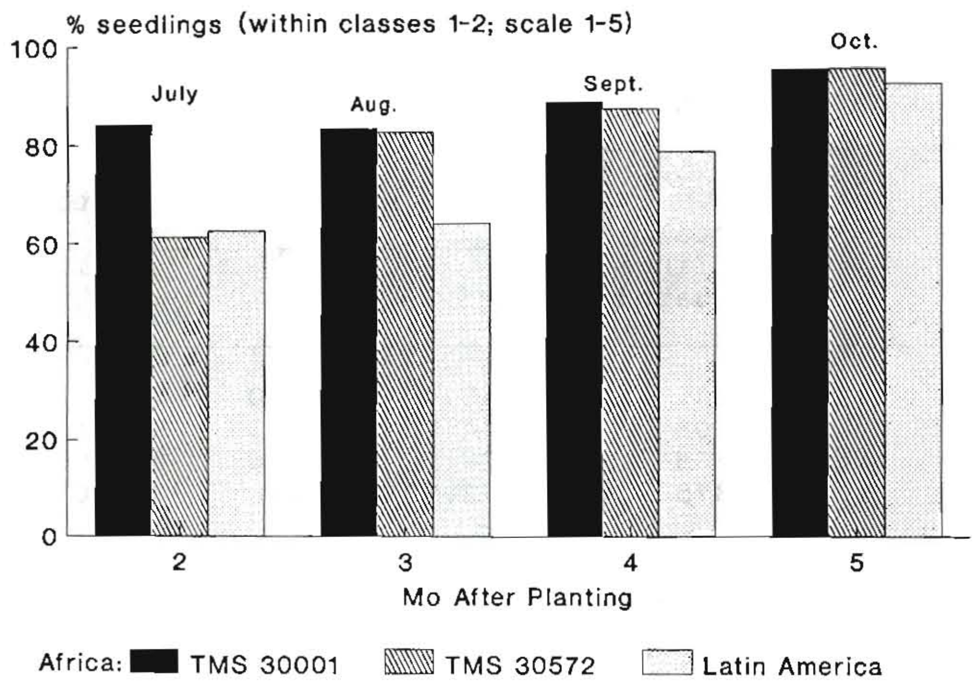


Figure 1.3 Tolerance to CBB in cassava progenies of African and Latin American origin.

Comparison of progenies originated from crosses involving pure Latin American and IITA/CIAT parents shows that the latter present a higher percentage of tolerant individuals (Table 1.30). These preliminary results may reflect not only the degree of resistance of both materials to the disease, but also the adaptation of IITA materials to the conditions prevalent at Onne.

1.4. **Asia**

Some of the world's strongest national programs in cassava varietal development, as well as institutions that are just beginning to develop their research capacity, are found in Asia. Through its regional office in Bangkok, CIAT tailors its collaboration according to individual program needs and requests. The principal areas of input are institutional strengthening through training and network activities; technical input through extensive consulting throughout the region; and facilitating germplasm exchange between CIAT HQ and national programs, and among national programs. Highlights of these areas are presented for 1990.

Table 1.30 Reaction to CBB of progenies of CIAT and CIAT x IITA origin at Ibadan, Nigeria (values represent total no. of individuals in classes 1 and 2 (tolerant) and 3-5 (susceptible) on each evaluation date.[1]

DAT	Total Seedlings Evaluated[2]	Origin of Parents: CIAT		IITA	
		T	S	T	S
50	1281	62.70	37.30	72.81	27.19
90	808	64.28	35.72	83.31	16.69
120	886	78.92	21.08	88.50	11.50
150	875	92.82	7.18	95.80	4.20

[1] Evaluation scale: 1-5 (1 = no symptoms).

[2] Increase in no. of seedlings from 50 to 90 DAP due to sprouting of seedlings previously wilted from CBB.

1.4.1 National program development

A certain structure is necessary for the efficient operation of varietal improvement. The most important is the structure of each national program, which varies greatly from one country to another. Past cooperation had been limited largely to strengthening each national breeding program; however, activities have gradually shifted toward helping national programs as a whole through the formation of a research network, of which CIAT is an important, but one of many, components.

It is useful to consider five phases of national cassava breeding program development in order to assess the present situation, achievements and future directions (Fig. 1.4). CIAT has been highly instrumental in Phase I, "Identification of research needs and establishment of a research program"; and many of the cassava research programs in Asia have been established through the Center's support in this area.

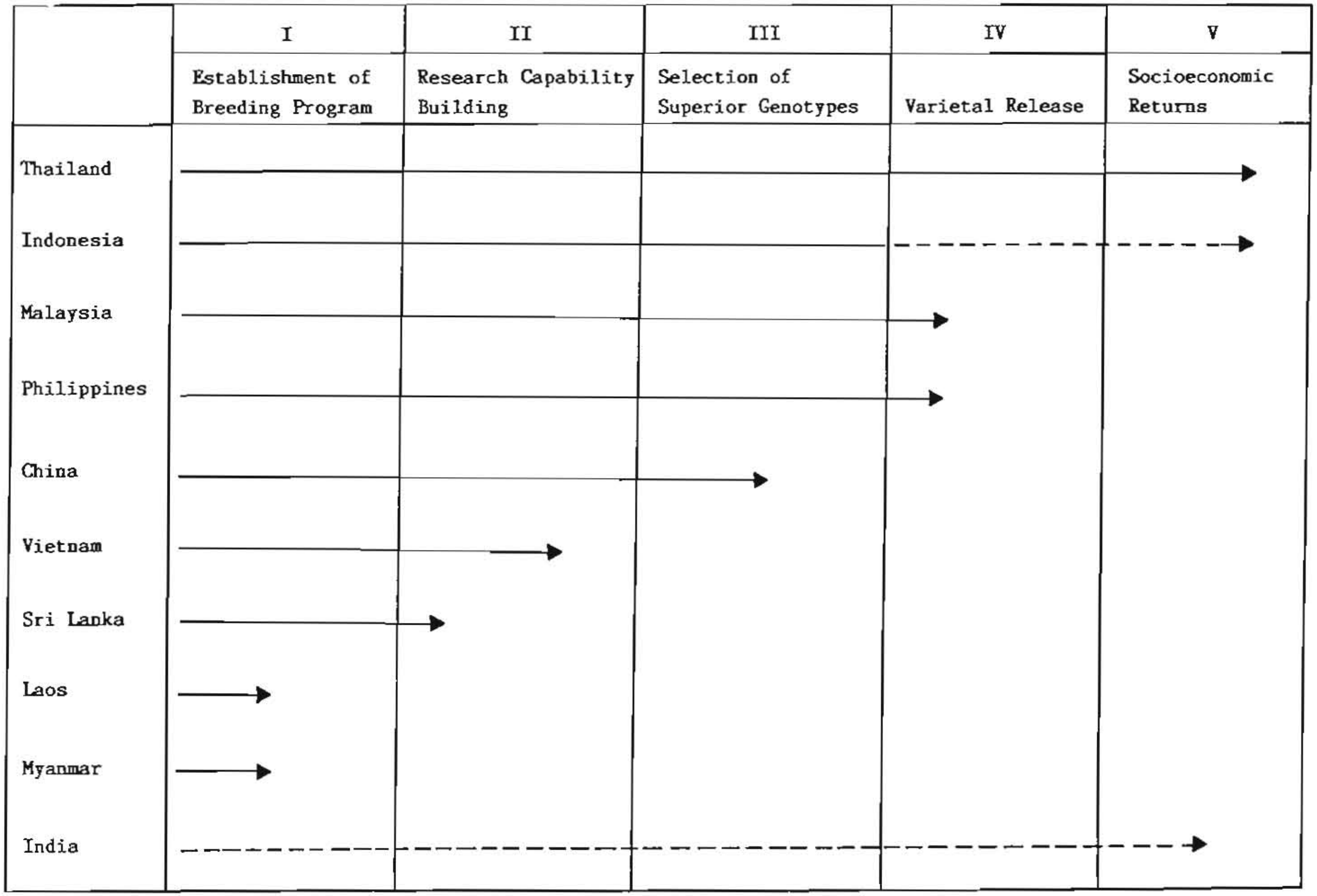
CIAT has acquired considerable expertise in cooperating in Phase II, "Research capability building of national programs." CIAT cooperation during this phase emphasizes training, contribution of genetic materials, and working together in actual varietal selection with the national program personnel.

Phase III, "Selection of superior genotypes," is where maximum progress is currently being made and is dealt with in depth in the next section.

The strength of national programs in Phase IV, "Varietal release and extension," is highly variable. Building on good cooperation in Phase II and III will help national programs gain momentum in varietal release and dissemination. Numerous new varieties have been released by the national programs in the past few years (see later discussion).

Phase V, "Socioeconomic returns of new varieties," is usually the ultimate objective of a breeding program. Given the increasing emphasis on environmental viability and social equity, the assessment of socioeconomic returns becomes ever more complex. Nevertheless, improved production efficiency by new varieties will remain one important facet of new technology to provide additional flexibility for producers and consumers. At last, some 18 years after starting from point zero at CIAT HQ, CIAT-related varieties can be seen planted on tens of thousands of hectares (see later discussion).

Figure 1.4 Development of national cassava breeding program in Asia in relation to CIAT cooperation.[1]



[1] The dotted line for Indonesia corresponds to the progress made with Adira 4, for which most of the credit goes to national organizations; the dotted line for India corresponds to the progress made mostly independent from CIAT cooperation.

1.4.2 Technical progress

Cassava varietal research in a national program typically starts with the collection and evaluation of local germplasm; proceeds to selection from locally produced or introduced hybrid populations; and then to selection from the hybrids among locally selected cross parents, which are often best adapted local varieties and best locally selected introduced genotypes. Selection from local landraces has produced several excellent varieties such as Rayong 1 in Thailand, South China 205 in China, and Black Twig in Malaysia, which are currently supporting the successful cassava industry in Asia. Selection from hybrids among local germplasm also produced an excellent variety (Adira 4) in Indonesia. However, initial selection progress seems to exhaust the chance of further selection with local germplasm rather quickly. Thus virtually all cassava breeding programs in Asia now largely depend on introduced germplasm from CIAT HQ or the Thai-CIAT program as the source of immediate varietal selection and useful cross parents. Many of the cross parents for the CIAT HQ cassava breeding materials distributed to Asia are selections from the original germplasm collection and the hybrids among them identified at CIAT HQ during the 1970s. These breeding materials are characterized by high HI, resistance to some of the major diseases and pests, and tolerance to acid soils. However, they do not necessarily possess vigorous vegetative growth, high root DM content, good plant type, adaptation to drier lowland climate, low root HCN content, or good eating quality. While efforts to further improve in these areas continue at CIAT HQ, the Thai-CIAT breeding program concentrates on improving these traits based on crosses between local varieties and CIAT parents.

During the past eight years, steady progress has been made in mean dry RY of the breeding populations in Thailand (Fig. 1.5a). This progress is even more appreciable when the data are expressed in relative values to the yield of Rayong 1, the highly successful local variety (Fig. 1.5b). The major part of this yield improvement was attributable to improved fresh root yield (Fig. 1.6a); yet improvement in root DM content (Fig. 1.6b) was also significant. As great emphasis had been given during the 1970s to improving HI at the CIAT HQ breeding program and at the Rayong Field Crop Research Center (RFCRC) in Thailand, the breeding population had a high HI at the start of this analysis, and no further improvement took place in HI thereafter (Fig. 1.7a). On the other hand, significant progress occurred in total plant weight of the breeding population (Fig. 1.7b). In recent years the majority of the breeding materials at the RFCRC and the Kasetsart University Sriracha Experiment Station (KU-SRC) breeding centers in Thailand are of good plant type, which is closely related to ease of field management,

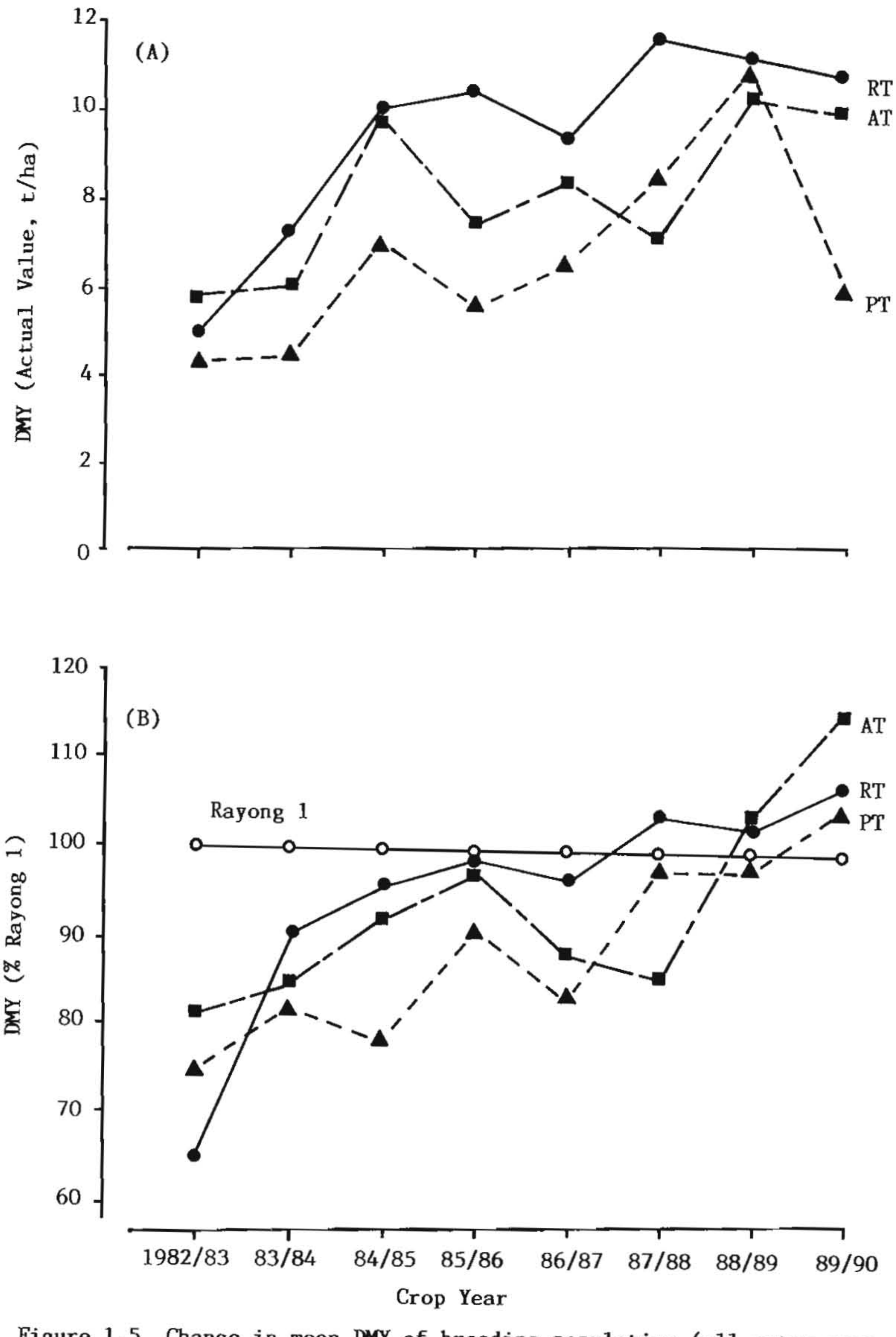


Figure 1.5 Change in mean DMY of breeding population (all-entry mean of yield trials) for 8 years in Thailand (PT = preliminary trial at Rayong, AT = advanced trials at 3 locations, RT = regional trials at 7 locations).

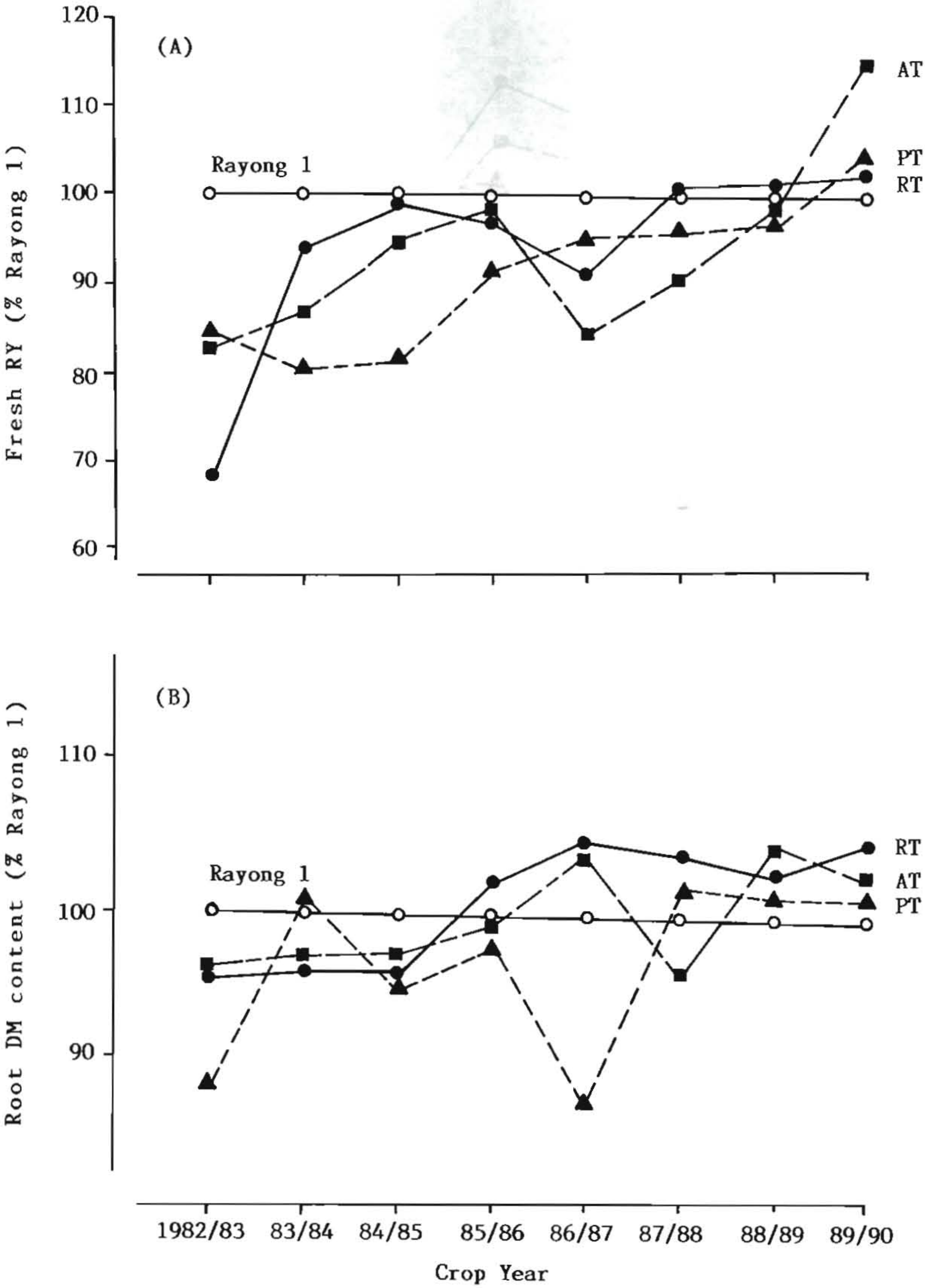


Figure 1.6 Change in mean fresh RY and root DM content (all-entry mean of yield trials) for 8 years in Thailand (PT = preliminary trial at Rayong, AT = advanced trials at 3 locations, RT = regional trials at 7 locations).

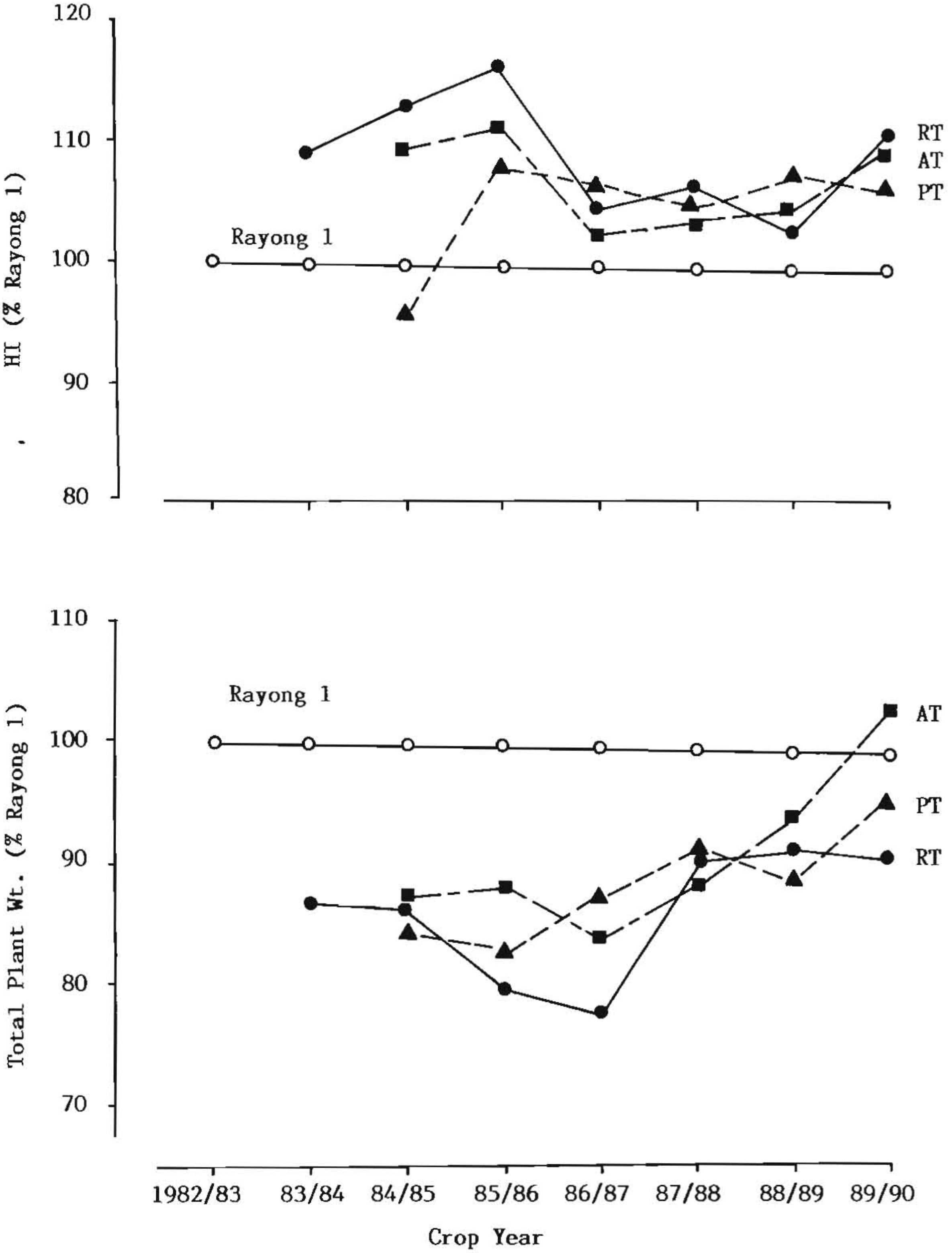


Figure 1.7 Change in mean HI and total plant wt (all-entry mean of yield trials) for 8 years in Thailand (PT = preliminary trial at Rayong, AT = advanced trials at 3 locations, RT = regional trials at 7 locations).

Table 1.31 Result of regional yield trials in Thailand, 1989-90.

Clone	Parents	DMY (t/ha) at (1) SPB	SRC	RAY	RET	BMS	MSK	Mean	Fresh Yield (t/ha)	Total Plant Wt (t/ha)	HI	Root DM(%)	Plant Type(2)
CMR 25-105-112	27-77-10 x Rayong 3	4.2	7.1	8.9	10.5	11.2	27.1	11.5	35.4	57.3	.617	32.4	4
M KUC 28-77-3	Rayong 1 x 21-1	4.9	7.4	6.2	14.1	16.6	18.7	11.3	35.4	59.5	.595	31.9	5
M KUC 28-71-67	Rayong 1 x CMR 23-29-15	4.2	5.6	5.0	13.7	16.6	20.5	10.9	35.4	64.0	.553	30.8	4
CMR 25-27-3	V1 x Rayong 1	4.9	5.4	5.5	10.3	15.6	21.5	10.5	35.7	58.8	.607	29.4	4
Rayong 60	M Col 1684 x Rayong 1	3.8	4.8	5.0	8.8	15.4	23.6	10.2	34.9	60.0	.582	29.2	5
CMR 25-33-105	Rayong 3 x Rayong 1	4.1	7.0	5.7	11.0	14.0	18.7	10.2	31.7	52.2	.607	32.2	4
CMR 28-67-76	Kaset x 21-1	3.8	5.0	6.7	8.6	14.5	20.0	9.8	32.1	57.8	.555	30.5	4
Rayong 1		3.3	4.5	3.4	11.7	13.3	20.3	9.4	32.6	63.1	.517	28.8	5
Rayong 3	M Mex 55 x M Ven 307	2.4	4.4	3.6	10.4	14.8	18.3	9.0	27.1	49.7	.545	33.2	2
CM 4054-40	CM 1015-34 x CM 849-1	3.0	3.3	5.3	7.7	10.4	17.2	7.8	29.5	49.6	.595	26.4	5
Mean		3.9	5.4	5.5	10.7	14.2	20.6	10.1	33.0	57.2	.577	30.5	4.2

(1) Location : SPB = Suphanburi; SRC = Sriracha; RAY = Rayong; RET = Roi et; BMS = Banmai Smarong; MSK = Mahasarakarm.

(2) Plant type (1 = poor, 5 = excellent); mean of 6 locations.

ease of handling planting stakes and good-quality planting material. Thus the significant improvement in total biological yield, root DM and plant type was the major breeding achievement in the Thai-CIAT and cassava breeding program during the 1980s.

One good example that demonstrates the present status of cassava varietal improvement in Thailand is the result of regional yield trials in 1989/90 (Table 1.31). Rayong 1, the world's most successful cassava variety, is basically a high-yielding variety capable of producing 20.3 t/ha dry roots or 61.4 t/ha fresh roots under the high-yielding environment of Mahasarakarm. Yet, in the overall average, virtually all the varietal entries gave higher dry root yield and root DM content than Rayong 1. CMR25-105-112 was outstanding, with an extraordinarily high yield (27.1 t/ha dry or 72.0 t/ha fresh roots) in 11 mo without irrigation and with 4 mo of no rain) at Mahasarakarm. M KUC28-77-3, a selection from the Kasetsart University breeding program, was also outstanding in its ability to give high yields throughout low- to high-yielding environments.

The Thai-CIAT cooperative breeding program--established in 1983 as a cooperative effort among the Dept. of Agriculture, Kasetsart University and CIAT--now has dual functions of varietal development for Thailand and generation of breeding materials for other Asian cassava improvement programs. Encouraging results came from a replicated yield trial conducted at Hong Loc Field Research Center in South Vietnam, in which three recommended varieties from Thailand were compared with a local industrial variety (Table 1.32). Rayong 60 and Rayong 1 outyielded the best local industrial var. Hong Loc 24, both in fresh RY and root DM content, suggesting that the Thai materials can do well under edapho-climatic conditions similar to those of Thailand.

In the wetter climate of Umas Jaya Farm (UJF), Lampung, Sumatra, Indonesia, selections both from CIAT HQ and Thai-CIAT hybrid populations gave encouraging results compared with the performance of a traditional local variety (Table 1.33). The selections of CIAT HQ origin appeared to be slightly superior to those of Thai-CIAT origin, at least in this particular trial. Thus the recent hybrid materials from CIAT HQ offer good opportunities for immediate varietal selection in the wet lowland tropics, while they are a good source of selecting useful cross parents in the seasonally dry lowland tropics of Asia.

1.4.3 Germplasm distribution

Three types of germplasm--i.e., germplasm accessions including recommended varieties, hybrid clones and hybrid seeds--are available from CIAT in the form of stakes, meristem

Table 1.32 Result of a replicated yield trial at Hong Loc Research Center, South Vietnam, 1989-90.

Clone	DMY (t/ha)	Fresh RY (t/ha)	Root DM Content (%)
Rayong 60	10.6	27.2	39.0
Rayong 1	9.9	26.1	37.9
Hong Loc 24 (local)	8.1	23.2	35.1
Rayong 3	7.9	20.9	38.4

Table 1.33 Result of an advanced yield trial at UJF, Lampung, Indonesia 1989-90.

Clone	Parents	DMY (t/ha)	Fresh Yield (t/ha)	Total Plant Wt (t/ha)	HI	Root DM Content (%)	Plant Type(1)	Root Skin Color(2)	Root Flesh Color(3
SM 566-8UJ	M Bra 35	16.0	42.9	60.2	.71	37.2	5	B	W
CM 4049-2UJ	CM 101-19 x CM 849-1	14.3	38.4	64.3	.60	37.2	5	W	WY
CM 4031-10UJ	CM 922-2 x CM 507-37	14.2	36.6	68.4	.54	38.9	3	B	Y
SM 445-2UJ	M Col 1468	13.2	37.6	64.9	.58	35.1	3	B	W
OMR 28-32-7UJ	CMR 23-102-198	12.9	34.7	69.4	.50	37.1	4	B	W
SM 554-3UJ	CM 681-2	12.8	35.3	58.7	.60	36.2	3	W	W
Adira 4	Bogor 528	12.3	33.1	74.9	.44	37.1	4	B	W
SM 564-15UJ	M Bra 5	11.9	32.3	54.3	.59	37.3	5	B	W
SM 483-23UJ	M Bra 5	10.8	29.9	56.0	.53	36.1	3	W	WY
OMR 28-47-10UJ	Rayong 60	10.4	29.0	45.8	.63	35.8	5	W	W
CMR 28-97-4UJ	Rayong 3 x 21-1	9.5	24.0	44.4	.54	39.5	3	W	W
CMR 28-42-3UJ	CMR 23-149-35	9.4	34.6	77.5	.45	36.8	4	B	W
SM 566-15UJ	M Bra 35	7.8	30.4	53.2	.57	35.8	5	B	W
OMR 28-42-1UJ	CMR 23-149-35	6.8	24.3	68.6	.35	35.7	4	W	W
Kretek (local)		5.9	17.8	54.7	.33	33.3	5	B	W

(1) Plant type, 1 = poor, 5 = desirable.

(2) Root skin color, B = brown, W = white.

(3) Root flesh color, W = white, WY = slightly yellow, Y = yellow.

culture or true seeds. The breeding materials from the Thai-CIAT program are being transferred to national programs in each of these forms, depending upon the capacity of the recipient program and the likelihood of accidentally introducing diseases or pests. From CIAT HQ, true seed is the major means of transfer, occasionally supplemented by meristem culture.

During the past 15 years, some 235,000 hybrid seeds from some 4000 crosses have been distributed to the cassava breeding programs in Asia from CIAT HQ (Table 1.34). From this source, various varieties have been selected in several Asian countries and numerous cross parents selected in Thailand. Encouraged by the favorable results of Thai hybrids, first in Indonesia and more recently in South Vietnam, a systematic distribution of Rayong hybrid seeds to Asian national programs started in 1989 (Table 1.35). More than 40,000 seeds had been distributed to 17 institutions in 11 countries by 1990.

A systematic transfer of selected clones, mostly in meristem culture occasionally supplemented by stakes, also started this year (Table 1.36). Recommended varieties in Thailand and the most promising clones from the RFCRC and KU-SRC are included in the list of clones transferred to the eleven countries (Table 1.37).

1.4.4 Varietal release

Varietal selection and multiplication take a long time with cassava. Dissemination of varieties takes still longer. Moreover, official release of recommended varieties has not been the principal means of disseminating new cassava varieties, at least in the past. Thus it will take a much longer time to be able to assess the socioeconomic benefits varietal improvement work brings about for cassava than for major cereal crops. Nevertheless, official release of varieties is one measure of the Program's commitment.

Several new names have been added to the list of recently released CIAT-related cassava varieties (Table 1.34). From now on, the number of varieties selected from local X introduced parents and from Thai-CIAT clonal introductions is expected to become more important.

Table 1.34 Cassava F1 hybrid seeds from CIAT HQ distributed to Asian programs.

	Year														
Country	1975	1977	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Thailand	900	6170	7720	3050	1400	7450	7900	8000	9300	8000	11800	14200	9400	14121	109411
Indonesia	900		700				4600		3050	4950		8600			22800
Philippines	900		950		5100	4700	5500	2350	5000			3850	2386		30736
China						2300	6100		3500	1800	2100	4400	8399	7400	35999
Malaysia	900	1500		2050	1250	4050				200		1490			11440
India	900		850				1050	7900							10700
Vietnam							1900						4250	4500	10650
Sri Lanka									1500						1500
Taiwan	500					1200									1700
Total	5000	7670	10220	5100	7750	19700	27050	18250	22350	14950	13900	32540	24435	26021	234936

Table 1.35 Cassava hybrid seeds from the Thai-CIAT program distributed Asian national programs and CIAT HQ.

Country	No. of Seeds Per Year					
	1985	1986	1987	1989	1990	Total
Indonesia	2950		3130	4893	2840	13813
China				2621	3250	5871
Vietnam				1950	2750	4700
Philippines				3334	2300	4634
Malaysia				1400	1100	2500
India				1350	1350	2700
Laos						
Myanmar					950	950
Sri Lanka					750	750
Israel					750	750
CIAT HQ		1300	2860		2561	6721
Total	2950	1300	5990	14548	18601	43389

Table 1.36 Cassava clones transfered from the Thai-CIAT program to Asian national programs and CIAT HQ.

Country	No. of Clones Per Year			
	1987	1988	1989	1990
Indonesia		3		
China				13
Vietnam			13	13
Philippines		3		13
Malaysia		3		13
India				13
Laos			4	13
Myanmar				13
Sri Lanka				13
Israel				13
CIAT HQ	8			13

Table 1.37 Description of promising clones distributed by the Thai-CIAT program to Asian national programs.

Clone	Parents	Location of Hybridizat.(1)	Location of Selection	Yield Potential	DM Content	Root HCN	Potential Use(2)	Main Characteristic
Rayong 1	(Thai local)	?	RFCRC	+	0	++	AF,ST	Proven industrial var.
Rayong 3	M Mex 55 x M Ven 307	CIAT	RFCRC	0	++	0	ST,AF,FC	High starch
Rayong 60	M Col 1684 x Rayong 1	RFCRC	RFCRC	+	0	++	AF	Early maturing
CMR 25-105-112	27-77-10 x Rayong 3	RFCRC	RFCRD	++	+	+	AF,ST	High DMY
CMR 26-65-13	Rayong 3 x M Col 22	RFCRC	RFCRC	+	0	0	FC,AF,ST	Dual purpose
CMR 29-56-101	CMR 23-149-128 x R1	RFCRC	RFCRC	++	0	++	AF	High yield
M KUC 28-77-3	Rayong 1 x 21-1	KU-SRC	KU-SRC	++	+	+	AF,ST	High DMY
CM 4231-32	CM 982-20 x CM 681-2	CIAT	RFCRC	++	-	0	AF	High yield

(1) CIAT: CIAT, HQ; RFCRC, Rayong Field Crop Research Center; KU-SRC: Kasetsart University Sriracha Experiment Station.

(2) AF = animal feed, ST = starch production, FC = fresh for human consumption.

Table 1.38 CIAT-related clones released as recommended varieties by Asian national programs.

Category/Name	Country	Year of Decision to Release(1)	Clonal Code	Location of Hybridization(2)	Location of Selection	Adaptation to(3)	Potential Use(4)	Main Characteristics
CIAT Clone								
VC 1	Philippines	1986	CM323-52	CIAT	CIAT/PRCRTC	WLT	ST,AF	High yield
Nanzi 188	China	1987	CM321-188	CIAT	CIAT/SCIB	ST	ST,AF	High yield
VC 2	Philippines	1988	M Col 1468	Brazil	Bra/CIAT/PRCRTC	WLT	FC,AF	Table use and high yield
M Col 1684	Philippines	1989	M Col 1684			WLT	ST	High yield
Selected from CIAT Seed Introduction								
Rayong 3	Thailand	1984	CM 407-7	CIAT	RFCRC	DLT	ST,AF,FC	High starch content
Rayong 2	Thailand	1985	CM 305-21	CIAT	RFCRC	DLT	FC	Snack food
Perintis	Malaysia	1988	CM 982-7	CIAT	MARDI	WLT	AF,ST	High yield on peat soils
CM 3590	Philippines	1990	CM 3590-1	CIAT	PRCRTC	WLT	FC,ST	Dual purpose
Selected from Local x CIAT Cross								
Rayong 60	Thailand	1987	CMR 24-63-43	RFCRC	RFCRC	DLT	AF,ST	High early yield
Rayong 5	Thailand	1990	(CMC 76 x V 43)21-	RFCRC	RFCRC	DLT	ST,AF	High starch content
Selected from Local Crosses								
Adira 4	Indonesia	1986	M-31	BORIF	BORIF/UJF	WLT	ST,AF	High starch yield

(1) Given slow multiplication rate of cassava planting stakes, there is usually a 3-yr time lag between the year of decision to release and the actual planting in sizable acreage.

(2) BORIF = Bogor Research Institute of Food Crops; CIAT = CIAT HQ; MARDI = Malaysian Agricultural R&D Institute; PRCRTC = Philippine Root Crop Research and Training Center; SCIB = South China Institute of Botany; UMJ = Umas Jaya Farm.

(3) WLT = wet lowland tropics, DLT = dry lowland tropics, ST = subtropics.

(4) ST = starch production, AF = animal feed, FC = Fresh for human consumption.

2. CASSAVA BIOTECHNOLOGY

The Biotechnology Research Unit (BRU) continued its research and information/technology transfer activities in support of cassava in the areas of germplasm conservation, cryopreservation of cassava shoot tips, pollen culture, genetic transformation of cassava, biochemistry of cassava fermentation, and a cassava biotechnology network.

2.1 **Germplasm Conservation**

2.1.1 Storage under minimal growth conditions and the effect of acetyl salicylic acid (ASA)

With the aim of increasing the transfer time to fresh medium of the in vitro cassava clones, the effect of ASA on the growth and viability of 15 different cassava varieties maintained under in vitro storage conditions for 15 mo was evaluated. This treatment has been reported to improve shoot growth in **Solanum cardiophyllum** (López, 1985) and other species (Dougall 1987).

Two time points (5 and 10 mo) were evaluated, the latter being due in December 1990. Response levels were dependent on the variety; qualitatively, however, all behaved similarly, with the control showing higher levels of defoliation.

10^{-5}M ASA gave the highest number of green nodes and shoots, as well as highest leaf retention. Thus far this concentration of ASA results in the highest viability, making it ideal for long-term storage. 10^{-4}M ASA, on the contrary, had a drastic effect on the plants, most of them dying soon after the onset of the experiment.

The varieties tested were chosen either for their field characteristics or their in vitro storage behavior. The life span of two of them--which show rapid deterioration under normal storage conditions in the Pilot In Vitro Active Genebank (P-IVAG) Project--could be expanded from 9-10 mo up to 14 mo with 10^{-5}M ASA. In general most varieties gave best results with 10^{-5}M ASA; in only a few cases did 10^{-6}M seem to give better results.

2.1.2 Cryopreservation of cassava shoot tips

After defining the conditions for the cryopreservation of seeds and zygotic embryos (BRU Annual Report 1989; Marin et al. 1990; Roca et al. 1989), the cryopreservation project concentrated its efforts on the difficult task of developing cryopreservation protocols for cassava shoot tips in liquid nitrogen. The methodology developed thus far for M Col 22 is simple and reproducible, yielding a high percentage of survival and plant recovery. The next step will be to verify whether this methodology can be applied without modifications to other cassava accessions. Experiments are presently under way involving 12 different cassava accessions, representative of Latin American germplasm, as a first step to test the methodology with a large germplasm collection.

To solve the problems encountered in the cryopreservation of cassava shoot tips required the study of every single factor involved. In 1988 the project was far from finding a solution to the problem: few shoot tips survived the storage in liquid N, and those that did lost their morphogenic capability completely. In 1989 it was possible to push the limit down to -25°C and grow plants from frozen shoot tips. The protocols for the best results obtained were the starting point for the work done during 1990, when it became possible to achieve a survival rate of 10-95% (avg 68%), while plant recovery ranged from 0-44% (avg 19%).

Discussion of the results follows.

2.1.2.1 **The preculture medium.** Previous studies had shown the favorable effects of cryoprotection over a long period of preculture before going into the liquid phase of cryoprotection, which is stronger and shorter in duration. Results of the preculture experiments in osmotic media are shown in Table 2.1. As can be observed, the first shoot tips frozen in liquid N suffered severe damage because only callus was formed by the surviving specimens.

Doubling of the dimethyl sulfoxide (DMSO) concentration with respect to the original protocol slightly increased the survival rate of the frozen tissue, but decreased the no. of plants recovered. Doubling of the sucrose concentration had an overall positive effect, but the contrary was true for the agar concentration.

2.1.2.2 **Cryoprotection.** Table 2.2 shows survival in several experiments and, for the first time, the recovery of plants from in vitro shoot tips frozen in liquid N. The main characteristic of this successful experiment is that the shoot tips were dehydrated after the liquid cryoprotection procedure. Drying the shoot tips for 1 h on sterile filter paper after liquid cryoprotection markedly increased the rate of recovery. Drying at room temp gave better results than drying on ice (35 vs 7% plant recovery).

2.1.2.3 **Shoot tip size.** Shoot tip size is a logistical factor, more labor being involved in isolating smaller specimens (< 1mm) than in large ones (2mm). Large shoot tips had a low survival rate (only 8%) and produced only calli; while for small shoot tips, tissue survival rate rose to 72%, with a plant recovery of 20%. In more recent

Table 2.1 Results obtained with different cryoprotectors in cryopreservation experiments with in vitro cassava (M Col 22) shoot tips.

Composition[1]	Cryoprotector Time (h)	Removed[2]	Survival Lowest Temp (°C)	Recovery (%)
N	2	+	- 25	10 P
	2	-	-196	25 CA
	2+1(3)	+	-196	30 CA
				14 P
N	2	+	- 30	20 CA
	3	+	- 25	90 P
	4	+	- 25	40 P
A	2	+	- 40	20 CA
B	2	+	- 35	20 CA
C	2	+	-196	20 CA
D	2	+	-196	60 CA
E	2	+	-196	20 CA
F	2	+	-196	20 CA
N	3	-	-196	32 CA
D	3	-	- 40	33 CA
E	3	-	-196	40 CA
F	3	-	-196	20 CA
N	3	-	-196	50 CA
N	3	-	-196	30CA

1 N = (MS salts + sucrose 2%) = (C) + sorbitol 1M + DMSO 10%
A = (C) + sorbitol 1M + DMSO 1M + sucrose 0.1M
B = (C) + sorbitol 1M + DMSO 0.5M + sucrose 0.5M
C = (C) + sucrose 1M + DMSO 0.5M + glycerol 0.5M
D = (C) + sorbitol 2M + DMSO 1M + sucrose 0.1M
E = (C) + sorbitol 2M + DMSO 0.5M + sucrose 0.5M
F = (C) + sucrose 2M + DMSO 0.5M + glycerol 0.5M
CA = Calli
P = Plants

2 Cryoprotective solution was removed (+ = yes; - = no) from the cryotube before the cooling-freezing process.

3 Shoot-tips were dehydrated on dry filter paper for one h after two h of cryoprotective action before cooling.

Table 2.2 Results obtained in experiments with different preculture treatments (cv. M Col 22).

	Preculture		Reculture Time (Days)		Survival	
	Medium M[1]	Time (Days)	Medium[2] 1	2	Lowest	Recovery
22	DMSO 0.1	3	3	4	-196	30 CA
23	Sucrose 0.25	7	2	5	- 30	29 CA
24	DMSO 0.1	5	2	5	-196	60 CA
25	ABA 10^{-5}	5	2	5	- 25	10 P
26	ABA 10^{-5}	10	2	5	- 20	50 CA
27	ABA 10^{-7}	10	3	4	- 25	60 CA
28	ABA 10^{-7}	5	2	5	-196	20 CA[3]

1 Sorbitol 1M is included in all precultured media.

2 Reculture medium: 1= sucrose 0.75 M + activated charcoal 0.2% = MS salts (1/2) + sucrose 0.3 M and inositol 1 mg/lt.

3 This surviving shoot tip was not treated with cryoprotective liquid before cooling.

experiments, plant recovery rates have been averaging 50% (Fig. 2.1).

2.1.2.4 **Recultivation conditions.** Washing the DMSO away with medium after thawing had no influence on survival rate, but had a detrimental effect on plant recovery. Several combinations of medium, duration of cultivation, photoperiod and temp were studied for recultivation (Table 2.2).

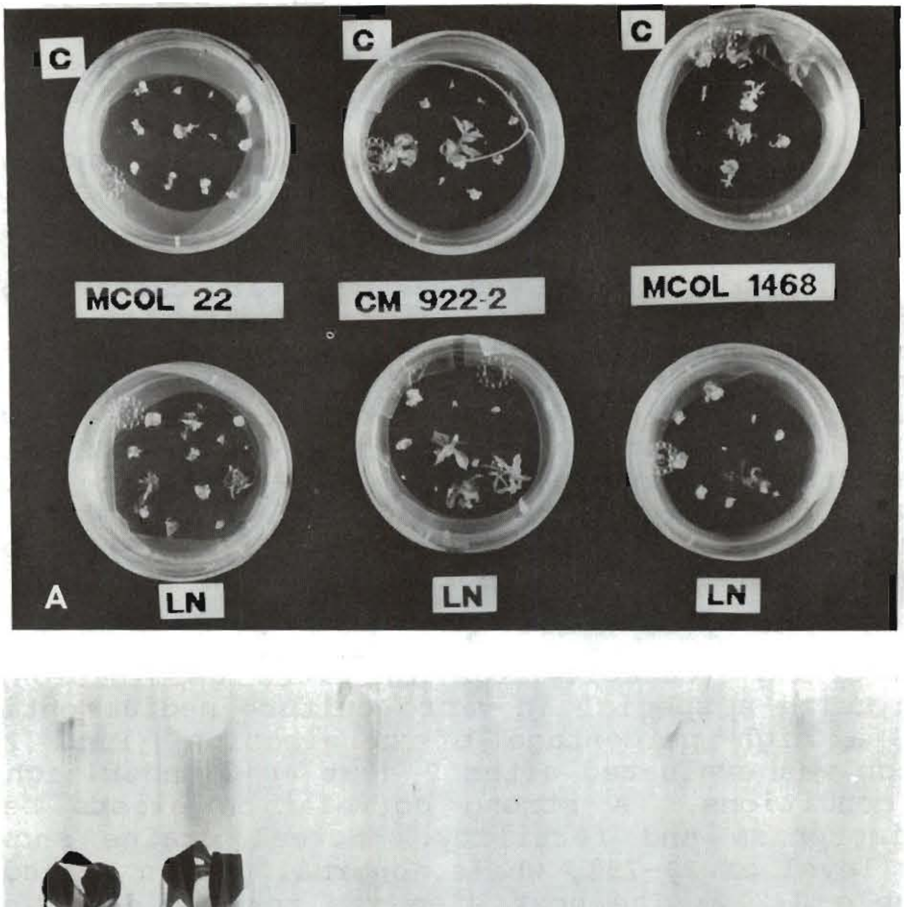


Figure 2.1 Cryopreservation of cassava shoot apical meristems: (a) meristem growth after retrieval from liquid nitrogen and (b) plant growth from cryopreserved meristems.

2.2 **Pollen Culture: Toward a Haploid Methodology in Cassava**

2.2.1 Cassava pollen

Morphologic variants of pollen are found in some plants at anthesis (P-grains), starting at very early stages of pollen development and reflected finally as sterile pollen grains. Such abnormal pollen grains have been considered as potentially embryogenic pollen grains as found in research done on tobacco, barley and peonies. To identify dimorphic pollen from cassava (normal and abnormal) growing in the field, an examination was made of mature flowers excised at anthesis.

At anthesis a dimorphism was evident in cassava pollen grains (Fig. 2.2). Normal pollen grains were 140-160 μm in diameter and contained abundant starch and densely stained cytoplasm. The smaller grains were 80-100 μm in diameter, contained little starch and were characterized by weakly staining cytoplasm (putative P-grains). In view of this, it seemed pertinent to study whether these P-grains represented a particular form of male sterility originating from a deviation from normal male development at the sporophytic-gametophytic transition in the microspore mother cell (Fig. 2.3A).

Pollen fertility (capacity for in vitro germination) was evaluated using a special in vitro culture medium optimized to reach a high percentage of germination (Fig. 2.3B). Germination was evaluated after 2 h at 40°C under light and high RH conditions. A strong correlation exists between pollen dimorphism and fertility. Normal grains showed a fertility level of 23-75%, while abnormal pollen ranged from 0-16% (Table 2.3). The next step was to elucidate whether normal and abnormal pollen grains would exhibit differential behavior in anther and isolated microspore culture.

2.2.2 Anther and microspore culture

Once having hypothetically defined abnormal pollen grains as embryogenic and having characterized cassava microsporogenesis and gametogenesis, the appropriate stage for anther and microspore in vitro culture seemed to be around the tetrad to the uninucleated stage of development; that is, when the flower bud is around 0.8-1.5 mm in size.

The methodology for microspore isolation was modified and optimized. The new method (Fig. 2.4) not only reduces labor time but also reduces sources of contamination. It starts from whole flower buds, which are subsequently macerated and filtered to yield very pure microspore preparations after washing and decantation steps.

Table 2.3 Correlation between pollen dimorphism (i.e., normal and abnormal pollen grains) and their capacity for in vitro germination (i.e., fertility).

	Pollen Dimorphism			
	"Normal" Pollen		"Abnormal" Pollen	
Clone	%	Fertility (%)	%	Fertility (%)
CM 2177-2	85.7	36	14.3	6
CM 2766-5	31.5	31	68.5	4.7
CM 922-2	89.7	23.3	10.3	0
CM 4181-1	84.7	32	15.3	12
CM 91-3	78.3	46	21.7	6.7
CM 507-37	40.3	42	59.7	14.5
HMC 1	80.7	61	19.3	0
CM 3372-4	74	47.5	26.0	6.9
CH 523-7	40	52.7	60	15.8
CM 723	75	37.5	25	5

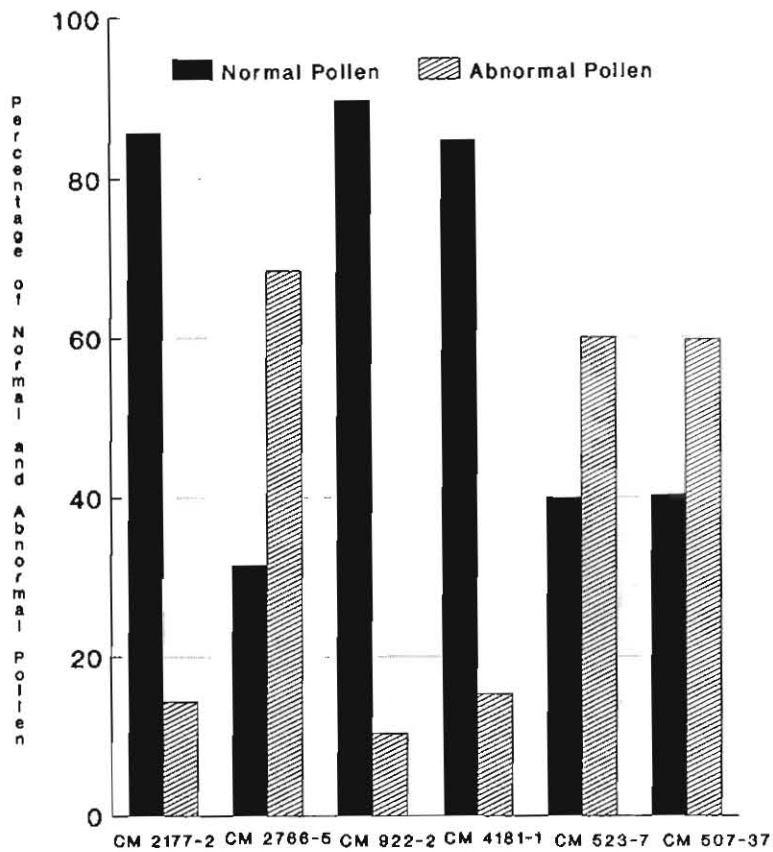


Figure 2.2 Pollen dimorphism in cassava at moment of anthesis.

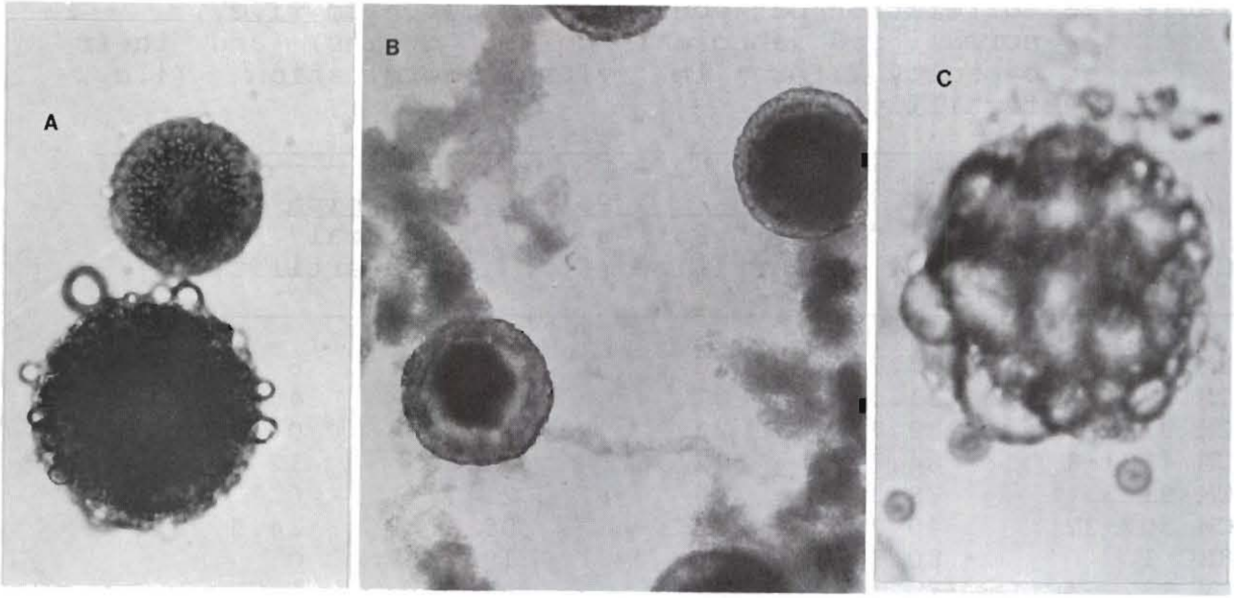


Figure 2.3 (a) Normal and abnormal cassava pollen grains at anthesis; (b) capacity of in vitro germination fertility in normal pollen grains; and (c) isolated microspore showing first mitotic divisions.

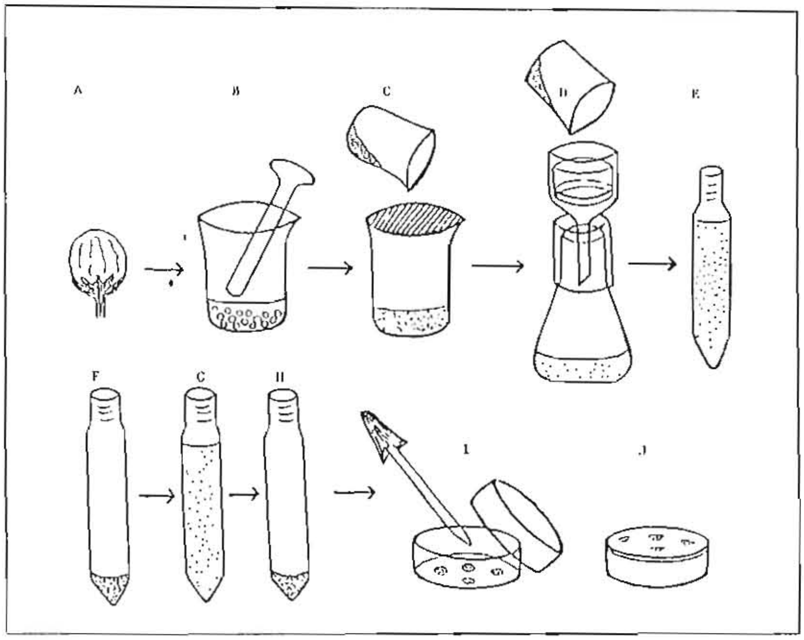


Figure 2.4 Modified, highly efficient methodology for isolating microspore cultures using complete flowers: (a) flower bud, (b) maceration of complete flowers, (c) filtration (750 μ), (d) filtration (double filter 150 μ), (e-f) decanted pollen, (g-h) washing twice with resuspension and decantation, and (i-j) isolated microspore culture in droplets.

Potential embryogenic pollen grains are determined early during pollen ontogenesis. As it has been reported that stressed plants give rise to abnormal pollen grains due to changes in general metabolism, work is being done with cassava plants stressed in the field in cooperation with the Cassava Program Breeding Section.

A total of 300 six-month-old plants representing 55 different clones were stressed in the field using stem girdling. Figure 2.5 shows their response to in vitro anther culture. Among the factors tested were temp, light and different basal media at different pH values modified with various levels of sucrose, vitamins, amino acids, organic additives (coconut water), and the N supplement ratio (NH_4^+/NO_3^-).

Stem girdling increased the frequency of abnormal pollen grains. High temp pretreatment and a specific hormonal balance induced microspores to undergo first mitotic divisions in vitro (CM91-3, CM2766-5), the first step toward androgenesis.

Producing stress by grafting did not work because of incompatibilities between the genera used (Jatrofa, Ricinus). Grafting onto wild species should be tried as the stress produced by the expected hormonal imbalance could lead to higher yields in abnormal pollen grains.

Work is under way to do single-cell culture with isolated microspores, trying to induce sporophytic microspore development. The utilization of conditioned medium for this purpose seems to be one of the relevant factors.

2.3 Genetic Transformation of Cassava

The development of a transformation and regeneration protocol for cassava is of central importance for breeding programs as a means of introducing useful agronomic traits asexually. Infection of cassava by **Agrobacterium tumefaciens** and the associated expression of foreign genes has already been demonstrated (Calderón, 1989), the next step being the production of transformed, regenerated plants.

As a model for developing the transformation/regeneration protocol, the pGV1040 plasmid (PGS, Gent-Belgium) is being used (de Block et al. 1987, de Greef et al. 1989). This plasmid shows the universal applicability of such approaches as it is being used also for developing transformation/ regeneration protocols in common beans and Stylosanthes. This plasmid contains two selectable markers: the **nptII** gene conferring resistance to the antibioticum kanamycin and the **bar** gene conferring resistance to the herbicide Basta (phosphinotricin), as well as a scorable marker, the **uidA** gene (Jefferson 1987), coding for β-glucuronidase (GUS),

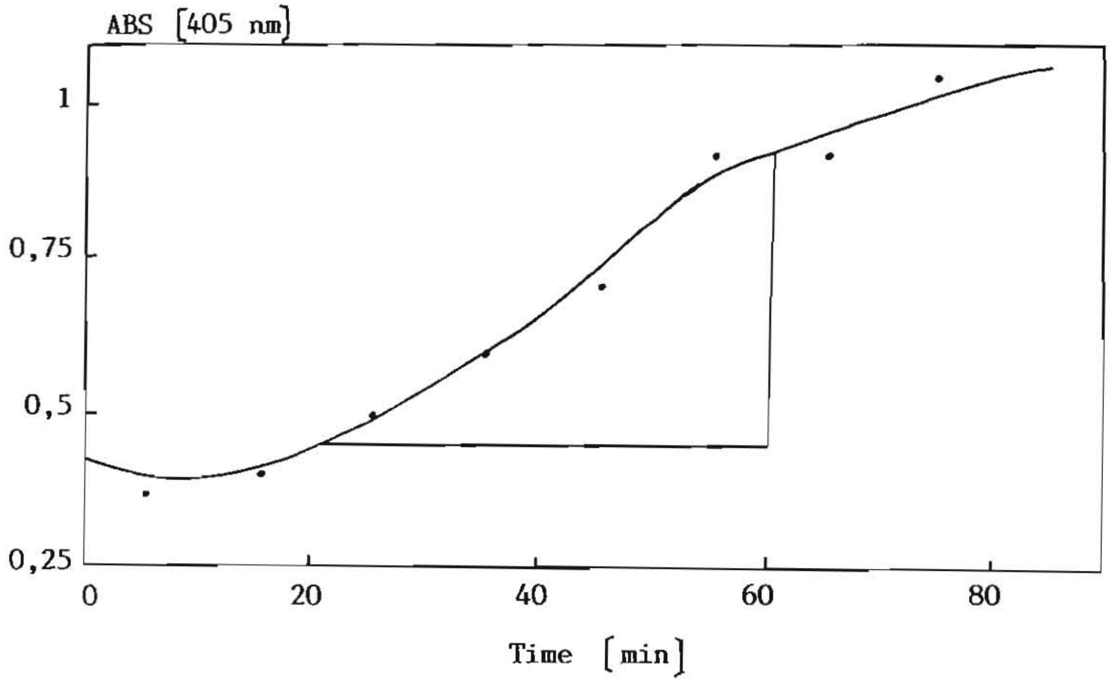


Figure 2.5 Bacterial amylolytic activity with acetone precipitation of supernatant.

which is very useful for histological characterization of the expression pattern and level of the gene in the transformed tissue using the chromogenic substrate X-Gal.

Var. M Col 1505 was chosen as the transformation model because it gave the best response to the somatic embryo regeneration procedure developed at the BRU (Szabados et al. 1986). Two wild **A. tumefaciens** strains isolated at CIAT (1182 and 1183) were chosen from 27 **A. tumefaciens** and **A. rhizogenes** strains tested on the basis of infectivity experiments conducted on var. M Col 22, M Col 1505, M Cub 74 and M Mex 55. Besides the wild-type **A. tumefaciens** strains, the disarmed, nontumorogenic strain EHA 101 (Hood et al. 1986) was used. The plasmid pGV1040 was introduced into all these strains by conjugation or by direct transformation. In the case of the wild-type strains, one can expect transformed tissues that are chimeric with respect to tumor formation and expression of the genes contained in the plasmid. Plants would be regenerated from the nontumorogenic regions of the transformed tissue.

The factors being determined presently are optimal age of embryos for infection, the inoculation system and the period of co-cultivation of the embryos with the bacteria. Other factors being determined are the addition of phenolic compounds that might induce the virulence functions of the

Ti-plasmid, the role of pH, and the influence of stress on bacterial virulence. Following three different protocols, embryos expressing GUS activity have already been obtained, but transformation efficiency has yet to be optimized.

Protocols are being developed for using the particle gun for transformation purposes. The gun accelerates DNA-coated metallic microprojectiles (1 μm in diameter) to high speed so that they can penetrate cell walls without killing the penetrated cell in many cases, thus being a useful vehicle for plant transformation with foreign DNA. Some preliminary bombardments were carried out on roots and embryos, showing GUS transient gene expression from 3 to 20 days later. A high level of transient gene expression usually correlates well with efficient stable transformation. This is one more advantage of the GUS system, which allows a quick assay at any stage of development.

2.4 Genetics of Esterase Isozymes in Cassava

There are only a few existing reports on cassava genetics and cytogenetics, for a number of reasons:

-- Cassava is traditionally propagated by means of stem cuttings from mature plants.

-- About 20% of CIAT's germplasm collection flowers only rarely or never (Hershey, pers. comm.).

-- Seed set through controlled pollination in cassava tends to be low; an avg of 0.8 seeds are formed per female flower (CIAT, 1980).

-- Cassava is probably an allotetraploid with a basic chromosome number, n = 9 (Magoon et al. 1969).

-- Cassava is generally heterozygous; both cross- and self-pollination occur naturally. Although variable among genotypes, selfing produces strong inbreeding depression.

-- The fact that male and female flowers of an inflorescence mature at different times tends to reduce selfing during open pollination.

-- The amount of variation found in cassava, both among and within plants (as heterozygosity), is great, hence the difficulty in finding useful heterozygotic lines for genetic studies.

The electrophoretic characterization of isozymes provides data that differ fundamentally from those derived from morphological characterization or the chemistry of secondary metabolites. The colored band patterns of isozymes on gels represent areas of enzymatic activity catalyzing a particular reaction. Differences in the electrophoretic mobility of enzymes usually reflect changes in the structural genes coding for the corresponding polypeptides, thus being the direct result of genetic differences (Crawford 1983).

Isozyme patterns are simple as compared with those of total proteins, which are very complex; however, some enzymes with nonspecific substrates such as phosphatases and esterases still provide large number of bands. Esterases have often been used for genetic studies given their high degree of polymorphism. Esterases have been reported as monomers and dimers depending on the plant species studied. In potato even a tetramer with three types of subunits has been postulated.

Chavez et al. (1988) reported 16 esterase bands among a population of 100 selected cassava accessions displaying a wide range of the variability present in CIAT's cassava collection. Hershey & Ocampo (pers. comm.) have already found 22 bands in 3288 accessions screened thus far. Based on knowledge from other crops, cassava esterase activities could be codified by 7-11 loci. Like in other crops, the fastest anodical esterase from cassava root tips shows the highest enzymatic activity. This region of the pattern, called EST-1, is codified by one single locus. In an analysis of 100 accessions, Sarria (1989) found the presence of 11 phenotypes in the locus EST-1, some of them displaying a one- or two-band pattern, as well as a null phenotype, suggesting a null allele at this locus. These 11 phenotypes were confirmed in 257 progenies from 7 additional crosses to the 4 (76 progenies) reported last year. The phenotypes observed exhibited 0-, 1- or 2-band patterns, but never a 3-band pattern, suggesting that the esterase at this locus behaves as a monomer. The data were analyzed under hypothetical diploid and tetraploid models, the result being more compatible with a diploid model.

In conclusion, the 11 phenotypes found for the locus EST-1 suggest the presence of 5 multiple alleles including a null allele (A_0 to A_4). These 5 alleles should yield 15 different phenotypes; the 4 invisible phenotypes corresponding to the null allele-carrying heterozygotes.

Preliminary study of the EST-2 locus (intermediate running group of moderate active bands) suggests that EST-2 is a single locus coding for a dimeric enzyme; however, this requires further substantiation.

2.5 **DNA Fingerprinting of Cassava**

The development of RFLP technology has opened a door to detecting, monitoring and manipulating genetic variation in plants in a previously not possible manner (Tanksley et al. 1989). One of the immediate applications of this technology is for assessing genetic variation in natural populations and in phylogenetic studies (Song et al. 1988).

DNA fingerprinting techniques are currently displacing other techniques used to characterize the genome because of their extensive coverage of the genome and their insensitivity to environmental and plant developmental factors--problems often encountered with morphological and even protein markers. DNA-based technology can also detect variation in coding as well as noncoding regions of the genome.

The work presented here involves producing a cassava genomic library and searching for clones that exhibit polymorphisms on 3 cassava varieties included in the P-IVAG project (BRU Annual Report 1989). The primary goal consists of obtaining an intermediate repetitive DNA probe. Such probes give more or less complex hybridization patterns (ca. 20 bands), which may detect differences between closely related accessions. The degree of variation in the P-IVAG, as well as genetic stability after long storage, will be evaluated.

A cDNA library of cassava is currently being prepared. Besides being the source of further clones for genome mapping, this library will be used to isolate genes involved in CO_2 fixation, as the pep-carboxylase, the pep-carboxykinase and the malate dehydrogenase genes. The aim is to elucidate the putative C3-C4 hybrid character of cassava at the molecular level.

2.5.1 Extraction of genomic DNA

The extraction protocol used was similar to that described by Dellaporta et al. (1983). Tissue from M Col 22 was frozen in liquid nitrogen and ground to a fine powder in a mortar. This powder was further extracted with a detergent-containing buffer at 65°C. Proteins and polysaccharides were removed by potassium acetate precipitation. DNA was precipitated from the supernatant with isopropanol and after resuspension, RNase treated, phenol extracted and reprecipitated with ethanol. After resuspension DNA was quantified spectrophotometrically and stored at 4°C.

2.5.2 Cloning of genomic DNA into pUC19

Aliquots of the genomic DNA were digested with one of the following restriction enzymes: Pst I, Eco RI, Bam HI, Xba I or Hind III. Digested DNA was ligated into pUC19 (Vieira & Messing 1982). The constructs were then transformed into Endamoeba coli DH5$_\alpha$, plated out on ampicillin-selective medium and checked for loss of β-galactosidase activity due to insertion into the plasmid's lacZ region with the help of the specific chromogenic substrate X-gal. Plasmids were reisolated from individual colonies, excised with the corresponding restriction enzyme, and their size determined with the aid of \-DNA mol wt standards. The sizes of the inserts obtained ranged from 0.2 to 7 kb.

2.5.3 Search for polymorphisms

The cassava varieties used in this study were M Col 22, M Col 1505 and CM 507-35 from the P-IVAG project. After isolation, DNA from each variety was digested with the following 13 restriction enzymes: Apa I, Bam HI, Dra I, Eco RI, Eco RV, Hae III, Hind III, Hinf I, Hpa II, Msp I, Pst I, Taq I and Xba I (Fig. 2.6). Methylation-sensitive enzymes such as Apa I, Msp I and Pst I cut the DNA ineffectively, suggesting a high degree of methylation of the genomic cassava DNA. There is some evidence that methylation of DNA plays a role in regulating gene expression. By cloning only the fragments cut by Pst I, for example, one can enrich a library for expressed genomic regions as Pst I will not cut highly methylated regions, which are supposedly inactive.

The digested DNA was run on an agarose gel and transferred to a nylon membrane by capillary force (Southern 1975). Whole plasmids containing inserts ranging from 0.2 to 3 kb were labeled by random priming with α^{32}P-dATP to high specific activities (1-10 x 10^8 cpm/μg) (Feinberg & Vogelstein 1983) and hybridized to the nylon membranes containing the blotted restricted cassava DNA.

Polymorphisms were detected with several clones, but usually two clones were necessary to discriminate among the three varieties (Fig. 2.6). Only one Hind III clone has been found that was able to discriminate among the three varieties analyzed. Of 40 clones tested to date, about 10% were intermediate repetitive clones, but none showed polymorphisms among the accessions tested. These clones could still be useful to discriminate among other accessions.

Recently a Pst I clone (P12, 0.7 kb) was found that hybridizes only to M Col 22. Two additional varieties tested (M Ven 82 and M Bra 191 from Venezuela and Brazil, resp.) did not cross-hybridize with P12 either. This sequence might be useful as an RFLP marker or for gene tagging. P12 has been partially sequenced, and homology searches are being run in the Genbank and EMBL databases to identify its function.

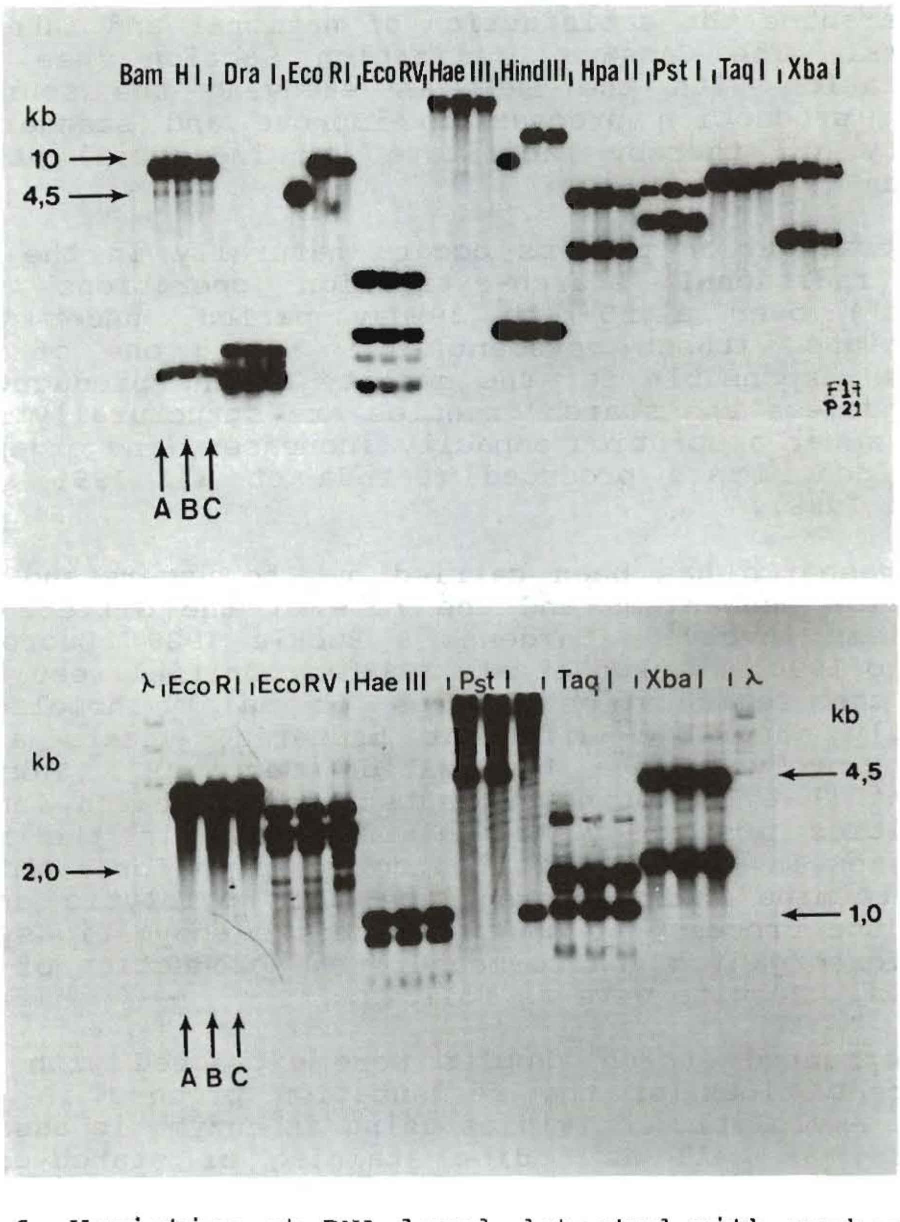


Figure 2.6 Variation at DNA level detected with probes P21 and X14. Restriction endocnucleases Eco RI, Hind III (I) and Pst I (II) detected DNA variation in CM 507-37 (I) and M Col 22 (II), resp. Southern blots were exposed by 2 days at -70°C with intensifier screens.

Sour cassava starch is a typical product obtained through natural fermentation of native cassava starch in Latin America. This product has many applications in the bakery and cookie industry, as well as in the production of some traditional specialties such as cheese bread ("pan de bono"), where its use is irreplaceable because of its specific functional properties. Nevertheless, the product presents many quality fluctuations that make it impossible to guarantee the satisfaction of national and international markets. The Cassava Utilization Section (see 7.4), in cooperation with the BRU, is studying the sour cassava starch production process to improve and standardize its quality and thereby facilitate its industrial utilization (Cereda 1986).

The fermentation process occurs naturally in the tanks of the traditional starch-extraction operations ("rallanderías") over a 25- to 30-day period, under anaerobic conditions without movement, this being one of the main stages responsible for the quality of the product. During this process the starch granules are structurally modified, their water absorption capacity increases, and organic acids and alcohols are produced (Cereda et al. 1985; Zapata & Parada 1988).

Some research has been carried out to understand the fermentation mechanisms and the role of the different microorganisms involved (Cárdenas & Buckle 1989; Ducrocq 1990; Gallego 1990; Nwankwo et al. 1988;). Initial results showed that the fermentation process is mainly homolactic and strictly anaerobic--different bacteria, yeasts and molds being involved (see Utilization Section). Taking into account that the principal substrate is starch, amylolytic activities must play the central role in the metabolic processes involved. This led to a search for a methodology to determine and differentiate the amylolytic activities along the process, to characterize the enzymatic systems of the microorganism and to measure the production of excreted enzymes. Results were as follows:

The fermented starch samples were extracted with water at different times of the fermentation process in order to detect amylolytic activities using an enzymatic assay for α-amylase, as well as iodine staining of starch-containing acrylamide gels. A new technique was adopted that involved running the samples in acrylamide gels and then electrotransferring the proteins to a second gel containing starch, where the iodine staining takes place (Kakefuda 1984).

To increase the sensitivity of the method, starch concentration in the gels was reduced from 0.52% as described, to

0.02% to detect better the amylolytic activities on the iodine-stained, otherwise dark, background. This modification improved detection considerably. Dilutions of the commercial α-amylase were made (1:5 to 1:3125) to determine the sensitivity of the method. The starting concentration was 6 u/μl. It was possible to detect the activity down to a dilution factor of 625, which is equivalent to 0.0096 u/μl.

Besides showing amylolytic activity, the iodine-staining procedure yields different colors for each amylolytic enzyme: orange and blue for β-amylase, purple for pullulanase, and transparent for α-amylase.

To find out whether this procedure was adequate for detecting excreted amylolytic activities, an amylolytic bacterium isolated from cassava starch fermentation was used. The bacterium was grown in starch-containing medium; pelleted by centrifugation; and the supernatant was either directly used for activity measurements or the proteins were acetone precipitated. Additionally, cassava extract was obtained (squeezed and centrifuged juice) to detect amylase activity on acrylamide gels (Fig. 2.5).

The transfer step has been simplified in that the electrophoretically separated proteins are directly blotted by capillary forces onto the starch containing gel. This process has been optimized, the entire procedure taking just 1 h at 28°C in a moist atmosphere. The amylolytic activities are detected with iodine as highly resolved, colored bands on the starch-containing gels. The control enzymes used were commercial preparations of α-amylase, β-amylase, amyloglucosidase, isoamylase, pullulanase and maltase.

A balance of the mineral salts was made to define better the fermentation conditions that will preferentially lead to homolactic and more efficient fermentation. Thus far samples of day 0 and 15 have been analyzed. Results indicate that P might be a limiting factor during the fermentation process. (Phosphorylation of the reducing sugars is one of the first metabolic steps in starch degradation.) Elemental analysis will also be done in fractions following the profile of the fermenting starch mass to determine whether the process is homogeneous.

This electrophoretic methodology will be used to select and classify isolated amylolytic microorganisms through their respective patterns. These patterns will make it possible to monitor the presence and development of the amylolytic activities throughout the fermentation process.

2.7 **The Pilot In Vitro Active Genebank (P-IVAG) Project**

During the three-year period of the P-IVAG project, important components of the establishment and operation of an in vitro active genebank were assessed (see the BRU 1989 report). This year the project concentrated on two objectives: monitoring the effect of (a) subculture frequency during in vitro storage on genetic stability of three cassava genotypes with striking morphological and isozyme pattern differences (M Col 22, M Col 2264 and M Pan 127); and (b) storage time on stability using 10 clones maintained under slow growth conditions for 9 to 10 years in the world cassava in vitro collection at CIAT. These clones have been micropropagated 8 times on the average.

2.7.1 Subculturing frequency

Polyacrylamide gel electrophoresis (PAGE) for two isozyme systems α β, EST and α, β ACP and morphological evaluation of the in vitro material were carried out. The morphological descriptors were: no. of shoots, presence or absence of callus, roots, aerial roots and etiolation.

The first micropropagation yielded four cultures, the second gave rise to eight, the third to 16, and so on. Of the four morphological evaluations performed to date, no differences from the patterns of the controls have been found. As for the electrophoretic patterns, the major bands also remained unchanged.

2.7.2 Storage time

Genetic stability was evaluated on the basis of changes in EST, ACP, GOT and DIAP electrophoretic patterns. The electrophoretic patterns of the control and the material from storage showed stability in every isozyme tested for 7 of the 10 varieties. Fourteen isozymes, in two running systems, were done with the P-IVAG material. No changes were found after storage. Results are summarized in Table 2.4.

The database developed for the P-IVAG has been updated systematically. The raw data collected during the four years of the project related to passport, field characterization, disease indexing, electrophoresis, storage location details, in vitro viability evaluation, and all the technical and logistical aspects of the project have already been classified and fed into the database.

Table 2.4 Results obtained with 14 isozyme systems using two buffer systems for root tips of 11 cassava varieties.[1]

	Buffer System[2]	
Isozyme System	Lithium-Borate (pH 8.1)	Histidine-Citrate (pH 6.5)
Peroxidase	HA-LP*	LA-LP
Malic enzyme	HA-LP*	HA-LP
Glucose 6 phosphate dehydrogenase	HA-LP*	LA-LP
Phospho-gluco dehydrogenase	HA-LP*	LA-LP
Glutamate dehydrogenase	LA-LP	HA-LP*
6 phospho-gluco dehydrogenase	HA-LP*	LA-LP
Malate dehydrogenase	LA-LP	HA-HP*
Shikimic dehydrogenase	LA-LP	LA-HP*
Diaphorase	LA-HP	HA-HP*
Isocitric dehydrogenase	LA-LP	HA-LP*
Phospho glucomutase	LA-LP	HA-HP*
Sulfoxide dismutase	NA	NA
Hexokinase	NA	NA

1 M Bra 12, M Bra 132, M Col 304, M Col 1684, M Col 2131, M Col 2264, M Ecu 72, M Mex 8, M Per 328, M Ven 82 and M Mex 55 as control.

2 HA = high degree of activity; LA = low degree of activity; HI = high degree of polymorphism; LP = low degree of polymorphism; NA = nonactivity.

* Suggested system.

2.8 The Cassava Biotechnology Network

Through the collaboration of CIAT, IITA and many other national and international agricultural research institutions interested in cassava, the Cassava Biotechnology Network (CBN) was organized in a workshop held at CIAT in September 1988. Feedback from individual scientists and research institutions has allowed prioritization of cassava constraints for advanced research. The approach through a network of cooperating researchers has been received with a wide level of general acceptance by the agricultural scientific community and national and international funding agencies. This is evidenced by the number of research projects under way in just two years. Table 2.5 shows the existing 20 research projects in developed and developing countries as of September 1990 in comparison with 4 projects in September 1988.

Table 2.5 Research projects under way in the CBN (Sept. 1990).

Subject	Institutions	Funding
Cyanogenesis	U. of Newcastle upon Tyne	RF/EEC
	Royal Vet. & Agric. U., Denmark	RF/EEC
	Mahidol U., Thailand	RF/EEC
	Ohio State U., Columbus, OH, USA	USAID
	Free U., Amsterdam, Netherlands	
Virus resistance	Washington U., St. Louis, MO, USA	ORSTOM/RF/ USAID
Insect resistance	Washington State U., Pullman, WA, USA	RF
Photosynthesis	Australian National U., Canberra	AIDAB
	U. of Georgia, Athens, GA, USA	USAID
Plant regeneration tech.	U. de Paris, Orsay, France	EEC
	U. of Bath, UK	ODA
	U. of Zimbabwe	DGIS
	U. de San Marcos, Lima, Peru	CAF
Genetic transformation tech.	CENARGEN, Brazil	ICGEB
	CIAT, Colombia	Core
Gene expression & regulation	U. of Singapore	
Radiation-induced variability	IAEC, Vienna, Austria	
Genome structure	CIAT, Colombia/IBPGR	
RFLP mapping/DNA fingerprinting	Washington U., St. Louis, MO, USA	RF
Other	CIAT, Colombia	Core
	IITA, Nigeria	Core

A proposal was presented to the Netherlands Agency for International Cooperation (DGIS) in order to seek financial support for the activities of the CBN in the next 5 years including coordination of the network, network meetings, training of developing countries scientists, bridging funds for critical research areas and research projects in developing countries. The proposed activities for which funding has been requested include two major interrelated components:

-- Bridging support of critical research initiatives and support for training of developing country scientists

-- Operation and coordination of the network activities

2.8.1 Research and training activities

-- Catalyzing and facilitating specific research initiatives including short-term bridging in support of particular research initiatives

-- In-service training: short-term technique-oriented training of developing country scientists in advanced laboratories

2.8.2 Network operation and coordination

-- **Scientific meetings** every second year to promote information exchange and discussion, encourage new ideas and new participation. (first meeting scheduled for August in Cartagena.)

-- **Steering Committee meetings:** Yearly meetings are proposed to guarantee continuous interaction among the constituting members, their role being to advise on the functioning of the network including periodic reviews of research projects under way and new proposals, planning of scientific meetings, training needs, communication media and funding possibilities.

-- **Communications:** Preparation of an introductory brochure on the Network; publication of a network newsletter twice a year; other network publications such as reports and proceedings on an ad-hoc basis.

-- **Coordination:** CIAT has been providing initial coordination since 1988; but as the network evolves, the increasing work load calls for the appointment of a full-time coordinator/scientist at CIAT.

2.9 References

Calderon, A. 1988. Transformation of **Manihot esculenta** (cassava) using **Agrobacterium tumefaciens** and expression of the introduced foreign genes in transformed cell lines. MSc thesis, Vrije Universiteit Brussels, Belgium.

Cárdenas, O.S. and Buckle, T.S. 1989. Preliminary studies of the reaction mechanisms involved in sour cassava starch production. Document IIT, Bogotá, Colombia.

Cereda, M.P. 1986. Tecnologia e qualidade do polvilho azedo. Reporte interno.

________; Bonassi, I.A.; Brasil, O.G.; Matsui, E. 1985. Ensaios de fermentacao da fecula de mandioca em diferentes condicoes de cultivo, RBM Cruz das Almas (BA) V, III, 2, pp. 69-81.

Chavez, R.; Roca, W.M.; Arias, D.I.; Withers, L.A.; and Williams, T. 1988. Cooperative IBPGR and CIAT pilot project test feasibility of in vitro conservation. Diversity 16:8-10.

Crawford 1983.

de Block, M.J.; Bottermann, J.; Vandewiele, M.; Dockx, J.; Thoen, C.; Gossele, V.; Rao Movva, N.; Thompson, C.; Van Montagu, M. and Leemans, J. 1987. Engineering herbicide resistance in plants by expression of a detoxifying enzyme. EMBO J 6:2513-2518.

de Greef, W.; Delon, R.; de Block, M.; Leemans, J. and Bottermann, J. 1989. Evaluation of herbicide resistance transgenic crops under field conditions. Bio/Technology 7:61-64.

Dellaporta, S.L.; Wood, J.; and Hicks, J.B. 1983. A plant DNA minipreparation: version II. Plant Mol Biol Rep 1:19-21.

Dougall, D.K. 1987. Primary metabolism and its regulation in plant tissue and cell culture. Proceedings of the VIth Internationl Congress of Plant Tissue and Cell Culture. Alan R. Liss Inc., NY, pp.97-117.

Ducrocq, S. 1990. Etude de la fermentation lactique de l'amidon de manioc. Thèse Ingenieur Agricole ESITPA, Angers.

Feinberg, A. and Vogelstein, B. 1983. A technique for radiolabeling DNA restriction endonuclease fragments to high specific activity. Anal Biochem 132:6-13.

Gallego, V. 1990. Perfeccionamiento de los métodos de estudio de la fermentación de almidón agrio. Reporte de trabajo CEEMAT/CIRAD.

Hood et al. 1986. The hypervirulence of Agrobacterium tumefasciens A281 is encoded in a region of pTiBo542 outside of t-DNA. J. Bacteriol. 168:1291-1301.

Jefferson, R.A. 1987. Assaying chimeric genes in plants: the GUS gene fusion system. Plant Molec Biol Rep.

Kakefuda, G.; Duke, S. 1984. Electrophoretic transfer as a technique for the detection and identification of plant amylolytic enzymes in polyacrylamide gels. Plant Physiol 75:278-280.

López, H.A. 1985. Efecto del ácido acetil salicílico en el crecimiento de yemas de Solanum cardiophyllum (Lindl.) cultivados en vitro. Tesis de Maestría, Colegio de Postgraduados, México.

Magoon, M.L.; Krishnan, R.; and Vijoyabai, K. 1969. Morphology of pachytene chromosomes and meiosis in Manihot esculenta Crantz. Cytologia 24:612-626.

Marin M.L.; Mafla, G.; Roca W.M.; and Withers, L.A. 1990. Cryopreservation of cassava zygotic embryos and whole seeds in liquid nitrogen. Cryo-Letters 11:257-264.

Nwankwo, D.; Anadu, E.; Usoro, R. 1988. Cassava fermenting organisms. MIRCEN Journal 5:169-179.

Ocampo, C.H. 1988. Identificación de genes marcadores en yuca (Manihot esculenta, Crantz). Tesis, Univ. del Valle.

Roca W.M.; Chavez R.; Marin, M.L.; Arias D.I.; Mafla, G.; and Reyes, R. 1989. In vitro methods of germplasm conservation. Genome 31:813-817.

Sarria, R. 1989. Estudios de la herencia y variabilidad genética de isoenzimas en poblaciones F1 de yuca (Manihot esculenta, Crantz). Tesis, Univ. del Valle.

Song, K.M.; Osborn, T.C.; and William, P.H. 1988. Brassica taxonomy based on nuclear restriction fragment length polymorphism (RFLP). Theor Appl Genet 75:784-794.

Southern, E. 1975. Detection of specific sequences among DNA fragments separated by gel electrophoresis. J Mol Biol 98:503.

Szabados, L.; Hoyos, R. and Roca, W.M. 1987. In vitro somatic embryogenesis and plant regeneration of cassava. Plant Cell Rep 6:248-251.

________ and Roca, W.M. 1986. Regeneration of isolated mesophyll and cell suspension protoplasts to plants in **Stylosanthes guianensis**, a tropical forage legume. Plant Cell Rep 3:174-177.

Tanksley, S.D.; Young, N.D.; Paterson, A.H.; and Bonierbale, M.W. 1989. RFLP mapping in plant breeding: New tools for an old science. Biotechnology 7:257-264.

Vieira, J. and Messing, J. 1982. The pUC plasmids, an M13mp7-derived system for insertion mutagenesis and sequencing with synthetic universal primers. Gene 19:259-263.

Zapata, L.E. and Parada, J.L. 1988. Almidón agrio de yuca: Aspectos tecnológicos y microbiológicos, Documento IIT, Bogotá, Colombia.

3. CASSAVA PATHOLOGY AND VIROLOGY

3.1 Research in Pathology

Special emphasis was given in 1990 to research on the mycoplasmlike disease witches' broom and root rots present in different ecological regions. Research on biocontrol of cassava diseases, cassava endophytes and storage of planting material was also carried out.

3.1.1 Witches' broom

Results are reported here of three years' research (CIAT Annual Reports 1987-1989) conducted in cooperation with the Cassava Integrated Development Project in Ceará, the Dept. of Agriculture of the State of Ceará, and the National Center For Research on Cassava and Fruits (CNPMF-EMBRAPA).

Data on plots of 11-month-old healthy and diseased plants of the traditional clone Cruvela Rastreira, derived from stakes collected from symptomless plants in plantations with different percentages of infection, show the following (Table 3.1):

-- Root weight and aboveground plant weight (AGPW), as well as HI, of healthy and diseased plants did not show any statistical difference among plots whose stakes were taken from plantations with different percentages of infection. This indicates the relatively stable sanitary condition of most plants during the growing cycle.

-- The root weight of healthy plants was 57.9% greater than that of diseased plants, indicating that disease losses induced by witches' broom can be of great magnitude in this traditional clone.

-- The ABPW of healthy plants was 28.6% less than that of diseased plants as a result of shoot proliferation induced by the pathogen.

-- As a consequence of the two foregoing findings, the HI of diseased plants was lower than that of healthy plants. Most carbohydrates produced by diseased plants are utilized to produce shoot tissue.

When stakes were taken from a 25%-affected plantation, the losses induced by witches' broom averaged 51%; but losses can range from 23.5 to 87.1%, depending on the level of infection of the mother plants (Table 3.2). This indicates that losses induced by this disease are related to the infection status of the mother plants.

Table 3.1 Root weight (RW) and AGPW (kg/plant),[1] and HI of healthy and witches'-broom diseased plants of 11-month-old Cruvela Rastreira after planting selected stakes from symptomless plants taken from plots with different percentages of infection.

% Infection of Source Plots	Replications	Healthy Plants			Diseased Plants		
		RW	AGPW	HI	RW	AGPW	HI
95	1	2.1	2.0	0.51	1.4	3.0	0.32
	2	2.4	2.8	0.46	2.2	3.6	0.38
	3	2.3	2.8	0.45	1.5	3.4	0.31
	$\bar{X}$	2.3	2.5	0.47	1.7	3.3	0.34
50	1	2.3	2.6	0.47	1.3	3.2	0.29
	2	2.2	2.1	0.51	1.9	3.6	0.35
	3	1.8	2.1	0.46	2.4	3.1	0.44
	4	2.2	2.3	0.49	1.8	3.0	0.38
	$\bar{X}$	2.1	3.0	0.48	1.9	3.2	0.28
25	1	2.8	2.1	0.57	1.8	3.7	0.33
	2	2.9	2.3	0.56	1.1	2.9	0.28
	3	2.7	2.5	0.52	2.1	3.3	0.39
	4	3.6	3.1	0.54	2.5	3.9	0.39
	$\bar{X}$	3.0	2.5	0.55	1.9	3.5	0.35

[1] Avg data taken from 5 plants each.

Table 3.2 Losses induced by the mycoplasmlike witches' broom of cassava in the regional clone Cruvela Rastreira 11 mo after planting unselected stakes from a 25%-affected plantation.

Replicate	Root Yield (t/ha)		Yield Reduction(%)
	Unselected Stakes	Healthy Controls	
1	13.2[1]	16.3	23.5
2	10.0	15.6	56.0
3	12.0	16.5	37.5
4	9.3	17.4	87.1
$\bar{X}$	11.3	16.5	51.0

[1] Data taken from 15 plants/rep/treatment.

The incidence of witches' broom disease of cassava was reduced drastically by planting stakes selected from symptomless plants; but percent disease reduction was related to the percent infection in plots from where mother plants were taken (Table 3.3). This indicates that the disease can be controlled by selecting symptomless plants from the least affected plantation in the endemic area.

The percent of symptom remission induced by the witches' broom pathogen was drastically reduced after planting stakes from infected plantations in a neighboring nonendemic area (Table 3.4). This indicates that the disease can also be controlled by producing planting material in areas where ecological conditions restrict pathogen multiplication and invasion into the host.

Thus witches' broom disease can be reduced both by planting stakes from symptomless plants and by producing stakes in locations where environmental conditions reduce pathogen infection. Commercial implementation of these control measures has commenced in the Ibiapaba region of Ceará State, Brazil.

3.1.2 Biological control of cassava diseases

3.1.2.1 **Control of root rot causal agents by fungal species.** A strain of Trichoderma sp., isolated from the root rhizosphere of a cassava plantation, showed promising results in vitro for controlling root rot causal agents. The strain inhibited growth of Diplodia manihotis, Fusarium solani and F. oxysporum; however, it was unable to inhibit the growth of Phytophthora dreschleri or P. nicotianae var. nicotianae. Nevertheless, these two species of Phytophthora were rapidly colonized only 5 days after infection (Table 3.5). Trials to determine the effectiveness of this strain in controlling root rots under field conditons, as well as attempts to isolate more efficient strains of this species from different ecological areas, are under way.

3.1.2.2 **Control of root rot pathogens by beneficial bacterial species.** Two strains of Pseudomonas fluorescens (Pf F-259 and Pf F-44) significantly increased the root weight of two cassava clones (M Col 1468 and CM 342-170) after root inoculation in the early stages (1 mo after germination) with P. nicotianae var. nicotianae under greenhouse conditions (Table 3.6).

These results are similar to those reported in 1988 for controlling other root rot pathogens under greenhouse conditions (CIAT Annual Report 1988), suggesting likelihood of success under field conditions. Commercial plots of M Col 2215 (susceptible) and M Col 1505 (resistant) were planted in a D. manihotis-endemic area (La Colorada, North

Table 3.3 Reduction of symptoms of witches' broom disease of cassava over two cycles by planting selected stakes from visually symptomless plants.

% Infection of Source Plots	Total No. Plants Evaluated[1]	Disease Symptom Reduction (%)		
		First Cycle		
		6 mo	12 mo	2nd Cycle
95.0	52	51.9	22.0	87.7
50.0	400	94.1	75.5	88.0
25.0	600	97.9	87.5	92.9
0	500	100.0	100.0	100.0

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

Table 3.4 Remission of symptoms of witches' broom disease by planting infected stakes in a location with unfavorable environmental conditions for disease development.

Clone	% Symptom Expression at Favorable Site (First Cycle)	% Symptom Expression at Unfavorable Site (2nd Cycle)	% Symptom Expression Back at Favorable Site (3rd Cycle)
Cruvela Rastreira	95.3[1]	0	4.5
Cruvela Vicosae	27.4	0	10.0

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

Table 3.5 Fungal inhibition and colonization of a Trichoderma sp. strain on 5 cassava root pathogens.

Pathogen Species	Inhibition[1]	Colonization[1]
Diplodia manihotis	+++[2]	++
Fusarium oxysporum	++	+
F. solani	+	+
Phytophthora drechsleri	-	+++
P. nicotianae var. nicotianae	-	+++

1 Inhibition = fungal growth inhibition; Colonization = mycoparasitism on fungal host colony.

2 -,+,++,+++ = Absent, low, intermediate, severe inhibition or colonization.

Table 3.6 Biocontrol of Phytophthora nicotianae var. nicotianae (P.n. var n.) with Pseudomonas fluorescens (P.f. C-259 and P.f. F-44) on two cassava clones under greenhouse conditions.

Treatment	Root Weight (g)[1]	
	M Col 1468	CM 342-170
P.n. var. n.+ P.f. C-259[2]	1.49a	3.35a
P.n. var. n.+ P.f. F-44	1.44a	2.85a
Control	1.96a	2.83a
P.n. var. n.	0.44b	1.07b

1 Avg root wt of 20 plantlets/treatment 2 mo after treatment; plantlets grown under greenhouse conditions (26°C ± 10°C, 80% RH).

2 Plantlets inoculated by pouring 30 ml of a suspension of 1.1 x 10^9 cfb/ml/pot of the P.f. strain; and 30 ml of 1 x 10^4 zoospore/ml/pot of the pathogen 5 days before planting.

Coast of Colombia), where CBB and anthracnose normally occur at low levels of severity. Stakes were dip-treated and plants sprayed monthly with a bacterial suspension (strain P.f. C5a). Results showed a yield increase of 28 and 123% for the susceptible clone M Col 2215 when planted with stakes taken from commercial plantations or from meristem culture-derived plants, resp. (Table 3.7). The lowest yield was obtained on plots planted with untreated stakes of the same susceptible clone obtained from meristem culture-derived plants (Table 3.7). The highest disease rating was also shown on untreated plants from stakes taken from meristem culture-derived plants, indicating the efficiency of the protective effect exerted by the native microflora living on stakes taken from commercial plantations. This microflora is probably acquired after many growing cycles. Finally, the bacterial treatments did not increase yield levels significantly on the resistant clone M Col 1505 because the intrinsic genetic resistance of this clone overcame the possible stresses caused by the pathogens.

These results open up the possibility of using strains of fluorescent pseudomonads commercially to prevent root and foliar diseases on susceptible cassava clones; their commercial deployment in various production systems is being investigated.

3.1.2.3 **Effect of native microflora on disease protection.** The effect of native microflora on disease protection was reported in 1988 from data taken on experimental plots planted with stakes taken from commercial plantations and from meristem culture-derived plants, comparing untreated and treated in a suspension of Pseudomonas putida (F-44) (CIAT Annual Report 1988). Results obtained in commercial plantations this year confirmed these data (Table 3.8). Disease severity and field infection (%) for CBB, SED and Choanephora leaf blight were higher on plantations from stakes taken from meristem-derived plants than from stakes taken from commercial fields (Table 3.8). Native microflora provide effective protection against cassava pathogens when they are living epiphytically on the plant epidermis. These results suggest that it is advisable to reestablish beneficial flora on the epidermis of meristem-derived stakes before their use for propagation; they can be dip-treated with the respective beneficial bacterial strain (i.e., efficient strains of P. putida or P. fluorescens) a few hours before planting.

3.1.3 Phytophthora root rot

For lack of a dependable field methodology for evaluating germplasm for resistance to Phytophthora spp. on cassava, the following root-bore inoculation method was developed: healthy swollen roots from 10-12 mo old are bored to a depth

Table 3.7 Effect of *P. fluorescens* (strain P.f. C5a)[1] on commercial yield (t/ha of fresh roots) of two clones (M Col 2215 = susceptible; and M Col 1505 = resistant) planted in a *D. manihotis*-endemic area, with moderate CBB blight and anthracnose infection during their growing cycle.

	Yield (t/ha)/Clone	
Source of Stakes	M Col 2215	M Col 1505
Commercial plantations-bacterized	23a[2]	20a
Meristem-derived plants-bacterized	29a	20a
Commercial plantations-untreated	18ab	17a
Meristem-derived plants-untreated	13b	18a

[1] Bacterization: stakes were dip treated in a bacterial suspension of 1 x 10^9 cfb/ml; and plots were spray-treated monthly with a bacterial suspension of 5 x 10^9 cfb/ml.

[2] Plots were harvested 10 mo after planting; results followed by the same letter were not statistically different.

Table 3.8 Disease severity and percent field infection caused by 3 foliar pathogens in commercial plantations of M Col 2215 planted with stakes taken from commercial plantations (C) and meristem-culture derived plants (M).

		Disease Severity[1]			
Disease	Stake Source	Mx	Mn	$\overline{X}$	Field Infection (%)
CBB	C	2.5	1.0	2.2	89.8
	M	4.0	2.0	2.8	100.0
SED	C	1.5	1.0	1.1	3.6
	M	3.5	1.0	1.6	18.3
Choanephora leaf blight	C	2.0	1.0	1.3	28.6
	M	4.0	2.0	2.9	100.0

[1] Disease severity: 1 = No symptoms; 5 = The highest infection; Mx = Maximum rating recorded; Mn = Minimum rating recorded. Avg values taken from more than 1-ha plantation for stake source; data taken at peak of epidemic.

of 3-4 cm, using a disinfested 0.1-cm diameter borer. The holes are filled with agar-mycelium taken from a 15-day-old PDA-growth culture and sealed with the peeled root cortex. Roots are then incubated in sealed plastic bags for 5 days. Resistance is related to the percentage of pathogen invasion through the root tissues from the inoculation point; clones with less than 15% invaded root tissue are considered resistant. This method makes rapid evaluation possible (i.e., 1 mo vs. 1 yr for field evaluation).

From among 46 elite clones evaluated for resistance to P. nicotianae var. nicotianae using the root-bore inoculation method, clones M Col 2302, M Col 2265 and SG 799-9 showed the highest grade of resistance.

As a result of nine years of cooperative research with the Center for Agricultural Research in the Amazon (CPAA) and CNPMF-EMBRAPA, two clones (Mae Joana and Zolhudinha) resistant to P. drechsleri and F. solani and adapted to the flooded Amazonian Basin zone ("várzea") were released in Manaos this year. In commercial trials the avg RY of these two clones in a 6- to 7-month period was 20 t/ha, which is 80% higher than the yield of traditional clones in non-infected plantations. Planting material of these two clones was delivered to more than 100 cassava growers who expressed a strong preference for these clones over the others for their yellowish colored cortex, which is highly valued for producing roasted cassava flour ("farinha").

3.1.4 Unreported stem and root rot cassava pathogens

Two unreported stem and root rot pathogens of cassava were isolated from several affected cassava plantations in the eastern and northern coastal areas of Colombia.

3.1.4.1 **Verticillium dahliae.** V. dahliae affects young plants, inducing light brown root deterioration. Stems are striated showing black microsclerotia at the base; stems of adult plants (> 6 mo) are also striated. Plants suddenly wilt and die. Swollen roots show necrotic spots very similar to those of the "smallpox" disease, but without signs of insect or wound damage on the epidermis surrounding the spots. The pathogen penetrates the root tissues through the root peduncle from affected stems. These symptoms are commonly found at the onset of the dry season. It appears that the fungus penetrates the stem or root peduncles through wounds induced by environmental stresses or any type of physical or mechanical damage.

It was found that the fungus grows well with abundant production of spores on PDA (potato-dextrose-agar) and LBA (lima bean-agar). The optimum temp for growth and spore production is 26°C. The hyphae are hyaline, whitish to cream after 1 wk, later becoming black with the formation of microsclerotia. Conidiophores are abundant, erect, hyaline, verticillately branched; phialides are variable in size; conidia arise singly at the apices of the phialides, ellipsoidal to irregularly subcylindrical, hyaline, mainly simple but occasionally 1-septate. Dark brown resting mycelia are formed only in association with microsclerotia. Each microsclerotium arises from a single hypha by repeated budding. They are highly variable in size and shape, from elongate to irregularly spherical.

3.1.4.2 Scytalidium sp. was found affecting stems and roots of 10-mo or older plants. Affected stems showed black necrosis of vascular strands, very similar to those symptoms induced by D. manihotis. However, the epidermis of affected stems swells and breaks longitudinally, releasing a mass of charcoal-like blackish conidia, which are easily disseminated. These symptoms differ from those of D. manihotis in the absence of pycniocarp formation on the bark of stems or roots (Fig. 3.1).

Colonies on PDA are effuse, dark blackish brown with immersed and superficial mycelia; hyphae are smooth with dark brown septae. They do not produce stroma (Fig. 3.1); their conidiophores are micro- or mononematous and branched. Conidiogenous cells fragment and form arthroconidia. Conidia are catenate, simple, smooth. There are two kinds: colorless, thin-walled; and medium or dark brown, thick-walled.

Damage induced by this pathogen is commoner at the end of the rainy season; it usually appears in association with D. manihotis, where they are hard to differentiate.

3.1.5 Diplodia stem and root rot

After four years of evaluating 90 clones for resistance to D. manihotis under field conditions in a Diplodia-endemic area (La Colorada, Atlantic Coast of Colombia), only seven clones survived (Table 3.9). Five had been previously rated as resistant or of intermediate resistance by the stake inoculation method under greenhouse conditions (CIAT Annual Report 1986). The other two clones were susceptible but had acquired resistance (bioprotection given by acquired epidermal microflora). These results stress the reliability of the method for identifying resistance to D. manihotis under greenhouse conditions; show the importance of Diplodia root rot when susceptible clones are planted in endemic areas; and partially explain the progressive decline of susceptible clones planted in soil-borne infested plots.

RY of these resistant and intermediate-resistant clones planted on a Diplodia-infested plot, with and without

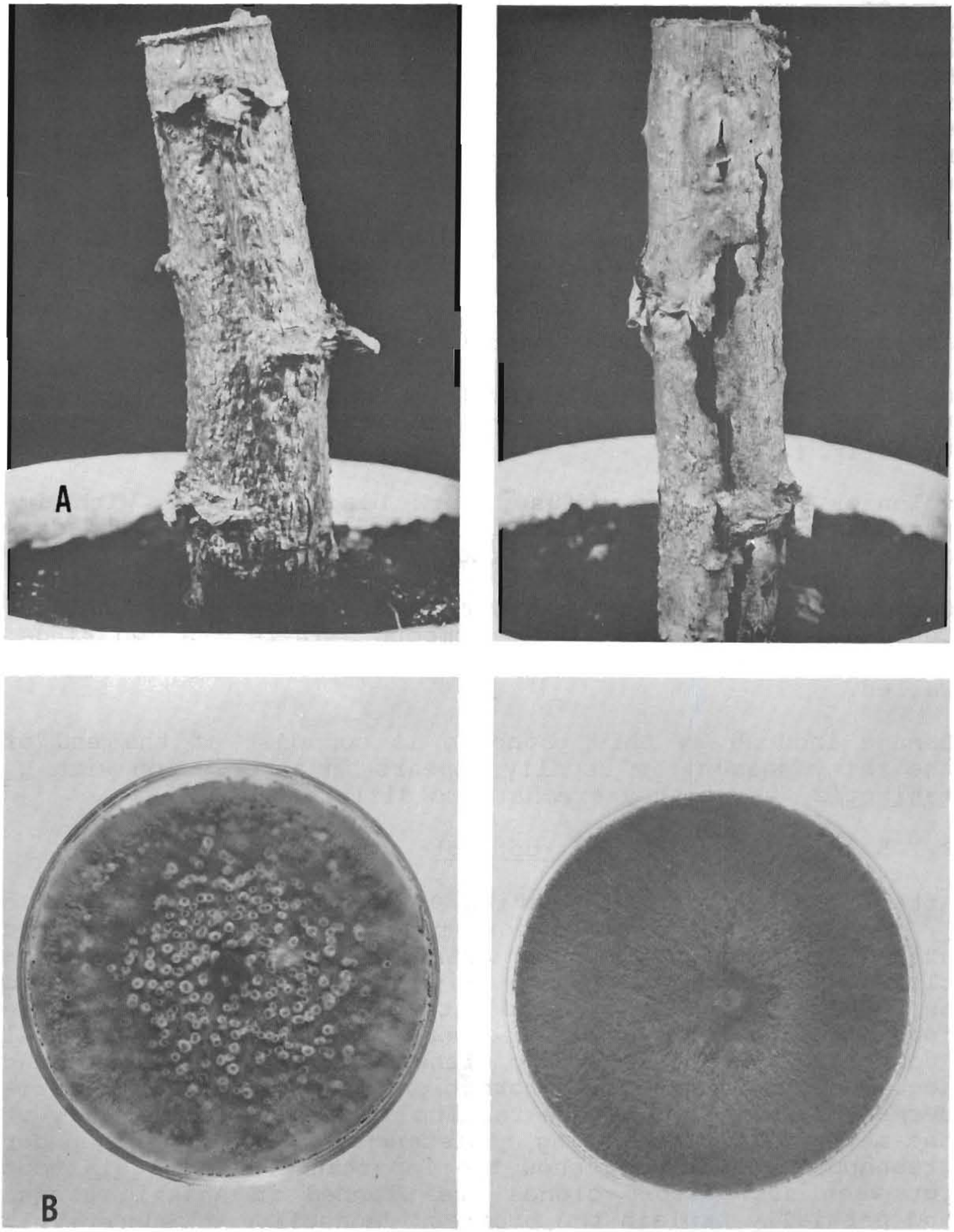


Figure 3.1 Difference between D. manihotis and Scytalidium on (a) cassava stems and (b) PDA medium: D. manihotis produces protuberant pycniocarpes.

Table 3.9 Four years of field evaluations of 90 clones where resistance/susceptiblity to D. manihotis was determined previously by the stake inoculation method (SIM) (CIAT Annual Report 1986).

Resistance Level Determined by SIM	Field Survival/Year of Evaluation[1]			
	1987	1988	1989	1990
Resistant	3(100)	3(100)	3(100)	3(100)
Intermediate	6(100)	5(83.3)	3(50)	2(33)
Susceptible	81(100)	47(58)	3(3.7)	0(0)

1 Mean of 5 pl/clone in each of 4 reps.

Table 3.10 Yield (t/ha)[1] of 5 resistant or intermediate-resistance clones that survived for 4 consecutive years of evaluation on a Diplodia stem and root rot-infested plot.

Clone	Level of Resistance	Fresh Root Yield		% Yield Increase
		Unfertilized	Fertilized[2]	
M Mal 2	R	41.0a	44.6a[3]	+ 8.8
M Ven 185	R	30.2a	27.8a	- 7.9
M Col 1505	R	24.8a	29.8b	+20.2
SG 104-57	I	18.4a	28.1b	+52.7
SG 104-284	I	17.6a	25.6b	+45.5

1 Avg RY taken from 4 reps/clone with 30 plants each.

2 Each fertilized plot received 100 kg/ha NPK applied at 1, 2 and 3 mo after planting.

3 Similar letters across fertilization treatments indicate no significant effect for this treatment.

fertilization, is shown in Table 3.10. There was a moderate or even negative effect of the fertilizer treatment on RY of resistant clones in contrast with the highly significant effect of the fertilizer on RY of the intermediate-resistance clones. These data also show the importance of the disease in the area, which can decrease RY by more than 45.5% on even intermediate-resistance clones. Additionally, these data stress the importance of genetic control as a means of partially overcoming the problem. This is supported by the data presented in Table 3.11 regarding the RY of a resistant (M Col 1505) and a susceptible (M Col 2215) clone obtained on plots by alternating different cropping systems over a 4-yr period. Percent RY increase by the fertilizer application was lower on plots planted with the resistant clone than on plots planted with the susceptible one, independent of the cropping system used. Similarly, the best cropping system for D. manihotis-endemic areas was a year rotation with maize and sesame; the worst was continuous cassava planting. By far the largest effect was variety, indicating the possibility of selecting varieties suited across a range of cropping systems and disease pressures (Table 3.11).

These results will be used to modify the production package promoted in 1987 (CIAT Annual Report 1989) and validated during 1988-1989. More than 30 cassava growers are now successfully growing cassava following this technological package. For example, data collected among 12 cassava growers who followed this production package showed a RY increase of 208% when they planted a resistant clone and 300% when the clone was susceptible (Table 3.12). It is expected that the new genotypes incorporating resistance to this pathogen and to other important constraints will greatly increase production in the area.

3.1.6 Superelongation Disease (SED)

Studies on genetic control of SED of cassava (caused by Elsinoe brasiliensis) covered the following subjects:

3.1.6.1 **Morphological resistance.** This type of resistance was suspected after finding that peeled stems of resistant clones showed susceptible reaction (CIAT Annual Report 1983). Histological studies carried out this year showed that the cuticles of three-mo-old shoots of resistant clones (CM 523-7 and M Ven 77) were 3.7 times thicker than those of susceptible clones (M Col 22 and M Col 113) when the plantlets were incubated at 24,000 lx. This stem-cuticle thickness ratio decreases at low light intensities; e.g., at 920 lx or lower the cuticle-thickness decreased dramatically and differences between resistant and susceptible clones disappeared (Table 3.13). Temp and RH had no effect on these parameters. Similarly, measurements on other stem tissues

Table 3.11 Yield (t/ha)[1] of a resistant (M Col 1505) and a susceptible (M Col 2215) clone planted for 4 consecutive cycles, after a year's fallow, or after a year's rotation with maize, sesame and cowpeas in a D. manihotis-endemic area.

Clone	Cropping System	Fresh Root Yield		Yield Increase
		Unfertilized	Fertilized[2]	(%)
M Col 1505	Maize-sesame	17.8	18.9	5.3
(Resistant)	Fallow	16.8	20.1	23.5
	Maize-cowpeas	16.3	20.8	27.7
	Cassava-cassava	14.1	18.7	32.4
	$\bar{X}$	16.3	19.6	22.2
M Col 2215	Maize-sesame	10.7	11.8	10.3
(Susceptible)	Fallow	11.7	15.7	34.2
	Maize-cowpeas	7.4	13.7	85.6
	Cassava-cassava	7.5	13.2	76.8
	$\bar{X}$			9.3

[1] Yield of 4 reps/clone/treatment of 30 plants each.

[2] Each fertilized plot received 100 kg/ha of NPK applied at 1, 2 and 3 mo after planting.

did not show significant differences between the susceptible and resistant clones used.

This finding opens up the possibility of devising a rapid screening system for resistance to E. brasiliensis, which can replace the field screening evaluation system that is currently being used for identifying genotypes resistant to this disease.

3.1.6.2 **Field evaluation.** To determine the most appropriate location for field evaluation of genotypes for resistance to SED, genotypes belonging to 17 families were planted at three locations where the disease is endemic: Carimagua and Villavicencio (Llanos Orientales of Colombia) and Huimanguillo (Tabasco, Mexico). Disease levels were recorded at the height of the epidemic in each location, and the probability of finding resistant clones among genotypes of each family per site was calculated according to Grizzle, Starmer & Koch (1969). Disease severity was highest at Carimagua,

Table 3.12 Avg yield (t/ha)[1] obtained by 12 cassava growers who planted resistant clone M Col 1505 and susceptible clone M Col 2215, using the cassava production system designed for Media Luna (CIAT Annual Report 1989), a Diplodia-endemic area.

Cassava Grower	Clone: M Col 1505	Clone: M Col 2215
Leandro Pérez	21.0	15.0
Miguel Pacheco	19.2	--
Enrique Herrera	18.8	12.3
Marcos Hernández	17.0	14.6
Francisco Yepez	15.5	--
Tomás Lara	14.9	--
Alejandro Gamero	14.9	--
Ebolo Escorcia	14.9	--
Miguel Pereyra	14.8	--
Antonio Charry	12.2	--
Juan Pertus	11.6	--
Tomás Hernández	10.1	--
$\bar{X}$	15.4	14.0
Avg yield by traditional system	5.0	3.5
% avg yield increase	208	300

[1] Avg yield of an area of 5000 m^2/clone/grower.

Table 3.13 Effect of light intensity on thickness of the stem cuticle of plantlets from two clones resistant or susceptible to Elsinoe brasiliensis, causal agent of SED of cassava.

Light Intensity (lx)	Average Thickness of Stem Cuticle (μ)/Clone: Resistant Clones: CM 523-7	Resistant Clones: M Ven 77	Susceptible Clones: M Col 22	Susceptible Clones: M Col 113
24,000	1.37[1]	1.37	0.37	0.37
20,600	0.37	0.37	0.12	0.12
7,200	0.75	0.25	0.12	0.12
920	0.06	0.24	0.12	0.03
6	0.03	0.04	0.03	0.02

[1] Stem sample data taken at 2 cm from the growing point of each plantlet; avg of 10-15 samples/light intensity/clone with CV no higher than 12%.

where disease stress reduced the probability of finding plants of low disease damage in each family (Fig. 3.2); similarly, the avg disease scores were highest. Consequently, this location appears to be the most appropriate for field evaluations of resistance to SED among the three locations investigated. As expected, the families that showed the highest proportion of resistant progenies in Carimagua were those obtained from crosses with high parental resistance.

3.1.6.3 **Stability analysis.** Stability of resistance to SED and CBB was investigated by planting clones belonging to three families over a 5-yr period. Stability analysis of these data, according to the modified joint regression method of Digby, showed the following (Fig. 3.3):

-- The general response of the evaluated clones to SED and CBB during the five growing cycles was unstable.

-- Despite this instability, differences in levels of resistance to these two diseases were identified among families and among genotypes belonging to the same family.

-- Disease pressure for both SED and CBB was different each year, which justifies clonal evaluation for several growing cycles.

-- The families that showed the best stability for resistance to SED and CBB were CG 890 (CM 723-3 x M Col 638) and CM 3581 (CM 849-1 x CM 523-7). All these parents have intermediate to high resistance to both SED and CBB.

3.1.7 Cassava endophytes

Thus far 20 species of fungal endophytes have been isolated from stem samples of native clones growing in different plots. The effect of 9 of these endophytes on 3 cassava clones (M Col 2215, M Bra 191 and M Col 1468) after inoculation by spray, immersion and puncturing methods was determined by comparing the root weights of inoculated and noninoculated controls (Figs. 3.4 & 3.5). It was found that:

-- Most endophytes had a detrimental effect on M Col 1468 (a root-rot susceptible clone), especially when plants were immersed in the fungal inoculum.

-- The detrimental/beneficial effect of some endophytes depended on the inoculation method; e.g., on M Col 2215, *Curvularia* sp. was detrimental when

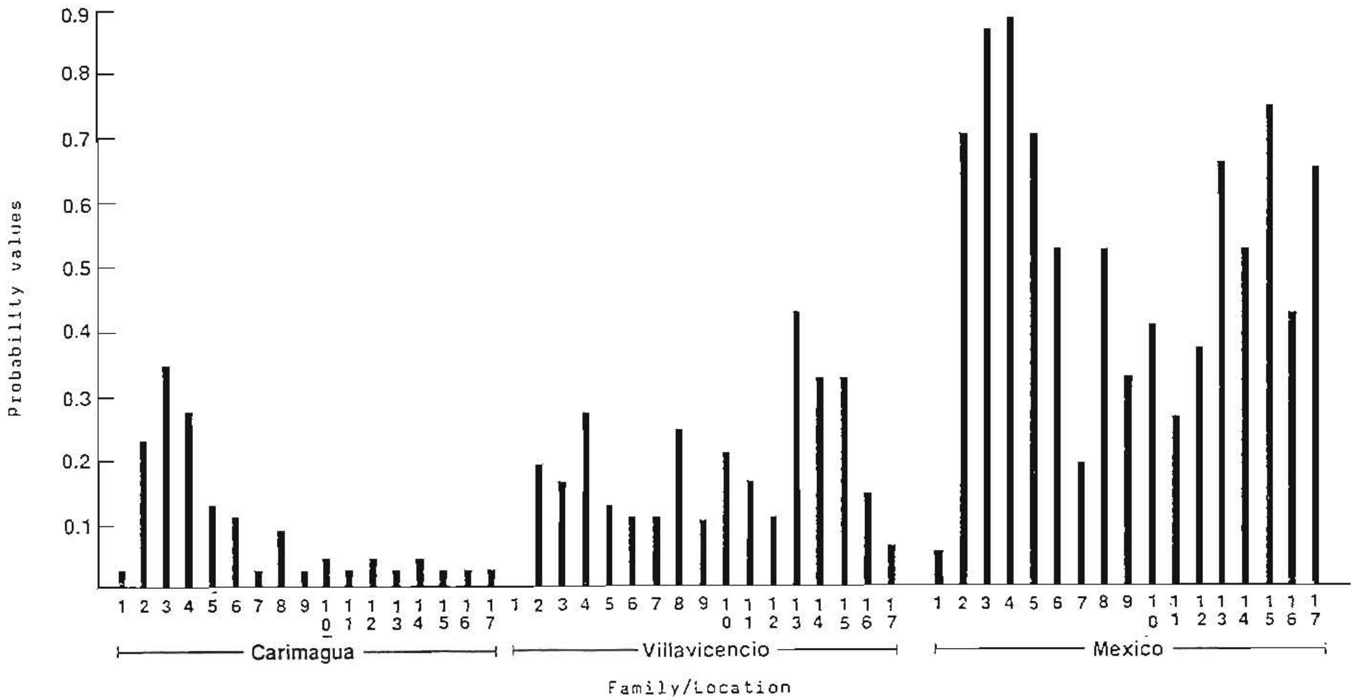


Figure 3.2 **Probability for SED resistance among genotypes belonging to 17 families planted at 3 SED-endemic locations.**

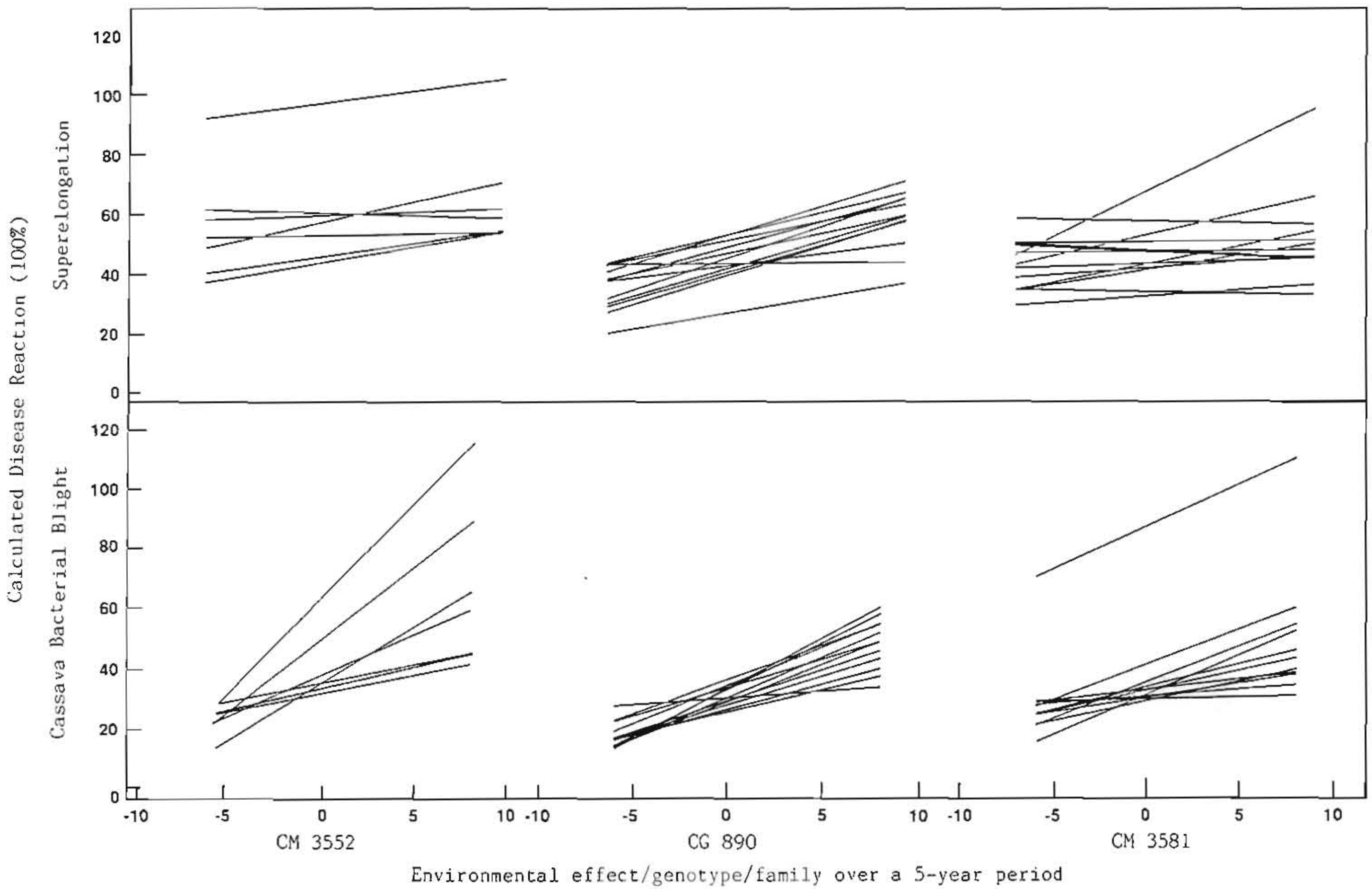


Figure 3.3 **Stability of genotypes beloging to 3 families planted over a five-year period (5 growing cycles) planted at a CBB- and SED-endemic location (Carimagua); stability analysis according to the modified joint regression method (Digby).**

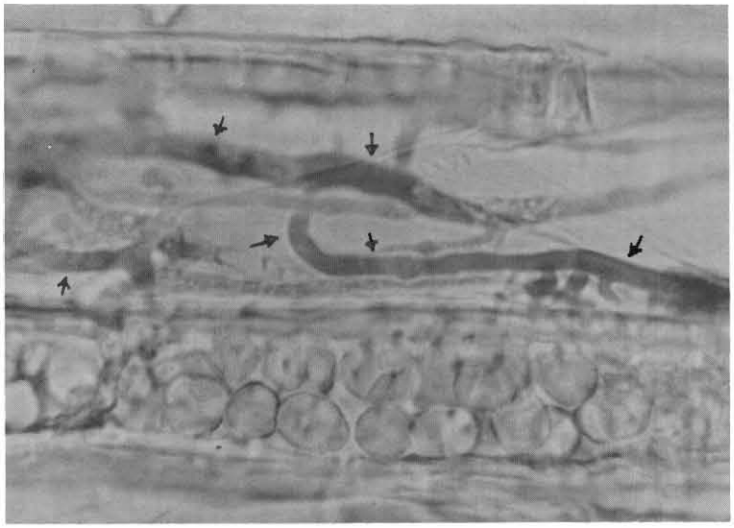


Figure 3.4 Hyphae of an enodphyte growing inter- and intracellularly in the vascular strands of stem tissues of M Col 1478.

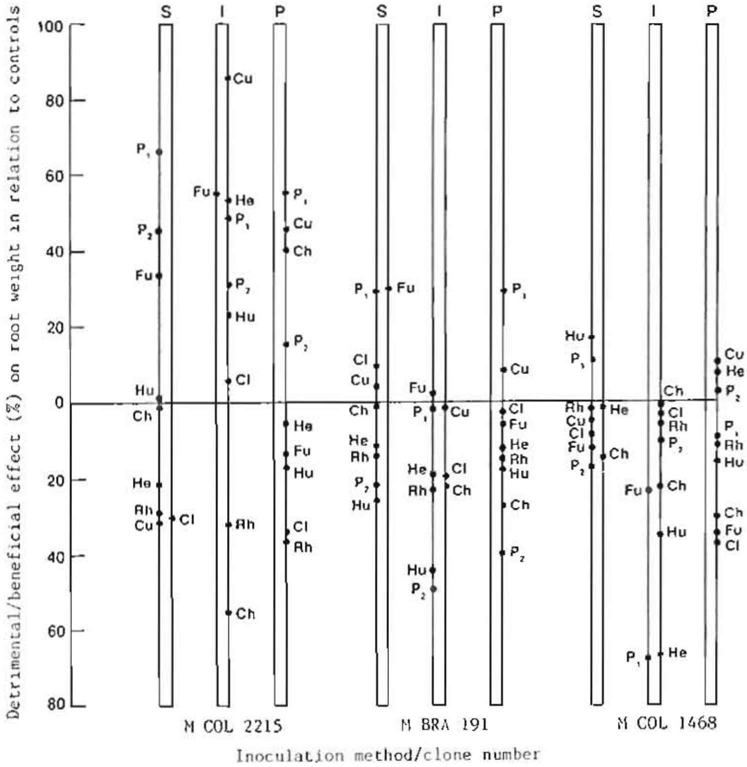


Figure 3.5 Effect of 9 cassava endophytes (inoculated by spray = S; immersion = I; and puncturing = P) on 3 cassava clones in relation to percent root wt of uninoculated controls. Inoculated endophyte species: Ch = Choanephora; Cl = Cladosporium; Cu = Curvularia; Fu = Fusarium; He = Hendersonula; Hu = Humicola; Rh = Rhizoctonia; P_1 = Penicillium; P_2 = Penicillium.

spray-inoculated and beneficial when inoculated by immersion or puncturing.

-- *Rhizoctonia* sp. did not induce symptoms in leaf and stem tissues, but was detrimental to root production in the three inoculated clones (all three inoculation methods); however, when the roots were mechanically wounded, the fungus induced root necrosis.

There were varietal differences in relation to the behavior of the endophytes on cassava, as well as in relation to the inoculation method used. Similarly, it appears that some fungal species can behave as endophytes on a given plant part (living as epiphytes on stems or leaves) or as pathogens on others (affecting the root tissues). Similarly, some endophytes appear to be beneficial when affecting the epidermis (epiphytic stage), but detrimental when infecting the host tissues (parasite stage). Further research is under way in relation to these interactions.

3.1.8 Storage of vegetative planting material

A summary of research on the storage of vegetative planting material of cassava was previously reported (CIAT Annual Reports 1987 & 1988). The storage method was improved in 1988 by watering the stem bundles during the first 2 wk of storage under open field conditions (full exposure to sunlight) in order to promote rooting and sprouting at the onset of storage. Additionally, it was found that all storage practices led to RY reduction after 2 mo, suggesting that this practice should be avoided or implemented only when necessary. This year, however, it was found that RY on plots planted with stakes stored for 4 mo under the very dry conditions of the Pivijay area (28°C avg; 60% RH) were similar to RY obtained on plots planted with unstored controls if there was adequate fertilization (Table 3.14). Fertilized plots also showed significant improvement in establishment, plant vigor and RY in relation to both control plots or plots planted with stakes stored in shade.

Based on these and previous findings, the following storage system is advisable in tropical environments:

-- Stakes should be selected from visually healthy plants of clones showing satisfactory levels of resistance to storage (more than 80% establishment after 60 days' storage of long-stem stakes). Mother plants should be those with the highest RY at harvest.

Table 3.14 Effect of fertilizer application on yield (t/ha of fresh roots) of plots planted with stored and nonstored stakes[1] of two clones planted in Media Luna.

	Fresh Root Yield (t/ha)/Clone			
	M Col 2216[2]		M Col 2215[2]	
Treatment[2]	Nonfertilized	Fertilized	Nonfertilized	Fertilized
Nonstored control	16.3	20.2	14.5	20.8
Storage in open field	15.2	17.9	15.6	20.8
Storage under shade	11.2	15.2	12.8	20.4

1 Stakes taken from the first half of the stem of 11-mo-old plants of each clone; long (1.20m) stem stakes stored for 4 mo (Jan.-March, the driest period of the region) after a 5-min dip treatment with benomyl (3 g), maneb (3 g) and malathion (2 cc).

2 Stems stored in the open field were positioned vertically and rooted; those stored under shade were not rooted.

-- Stakes should be more than 1.20 m long, taken from the bottom half of 8- to 11-mo-old mother plants. They should be arranged in bundles (no more than 10 stakes each) and treated prior to storage with a fungicide-pesticide mixture (benomyl, 3 g/lt; maneb, 3 g/lt; and malathion, 1-2 cc/lt).

-- Bundles should be stored vertically under open field conditions by burying the first 5-10 cm of the stakes in the soil and watering during the first 2 wk of storage.

-- At planting time, 10 cm of both ends of each stake should be removed, as well as any shoots produced during the storage period. Stakes for planting should be 15-20 cm long and treated again with the fungicide-pesticide mixture before planting. Fertilization (based on soil or plant-tissue analysis) should be done within the first 45 days after planting.

3.1.9 Geographic distribution and potential risk for six cassava diseases

Based on epidemiological studies, surveys on disease severity, and climatological data extrapolations done with the Agroecological Studies Unit, it was possible to determine the geographic distribution in Latin America and the potential risks of CBB, SED, the mycoplasm-induced witches' broom, _Phytophthora_ root rot, and _Fusarium_ and _Diplodia_ stem and root rots (Figs. 3.6a-f). These data show that:

-- The highest potential risks for foliar and stem pathogens (CBB and SED, Figs. 3.6a & b) exist in areas with moderate temp (18-25°C) and more than 1200 ml rainfall/yr, where prolonged periods of high RH occur (in the case of SED, Fig. 3.6b) and/or where day/night temp fluctuate more than 10°C (in the case of CBB, Fig. 3.6a).

-- The highest risks for stem and root rot pathogens (_Fusarium_ and _Diplodia_) exist in areas where high temp (> 25°C) and heavy rainfalls for short periods of the wet seasons are frequent (Figs. 3.6c & d). If the temp of the area is more than 20°C and the land is periodically flooded during the rainy season or badly drained, _Phytophthora_ root rot can be of great importance (Fig. 3.6e).

-- The mycoplasm-induced witches' broom is characteristically found in areas where the temp ranges from 15-20°C for a period of more than 3 mo/yr (Fig. 3.6f). Symptoms of this mycoplasmlike disease are moderate to mild, or might disappear as temp increases. Consequently, witches' broom can be a threat in areas where cool temp occur during the year or for more than a 3-mo period.

3.1.10 References Cited

Grizzle, J.E., Starmer, C.F. & Koch, G.G. 1969. Analysis of categorical data by linear models. _Biometrics_ 25:489-504.

3.2 Cassava Viruses

Progress was made over a broad range of cassava viruses and viruslike diseases. Cassava Colombian Symptomless (CCSpV) and Cassava American Latent viruses (CALV) were added to the cassava viruses that can be routinely identified using ELISA. The molecular characterization of Cassava Common Mosaic Virus (CCMV) is progressing, and the sequencing of over half of the virus is complete. The area that has progressed most is the characterization of the agents of Caribbean mosaic (CMD) and frogskin diseases (FSD). The causal agent of CMD is a member of a new subgroup of the phyto-reoviruses. A similar but distinct virus is the causal agent of the mosaic symptoms associated with FSD.

Figure 3.6 Geographic distribution and potential risks of six important cassava diseases in Latin America: (a) CBB and (b) SED.

Figure 3.6 Geographic distribution and potential risks of six important cassava diseases in Latin America: (c) Fusarium and (d) Diplodia stem and root rots.

Figure 3.6 Geographic distribution and potential risks of six important cassava disseases in Latin America: (e) Phytophthora root rot and (f) witches' broom.

3.2.1 FSD and CMD

Both these diseases are viruslike disorders of unknown etiology that are present in Colombia. These two diseases were reported as distinct because the root symptoms associated with FSD are either absent or very mild in plants with CMD. Although CMD can cause significant RY loss in susceptible clones, there are many tolerant clones. There are few reports of clones that are resistant or tolerant to FSD, however. Secundina is the cassava clone used for detecting both CMD and FSD as both diseases produce mosaic symptoms on its leaves. CIAT has disease-free, in vitro culture clones and greenhouse-grown stakes of Secundina available for indexing programs.

Viruslike particles were found in the leaves, petioles and stems of cassava plants infected with either FSD or CMD (Fig. 3.7). These particles, which are approx. 80 nm in diameter, are similar in size and morphology to reovirus particles. Viruslike inclusion bodies were found only in the roots of the cassava var. M Col 113, which develops root but no leaf symptoms.

Double-stranded RNAs were purified from cassava plants infected with either CMD or FSD and run on both agarose and polyacrylamide gels. On agarose gels, there appear to be 3 or 4 bands; but on polyacrylamide gels there are 10 bands for FSD and 9 for CMD (Fig. 3.8). The no. and size of the ds-RNA bands differ between FSD and CMD. The relative molecular weights (M_r)--the number of the ds-RNAs found in CMD- and FSD-infected plants--are similar to genomes of the Fiji subgroup of phyto-reoviruses (Table 3.15). Reoviruses have unique genomes that consist of either 10 or 12 segments of ds-RNA. Table 3.15 gives the sizes of the ds-RNA segments of selected phyto-reoviruses and the ds-RNA segments found in CMD- and FSD-infected plants. The genomic segments are often of similar or equal size in the characterized phyto-reoviruses. As several of the bands in both FSD and CMD are similar in size, only 3 or 4 are detected by agarose gels; and 9 or 10 bands are resolved using polyacrylamide gels, which have greater resolving power. It is predicted that there are 10 segments of ds-RNA, but only 9 bands found in polyacrylamide gels of CMD. There are probably two genomic segments of equal M_r.

The whitefly Bemisia tuberculata has been suspected as the vector of FSD based on experiments using field-collected whiteflies. Until this year, the only viruslike disease that had been transmitted by whiteflies was the WF isolate, which originates from whiteflies collected in the field. Healthy cassava plants infected with the WF isolate showed mosaic symptoms on the indicator clone Secundina but did not show root symptoms typical of FSD.

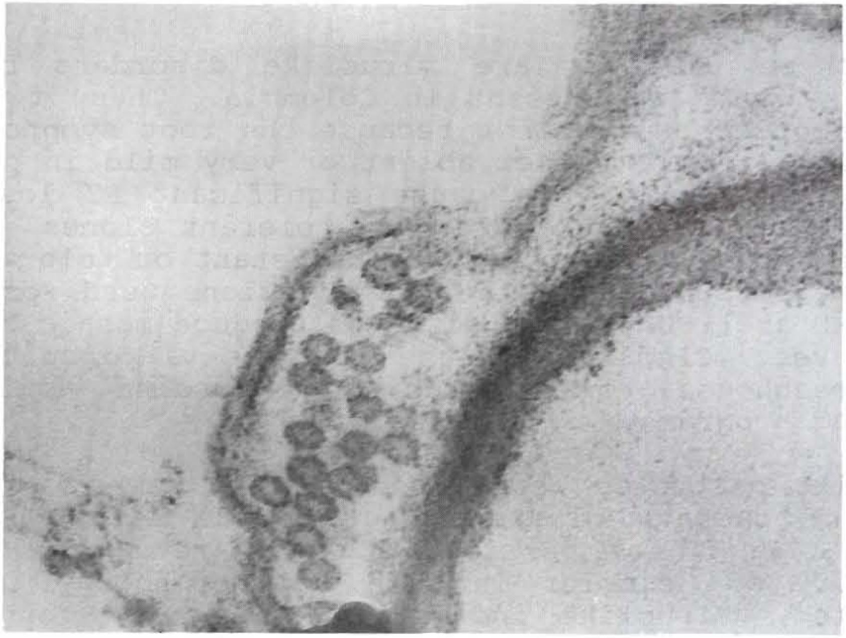


Figure 3.7 Viruslike particles found in a thin section of cassava leaves. They were sometimes found in groups as shown in the photograph, but were more frequently scattered through the cytoplasm.

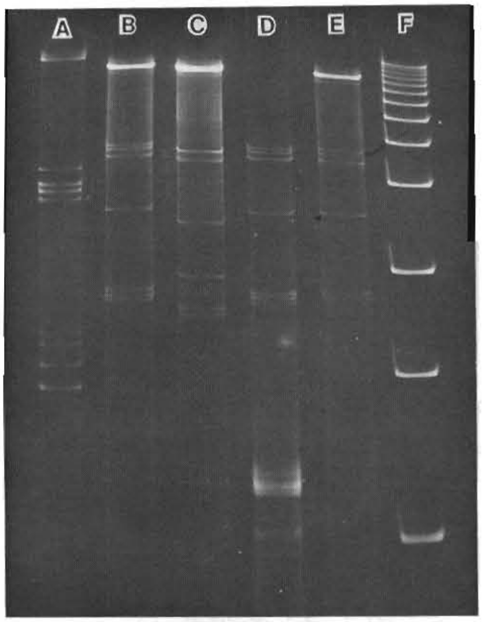


Figure 3.8 A polyacrylamide gel showing the ds-RNA segments associated with infected FSD and CMD. Lane A is a molecular weight marker of ds-RNAs, lane B is CMD isolate 5, lane C is FSD isolate 29, lane D is FSD isolate 80, lane E is CMD isolate 86, and lane F is ds-DNA markers.

Table 3.15 Molecular weights of dsRNA segments of phyto-reoviruses and Fijiviruses compared with ds-RNA segments of selected isolates of frogskin disease (FSD) and Caribbean mosaic disease (CMD).[1]

Genomic Segment	WTV	RDV	FDV	RBSDV	FSD	CMD
1	2.90	3.10	2.90	2.75	2.70	2.75
2	2.40	2.50	2.50	2.24	2.60	2.60
3	2.20	2.20	2.48	2.19	1.80	2.30
4	1.80	1.80	2.48	2.14	1.75	1.80
5	1.78	1.76	2.12	2.00	1.35	1.30
6	1.10	1.05	1.80	1.82	1.30	1.25
7	1.05	1.02	1.45	1.37	1.25	1.20
8	0.83	0.78	1.21	1.17	1.20	0.71
9	0.57	0.70	1.12	1.11	1.15	0.67
10	0.55	0.67	1.08	1.06	0.68	
11	0.54	0.48				
12	0.32	0.48				

1 Size estimates for the phyto-reoviruses and the Fijiviruses (WTV, RDV, FDV, MRDV) are from <u>Plant Viruses</u>, vol. 1: Structure and Replication, C.L. Mandahar, ed., pp. 220-221. The estimate for FSD is from isolate 29; for CMD, isolate 5. These were compared with ds-RNA markers, which were isolated from mycoviruses provided by Dr. R.L. Bozarth, Indiana State University.

Manipulating the acquisition times of the vector increased efficiency of transmission. Isolate 29 of FSD was consistently transmitted although the rate of transmission varied from 10-60% (Table 3.16). An acquisition period of one day gave the highest rates of transmission. According to these results, the disease agent does not need to replicate in the vector, but the whiteflies do need a minimum acquisition period of one day before they are able to transmit the virus. Table 3.17 lists the viruslike diseases transmitted by B. tuberculata.

The plants that developed the mosaic symptoms in the transmission tests were analyzed for the presence of ds-RNA species. Both the mother plants used as the source of inocula and the plants infected in the transmission experi-

Table 3.16 Virus transmission tests of the FSD isolate 29 (source plant Secundina), using **B. tuberculata** as the vector.[1]

No. Plants with Symptoms[2]	Appearance of Symptoms (days)
3/5	13-15
2/10	12-15
1/10	12
1/10	15
2/10	12-14
1/10	12

1 25 **B. tuberculata** were used per plant for all experiments; acquisition period, 24 h; transmission period, 5 days.

2 The no. (infected/total no.) of plants in the experiment.

Table 3.17 List of isolates of viruslike diseases transmitted to cassava var. Secundina by the whitefly **B. tuberculata**.

Disease	Isolate	Source Plant	Transmission Date
WF-mosaic	3	WF from field[1]	1986
FSD	29	Secundina	1990
CMD	80	Secundina	1990
CMD	86	Secundina	1990

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

ments had similar ds-RNA patterns. Also leaf dips of the infected plants contained viruslike particles with diameters of 80 nm. There were no viruslike particles or ds-RNAs in the healthy control plants.

B. tuberculata were fed on plants infected with either CMD or FSD and examined using insect dip preparations for viruslike particles. Particles 80 nm in diameter, similar in size and morphology to the viruslike particles found in plants infected with CMD or FSD, were found in these samples. The structure of the viruslike particles extracted from B. tuberculata is more distinct than that of the particles found in the plants (Fig. 3.9). Whiteflies that fed on healthy plants contained no viruslike particles. In blind tests, the whiteflies that had fed on the infected plants were consistently identified.

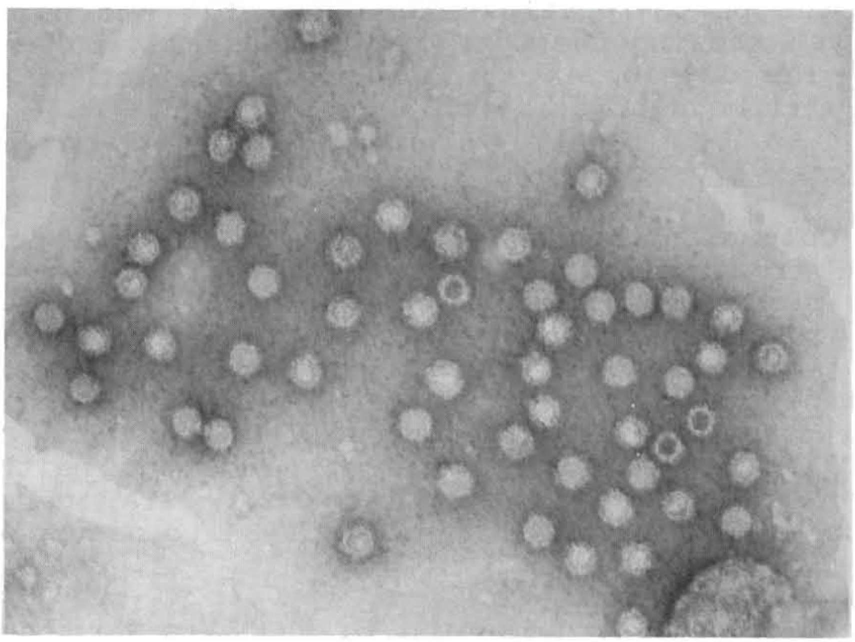


Figure 3.9 Viruslike particles found in B. tuberculata that were fed on plants infected with isolate 29 of FSD. Similar particles were found in B. tuberculata fed on CMD-infected plants. No viruslike particles were found in whiteflies that fed on healthy plants.

In conclusion, viruses similar in morphology and genomic structure to the phyto-reoviruses are associated with CMD and FSD. Both viruses are transmitted by the whitefly B. tuberculata. Additional experiments are needed to determine that all symptoms associated with CMD and FSD are present in the plants infected by the whiteflies. Currently some of the plants infected in the transmission experiments are being grown in a small field plot in a screen house to determine the type of root symptoms caused by the virus transmitted by B. tuberculata. Additional experiments will be conducted in field trials.

Based on the ds-RNA patterns, the virus associated with CMD appears to be distinct from the one associated with FSD. Based on their morphology and genomic structure, these viruses appear to be members of a new subgroup of phyto-reoviruses. The main difference between the Fiji subgroup of the phyto-reoviruses and those associated with CMD and FSD is the type of vector. The vectors of phyto-reoviruses are leaf- or planthoppers; and all, except wound tumor virus (WTV), infect only monocotyledons. The vector of viruses associated with CMD and FSD is B. tuberculata, and the only known host for these viruses is cassava, a dicotyledon.

Most of the phyto-reoviruses are unstable and difficult to purify; yet knowing the type of virus usually makes the task easier. The development of a rapid assay method for these viruses will be a priority this coming year.

3.2.2 Potexviruses in cassava

Cassava Colombian Symptomless Virus (CCSpV) was originally isolated from cassava infected with CMD. There are no symptoms produced in cassava infected only with CCSpV, which is only present in some of the characterized isolates of CMD or FSD. An antiserum to CCSpV (provided by Dr. Harrison at SCRI) is being used to screen germplasm for the presence of this virus. CCSpV is serologically related to Cassava X Virus (CsXV) but distinct from it. Although neither virus causes any apparent disease in cassava, CIAT germplasm is being screened for both of them by ELISA to assure virusfree germplasm.

The molecular characterization of CCMV is continuing, and the sequence of approx. half the genome is complete. Figure 3.10 is a diagram of the predicted molecular organization of the virus. Based on homology at the RNA and protein sequences, CCMV is most closely related to potato virus X (PVX). The Cassava Trans project (Dr. R. Beachy, Washington University, has successfully demonstrated that coat protein-mediated cross protection of CCMV is effective in Nicotiana benthamiana. The major technical limitation of its deployment as a resistance gene in cassava is the transformation of cassava.

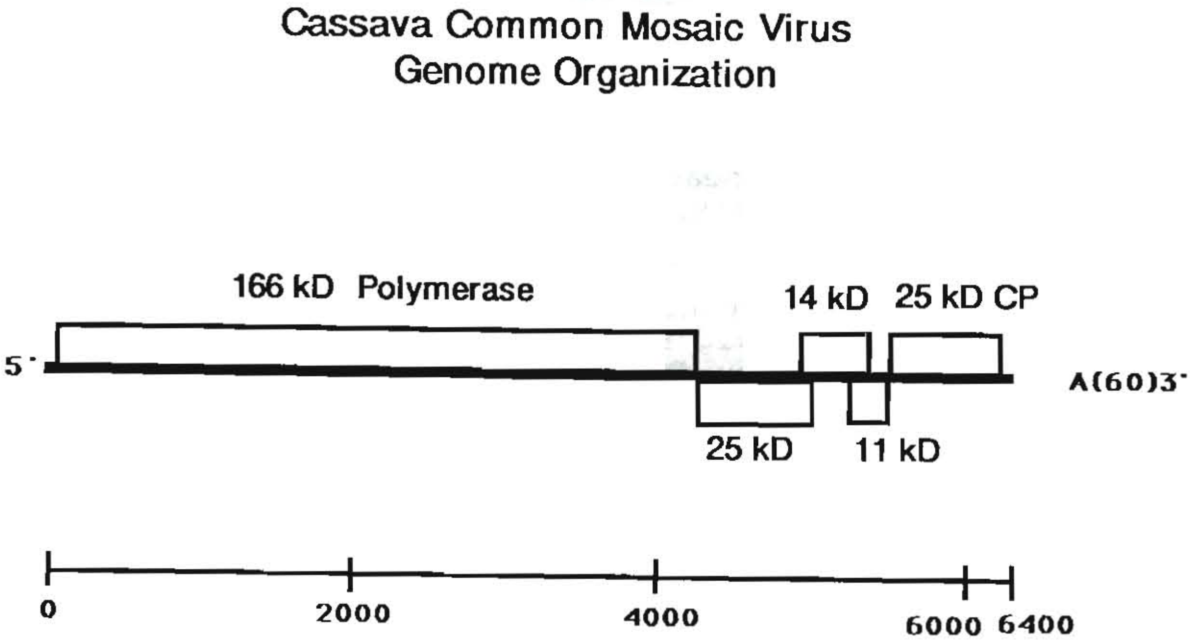


Figure 3.10 The size (kD) of the four putative proteins and their position on the genomic map are shown in the diagram. The 166-kD protein shares homology with other polymerase genes; the 25-kD CP is the coat protein.

3.2.3 Cassava Vein Mosaic Virus (CVMV)

A survey was conducted of viruses infecting cassava in NE Brazil (states included parts of Bahia, Perambuco and Ceará). Much of this semiarid area is used for selecting and producing the germplasm for the IFAD project (emphasis on Africa). Based on the observations of symptoms, CVMV is widespread throughout these areas of Brazil. Typical infection rates were 20-30%, but some fields had 100% infection. Exact losses in cassava infected with CVMV are unknown, but the plant does produce good RY even though the virus is prevalent. This viral disease is probably similar to CCMV, which causes 20-30% RY losses in infected plants. More information on the losses caused by this virus is needed to determine its importance. The development of rapid diagnostic techniques for detecting CVMV is also needed to facilitate the exchange of clean germplasm.

3.2.4 Cassava American Latent Virus (CALV)

A new nepovirus of cassava was reported (Dr. B. Walter, CIRAD, Colmar, France), isolated from samples infected with CCMV that had been collected in humid lowland areas around Manaus, Brazil and in French Guyana. CALV does not produce symptoms or apparent disease in cassava. It is not known whether the virus causes RY losses or if it is seed transmitted.

As nepoviruses are frequently seed transmitted, the seeds being sent to IITA in Nigeria were studied using an antiserum to the virus (provided by Dr. Walter, CIRAD). Both seed lots and mother plants of seed lots to be sent to IITA in 1991 were tested for the virus. Results were negative, and it appears that this virus is not present at CIAT. CALV (like CCSpV and CsXV) is a minor problem that causes no obvious disease. More work needs to be done to determine its distribution, seed transmission and effect on RY.

4. CASSAVA ENTOMOLOGY AND ACAROLOGY

Research in cassava entomology and acarology stresses the need to develop effective, cost-efficient, environmentally sound crop protection methologies that will assist in stabilizing production and eliminate the need for pesticide use. Host plant resistance, biological control and agronomic practices are emphasized.

Recent research results in entomology are as follows:

4.1 Cassava Mealybug

Two species of cassava mealybugs--Phenacoccus manihoti and P. herreni--can cause serious yield losses in cassava. P. manihoti, native to Paraguay and limited areas of SW Brazil (Mato Grosso do Sur), appears to be under control because of the presence of two natural enemies. In Africa, on the other hand, this pest caused severe damage until key natural enemies were introduced from the neotropics to bring P. manihoti under control. The CIAT Cassava Entomology Section continues to collect, evaluate and send natural enemies to IITA for evaluation and possible release for P. manihoti control on that continent. Two predators recently sent were Cleothera onerata and Hyperaspis sp. Life table and consumption studies with C. onerata are presented here.

P. herreni has caused severe damage in NE Brazil and the Colombian Llanos. Research at CIAT has concentrated on biological control and host plant resistance.

4.1.1 Biological control

The sudden appearance of P. herreni in NE Brazil in the mid-1970's suggested that it was introduced into that area. Possible areas of origin are being explored in order to study the natural enemies associated with this mealybug. In order to define the geographic distribution of P. herreni, a survey of cassava-growing regions of Venezuela (Fig 4.1) was initiated in 1989 and continued during 1990.

Of 47 farms visited, 14 had P. herreni infestations. Nine of the 14 infested fields were planted to bitter cassava from 6-12 mo of age, three were planted to sweet cassava of 9-12 mo, and two fields had a mix of 10-mo-old sweet and bitter varieties. The altitude and weather conditions were recorded for each site. The mealybug-infested cassava fields occurred from 25-275 masl, with temp between 28-35°C and RH from 40-70%. This information supports previous observations and studies that show that P. herreni is primarily a pest of the lowland tropics with high temp and prolonged dry seasons.

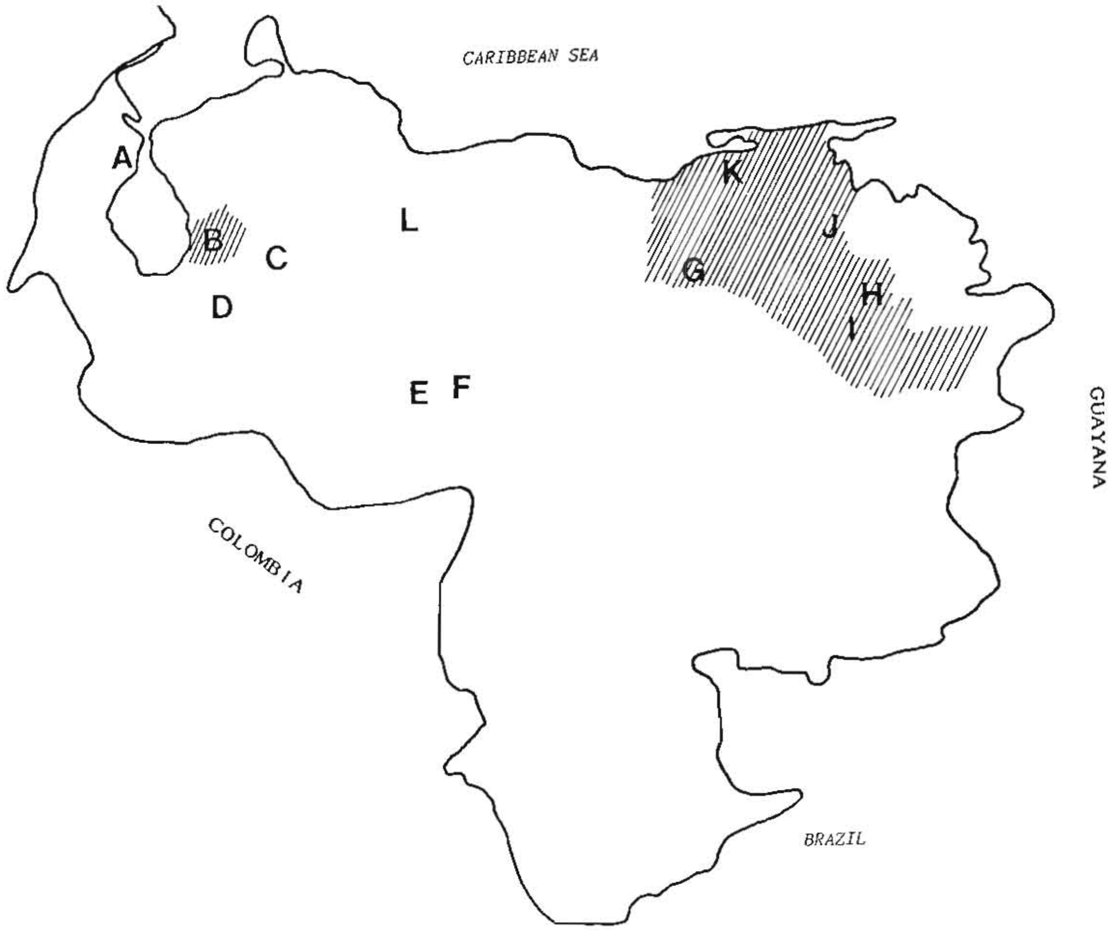


Figure 4.1 Exploration of cassava-growing zones in Venezuela surveyed during 1990 (A-L); shaded area indicates distribution of P. herreni and letters indicate sites where parasitoids A. vexans (G-K) and A. coccois (B) were found.

Parasites and predators found during this year's survey added valuable information to 1989 observations. The most frequently found predators were Nephus sp. (Coccinellidae) and Ocyptamus sp. (Syrphidae) (Table 4.1). Three other coccinellids of the Hyperaspini tribe were present in a few fields.

The two wasp (Hymenoptera) species found parasitizing P. herreni were subsequently identified as Aenasius vexans (Encyrtidae) and Acerophagus coccois (Encyrtidae) by R. Noyes of the British Museum. A. vexans was found in nearly

Table 4.1 Important natural enemies associated with populations of P. herreni in Venezuela, 1990.

No. Parasitoids (%)			No. Predators (%)		
A. vexans	104	(45.6)	Nephus sp.	57	(40.7)
A. coccois	124	(54.4)	Ocyptamus sp.	55	(39.3)
			Hyperaspini sp.	28	(20)

all mealybug-infested fields, while large numbers of A. coccois were found in El Jaquito and Trujillo. Colonies of Nephus sp., A. vexans and A. coccois were established in the CIAT lab. Approximately one generation per month of Aephus sp. and two generations per month of the two encyrtid parasites can be reared under lab conditions.

Lab studies were conducted of the two parasitoid species on two mealybug species: P. herreni and P. madeirensis (= P. gossypii). The latter will feed on cassava but is not considered an important pest of this crop and is usually observed only at low populations. (For details on rearing techniques utilized for mealybug and parasitoid species, see previous Annual Reports).

Whereas A. vexans preferred to parasitize P. herreni over P. madeirensis under free-choice lab conditions, host preference was found when these two mealybug species were offered to A. coccois (Table 4.2). These data indicate that A. vexans may be more specific for P. herreni--a hypothesis that will require further evaluation. No evidence was found for host stage preference in A. vexans (Table 4.3). Second and third instar nymphs and adult females of P. herreni were parasitized with equal frequency; whereas first instar nymphs were not preferred although occasional parasitism did occur (Table 4.3). A. coccois showed a strong preference for second instar nymphs of both P. herreni and P. madeirensis (Tables 4.3 & 4.4). Whereas A. coccois oviposited in adult females of P. madeirensis, parasitism of this stage was insignificant in P. herreni. Neither A. coccois nor A. vexans appears to parasitize eggs of P. herreni (Table 4.3).

A. coccois was previously found parasitizing P. herreni in Colombia and has been studied at CIAT (Annual Report 1985). The Colombian species showed a marked preference for P. madeirensis. Although the second instar of P. herreni was preferred (as with the Venezuelan species), the Colombian species had equal preference for the adult female stage, as

Table 4.2 Preference of two parasitoids, A. coccois and A. vexans, in a choice test for adults of two cassava mealybug species, P. herreni and P. madeirensis.

Mealybug Spp.	No. of Hosts Subjected	No. of Eggs of A. vexans	No. of Eggs of A. coccois
P. herreni	250	92+	78[ns]
P. madeirensis	250	5	68

+ = Significantly different; Student "t" test $P<0.05$.

ns = No significant difference.

Table 4.3 Preference of two parasitoids in a choice test for life stages of the cassava mealybug P. herreni.

Life Stage	No.	No. Eggs of A. vexans	No. Eggs of A. coccois
I	125	4+	5
II	125	40	38+
III	125	40	16
Adult female	125	30	1

+ Significantly different; Student "t" test $P < 0.05$.

Table 4.4 Preference of two parasitoids in a choice test for life stages of the cassava mealybug P. madeirensis.

Life Stage	No.	No. Eggs of A. vexans	No. Eggs of A. coccois
I	125	9[ns]	7
II	125	10	32 +
III	125	4	11
Adult female	125	0	14

+ = Significantly different; Student "t" test $P < 0.05$.

ns = No significant difference.

well as parasitizing all other P. herreni stages including the male cocoon. This apparent difference in behavior indicates the possibility of biotypes and should be further investigated.

P. herreni predator studies concentrated on two species (Col: Coccinellidae): Cleothera onerata and Hyperaspis sp. Data on the former are presented. Methodologies for rearing coccinellids, life table and predation/consumption studies have been described elsewhere (Annual Report 1989). Development time for C. onerata was studied at four temp (17°, 20°, 25° and 30°C). Development time was most rapid at 30°C (26.1 days) and progressively longer at lower temp (39.1 days at 25°; 64.3 at 20°, and 106.8 at 17°C) (Table 4.5). Rate of development increased with higher temp (0.9, 1.5, 2.5 and 3.8 at 17°, 20°, 25° and 30°C, resp.) (Fig. 4.2), indicating that this predator would be more successful in the warmer climates where P. herreni dominates.

Life stages of C. onerata include egg, four larval stages, prepupa, pupa, preadult and adult (Fig. 4.3). Higher mortality occurs during the early instars and at lower temp. Overall mortality was 93% at 17°, but only 33% at 30°C. Percent mortality decreased as development stages progressed. The minimum temp developmental threshold for C. onerata is 12.9°C, with the physiological time equivalent to 452.9 degree-days. The net reproductive rate (Ro) is greater at 25°C, while the intrinsic rate of increase (Rm) is higher at 30°C (Table 4.6). Generation time and population doubling time are lowest at the higher (30°C) temp. Highest fecundity occurred at 25°C, with 195 eggs/female.

Table 4.5 Development times (days) at four constant temp for C. onerata feeding on P. herreni.

Temp (°C)	Egg	Larval Stages				Prepupa	Pupa	Preadult	Total Development Time
		I	II	III	IV				
17	21.7	13.2	8.3	9.2	23.9	6.2	18.7	5.6	106.8
20	13.7	8.4	4.4	4.8	12.1	4.0	12.8	4.2	64.3
25	8.1	3.8	2.3	2.8	7.7	2.3	9.0	3.1	39.1
30	5.9	2.3	1.8	2.1	4.7	1.5	5.9	1.9	26.1

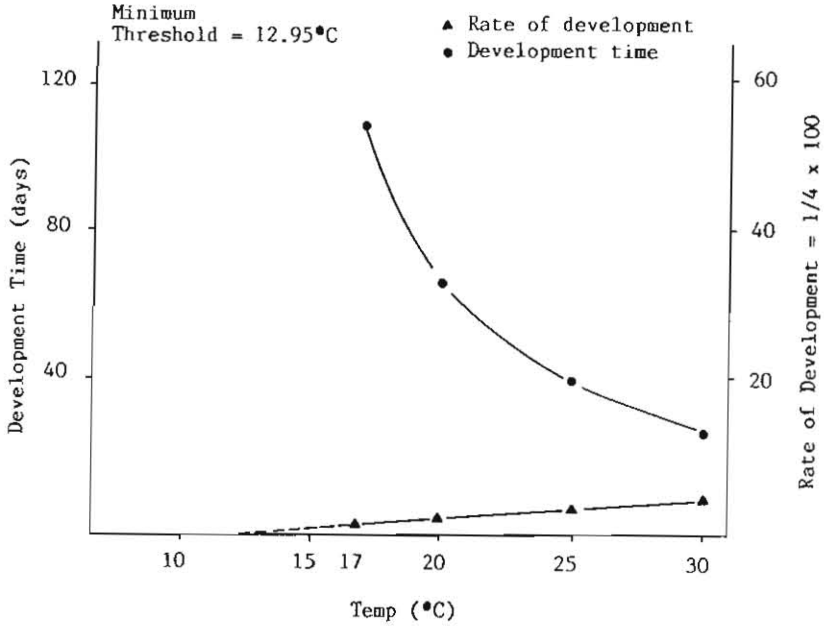


Figure 4.2 Effect of temp on the time and velocity of development of C. notata.

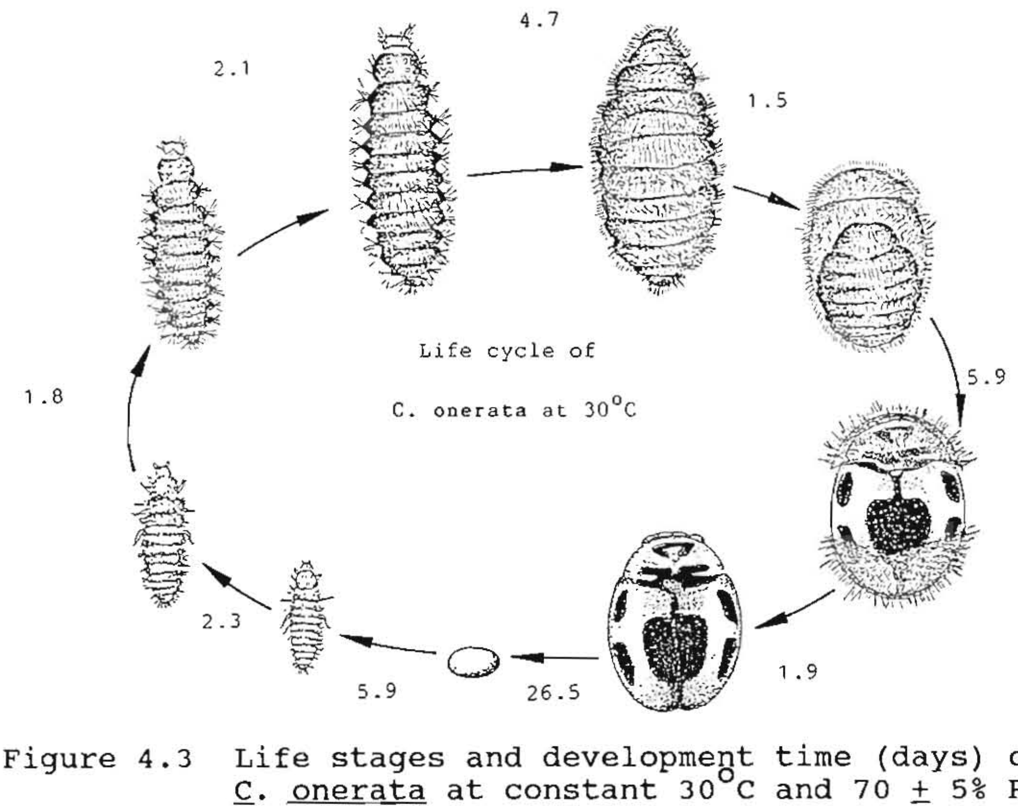


Figure 4.3 Life stages and development time (days) of C. onerata at constant 30°C and 70 ± 5% RH.

Table 4.6 Effect of temp on life table parameters of C. onerata.

Parameters	20°C	25°C	30°C
Egg-to-egg development	119.3	63.4	52.6
Oviposition period (days)	60.8	108.8	26.5
Fecundity (total eggs)	60.3	195.2	33.4
Net reproductive rate, R_o	24.5	74.4	20.3
Generation time	140.4	115.0	74.8
Intrinsic rate of increase, R_m	0.023	0.037	0.040
Finite rate of increase ( )	1.02	1.04	1.04
Doubling time	30.4	18.5	17.2

Predation studies show that C. onerata prefers feeding on the egg stage, followed by the P. herreni instars and adult stages. It is most voracious during its fourth instar when it can consume over 1300 eggs at an avg rate of 182 eggs/day (Table 4.7). During oviposition, one pair of adults can consume about 120 eggs daily, for a total of more than 6500 eggs during an avg adult life span of 70 days.

Table 4.7 Total consumption of P. herreni eggs by different development stages of C. onerata.

Development Stage	Avg Total Consumption	Direction	Standard
I instar	34.3	F[1]	10.8
II instar	111.4	E	54.1
III instar	270.4	D	128.7
IV instar	1338.8	A	280.9
Adult female	875.2	B	81.6
Adult male	722.9	C	167.6

[1] Avg followed by the same letter are not significantly different at the 5% level (DMRT).

4.1.2 Resistance to *P. herreni*

Screening of cassava germplasm for mealybug resistance has been ongoing for several years. Selected clones were evaluated first at CIAT and ultimately at Carimagua, where there are high natural mealybug populations. In addition to natural populations, artificial infestations are used to ensure the uniform, adequate infestation needed for effective screening. Nearly 3000 cassava varieties have now been evaluated over several screening cycles.

One hundred clones were screened for resistance to *P. herreni* in Carimagua. They were planted in 4 blocks in plots of 5 plants/clone. Each plant was infested with 1-2 ovisacs of *P. herreni*. Highly branched clones were infested with two ovisacs/plant. Three months afterward, damage was evaluated using a scale of 1 (no damage) to 9 (necrosis of branches and plant death). Three clones were selected: CM 6069-3, CM 5263-1 and SM 540-8 (Table 4.8) for continued evaluation. These clones are also reported as tolerant to Cercospora, CBB and SED, which severely limit production in the savannas of Colombia. RY ranged from 13.6 t/ha for SM 540-8 to 24.8 t/ha for CM 6068-3. Damage levels for CM 6068-3 and CM 5263-1 were at 4, but only at 1 for SM 540-8. The selected clones will be evaluated further in an experiment with a larger plot size to determine resistance levels.

Three clones selected during 1989 (SG 250-3, SG 106-54 and CM 2177-2) were sown in 36-plant plots, using a split plot design with four replications. Some plots were protected with aldicarb, while nonprotected plots were infested with mealybug ovisacs to ensure adequate populations. Yield depression due to mealybug attack is an indication of

Table 4.8 Yield and damage level of 3 selected clones for mealybug (*P. herreni*) resistance in Carimagua.

Clone	Yield t/ha	Damage Level[1]	No. Stakes/ Plant	% DM
CM 6068-3	24.8	4	10	30.62
CM 5263-1	16.3	4	6.5	33.36
SM 540-8	13.6	1	10	31.95

1 Based on a damage scale of 1 (no mealybugs) to 9 (necrosis and plant mortality).

resistance levels in protected clones. Results showed only a 10.1 and 9.3% reduction in yield between the protected and nonprotected plots of clones SG 250-3 and CM 2177; while SG 106-54 had a 34.2% reduction in yield (Fig. 4.4). These results indicate that there exist adequate levels of resistance or tolerance in clones SG 250-3 and CM 2177-2, which are suitable for use in a resistance breeding program. Additional greenhouse and lab studies are required to determine whether this resistance is due to an antibiosis mechanism or tolerance due to high plant vigor.

4.1.3 Yield loss studies

To obtain more information on RY loss potential in cassava due to mealybug attack, an experiment using M Col 77 was conducted in Carimagua. A random plot design with three reps and treatments of dimethoate 48% (0.720 kg a.i./ha), monocrotophos 50% (0/5 kg a.i./ha), and dimethoate + monocrotophos. The control received no pesticide; but at 30 days, each plant was infested with 2 mealybug ovisacs. Pesticides were applied at 30 and 75 days after germination.

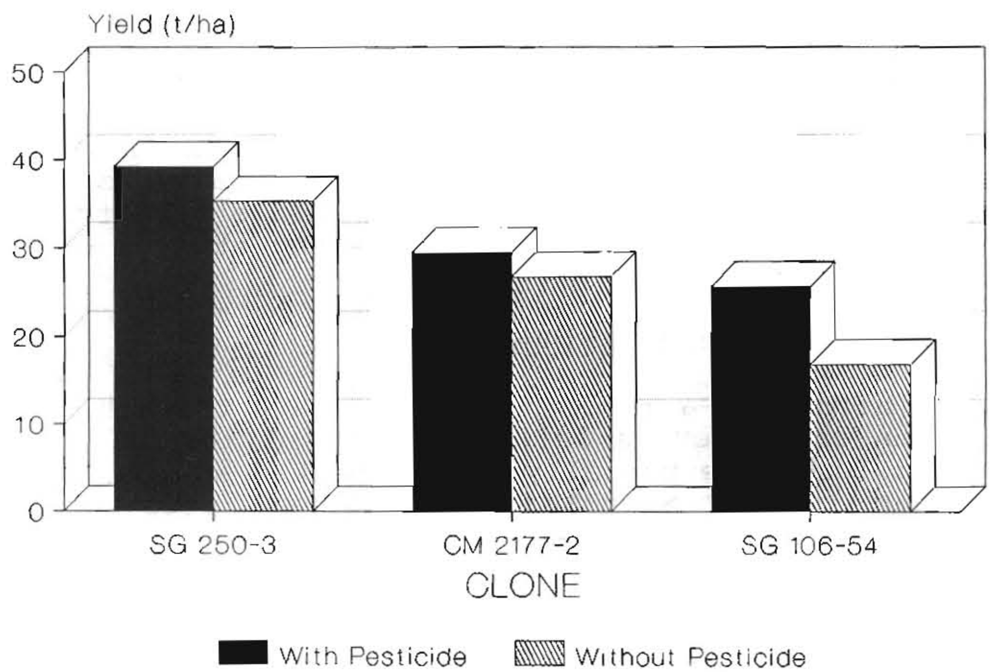


Figure 4.4 Yield comparisons, with and without pesticide treatment, of 3 cassava clones selected for mealybug (P. herreni) resistance.

RY (8.6 t/ha) in the control plots was reduced by an avg of 28%; there was no significant difference among the three insecticide treatments (avg RY 11.9 t/ha). When aldicarb 10% (3 kg a.i./ha) was applied, RY increased 47.3% over the control (16.4 t/ha); however, aldicarb is prohibitively expensive (one application costs US$297/ha vs. US$9.52/ha for monocrotophos) and its high toxicity makes it unacceptable for mealybug control on cassava.

4.1.4 Pseudococcus mandio: the cassava root mealybug

P. mandio was first reported attacking both bitter and sweet cassava varieties in Sombrio (SC, Brazil) in 1986. This mealybug has since been observed attacking cassava roots in the subtropical cassava-growing areas of South America; that is, Paraguay, Argentina and southern Brazil (especially in Santa Catarina). Additional hosts are *Cyperus rotundus* and *Ergeron bonairensis*. The mealybug is normally found feeding on underground plant parts including the underground portion of the stem. Root damage is manifested by darkened spots, possibly caused by fungal pathogens introduced through mealybug feeding. This damage not only reduces the commercial value of the root but also its culinary quality (roots become harder when cooked). Highly infested plants display chlorosis and defoliation of lower leaves.

A collaborative project, using contract research funds, was set up with the EMPASC Experiment Station at Itajai, SC to study the occurrance, behavior and damage caused by *P. mandio*. Preliminary data indicate that mealybugs appear during warmer temp which, under subtropical conditions, corresponds to about 3- to 4-mo-old plants. The number of plants attacked and *P. mandio* populations increase as plants mature and warmer temp occur. The female life span from egg to adult is about 45 days. Observations and studies of this pest will continue.

4.2 The Cassava Hornworm, *Erinnyis ello*

The cassava hornworm--a major pest of cassava throughout the Americas--can cause severe defoliation resulting in considerable yield losses, especially when repeated attacks occur. Over 40 natural enemies including parasites, predators and pathogens have been identified. It is speculated that due to the highly migratory habits of the sphingid moth adult, stable biological control is difficult to achieve and maintain in cassava fields.

Recent research at CIAT has concentrated on using a naturally occurring baculovirus, which has been shown to be effective in controlling hornworm populations. The advantage of this virus is that it is storable (under refrigeration) by farmers; and when hornworm attacks occur, it can be applied similar to a pesticide. This technique is being used by farmers in Brazil and certain areas of Colombia.

The pathogenicity of the baculovirus on hornworm larvae was evaluated using seven concentrations prepared in distilled water. The number of inclusion bodies per liter water was estimated by electron microscopy. A standard curve was prepared from these data (Fig. 4.5). An objective of the study was to determine the mean lethal concentration (LD_{50}) for each instar and the incubation period required to obtain this mortality level. Evaluations for each instar were run until 90% mortality was obtained.

The effect of virus concentration and larval instar on mortality was tested. After 72, 96, 120 and 144 h for instars I, II, III and IV, resp., 90% mortality was obtained with the highest virus concentration (0.9 ml virus/lt H_2O = to 1.5 x 106 inclusion bodies) (Fig. 4.6). A sigmoidal relationship between concentration and mortality was found for instars I, II and IV. In the third instar, the relationship was asymptotic, with high mortality at a much lower concentration than in the other instars (Table 4.9). In the control larvae, mortality was never higher than 10%.

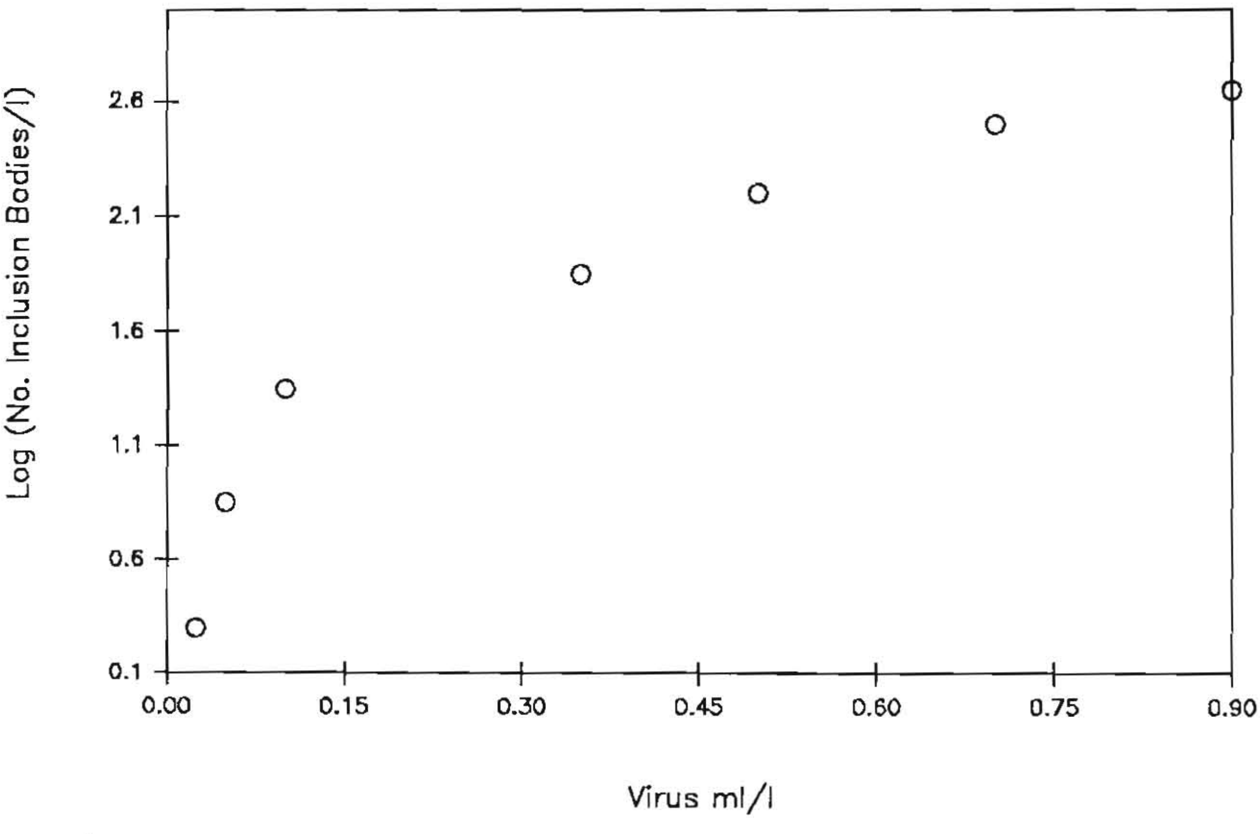


Figure 4.5 No. of virus inclusion bodies at each of 7 concentrations of E. ello baculovirus solution.

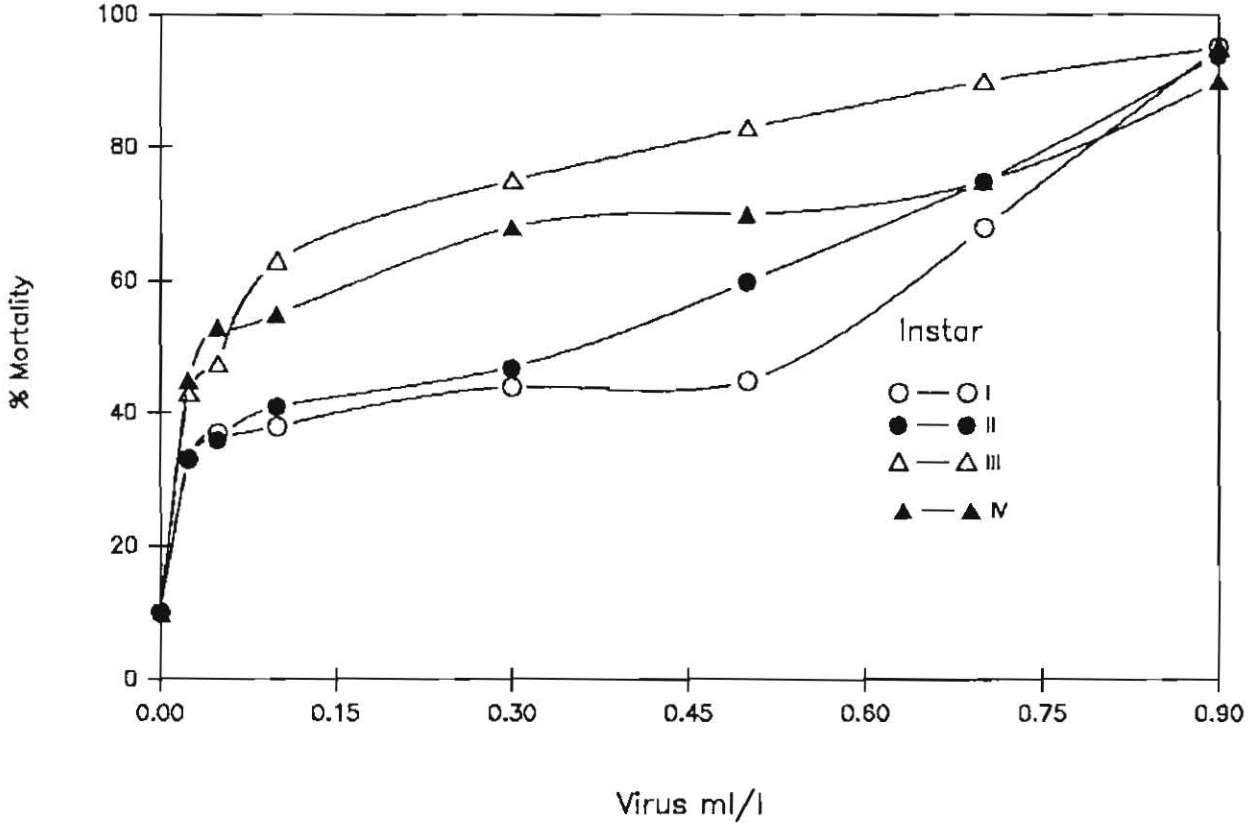


Figure 4.6 Percent mortality of four instars of _E. ello_ at 7 virus concentrations.

Table 4.9 Percent mortality of four _E. ello_ instars at seven virus concentrations.

Concentration Inclusion Bodies/lt H_2O	1st Instar[1] (%)	2nd Instar[2] (%)	3rd Instar[3] (%)	4th Instar[4] (%)
1.85×10^4	33	33	43	45
7.4×10^4	37	36	47.5	53
2.2×10^5	38	41	63	55
6.8×10^5	44	47	75	68
1.9×10^6	45	60	83	70
3.3×10^6	68	75	90	75
4.5×10^6	95	94	95	90
Control	10	10	10	10

[1] = 72 h; [2] = 96 h; [3] = 120 h; [4] = 144 h.

Preliminary tests with fifth instar larvae resulted, even at the highest concentration, in most larvae reaching the prepupal stage; but 22.5% and 40% of these died within 144 h after virus application for the lowest (185 x 104 inclusion bodies/lt H_2O) and the highest (4.5 x 106 inclusion bodies/ lt H_2O) concentrations, resp. Of those that reached the prepupal stage, 80% also reached adult stage. Of the remaining 20%, some mummification was observed, and no adult emergence occurred for some pupae. Determination of LD_{50} and a detailed study of the interaction of virus concentration and time of mortality is in progress.

4.3 The Cassava Whitefly

Whiteflies, which can cause severe yield losses in cassava as a result of direct feeding, are also major vectors of cassava virus diseases. High whitefly populations have been reported from certain areas of Colombia (Tolima, Valle del Cauca), Paraguay and NE Brazil. Several species have been reported, and no single species appears to predominate. Bemisia tabaci transmits ACMD in Africa. Although present in the Americas, it had not been reported feeding on cassava until recently, suggesting the existance of a distinct biotype in the Americas. In recent years, however, B. tabaci has been reported feeding on cassava in Florida, Puerto Rico and the Dominican Republic, indicating the possible introduction of a new biotype in these areas. If this biotype is capable of transmitting ACMD and the disease enters the Americas, it could have devastating effects on cassava production; therefore, continued research on whitefly dynamics is a priority.

Recent research at CIAT has concentrated on identifying resistant clones. The predominant whitefly species present is Aleutotrachellus socialis although field populations usually contain Trialeurodes variabilis and B. tuberculata as well. Screening cassava germplasm in the presence of this species complex has been in progress for several years. Four clones (CG 489-34, CG 489-4, CG 489-23 and CG 489-31) have been selected and evaluated in the field (ICA-Nataima, Tolima, Colombia).

Whitefly population estimates, damage scores and yield in the clones were compared to the regional var. Quindiana and to CMC 76 and CMC 40 in an area of high whitefly population pressure. Four reps of 36-plant plots of each clone and variety were treated with a pesticide and compared to untreated plots.

The lowest damage scores and highest yields were obtained from the clones. Clone yields in the unprotected plots were higher than the checks (CMC 76 and CMC 40) and regional variety in the protected plots (Table 4.10). There was no

Table 4.10 Evaluation of four selected whitely-resistant cassava clones, compared to var. CMC 76 and CMC 40 and the regional var. Quindiana in ICA-Nataima, Tolima, Colombia.

	With Insecticide		%	Without Insecticide	
Variety	Yield t/ha	% DM	Difference Yield	Yield t/ha	% DM
CK 489-34	30.3 B	28.6	3	29.3	27.1
CK 489-4	32.9 B	32.4	17	27.1	30.8
CK 489-23	39.1 A	33.1	9	35.4	31.9
CK 489-31	27.9 C	33.2	10	24.9	32.7
CM-76	22.8 E	34.6	31	15.8	32.1
CM-40	25.0 D	27.1	38	15.6	25.0
Regional Quindiana	25.1 D	35.5	31	17.3	34.5

significant difference in clone yields between protected and nonprotected plots (9% avg reduction), indicating that effective levels of resistance exist in these clones. Yield depression for the two checks and the regional variety averaged 33%.

The high DM content and culinary quality of the regional var. Quindiana are primary criteria for farmer selection and probably account for this variety's success in the Tolima region. Crosses between whitefly-resistant clones and the regional var. Quindiana have already been made in collaboration with the Breeding Program; and progeny will be evaluated in future trials.

4.4 Cyrtomenus bergi: The Cassava Burrowing Bug

The feeding of C. bergi, a soil-borne hemipteran, causes severe deterioration to the roots and the loss of their commercial value. This polyphagous insect feeds on numerous other hosts (CIAT Annual Report 1989), thereby complicating control efforts. Although previous studies have shown that C. bergi can complete its development stages feeding only on cassava, it appears that cassava is not its preferred host. Bitter cassava is detrimental to its development and causes marked mortality; but even sweet cassava does not permit optimal population growth.

4.4.1 Development studies

Twenty pairs of C. bergi adults were placed in soil-filled plastic boxes with onions, cassava or maize as feeding media. Fresh roots were provided every 4 days. The no. of surviving adults was counted every 7 days, and oviposited eggs were separated from the soil by washing and filtering. Egg and adult counts continued until all adults had died.

Oviposition was highest when maize was provided and lowest on the cassava diet. A peak in oviposition on maize occurred in the first half of the adult stage; thereafter, egg production was sustained at a constant level until death. Egg production was appreciably lower on both the bitter (M Col 1684) and sweet (CMC 40) cassava varieties. On onions and cassava, eggs were produced in the latter part of the adult stage, suggesting that essential nutrients for egg production are lacking in these hosts (Fig. 4.7).

The death rate on all food types was constant (Fig. 4.8); the principal effect of food type on survivorship was lifespan. The LD_{50} on maize was 95 days, compared with 68.5 on onions and 66 and 64 days, resp., on cassava clones CMC 40 and M Col 1684. Maize is clearly the superior host in terms of survival and fecundity. The major difference between cassava and onions is that the latter is a better host for reproduction. Although survival and fecundity of C. bergi were similar on CMC 40 (a sweet variety) and M Col 1684 (a bitter variety), the sweet variety is the preferred host when a choice is offered. Root damage levels were always severer on sweet varieties.

These fecundity data help explain two observations on C. bergi behavior. Difficulties in maintaining C. bergi colonies in the lab had been experienced when sweet cassava was the medium provided for fecundity and reproduction. Since maize has been introduced as the feeding substrate, reproduction and subsequent colony maintainance has improved dramatically. During 1990 an avg of more than 10,000 nymphs and adults was provided each month, thereby facilitating numerous ongoing lab studies.

In addition, it has been observed in field trials (especially in Santander de Quilichao) that after several cycles, C. bergi populations and subsequent root damage decrease, resulting in disappointing experimental results. As cassava is such a poor medium for oviposition, C. bergi populations may be decreasing over time for lack of a suitable host for maximum oviposition. Cassava and onions appear to be alternate hosts, which represent a viable means for survival but are not suitable for reproduction and population increases.

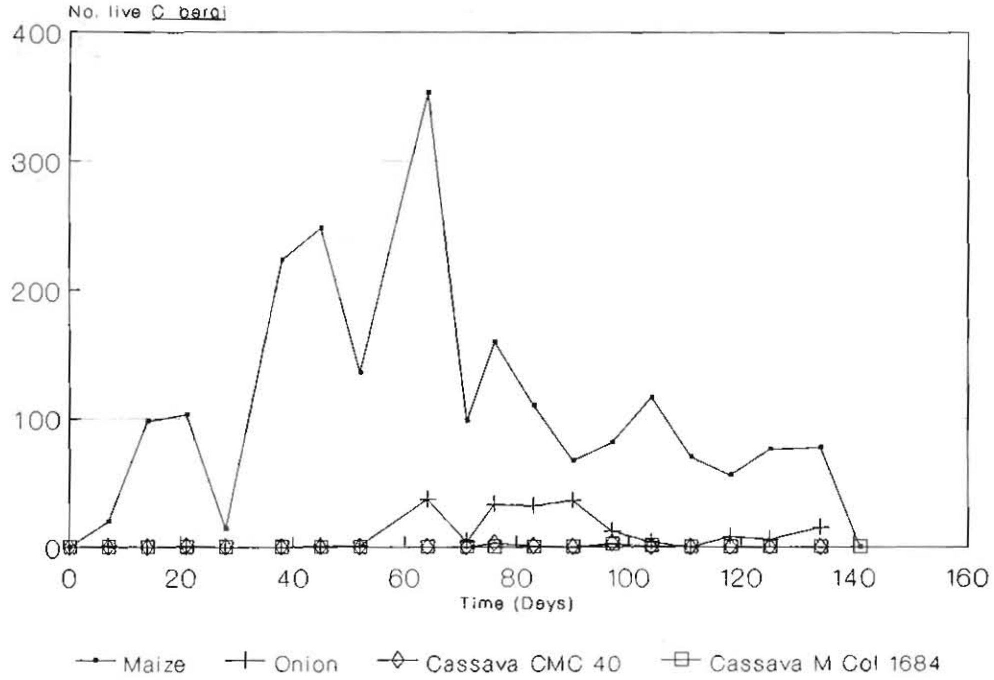


Figure 4.7 C. bergi oviposition on three hosts.

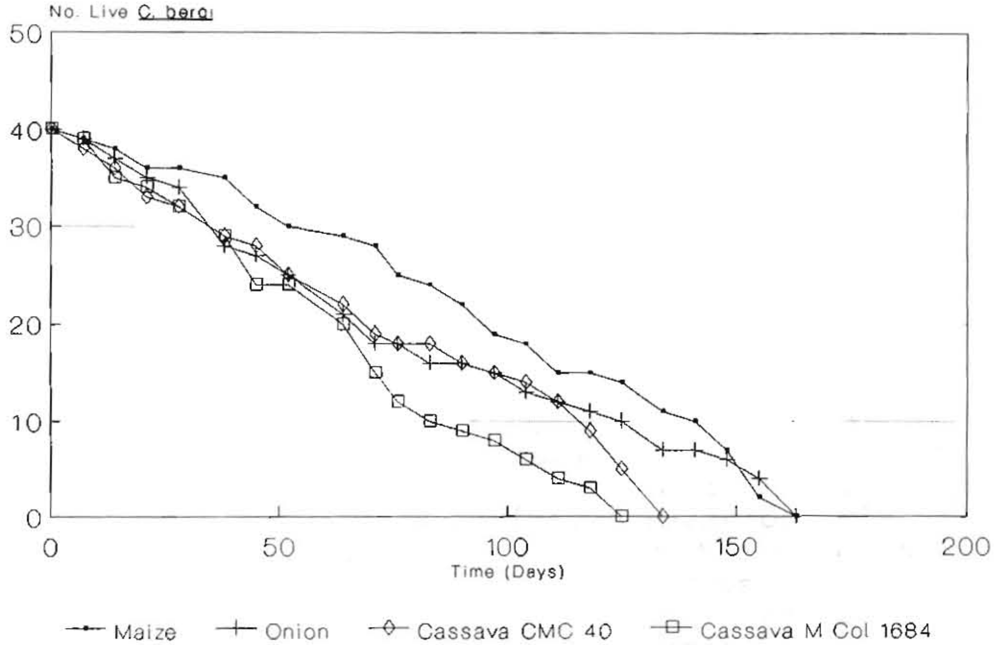


Figure 4.8 C. bergi survival when feeding on 3 hosts: maize, onions and cassava (CMC 40 and M Col 1884).

4.4.2 Field trials

Recent observations have indicated that C. bergi damage is increasing in cassava-growing regions on the Atlantic Coast of Colombia. Data on C. bergi attack were recorded from three experiments in Pivijay (Magdalena) and Ciénaga de Oro (Córdoba).

Five cassava clones (M Bra 12, M Ven I, M Ven II, M Col 1505 = P12) were evaluated for C. bergi damage at Pivijay. The clones and Sardina were planted in rows of 6 plants with three reps. The vegetative period was from May 1989-May 1990, and damage evaluations were made at harvest. Avg damage levels (grades 2-4 on a 0-5 damage scale) for commercial and noncommercial roots were 26.6% and 36.8%, resp. (Table 4.11). However, damage to roots (especially commercial roots) of M Bra 12, M Ven II and M Ven I was considerably higher than to roots of M Col 1505 and Sardina. These results are confusing in that M Bra 12, a high-HCN variety, should be the least attacked and show less damage than the sweet varieties. In this trial M Bra 12 had the greatest damage of the 5 varieties. The "susceptibility" of M Bra 12 indicates a possible "behavior" change; it may have a greatly reduced HCN content when grown under the edaphic and climatic conditions of Pivijay.

Table 4.11 C. bergi damage to five cassava varieties in La Colorada (Pivijay, Magdalena) during the May 1989 cropping cycle.

	% Commercial Roots			% Noncommercial roots		
	Damage Grade		Total Root	Damage Grade		Total Root
Variety	II	III-IV	Damage	II	III-IV	Damage
M Bra 12	40.0	10.0	50.0	30.0	10.0	40.0
M Ven II	33.0	6.6	39.0	17.0	37.0	54.0
M Ven I	30.0	0.0	30.0	43.0	3.0	46.0
M Col 1505 (P12)	7.0	0.0	7.0	23.0	14.0	37.0
Sardina	7.0	0.0	7.0	0.0	0.0	7.0
Avg	23.4	3.3	26.6	22.6	12.8	36.8

Table 4.12 Effect of planting data and locality on C. bergi damage to cassava roots on the Colombian North Coast.

Vegetative Cycle	Locality	% Commercial Roots			% Noncomercial Roots		
		II	III IV	Total	II	III IV	Total
05/89-05/90	Pivijay	20.4	3.9	24.3	18.3	10.3	28.6
10/89-10/90	Pivijay	0.58	0.0	0.58	0.58	0.0	0.18
05/89-05/90	Pivijay	23.4	3.3	26.6	22.6	12.8	36.8
05/89-05/90	Ciénaga de Oro	38.4	22.0	60.4	24.0	34.0	58.0

In a separate trial, 7 varieties were sown at 2 distinct vegetative cycles (May-May and Oct.-Oct.) and evaluated for insect and mite populations and damage. C. bergi damage averaged 24.3% for the 7 varieties during the May-to-May vegetative cycle, but only 0.6% during the Oct.-to-Oct. planting (Table 4.12). These results indicate that environment and/or edaphic conditions are more favorable to C. bergi activity during the May-to-May cycle when high precipitation and subsequent greater soil moisture (combined with lower soil temp) may alter C. bergi behavior, resulting in less root damage. This hypothesis will be evaluated further.

In Ciénaga de Oro, damage reached 60% root damage in C. bergi control experiments. It can be seen that C. bergi is becoming an important pest in cassava fields on the Colombian North Coast and requires monitoring in the future. Varieties that expressed little or no damage symptoms in other cassava-growing regions (i.e., Valle del Cauca) display severe damage symptoms on the North Coast. This phenomenon needs further investigation.

4.5 The Black Lacebug: Amblystira machalana

The black lacebug, A. machalana (Hemiptera: Tingidae), was first reported on cassava in Colombia, Venezuela and Ecuador in 1987. A closely related species, A. opaca Champion, which has also been identified, is indistinguishable from A. machalana in field infestations. Damage, which is primarily to the lower plant leaves, is manifested by considerable speckling, which in severe infestations whitens the leaves.

4.5.1 Yield loss studies

To evaluate the potential economic importance of this pest on cassava, a field trial was conducted at CIAT from Oct. 1989 to Sept. 1990 using var. M Col 22 in a random plot design, with and without pesticide application (2 cc dimethoate/lt water). In naturally infested fields, a damage grade of 3 (0 to 5 scale) was recorded from the 4th to the 9th mo after planting, while damage level reached 0.8 in the control plots. There was a 39% reduction in RY compared to the control (pesticide-applied plots) (Fig. 4.9).

The within-plant distribution of A. machalana was evaluated in four clones (M Bra 12, M Ven 77, M Bra 677 and HCM 1). Within-plant distribution was similar for all clones: The lower and intermediate leaves supported 83% of the adults and immatures (Fig. 4.10).

4.5.2 Resistance evaluations

The relationships among damage, population density and duration, and yield loss is unknown; thus preliminary screening for sources of resistance was based on the selection of clones from yield trials. Under natural field infestation, 278 clones were evaluated during high lacebug populations using a damage scale of 0 (no damage) to 5 (necrosis and defoliation). Low damage scores (Grade 0-1.5) were found on 94 clones (Fig. 4.11). As screening was done with natural populations of A. machalana, escapes are probably included in this group; thus continued evaluation of selected clones as well as additional material from the germplasm bank is planned.

4.5.3 Biology studies

Preliminary studies on the life cycle of A. machalana were done in the lab on excised leaves of the var. CMC 40 in petri dishes at a constant temp of 28°C and 50-60% RH. Mean egg-to-adult development time was 42.5 days (Table 4.13). The life stages consist of the egg, 5 nymphal stages and the adult stage. Adult males and females lived a mean of 22 and 18 days, resp.; and a mean of 36 eggs/female were oviposited.

4.6 **Cassava Pest Complexes**

Pest complex studies provide a view of the fluctuations in insect and mite populations and their effect on the stability of cassava yields over several cropping cycles. A long-range study of pest complexes at CIAT is into its tenth year. More recently these studies were initiated in Pivijay (Magdalena) and Villavicencio (Meta).

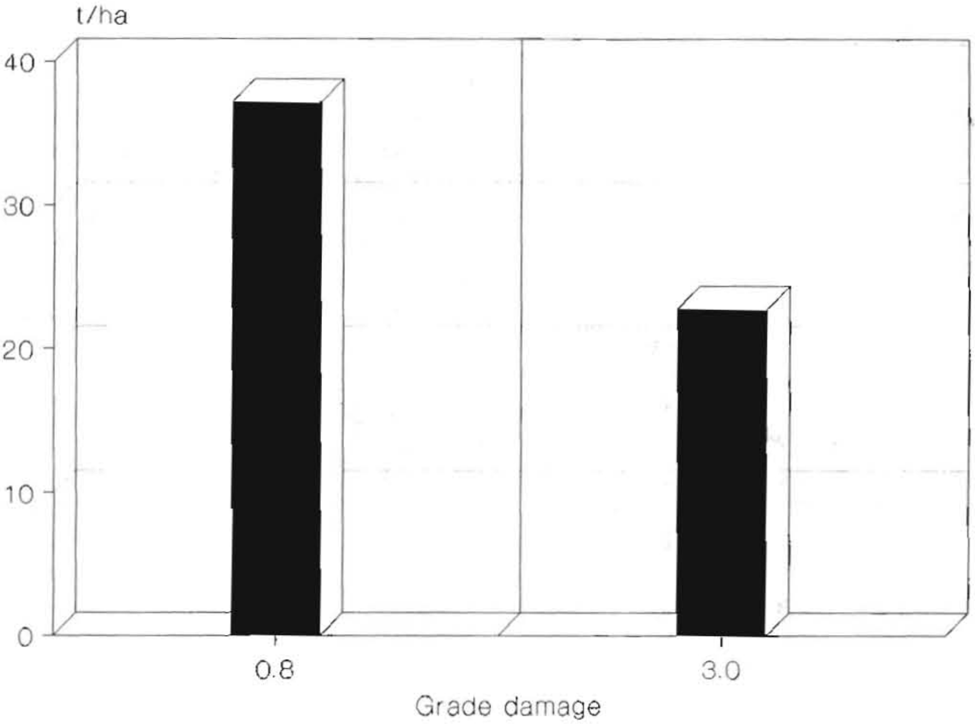


Figure 4.9 Yield depression caused by A. machalana during 6-mo attack (mo 4-9), Clone M Col 22).

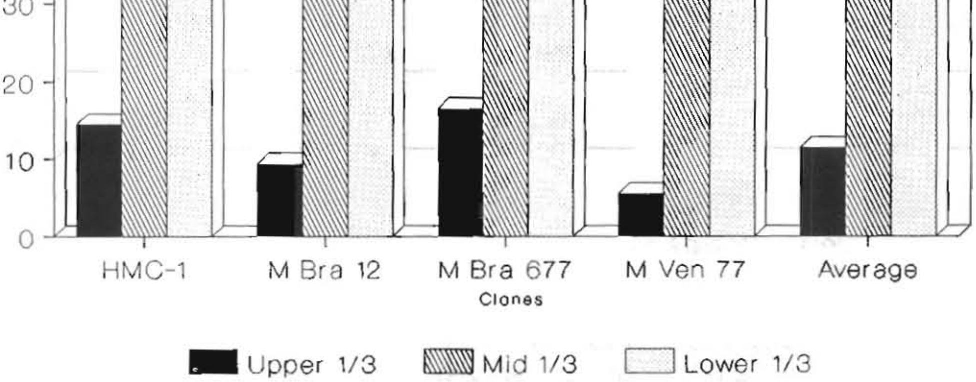


Figure 4.10 Within-plant distribution of A. machalana during vegetative plant cycle (Oct. 1989-Oct. 1990) at CIAT (avg of 4 cassava clones).

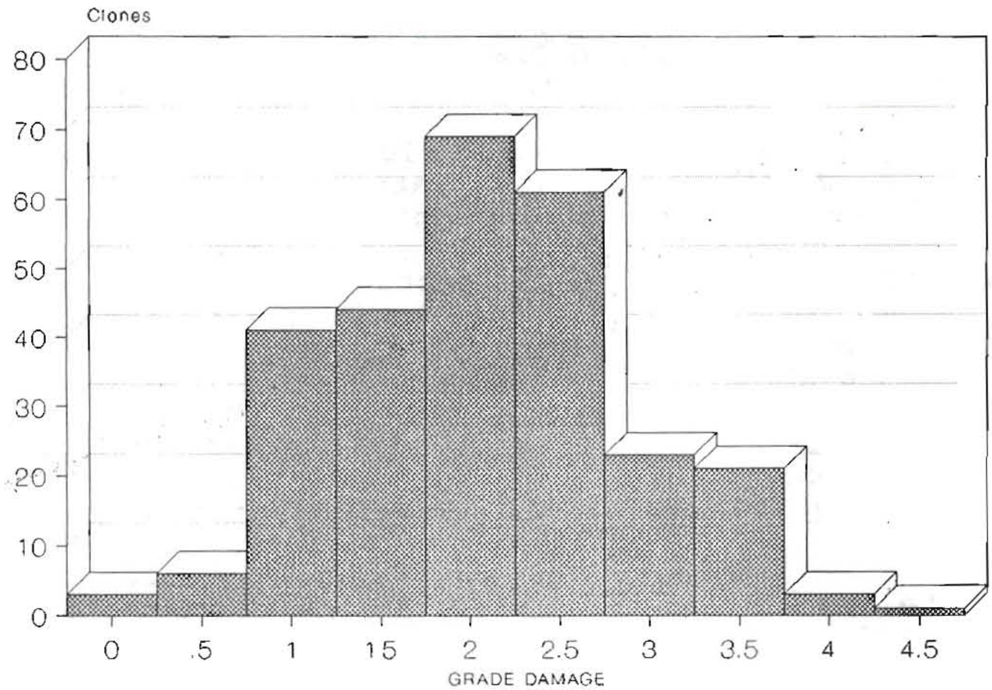


Figure 4.11 Field evaluation of 272 cassava clones for A. machalana damage at CIAT.

Table 4.13 Life cycle of A. machalana (Hemiptera:Tingidae) under lab conditions (28°C, 50-60% RH) on cassava var. CMC 40.

Life Stage	No. Observations	Avg Duration (days)	CV %
Egg	22	8.2	11
Nynphal Instar			
I	27	2.5	26
II	26	2.2	18
III	24	2.4	24
IV	22	3.0	17
V	19	4.0	4
Adults			
Male	18	22.0	38
Female	18	18.3	

[1] Oviposition: Avg 36 eggs/female.

Seven cassava varieties (P12, M Bra 12, M Ven I, CMC 40, M Col 22, M Col 1684 and M Col 113) were planted in May (May 1989-May 1990 cropping cycle) and October (Oct. 1989-Oct. 1990 cropping cycle). Three 36-plant plots of each variety were treated with dimethoate (2 cc/lt water) and Omite (1 cc propargite/lt water); and four plots of each variety were left untreated. Monthly evaluations of insect and mite populations were recorded. Major pests encountered were mites (Mononychellus and Oligonychus spp.), thrips, whiteflies and termites. An evaluation of C. bergi damage to roots was recorded at harvest.

By comparing results between treated and nontreated plots for each variety, the stability of the variety in relation to pest attack can be evaluated. Results indicate that planting time also has an influence on varietal reaction. Overall yields were higher for the May-to-May cropping cycle, with the avg RY (for the 7 var.) in the treated plots 24.4 t/ha--a 20% reduction over the Oct. planting (19.4 t/ha). In the nontreated plots, yield differences were greater. For the May planting, avg RY was 24.1 t/ha; for the Oct. planting, only 11.8--a 51% reduction (Tables 4.14 & 4.15).

There was no RY reduction during the May-to-May cycle in either the treated or nontreated plots; however, RY from the Oct.-to-Oct. cycle were reduced by 39% in the nontreated vs. treated plots (Tables 4.14 & 4.15). These results indicate that insect and mite pressure is only one factor in RY reductions during the Oct.-to-Oct. cycle. The two planting cycles differ in that the May planting is at the beginning of the rainy season, thereby allowing for rapid plant growth (no stress for lack of moisture) when foliar insect and mite populations are greatly suppressed (Figs. 4.12 & 4.13) due to heavy precipitation. The Oct. planting is at the end of the rainy season so initial plant growth occurs during the drier months when insect and mite pressures and damage are greatest (Figs. 4.14 & 4.15) and plants are subjected to drought stress. Previous studies have shown that it is during the first 5 mo of growth that the plant is most susceptible to yield reductions due to arthropod attack. This combination of factors probably contributes to the differences in cassava RY recorded from this experiment.

Varietal preference also differed considerably. RY of var. P 12 and M Col 22 were reduced by 45 and 53%, resp., between the treated vs. nontreated plots during the Oct. cycle, but showed no yield reduction during the May cycle (Tables 4.14 & 4.15). M Ven I was stablest, with almost identical yield reductions of 14 and 16% in the treated and nontreated plots for the Oct. and May planting cycles, resp.

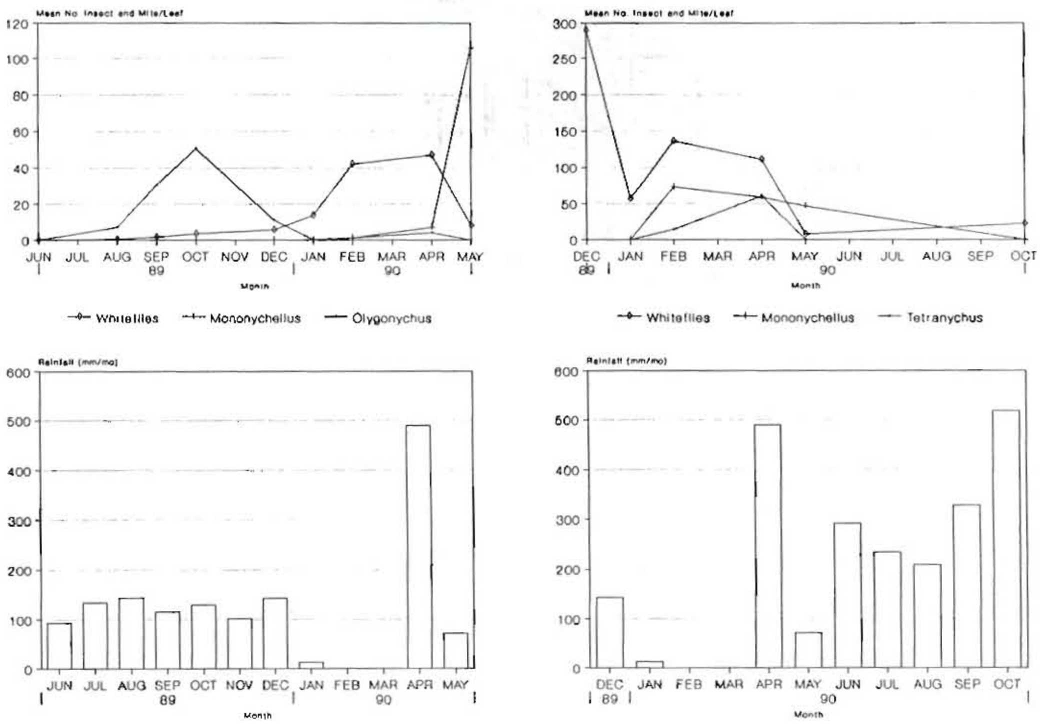


Figure 4.12 Population fluctuations of insect and mite complexes on cassava var. P12 (M Col 1505) during two planting cycles in Pivijay (Magdalena).

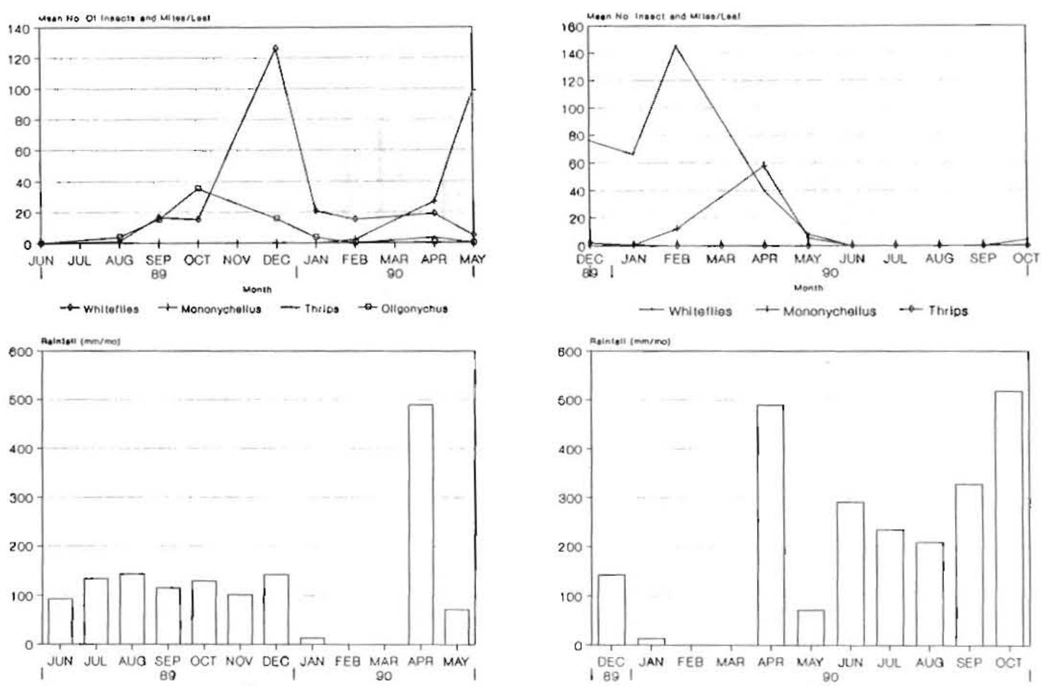


Figure 4.13 Population fluctuations of insect and mite complexes on cassava var. M Ven I during two planting cycles in Pivijay (Magdalena).

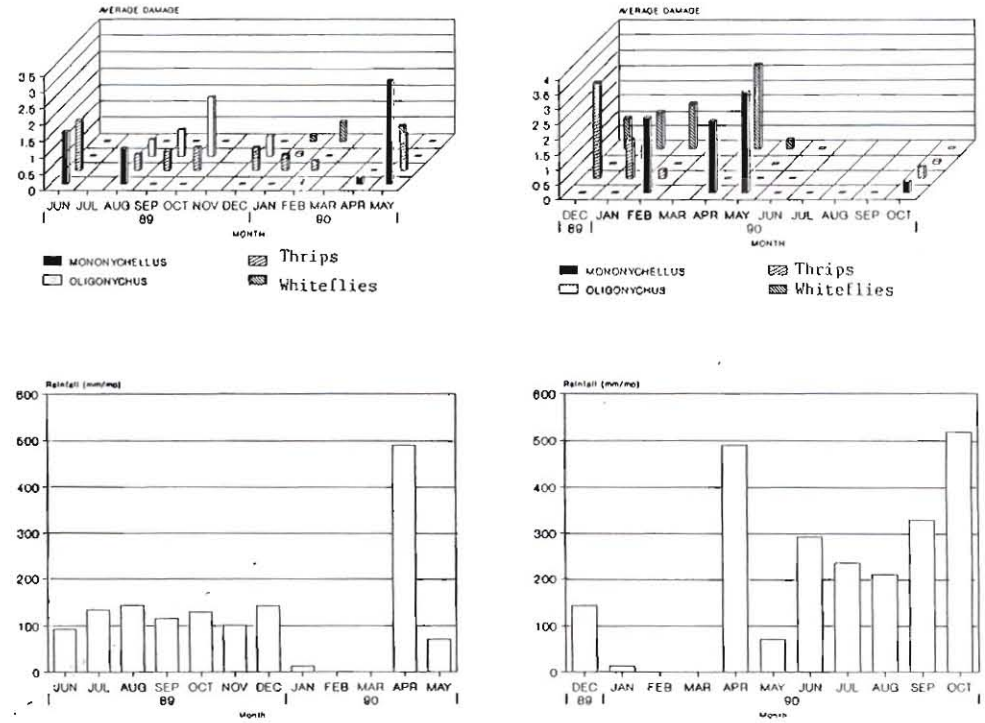


Figure 4.14 Mean damage of insect and mite complexes on cassava var. M Ven I during two planting cycles in Pivijay (Magdalena).

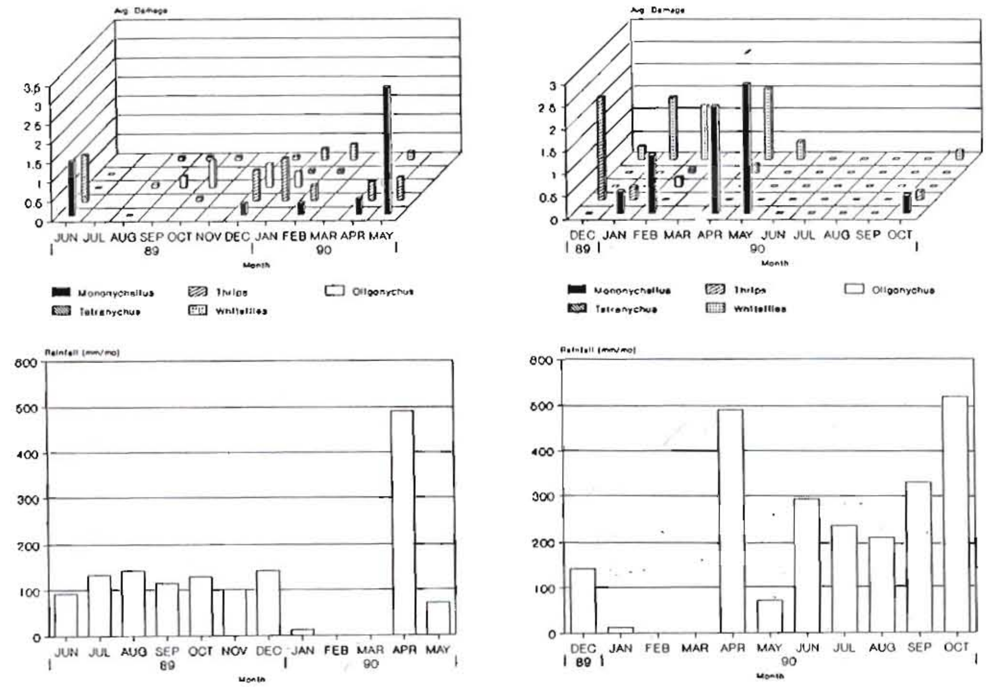


Figure 4.15 Mean damage of insect and mite complexes on cassava var. P 12 (M Col 1505) during two planting cycles in Pivijay (Magdalena).

Table 4.14 The effect of an arthropod pest complex on cassava root yields during a May 1989 to May 1990 cropping cycle in Pivijay, Magdalena.

Variety	Treatment	Root Production (t/ha)	% Difference	Starch	% % DM
	W/I	22.4		26.7	28.7
P12				-0.46	
	Wo/I	23.5		28.3	30.3
	W/I	27.5		26.1	28.1
M Bra 12			14.5		
	Wo/I	23.5		24.1	26.0
	W/I	24.6		31.7	22.8
M Ven I			16.3		
	Wo/I	20.6		30.9	33.0
	W/I	17.1		19.1	20.9
CMC 40			-24.7		
	Wo/I	22.7		19.4	21.2
	W/I	28.0		25.6	27.6
M Col 22			0.0		
	Wo/I	28.0		23.9	25.8
	W/I	35.4		23.4	25.3
M Col 1684			-0.8		
	Wo/I	35.7		25.7	27.7
	W/I	15.6		20.1	22.0
M Col 113			6.0		
	Wo/I	14.7		20.7	22.5

Table 4.15 The effect of an arthropod pest complex on cassava RY during an Oct. 1989 to Oct. 1990 cropping cycle in Pivijay, Magdalena.

Variety	Treatment[1]	Root Production (t/ha)	% Difference	% Starch	% DM
P12	W/I	21.5	45.6	29.5	31.6
	Wo/I	11.7		29.8	31.9
MBra 12	W/I	19.8	25.8	27.5	29.6
	Wo/I	14.7		27.6	28.6
MVen I	W/I	16.8	13.4	32.0	34.2
	Wo/I	14.5		29.4	31.5
CMC-40	W/I	25.1	37.5	27.3	29.3
	Wo/I	15.7		26.1	28.1
MCol 22	W/I	23.8	53.4	27.4	29.4
	Wo/I	11.1		27.1	29.1
MCol 1684	W/I	24.0	37.0	26.5	28.5
	Wo/I	15.1		26.4	28.4
MCol 113	W/I	4.5	100.0	19.5	21.3
	Wo/I	0.0		-	-

[1] (WI = with insecticide treatment; WoI = without insecticide treatment).

Although the May-to-May planting cycle was most favorable for RY and foliar arthropod pressure was reduced, the reverse was found for C. bergi activity. Damage due to this soil-borne hemipteran was 24% of roots damaged during the May planting cycle vs. only 0.6% during the Oct. cycle.

Termite activity was slightly higher during the Oct. planting cycle. Damage to the original planted stakes was high during both cycles; whereas root damage--although quite low overall--increased during the May planting cycle (Table 4.16). Insect and mite foliar damage was higher during the Oct. planting, which corresponds to those months of low precipitation (Figs. 4.14 & 4.15).

4.7 Cassava Acarology

Research has focused on biological control of the cassava green mite (CGM), Mononychellus tanajoa, which was accidentally introduced to Africa from the Neotropics in the 1970s. From its initial foothold in Uganda, CGM spread throughout most of the African cassava belt. Control of CGM in Africa is considered to be one of the most important challenges facing crop protection today.

Shipments of natural enemies from CIAT to IITA have been made regularly since 1984. Eight species of phytoseiid predators of CGM have been shipped; but up until 1989, establishment for longer than one growing season in Africa

Table 4.16 Effect of planting cycles on termite damage on seven cassava varieties in Pivijay, Magdalena.

	Planting Cycle			
	May 1989 to May 1990		Oct. 1989 to Oct. 1990	
	Termite Damage (%)		Termite Damage (%)	
Variety	Stakes	Roots	Stakes	Roots
P12	80	2.8	98	0.6
MBra 12	93	0.9	98	0
MVen I	83	2.2	94	0
CMC-40	99	6.4	100	3.6
MCol 22	74	0.4	98	0
MCol 1684	81	0.6	87	0
MCol 113	95	5.8	95	0

had not been reported for any species. The initial introduction strategy involving release of multiple species was modified once difficulties in establishment became apparent. Typhlodromalus limonicus, the most geographically widespread and numerically abundant species throughout most of the the northern Neotropics, was highly recommended for release; and an intensive effort to establish it in Africa commenced in 1989. Neoseiulus idaeus, the most widespread and abundant CGM predator in Brazil, was also included in the release program.

Difficulties in establishing T. limonicus in Africa have persisted; thus recent research has focused on identifying possible causes for this. Strain differences between distinct geographical subpopulations have been found for several species of cassava-inhabiting phytoseiids, including T. limonicus and N. idaeus. The introduction of poorly adapted strains was hypothesized to be involved in the failure of establishment, and shipments of T. limonicus populations from inter-Andean valleys were suspended in favor of populations from the Caribbean coast of Colombia and NE Brazil. After shipments of an N. idaeus strain from the Colombian Guajiran Peninsula were suspended in favor of a Brazilian strain, regular recoveries of progeny from released populations were made in several sites; however, several phenomena were noted. N. idaeus appeared to be feeding on Oligonychus gossypii, a tetranychid mite of negligible economic importance on cassava, rather than on CGM. T. limonicus attained peak populations during the wet season when CGM density is low, corroborating observations of similar behavior in Colombia (Fig. 4.16) and Brazil (Moraes et al. 1991). This pattern of occurrence has not been observed for other species of phytoseiids. The objective of the research presented here is to explain these and other phenomema related to the process of establishing phytoseiids in Africa.

4.7.1 CGM and natural enemies in Brazil and Northern S. America

4.7.1.1 **CGM.** Explorations for natural enemies of CGM were conducted from 1985-90 in most cassava-growing countries of the Neotropics. The area explored by CIAT included Colombia, Venezuela, Ecuador, Trinidad, Mexico, and several Central American and Caribbean countries. This area will be referred to as Northern S. America (NSA). In NE Brazil, a parallel effort was conducted by EMBRAPA from 1988-90. The explorations involved qualitative and quantitative evaluation of CGM, other tetranychid mites, and natural enemy populations on cassava and on neighboring vegetation and weeds. Over 1000 cassava fields were evaluated. Comparative analyses of the phytoseiid mite complex in different ecological zones showed that species tended to

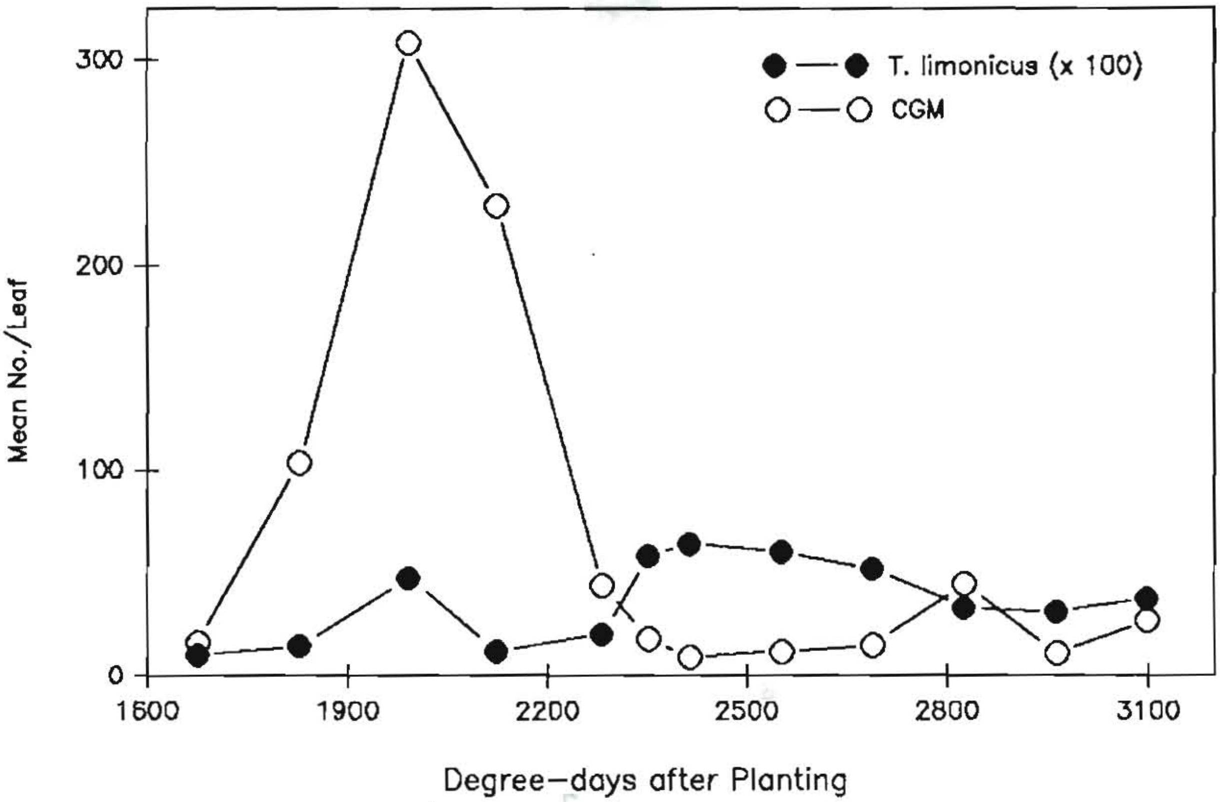


Figure 4.16 Population dynamics of CGM and T. limonicus in cassava.

separate out along ecological gradients such as the number of dry months per year (CIAT 1989), and that well-defined species complexes occur. The composition of these complexes varies with ecological zone; however, species composition also varies within ecologicaly similar areas (Tables 4.17-4.19).

Comparative analysis of CGM and natural enemy distribution and abundance in Brazil and NSA has important implications for classical biological control of CGM. A number of species of the genus Mononychellus occur on cassava in NSA, with the greatest number reported in Colombia. Colombia and Venezuela are the only countries outside Brazil, where M. tanajoa is widespread. Throughout most of NSA, Mononychellus caribbeanae is either the only species of Mononychellus reported (Cuba, Mexico, Nicaragua), or the predominant species (Panama, Ecuador) (Table 4.20).

In Brazil, only one Mononychellus spp., M. tanajoa (CGM), occurs on cassava (Table 4.20). Taxonomic analysis of CGM specimens collected throughout the Neotropics revealed that the length of the dorsocentral setae used in classifying

Table 4.17 Cassava tetranychid and phytoseiid complexes on the Colombian North Coast.

State	Ecological Zone[1]	No. Fields Sampled	No. Species Identified[2]	No. Fields /Species	Phytoseiidae Species	Sampling Frequency[3]	Tetranychidae Species	Sampling Frequency[3]
San Andrés	HL	5	7	0.7	A. largoensis	0.60	M. caribbeanae	0.40
					N. anonymus	0.40	M. tanajoa	0.20
					E. alatus	0.20	T. urticae	0.20
					G. alveolaris	0.20		
					G. helveolus	0.20		
					P. neotropicus	0.20		
					E. sp. near ovalis	0.20		
Atlántico	SDL	8	9	0.9	T. limonicus	1.00	M. tanajoa	0.62
					T. rapax	0.38	O. peruvianus	0.62
					T. dentilis	0.38	O. gossypii	0.25
					A. aerialis	0.25	M. caribbeanae	0.13
					G. annectens	0.25		
					T. aripo	0.25		
					T. bellottii	0.13		
					G. helveolus	0.13		
					E. alatus	0.13		
Sucre	SDL	94	18	5.2	T. limonicus	0.71	O. peruvianus	0.56
					A. aerialis	0.34	O. gossypii	0.40
					T. dentilis	0.33	M. tanajoa	0.35
					T. rapax	0.21	T. tumidus	0.09
					P. cannaensis	0.20	M. mcgregori	0.02
					T. bellottii	0.11	T. canadensis	0.02
					I. zuluagai	0.10	M. caribbeanae	0.01
							M. planki	0.01
							T. ludeni	0.01

Table 4.17 cont.

State	Ecological Zone[1]	No. Fields Sampled	Phytoseiidae: No. Species Identified[2]	No. Fields /Species	Species	Sampling Frequency[3]	Tetranychidae: Species	Sampling Frequency[3]
Córdoba	SDL	181	18	10.2	*T. limonicus*	0.70	*O. peruvianus*	0.76
					T. dentilis	0.15	*M. tanajoa*	0.54
					A. aerialis	0.13	*O. gossypii*	0.34
					T. rapax	0.12	*M. caribbeanae*	0.11
					N. anonymus	0.10	*T. tumidus*	0.03
							T. canadensis	0.02
							M. mcgregori	0.01
							M. planki	0.01
							T. cinnabarinus	0.01
							T. truncatus	0.01
Magdalena	SDL	33	11	3.0	*T. limonicus*	0.81	*M. tanajoa*	0.30
					T. aripo	0.12	*O. peruvianus*	0.27
							M. caribbeanae	0.15
							O. gossypii	0.12
							T. tumidus	0.06
Bolivar	SDL	29	13	2.6	*T. limonicus*	0.68	*M. caribbeanae*	0.03
					T. aripo	0.21	*M. tanajoa*	0.31
					T. dentilis	0.14	*O. gossypii*	0.24
					T. rapax	0.10	*O. peruvianus*	0.31
					G. helveolus	0.10		

Table 4.17 cont.

State	Ecological Zone[1]	No. Fields Sampled	Phytoseiidae: No. Species Identified[2]	No. Fields /Species	Species	Sampling Frequency[3]	Tetranychidae: Species	Sampling Frequency[3]
Cesar	SDL	15	12	1.3	*T. limonicus*	0.80	*O. peruvianus*	0.33
					N. anonymus	0.20	*M. caribbeanae*	0.20
					A. chiapensis	0.13	*O. gossypii*	0.20
					E. concordis	0.13	*M. tanajoa*	0.13
					E. helveolus	0.13	*M. mcgregori*	0.07
					N. idaeus	0.13	*T. tumidus*	0.07
					E. sibelius	0.13		
La Guajira	SDL,SAL	38	12	3.1	*N. idaeus*	0.55	*M. caribbeanae*	0.71
					T. limonicus	0.45	*M. tanajoa*	0.53
					G. annectens	0.42	*O. peruvianus*	0.37
					G. helveolus	0.24	*O. gossypii*	0.03
					E. concordis	0.11	*T. tumidus*	0.03

[1] Ecological zones: HL = humid lowland; SDL = seasonally dry lowland; SAL = semiarid lowland.

[2] Phytoseiid species found in less than 10% of fields sampled are not listed.

[3] Sampling frequency is the proportion of fields containing a given species.

Table 4.18 Cassava tetranychid and phytoseiid complexes in the Colombian inter-Andean zone.

			Phytoseiidae				Tetranychidae	
State	Ecological Zone[1]	No. Fields Sampled	No. Species Identified[2]	No. Fields /Species	Species	Sampling Frequency[3]	Species	Sampling Frequency[3]
Valle	HH	186	27	6.9	*T. limonicus*	0.57	*M. tanajoa*	0.49
					N. anonymus	0.37	*O. peruvianus*	0.24
					E. concordis	0.30	*T. urticae*	0.16
					G. helveolus	0.25	*M. mcgregori*	0.05
					G. annectens	0.22	*M. planki*	0.01
					T. pergrinus	0.19	*T. cinnabarinus*	0.01
					T. aripo	0.17		
Cauca	HH	56	13	4.1	*T. limonicus*	0.50	*M. tanajoa*	0.45
					E. concordis	0.16	*O. peruvianus*	0.21
					N. anonymus	0.11	*M. mcgregori*	0.14
							T. urticae	0.09
							T. cinnabarinus	0.02
Huila	HH	49	14	3.5	*T. limonicus*	0.33	*M. mcgregori*	0.64
					E. ho	0.31	*O. peruvianus*	0.27
							M. tanajoa	0.24
							T. urticae	0.02
Tolima	HH	23	5	4.6	*T. limonicus*	0.22	*M. tanajoa*	0.52
					N. anonymus	0.13	*M. mcgregori*	0.22
							O. peruvianus	0.04

[1] Ecological Zones: HH = humid highland; HL = humid lowland.

[2] Phytoseiid species found in less than 10% of fields are not listed.

[3] Sampling frequency is the proportion of fields containing a given species.

Table 4.19 Cassava tetranychid and phytoseiid complexes in Central Colombia.

			Phytoseiidae				Tetranychidae	
State	Ecological Zone[1]	No. Fields Sampled	No. Species Identified[2]	No. Fields /Species	Species	Sampling Frequency[3]	Species	Sampling Frequency[3]
Santander	HH,HL	23	12	1.9	*T. limonicus*	0.52	*M. tanajoa*	0.39
					T. rapax	0.22	*M. caribbeanae*	0.30
					G. helveolus	0.22	*O. peruvianus*	0.26
							O. gossypii	0.04
Meta	HL	93	7	13.3	*T. limonicus*	0.24	*M. tanajoa*	0.66
							O. peruvianus	0.11
							M. mcgregori	0.01
							M. planki	0.01
							O. gossypii	0.01

[1] Ecological Zones: HH = humid highland; HL = humid lowland.

[2] Phytoseiid species found in less than 10% of fields sampled are not listed.

[3] Sampling frequency is the proportion of fields containing a given species.

Table 4.20 Relative abundance of Tetranychid species on cassava in Brazil and the northern Neotropics.

Country	No. Fields Sampled	Species Reported	Sampling Frequency[1]
Brazil	49	*M. tanajoa*	0.53
		T. neocalidonicus	0.06
Cuba	43	*M. caribbeanae*	0.09
		T. tumidus	0.27
		T. urticae	0.02
Colombia	838	*M. tanajoa*	0.49
		O. peruvianus	0.37
		O. gossypii	0.11
		M. caribbeanae	0.08
		M. mcgregori	0.07
		T. urticae	0.05
		T. tumidus	0.02
		M. planki	0.01
		T. canadensis	0.01
		O. mcgregori	0.01
Ecuador	132	*M. caribbeanae*	0.49
		O. peruvianus	0.27
		M. mcgregori	0.10
		M. tanajoa	0.02
		T. urticae	0.01
		O. gossypii	0.01
Mexico	27	*M. caribbeanae*	0.44
		O. mcgregori	0.19
		T. marianae	0.07
		T. mexicanus	0.07
		T. tumidus	0.04
		O. peruvianus	0.04
		T. turkestani	0.04
Nicaragua	2	*M. caribbeanae*	0.50
Panama	17	*M. caribbeanae*	0.76
		M. tanajoa	0.18
		M. mcgregori	0.12
		O. peruvianus	0.12
Venezuela	43	*M. tanajoa*	0.84
		M. caribbeanae	0.72
		O. peruvianus	0.14
		T. tumidus	0.05
		O. gossypii	0.02

[1] Sampling frequency is the proportion of fields containing a given species.

tetranychids, varies greatly, particularly in Colombia. CGM from Brazil vary little in setal length; however, the measurements fall within the range found in NSA. Cluster analysis showed that Brazilian material is confined to the short extreme of the range of morphological variability (Fig. 4.17). CGM with short setae--whether from NSA or Brazil--have higher esterase activities than mites with long setae, suggesting the existence of physiological differences between morphs.

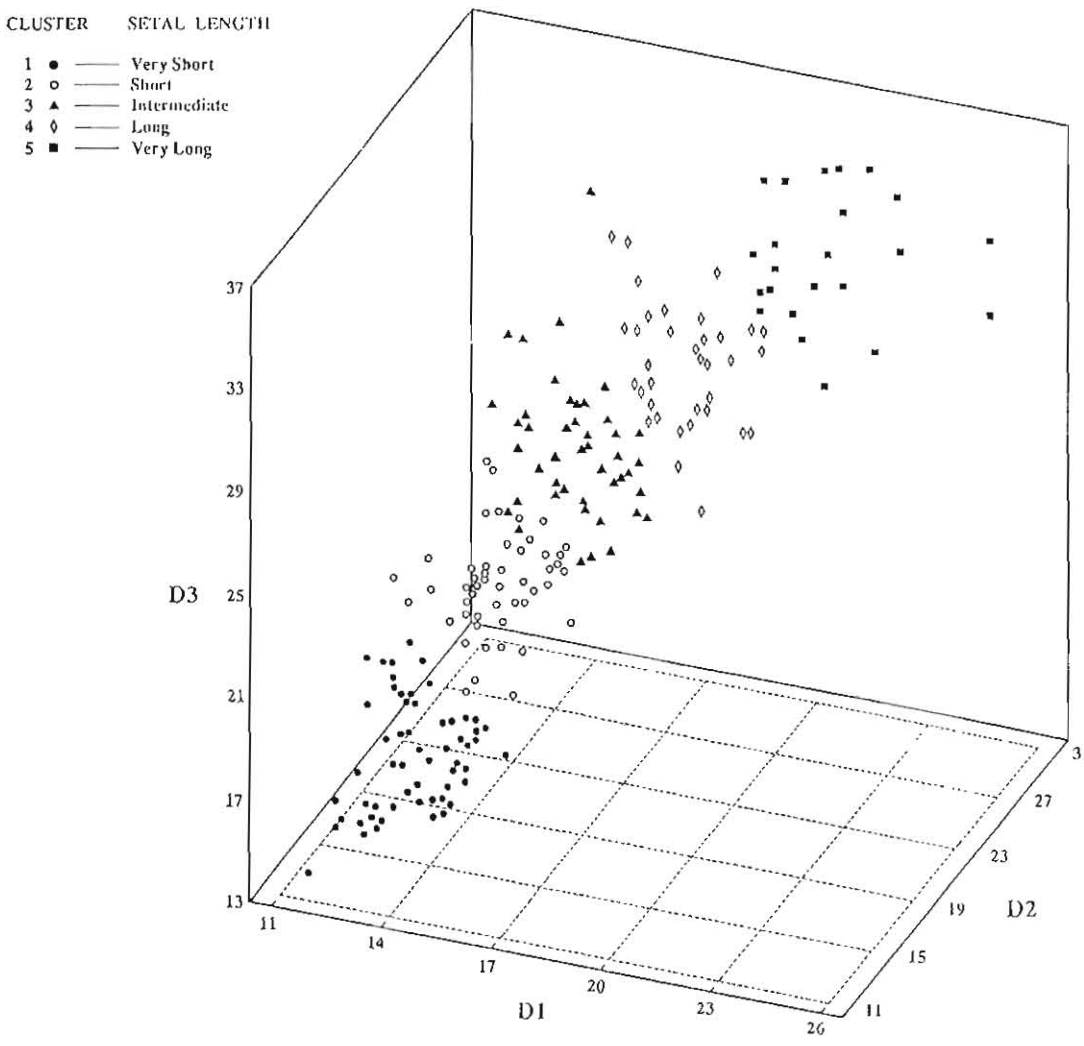


Figure 4.17 Graphic representation of cluster analysis of lengths of dorsocentral setae, D1, D2 and D3 of M. tanajoa (Bondar) from six SA countries. Geographic membership by cluster: 1-Colombia, Brazil, Paraguay, Panama, Venezuela; 2-Colombia, Venezuela; 3-Colombia; 4-Colombia, Trinidad, Venezuela; 5-Colombia, Ecuador, Panama, Paraguay, Venezuela, Trinidad.

The phytoseiid natural enemy complex associated with CGM in NSA attains maximum species diversity in Colombia, where 40 species have been identified and 18 are common (CIAT 1989). In NSA, up to 12 phytoseiid species were found per cassava field, and 29% of the fields contained three or more species (Fig. 4.18). In Brazil 22 phytoseiid species were recorded on cassava (Moraes et al. 1991); but only two were common. Only 3% of the fields contained three or more species, 56% contained only one, and 28% were devoid of phytoseiids (Fig. 4.18). In quantative evaluations of CGM population density in 486 cassava fields, intermediate to high levels of CGM were found in 23% of the Brazilian fields. Of the fields surveyed in NSA, 93% had low populations or were devoid of CGM (Fig. 4.19). Fig. 4.20, which is a geographical representation of the CGM incidence data, shows the greater prevalence of heavy infestations in Brazil.

CGM is a dry season pest. Rainfall is a direct mortality factor, and populations are rapidly decimated at the onset of the rainy season. During the dry season, actively growing mite populations are sustained only as long as soil moisture is adequate to support production of new cassava foliage (Yaninek et al. 1989). In Africa, where CGM is an introduced pest, seasonally dry areas (4-6 dry mo/yr) run the greatest risk of severe CGM infestations (Yaninek & Bellotti 1987). Of the Brazilian cassava fields sampled, 14% were in areas with 365-700 mm annual precipitation.

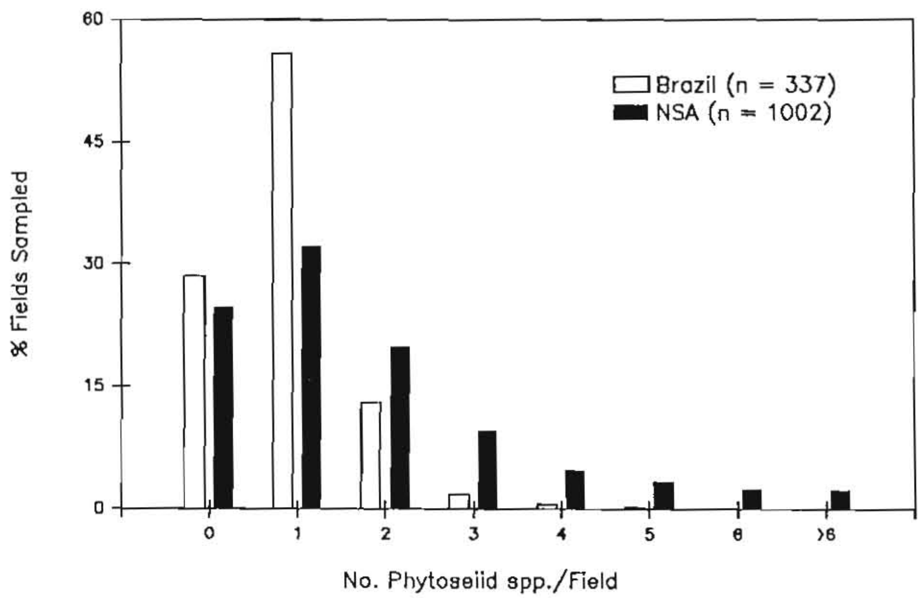


Figure 4.18 Phytoseiid species diversity in Colombia and Brazil.

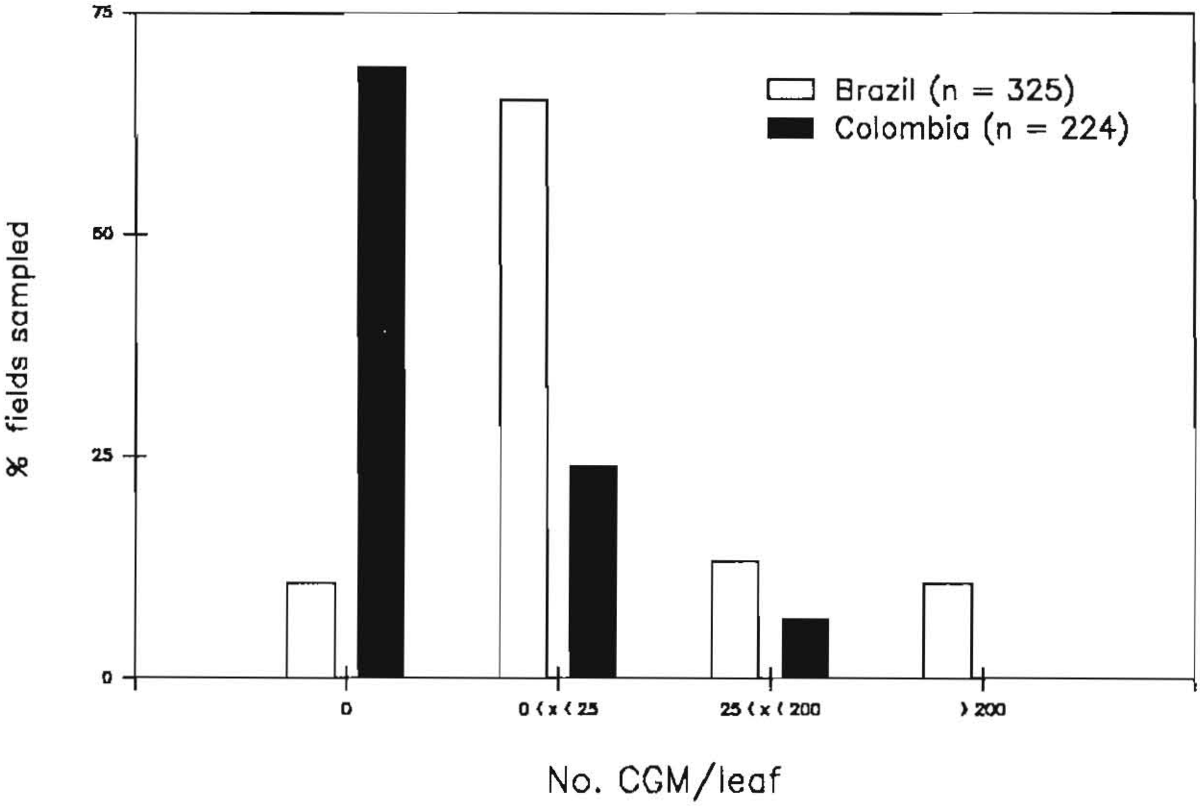


Figure 4.19 CGM incidence in Colombia and Brazil.

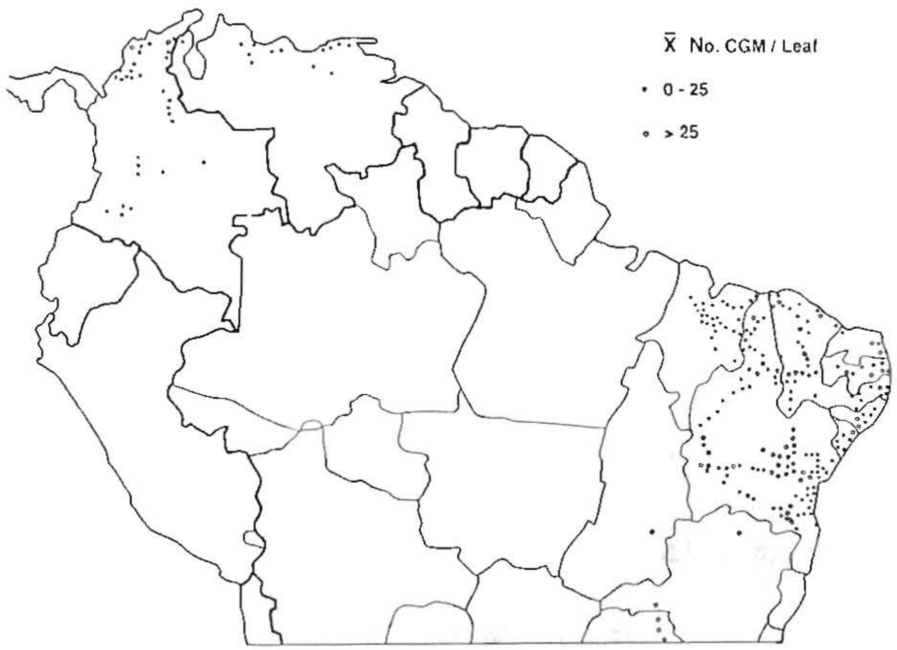


Figure 4.20 Infestation foci of CGM in NSA and Brazil. Each point represents the mean no. of CGM/leaf, averaged over 4 and 2 cassava fields in NSA and Brazil, resp.

These areas are semiarid with more than 6 dry mo during the year. Surprisingly, the severest outbreaks of CGM were found in these, rather than in the seasonally dry areas of NE Brazil (Fig. 4.21). In NSA, intermediate to heavy infestations of CGM were not found in semiarid areas (Colombian Guajiran Peninsula, Coastal Venezuela, Coastal Ecuador); however, moderate to heavy infestations of a sibling species, M. caribbeanae were frequently recorded in these areas.

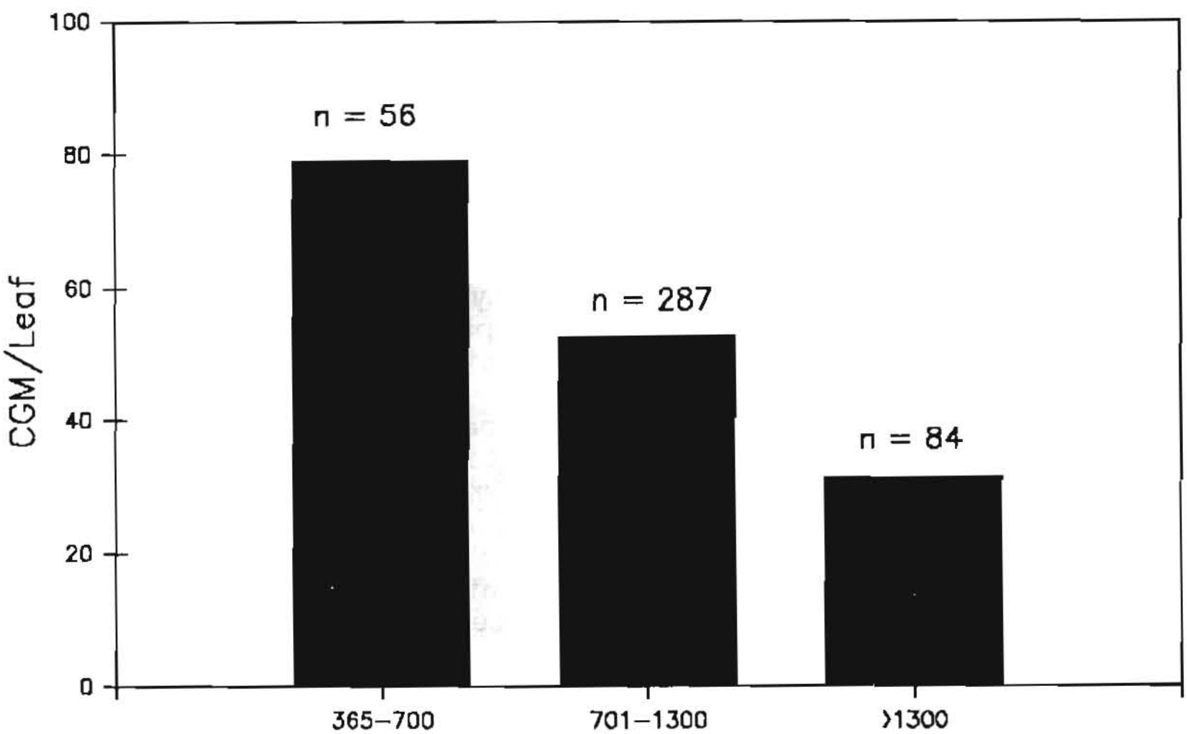


Figure 4.21 Effect of rainfall on mean CGM population levels in NE Brazil (Rainfall Zones: 365-700 mm/yr - semiarid; 701-1300 - seasonally dry; > 1300 - humid. n = no. cassava fields averaged to obtain a mean CGM population density-leaf for each rainfall zone); effect of rainfall on CGM density is significant [Kruskal-Wallis test statistic = 8.93 P = 0.01]. (Source: Moraes et al. 1991).

The largest, most effective complex of natural enemies of an herbviorous arthropod has often been found in its area of origin. The diversity of *Mononychellus* spp. and their natural enemies in NSA suggests that this region is the area of origin of the genus *Mononychellus* and, therefore, of the CGM. The occurrence of only a single species of *Mononychellus* (CGM) on cassava in Brazil, which frequently reaches intermediate-to-high densities--together with the absence of the diverse complex of natural enemies associated with this species in NSA--suggests that CGM may have been introduced to Brazil. The morphological differentiation and low variability of Brazilian CGM compared to other neotropical populations suggest that the introduction is not recent and that the Brazilian population has remained relatively isolated.

The striking ability of Brazilian CGM to colonize semiarid areas may represent ecological adaptation to dry conditions. Alternatively, the success of the mite in the Brazilian semiarid zone may be related to the absence of competing species of other tetranychid mites, including sibling species such as *M. caribbeanae*, and/or to the lack of effective predators that are themselves adapted to dry conditions. The morphological differentiation of Brazilian CGM, its related difference in esterase activity, and its adaptation to semiarid areas suggest that the population of CGM in NE Brazil may be a distinct strain or biotype.

The possibility that CGM is an introduced pest suggests that classical biological control could contribute to its management; however, the semiarid areas may require the introduction of strains that have been genetically manipulated in order to improve their tolerance to low RHs. Under Brazilian conditions, classical biological control should form part of an integrated pest management strategy, which would also include augmentation and conservation of natural enemies, appropriate cultural practices, and the deployment of resistant varieties.

The NSA origin of CGM implies that natural enemies from this region should receive higher priority for introduction and release in Africa than has been the case recently. This does not necessarily imply, however, that the priority given to Brazilian natural enemies should be lowered. As discussed in a subsequent section, the behavior of phytoseiid species/strains associated with cassava cannot always be predicted reliably from predator/prey association patterns in the field. Although *T. limonicus* and *N. idaeus* do not appear to be effective in NE Brazil, it is conceivable that Brazilian strains of these species could be more effective against African than Brazilian CGM. It is therefore recommended that the introduction, release and evaluation of Brazilian strains of these species in Africa be continued.

4.7.1.2 T. limonicus and N. idaeus. T. limonicus was originally described on avocados and citruses in California (Garman & McGregor 1956). In South America 96% of the collection records (n = 663) for this species are on cassava. An exploration trip was made specifically to search for this species in avocado and citrus-growing regions of Colombia; however, no T. limonicus were found. T. limonicus were obtained from California and were crossed with those collected from cassava. No progeny were obtained, and electrophoresis corroborated that these are distinct species. This new species of Typhlodromalus is being described by Moraes et al. (in preparation); in the interim, the name T. limonicus will refer to T. limonicus sensu lato. The phytoseiid T. limonicus is the most widespread CGM predator throughout NSA (Bellotti et al. 1987). The only areas where it does not predominate numerically are semiarid regions where CGM is replaced by M. caribbeanae, and N. idaeus becomes the dominant phytoseiid (Table 4.17). Predator-exclusion experiments have demonstrated that natural enemies of the CGM provide a protective effect, equivalent to applying a biweekly acaricide treatment through the dry season (Braun et al. 1989; CIAT 1988). The predominant natural enemy in the area where these results were obtained was T. limonicus, and electrophoretic analysis of T. limonicus gut contents in areas where tetranychid prey other than M. tanajoa were present suggests that T. limonicus prefers M. tanajoa over other cassava-feeding tetranychids.

N. idaeus is the predominant phytoseiid species in cassava throughout much of NE Brazil (Moraes et al. 1988); however, in NSA, N. idaeus has been reported only in areas where M. caribbeanae either predominates or occurs without M. tanajoa (Table 4.17). T. limonicus is the only other widely distributed phytoseiid in NE Brazil; however, hybridization experiments (CIAT 1989) showed that a degree of reproductive isolation exists between T. limonicus populations from Colombia and Brazil, and electrophoretic analyses of esterase isoenzymes have demonstrated that Brazilian T. limonicus is a distinct strain. Although strain differentiation of both CGM and T. limonicus may explain the apparent failure of T. limonicus in biological control in NE Brazil, a re-evaluation is being made of the importance ascribed to T. limonicus as the principal natural enemy of CGM in NSA.

4.7.2 Electrophoretic differentiation of phytoseiid strains

Strain differences among Brazilian and other neotropical populations of phytoseiids have been reported for three species with respect to reproductive capacity (CIAT 1989), and the strains of many species appear to differ in their ecological ranges. It may be possible to improve the level of biological control in NE Brazil by introducing phytoseiid strains with higher consumption or oviposition rates, or better adaptation to ecological conditions. To determine whether introduced strains establish, it must be possible to distinguish them from their local counterparts. Morphological differentiation of strains is not possible; however, electrophoresis has been used successfully.

T. limonicus was used to study the feasibility of electrophoretic differentiation of strains using polyacrylamide gels. After testing several isoenzymes, the esterase system was chosen for its superior polymorphormism. Five strains of T. limonicus have been identified. The first strain encompasses eight populations from the North Coast of Colombia. Two strains were identified from the State of Valle (Colombia). T. limonicus from Cruz das Almas, Brazil and Puerto España, Trinidad comprises a fourth strain; and a Venezuelan population collected in Carora, a fifth. Statistical analyses of esterase banding patterns are in progress to elucidate the phylogenetic relationships among strains.

4.7.3 Geographical associations among cassava mites

The tetranychid and phytoseiid complexes on cassava reach their maximum species richness in Colombia; however, different species associations occur in different cassava-growing areas. For phytoseiids this phenomenon holds for both common and rare species (Table 4.21). Phytoseiid and tetranychid species diversity is positively correlated ($n = 14$, $r = 0.65$; $P = 0.01$).

On the North Coast, the most frequently reported species was T. limonicus (Table 4.17). The island of San Andrés was the only area sampled where T. limonicus has not been reported, and where M. caribbeanae occurs in the absence of N. idaeus. Several of the phytoseiids species reported on San Andrés (Amblyseius largoensis, Proprioseiopsis neotropicus, Galendrominus alveolaris) are extremely rare in other regions of Colombia. This site could be appropriate for experimental releases of phytoseiids. Although a number of species such as T. limonicus, N. anonymus, Galendromus annectens, G. helveolus (Tables 4.17-4.18) are geographically ubiquitous, the distribution of others is restricted. T. rapax, Typhlodromips dentilis and T. bellottii occur only on the North Coast. Comparison of an indicator of the profitability of exploration in a given region (no. fields sampled per species encountered, Tables 4.17-4.19) suggests that San Andrés, Atlántico, and Cesar may be underexplored. Magdalena, Bolivar and Guajira should also receive some additional attention.

Table 4.21 Rare cassava phytoseiids in Colombia.

Species	Zone[1]		
	North Coast	Inter-Andean	Central
A. chiapensis	C[2]	X	X
A. herbicolus	X	X	NF
P. macropilis	X	C	NF
N. californicus	X	X	NF
P. mexicanus	X	X	NF
Typhlodromips n. sp.	X	NF	NF
P. pursglovei	X	NF	NF
T. tenuiscutus	X	X	NF
E. ho	X	C	X
T. neotunus	X	X	NF
E. naindaimei	X	X	NF
C. transvaalensis	X	X	NF
A. aerialis	C	X	X
E. alatus	C	X	X
T. rapax	C	X	NF
T. mangleae	NF	X	NF
T. tropica	NF	X	NF
E. sibelius	C	X	X
P. caliensis	NF	X	NF
P. neotropicus	C	X	X
I. zuluagai	C	X	X
E. sp. near *ovalis*	C	X	X
T. aripo	C	C	X
N. anonymus	C	C	X
G. helveolus	C	C	X
G. annectens	C	C	X
P. cannaensis	C	X	X
E. concordis	C	C	X
N. idaeus	C	X	X

[1] North Coast = the states of San Andrés, Atlántico, Sucre, Córdoba, Magdalena, Bolívar, Cesar and Guajira; Inter-Andean = the states of Valle, Cauca, Huila and Tolima; Central = the states of Meta and Santander.

[2] X = Found in less than 10% of fields sampled; NF = Not found; C = Found in more than 10% of fields sampled.

4.7.4 Phytoseiid diet analysis

4.7.4.1 **Acarine food types.** In NSA a number of species of tetranychid mites other than CGM are common in cassava and may occur together on the same plant, even on the same leaf. The most important of these species in terms of numerical abundance and widespread geographical distribution are M. caribbeanae, Oligonychus gossyppi, O. peruvianus and Tetranychus urticae. T. urticae and O. gossyppi also occur on cassava in Africa. In order to identify species that might prefer prey species other than CGM, survival and reproductive rates of 11 species and strains of phytoseiids were compared for CGM and the aforementioned tetranychid prey. The possible importance of inter- and intraspecific cannibalism as a survival mechanism during periods of prey shortage was also evaluated.

All species of phytoseiids tested were able to complete development from egg to adult on all the prey species tested; however, survival was strongly affected by prey type (Table 4.22). Neoseiulus spp. had high egg-to-adult survival rates on all prey types except O. peruvianus. The Typhlodromalus spp. had high survival rates with M. caribbeanae and M. tanajoa as prey with significant differences between strains (ANOVA, $P \leq 0.05$). Survival rates were generally low on the other prey species.

Because of low survivorship from egg to adult, reproduction with O. peruvianus as prey was observed only in N. idaeus (Brazilian strain) (Table 4.23). Fewer eggs were laid per female with O. peruvianus as prey than with any of the other species tested. The capacity of N. idaeus from Brazil to survive and reproduce with O. peruvianus as prey was unexpected since O. peruvianus does not occur in Brazil. Survival of Typhlodromalus spp. from egg to adult was low when O. gossyppi was the prey (Table 4.22). T. rapax and T. tenuiscutus (Colombian strain) were the only species that reproduced when fed O. gossyppi (Table 4.23).

None of the T. limonicus strains tested achieved oviposition when T. urticae was the prey although survival from egg-to-adult was as high as 31.2% in the Guajiran strain. Reproduction was observed only when M. caribbeanae or M. tanajoa were provided, and there was a significant effect of strain on fecundity ($P \leq 0.001$). When fed M. caribbeanae, fecundity was similar or superior to when M. tanajoa was the prey for all T. limonicus strains except a population collected at CIAT (Table 4.23). Two strains (Guajira and Trinidad) come from areas where M. caribbeanae is the predominant species. The third strain, which had a higher oviposition rate when M. caribbeanae was the prey, was collected from an area where only M. tanajoa occurs (Pivijay).

Table 4.22 Effect of prey on survival from egg to adult of cassava-inhabiting phytoseiid mites.

Phytoseiid Spp.	Strain[1]	% Survival[2] Prey Species				
		T. urticae	*M. tanajoa*	*M. caribbeanae*	*O. peruvianus*	*O. gossypii*
N. californicus	COL, Bogotá	98.0	99.0	94.0	37.0	100.0
N. anonymus	COL, CIAT	93.7	93.0	86.0	61.0	72.0
N. idaeus	COL, Fonseca	90.7	86.7	91.8	35.7	73.0
N. idaeus	BRA, Petrolina	93.0	99.0	89.0	70.1	95.0
N. idaeus	VEN, Carora	86.0	99.0	89.0	42.8	81.0
T. rapax	COL, Las Córdobas	72.0	50.0	83.0	39.8	27.0
T. limonicus	COL, Pivijay	11.3	96.0	88.0	38.0	12.0
T. limonicus	COL, CIAT	6.0	79.0	64.6	36.0	16.0
T. limonicus	COL, Las Flores	31.2	83.7	88.0	61.0	8.0
T. limonicus	TRI, Puerto España	10.0	73.0	68.0	14.0	20.0
T. tenuiscutus	ECU, Quevedo	32.0	90.0	72.0	21.8	1.0
T. tenuiscutus	COL, Las Córdobas	10.0	81.0	84.7	36.7	18.0

[1] COL = Colombia; BRA = Brazil; VEN = Venezuela; TRI = Trinidad; ECU = Ecuador.

[2] The effect of prey species on % survival was significant (X^2 test of independence; $P \leq .001$) for all phytoseiid species, $50 \leq n \leq 202$.

Table 4.23 Effect of prey species on fecundity of cassava-inhabiting phytoseiid mites.

Phytoseiid Spp.	Strain[1]	Mean No. of Eggs/Female[2] Prey Species				
		T. urticae	M. tanajoa	M. caribbeanae	O. peruvianus	O. gossypii
N. californicus	COL, Bogota	43.7 a	34/8 ab	23.4 bcde	0.0	15/1 ijklm
N. anonymus	COL, CIAT	34.4 abc	14.5 ghijkl	27.7 bcdef	0.0	16.9 hijkl
N. idaeus	COL, Fonseca	32.3 abc	13.8 lmn	12.5 mn	0.0	10.2 n
N. idaeus	BRA, Petrolina	28.5 bcd	22.2 cdefg	19.9 defghi	3.6 op	17.7 efghij
N. idaeus	VEN, Carora	23.4 cdefgh	22.4 cdefgh	16.2 jklm	0.0	20.0 defghi
T. rapax	COL, Las Córdobas	12.0 jklm	6.0 o	19.4 fghijk	0.0	1.3 q
T. limonicus	COL, Pivijay	0.0	10.3 n	15.8 ghijk	0.0	0.0
T. limonicus	COL, CIAT	0.0	14.2 ijklm	3.5 p	0.0	0.0
T. limonicus	COL, Las Flores	0.0	15.5 hijkl	13.1 lmn	0.0	0.0
T. limonicus	TRI, Puerto España	0.0	12.7 klmn	18.2 efghij	0.0	0.0
T. tenuiscutus	ECU, Quevedo	2.5 op	32.0 abc	16.1 ghij	0.0	0.0
T. tenuiscutus	COL, Las Córdobas	0.0	14.6 ijklm	18.6 efghi	0.0	0.6 qr

[1] COL = Colombia; BRA = Brazil; VEN = Venezuela; TRI - Trinidad; ECU - Ecuador.

[2] Predator/prey combinations followed by the same letter are not significantly different (DMRT; $P = 0.05$). $7 \leq n \leq 100$.

T. tenuiscutus, collected from Quevedo, Ecuador, occurs in an area where only M. caribbeanae has been reported; however, this species laid significantly more eggs per female when M. tanajoa was the prey (Table 4.23); whereas oviposition by T. tenuiscutus from Las Córdobas (Colombia) was similar on the two prey types. The foregoing data demonstrate that behavior of species and strains with different prey types can not be predicted from predator/prey association patterns in the field and that strains react differently to the same prey type.

Oviposition was highest for all Neoseiulus spp. tested when T. urticae was the prey. If optimization of fecundity is a significant factor in the evolution of prey preference, then the Neoseiulus spp. may be less likely to succeed as biological control agents of M. tanajoa in Africa than Typhlodromalus spp., particularly as more profitable prey types such as T. urticae and O. gossyppi inhabit cassava in Africa.

The superior fecundity of Neoseiulus spp. as predators of T. urticae, O. peruvianus and O. gossyppi is probably related to their ability to move and hunt prey in webbing. Of the three web-forming species in the assay, O. peruvianus forms the densest web. Although egg-to-adult survival was as high as 61%, N. idaeus (Venezuela), N. californicus and N. anonymus were not able to reproduce when O. peruvianus was the prey, suggesting that adult females were not able to consume enough to provide for egg production.

The Typhlodromalus spp. tested performed poorly when web-forming species were the prey, with the exception of T. rapax on T. urticae. The webbing of T. urticae is the least dense of the three web-forming species. The ability of T. rapax to oviposit when T. urticae was the prey suggests that this species has some ability to forage in tetranychid webbing.

4.7.4.2 **Nonacarine food types.** The ability of T. limonicus not only to survive periods of low CGM density but also to reach relatively high population densities when CGM is rare has raised doubts as to the capacity of this predator for regulating CGM populations. In an example of this phenomenon from the untreated plots of a predator exclusion experiment, T. limonicus density increases were correlated with increases in CGM numbers; however, a second peak in T. limonicus numbers occurred and was sustained over a long period of low CGM density (Fig. 4.16). These data suggest that doubts about the effectiveness of T. limonicus and questions concerning the mode of survival of this species in the absence of prey are related issues.

In an assay of *T. limonicus* survival and reproduction on nonacarine foods, mycelia and conidia of the fungus *Oidium manihotis*, first and second instars of the thrips *Frankliniella williamsi*, cassava exudate, and pollen of the castor bean *Ricinus communis* were compared with diets of *T. urticae* and *M. tanajoa* (all stages). Egg-to-adult survival occurred on all diets tested, being highest for the *M. tanajoa* diet and lowest for the *T. urticae* diet (Table 4.24). Food type had a significant effect on egg-to-adult development time (ANOVA, $P \leq 0.05$). Oviposition occurred on all food types, but was extremely limited when *O. manihotis*, pollen, *T. urticae* or cassava exudate were supplied (Table 4.24). Furthermore, it should be noted that the oviposition studies employed virgin adult females collected from colonies. Less oviposition would be expected from survivors of the development portion of the study.

4.7.4.3 **Cannibalism.** Defined as consumption of phytoseiids of the same or other species, cannibalism was also examined as a possible survival mechanism during periods of prey scarcity. Well-fed and starved (24 h) female *T. limonicus* and *N. anonymus* were presented with eggs of other females of

Table 4.24 Effect of acarine and nonacarine foods on egg-to-adult survival and development time, and on fecundity of *T. limonicus*.

Food Type	% Survival[1]	Development Time (h)[2]	No. Eggs/ Female[2]
T. urticae	18	150 a	2.0 b
M. tanajoa	86	130 c	25.4 a
F. williamsi	44	128 c	22.9 a
R. communis	76	132 bc	2.6 b
O. manihotis	56	138 b	2.6 b
Cassava exudate	56	144 a	2.0 b

[1] Effect of food type on % survival was significant (X^2 test of independence; $P \leq 0.01$). % survival and development time: n = 100 (*T. urticae*, *M. tanajoa*, *O. manihotis*); n = 50 (*F. williamsi*, *R. communis*, exudate). No. eggs/ female: n = 50 (*T. urticae*, *M. tanajoa*, *O. manihotis*); $30 \leq n \leq 39$ (*F. williamsi*, *R. communis*, exudate).

[2] Means followed by different letters are signifcantly different (DMRT; P = 0.05).

the same species and of several others. N. anonymus females were also presented with their own eggs.

More cannibalism occurred in T. limonicus than in N. anonymus (CMH statistic; P ≤ 0.001). Cannibalism on all prey types occurred, regardless of hunger state in T. limonicus, and well-fed females consumed more eggs of P. cannaensis than of other species (X^2; P ≤ 0.001) (Table 4.25); however, after 48 h no significant differences in consumption were found between prey types. With N. anonymus, however, well-fed predators did not begin to consume their own eggs or eggs of other N. anonymus until 48 h had passed (Table 4.26). Less consumption of conspecific than eggs of other species occurred (X^2; P ≤ 0.001). These data suggest that N. anonymus is cannibalistic under conditions of food shortage; whereas T. limonicus will consume phytoseiid eggs regardless of hunger state. This may explain why it, and not other species of phytoseiids, is frequently found under conditions of low CGM density.

Although their own progeny were not offerred as food to T. limonicus females, these were observed to consume their own eggs. Fewer eggs were oviposited by starved than by well-fed T. limonicus, suggesting that oviposition depended on nutrients acquired prior to the experiment.

Table 4.25 Effect of phytoseiid prey species on egg cannibalism in T. limonicus.

	% Phytoseiid Eggs Consumed[1]					
	T. limonicus		P. cannaensis		P. persimilis	
Hunger State	24 h	48 h	24 h	48 h	24 h	48 h
Well-fed	36.0	94.0	58.3	90.0	30.0	50.0
Starved	78.0	82.0	42.0	60.0	60.0	86.0

1 10-12 T. limonicus females were used per test; each was supplied with 5 eggs. Observations were made after 24 and 48 h (After 24 h effects of hunger state and prey type were significant, X^2; P ≤ 0.001; after 48 h, effect of prey type was significant, X^2; ≤ P 0.001).

Table 4.26 Effect of phytoseiid prey species on egg cannibalism in *N. anonymus*.

	% Phytoseiid Eggs Consumed[1]									
	Progeny		*N. anonymus*		*P. cannaensis*		*P. persimilis*		*T. limonicus*	
Hunger State	24 h	48 h	24 h	48 h	24 h	48 h	24h	48h	24h	48h
Well-fed	0.0	9.7	0.0	8.0	0.0	16.0	36.0	70.0	16.0	42.0
Starved	---	---	---	---	44.0	70.0	32.0	64.0	44.0	66.0

[1] 10 *N. anonymus* females were used per test; each was supplied with 5 eggs. When eggs were the progeny of test females, 31 eggs were available to 10 females. Observations were made after 24 and 48 h (After 24 and 48 h, effect of hunger state and prey type were significant, X^2; $P \leq 0.001$).

Neither cannibalism nor exudate, pollen, or O. manihotis permit T. limonicus oviposition levels comparable to that of acarine prey. Although the nonacarine foods tested may contribute to survival during periods of prey scarcity, they cannot account for the population levels of T. limonicus observed in the field during periods of low CGM density (Fig. 4.16). Other T. limonicus diet components are the primary focus of research by Bakker & Klein (1989).

4.7.5 Hypotheses about T. limonicus

A number of different lines of evidence (predator exclusion studies, feeding assays, geographical data, electrophoretic analysis of gut contents) suggest that T. limonicus is an effective predator and perhaps the key natural enemy of CGM. This conclusion appears to be contradicted by the observation that CGM is not under effective biological control in Brazil even though T. limonicus is widespread and numerically abundant. The strain differentiation of both CGM and T. limonicus in Brazil could account for this discrepancy. When confronted with the data supporting an important role for T. limonicus in biological control of CGM and with field data showing peak populations of T. limonicus in the virtual absence of CGM (Fig. 4.16), two hypotheses emerge: One possibility is that T. limonicus is an effective predator of CGM, but equally successful on nonacarine foods under low CGM densities or in its absence. An alternative hypothesis is that although T. limonicus appears to be regulating CGM, another agent(s) is responsible. Although sufficient data are not yet available for deciding between these hypotheses, a possible alternative biological control agent has been identified.

4.7.6 Alternative biological control agents

The predator exclusion experiments which demonstrated an impact of T. limonicus on CGM (Braun et al. 1989) did not take into account the possiblity of CGM pathogens. Subsequently, Neozygites sp. (Entomopthorales: Entomopthoraceae) were reported attacking CGM in Brazil (Delalibera et al. 1990) and Colombia (Alvarez et al. 1990).

Although attempts to culture Neogygites sp. in artificial media have been unsuccessful, a number of research advances can nevertheless be reported. Neozygites sp. is pathogenic to all mobile stages of CGM. No evidence was found for pathogenicity of this fungus to phytoseiids; however, these may aid in the dissemination of the anadhesive conidia responsible for propagation of Neozygites sp. Conidiogenesis does not occur when the RH is less than 65%; however, the formation of anadhesive conidia is inhibited by high RH. Epizootics of Neozygites sp. have been detected on the North Coast of Colombia; however, in order to evaluate the potential importance of this fungus in the biological control of CGM, field impact assessments which can separate the contribution of phytoseiids in regulation of CGM from that of Neogygites sp. are needed. The importance of rare species of phytoseiids (Table 4.21) also requires more research attention.

4.8 References

Alvarez, J.M. 1990. Estudios de patogenicidad de un hongo asociado a Mononychellus tanajoa (Bondar) y Tetranychus urticae (Koch) ácaros plaga de la yuca. Unpublished undergraduate thesis. Universidad Nacional, Facultad de Agronomía, Bogotá, Colombia.

Bakker, F.M. & M.E. Klein. 1989. The significance of cassava exudate for predacious mites. Proceedings 7th International Symposium on Insect-Plant relationships; Budapest Hungary. May 1989.

Bellotti, A.C.; N.C. Mesa; M.S. Serrano; J.M. Guerrero & C.J. Herrera. 1987. Taxonomic inventory and survey activity for natural enemies of Cassava Green Mite in the Americas. Insect Science and its Application 8:845-849.

Braun A.R.; J.M. Guerrero; A.C. Bellotti & L.T. Wilson. 1989. Effect of predator exclusion on cassava infested with tetranychid mites (Acari:Tetranychidae). Environmental Entomology 18:711-714.

CIAT. 1988. Annual Report. Centro Internacional de Agricultura Tropical, Cali. Colombia.

————. 1989. Annual Report. Centro Internacional de Agricultura Tropical, Cali. Colombia.

Delalibera, I.; G. de Moraes; D. Sosa & J.A. Alencar. 1990. Distribution of Neozygites sp. pathogens of Cassava Green Mites in northeastern Brazil. (submitted)

Garman, P. & E.A McGregor. 1956. Four new predaceous mites (Acarina: Phytoseiidae). Bulletin of the Society of the California Academy of Science 55:7-13.

Guerrero, J.M.; C.H.W. Flechtmann; M.C. Duque; A.R. Braun & A.C. Bellotti. 1991. An hypothesis on the evolution of Mononychellus species on Manihot esculenta in the Neotropics. (in preparation)

Moraes, G. de; J.A. de Alencar; F.W. Neto & S.M.R. Mergulhao. 1988. Exploration for natural enemies of Cassava Green Mite in Brazil. Proceedings 8th Symposium International Society for Tropical Root Crops. Bangkok, Thailand. pp. 351-353.

———; A.R. Braun; J.S. Yaninek & J.A. de Alencar. 1991. Distribution and abundance of phytoseiid predators of the Cassava Green Mite in Brazil. Proceedings 8th International Congress of Acarology. Ceske Budejovice, Czechoslovakia. (in press)

Yaninek, J.S. & A.C. Bellotti. 1987. Exploration for natural enemies of Cassava Green Mite based on agrometeorolocal criteria in Rijks, D. & Mathys, G. (Eds.) Proceedings of the Seminar on Agrometeorology and Crop Protection in the Lowland Humid and Subhumid Tropics. Cotonou, Benin 7-11 July, pp. 69-75.

——— & H.R. Herren. 1988. Introduction and spread of the cassava green mite, Mononychellus tanajoa (Bondar) (Acari: Tetranychidae), an exotic pest in Africa and the search for appropriate control methods: a review. Bulletin of Entomological Research 78:1-13.

———; H.R. Herren & A.P. Gutierrez. 1989. Dynamics of Mononychellus tanajoa (Acari: Tetranychidae) in Africa: seasonal factors affecting phenology and abundance. Environmental Entomology 18: 625-632.

5. CASSAVA PHYSIOLOGY AND CROP MANAGEMENT

5.1 Physiology, Soil Fertility and Erosion Research

5.1.1 Performance of cassava under prolonged mid-season water stress

Previous research at CIAT (Annual Reports 1982-89) has shown that cassava can tolerate long periods of water shortage without large reductions in RY. Varietal differences in response to water stress were detected and found to be related to the plant's vegetative vigor, particularly its LAI throughout the growth cycle (Fig. 5.1). Vigorous varieties such as M Mex 59 usually yield more under mid-season stress than less vigorous ones such as M Col 22, which yield better under wet conditions. However, yield stability requires selecting varieties that yield well under both wet and stress conditions. Varieties such as CM 507-37, which maintain relatively higher than optimal LAI under wet conditions, were found to produce well under both wet and stress conditions. This performance was found to be associated with better leaf retention, a higher leaf area ratio (partitioning DM between leaf and stem), and a more extensive fine root system.

Because most cassava varieties show increased HCN content under stress and become less suitable for human consumption in fresh form, research was continued to find out whether some genotypes can maintain low levels of HCN under stress. Only a few clones tended to keep their HCN at reasonably low levels (CIAT Annual Report 1989). These clones were grown for the third year at the Quilichao Station to determine, beside yield performance, some physiological parameters related to photosynthesic efficiency as affected by prolonged drought. The clones were grown in the field drainage lysimeter; and commencing 100 days after planting, half the experimental area ($\approx$ 2000 m^2) was subjected to three months' water stress by covering the soil surface with white plastic sheeting. The second half of the experimental area received natural precipitation as well as supplementary irrigation in periods with rainfall less than the potential evapotranspiration of that station ($\approx$ 4.4 mm/day). Data were collected on leaf water potential (indicator of stress), canopy light interception (indicator of leaf area) and leaf gas exchanges (indicators of leaf photosynthetic capacity) during the entire stress period. These data are illustrated by Figures 5.2-5.9.

Predawn leaf water potentials (Fig. 5.2a) were found to remain stable around -5 bars throughout the 3-mo stress period for all four genotypes, with virtually no differences between the stressed and unstressed crops. The morning leaf water potential remained unaffected by stress during the

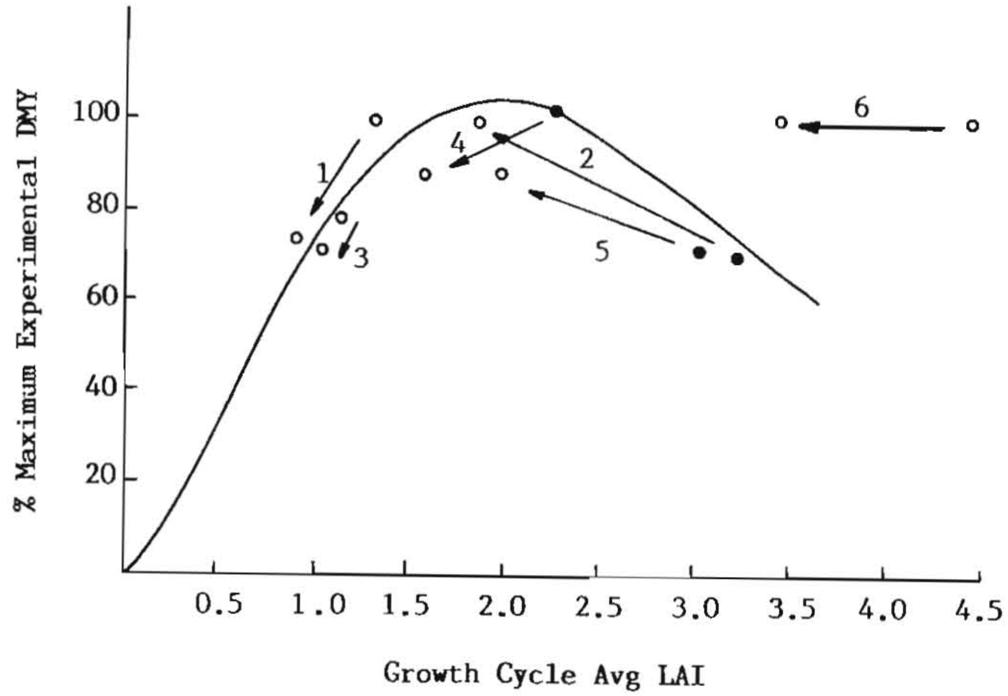


Figure 5.1 DMY as function of mean LAI under nonstress and mid-season water stress conditions for 4 varieties with different vigor: (1) M Col 22; (2) M Mex 59, maximum yield 11.2 t/ha for M Col 22 over 306 days, 1980 season; (3) M Col 1684; (4) CM 507-37, maximum yield 19 t/ha for CM 507-37 over 345 days; 1984 season; (5) M Col 1684; (6) CM 507-37, maximum yield 18.5 t/ha for CM 507-37 over 364 days; 1987 season. Arrows indicate changes from nonstress (closed symbols) to stress (open symbols).

first half of the stress period; whereas in the second half of the stress period, it showed significant reduction (Fig. 5.2b). The mid-day leaf water potential (Fig. 5.2c) was 1 to 2 bars less in the stressed crops, except for clone CM 1335-4. The values of mid-day leaf water potential oscillated between -8 to -15 bars for both stressed and unstressed crops, depending on measurement dates. These values, which are strikingly high compared to the much lower values usually encountered for other field crops under stress, indicate the ability of cassava to regulate its stomata, preventing water loss. This characteristic is of a paramount importance for the tolerance of cassava to prolonged drought. Such a "stress-avoidance mechanism"

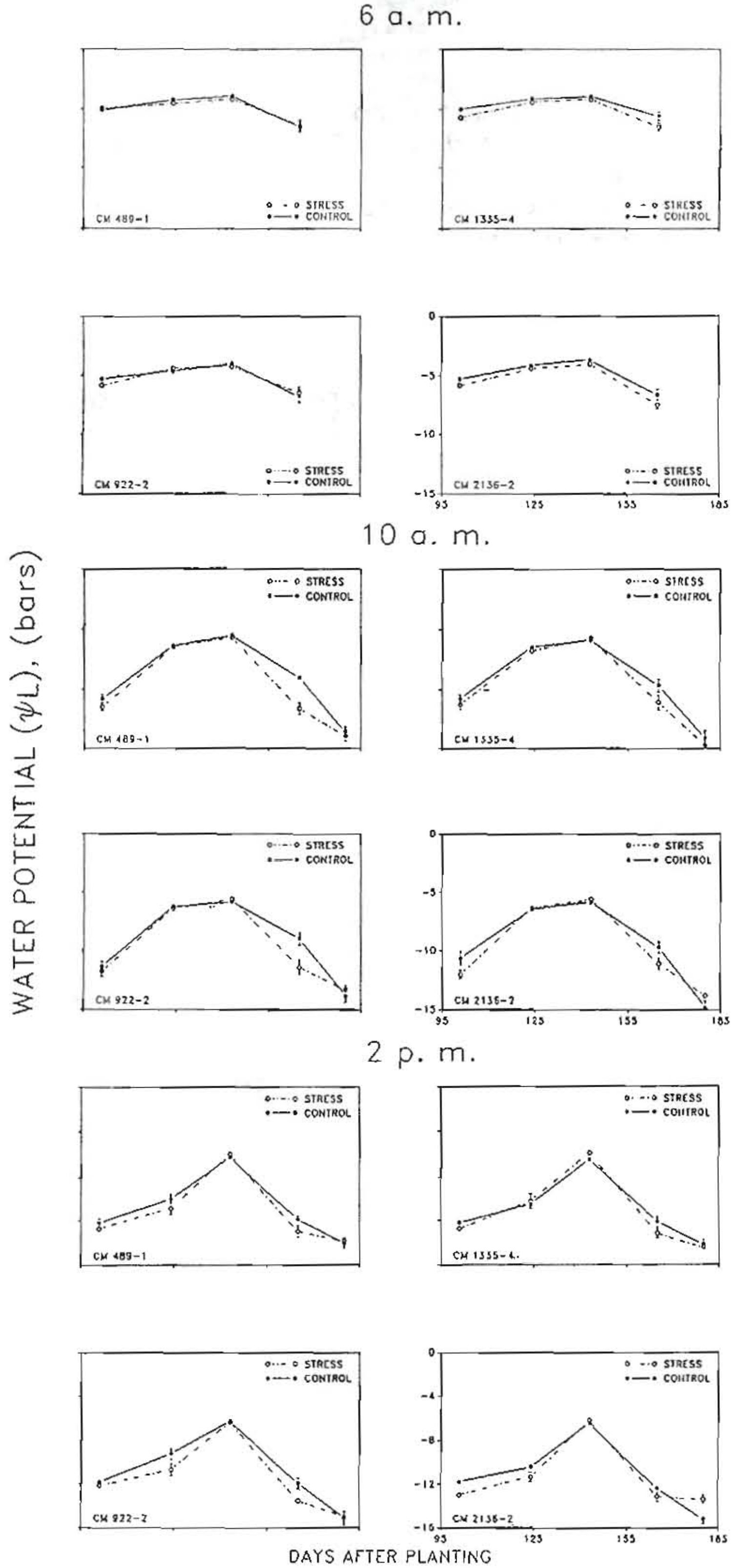


Figure 5.2 Leaf water potential of 4 cassava clones as affected by prolonged mid-season water stress at (a) predawn, (b) in the morning and (c) at mid-day; bars indicate SE; data points are means of 8 leaves.

underlies the crop's ability to endure months of little or no rainfall in seasonally dry and semiarid regions. Coupled with this mechanism is the ability of the cassava crop to reduce levels of light interception dramatically--a factor of great importance in water loss--through reduction in its leaf canopy under stress (Fig. 5.3). Although reduction in leaf area would lead to water conservation, it would also lead to reduced total biomass and RY. Nevertheless, the cassava crop can recover rapidly, once released from stress, by forming a whole new leaf canopy that can be effective in light interception and hence in compensating for yield losses during stress (Fig. 5.3).

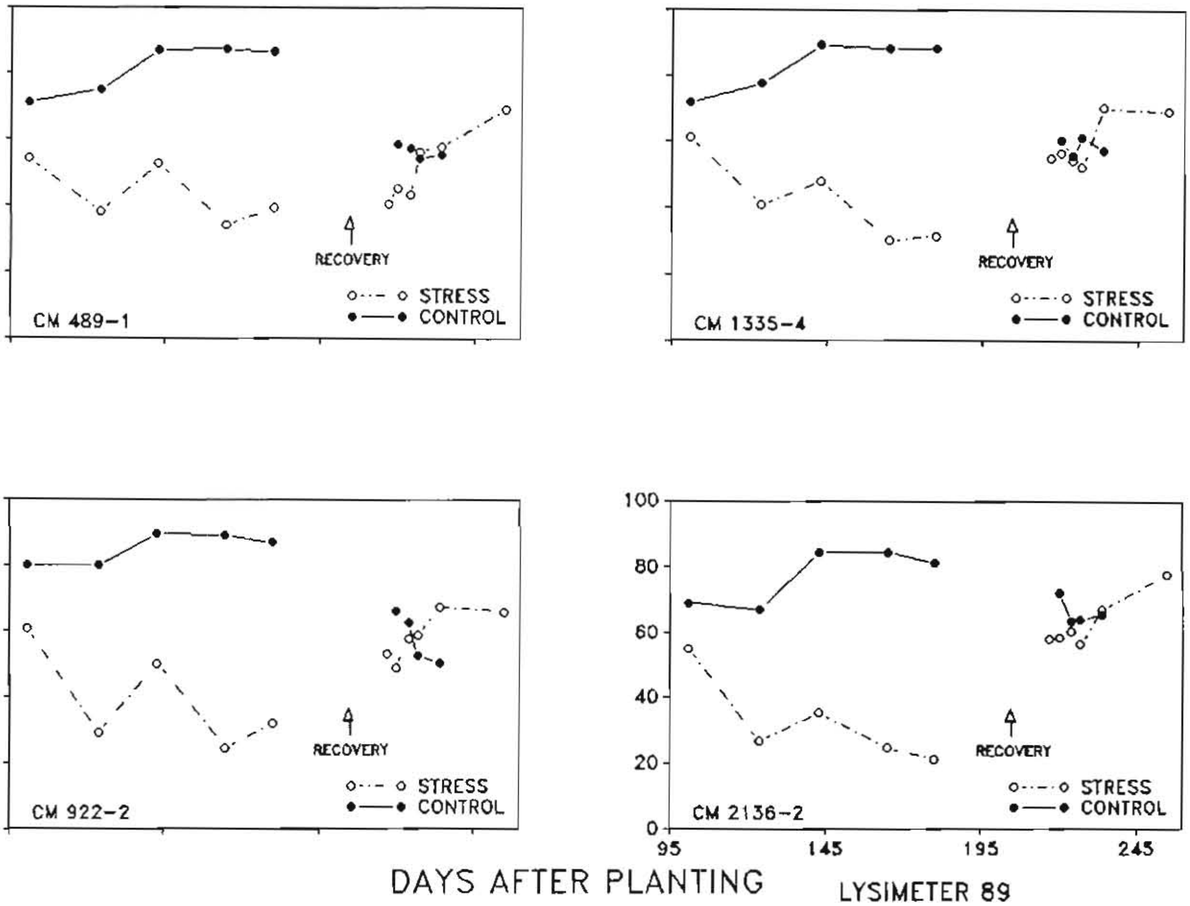


Figure 5.3 Light interception of 4 cassava clones as affected by prolonged mid-season water stress.

Cassava leaves also remain fairly active during the prolonged water stress (Figs. 5.4-5.9). The stressed leaves are capable of maintaining photosynthetic rates around 40-60% of the nonstressed leaves during the entire stress period of 3 months. Upon recovery from stress, the old leaves can approach the efficiency of the nonstressed leaves. Furthermore, the new leaves of the previously stressed crop showed even higher photosynthetic rates than those of the nonstressed crop (Figs. 5.4 & 5.5). This characteristic is associated with both higher mesophyll conductance (more active enzyme systems) (Fig. 5.6) and higher stomatal conductance (Figs. 5.7 & 5.8), hence more CO_2 supply. The instantaneous leaf water-use efficiency (CO_2 uptake/H_2O loss) of the new leaves was higher than that of the nonstressed crop (Fig. 5.9). During stress the plant closes its stomata partially, thus restricting transpiration (Figs. 5.7 & 5.8). Although the partial closure of stomata also restricts CO_2 supply to the leaf (Fig. 5.5), it leads to a stable leaf water potential (Fig. 5.2), which partly explains the ability of cassava leaves to remain photosynthetically active during stress (Fig. 5.4).

There are apparent genotypic differences in stress tolerance as indicated by the magnitude of reduction in photosynthesis. Clone CM 489-1, which appears to maintain higher photosynthesis during the entire stress period than other clones, is known to have high yield potential under both low and adequate soil P and is also capable of forming large numbers of storage roots, hence greater sink capacity (see Section 5.2).

Yield, top and total biomass, HI and percent starch in storage roots at final harvest (11 mo after planting) are presented in Table 5.1. Across all varieties, reductions due to water stress were 10% in dry roots, 46% in top growth and 21% in total biomass. On the other hand, water stress increased HI by 16% and starch content by 7%. In general the greatest reduction in biomass occurred in the top portion (stems + leaves); the least, in the roots. This resulted in better partitioning of assimilates toward the storage root as indicated by the improved HI and starch content (fresh wt basis). These data suggest that prolonged mid-season water deficit does not seriously limit cassava productivity and clearly confirm that cassava is a highly productive crop where a long dry season occurs.

Genotypic differences in response to water stress also exist. CM 489-1 produced the highest yields under both wet (19.3 t DMY/ha) and stress (18.5 t DMY/ha) conditions. This clone also maintained the highest leaf photosynthetic rates during the entire stress period (Fig. 5.4), suggesting that high photosynthetic capacity during stress could be used as a selection criterion for high yields. Previous findings

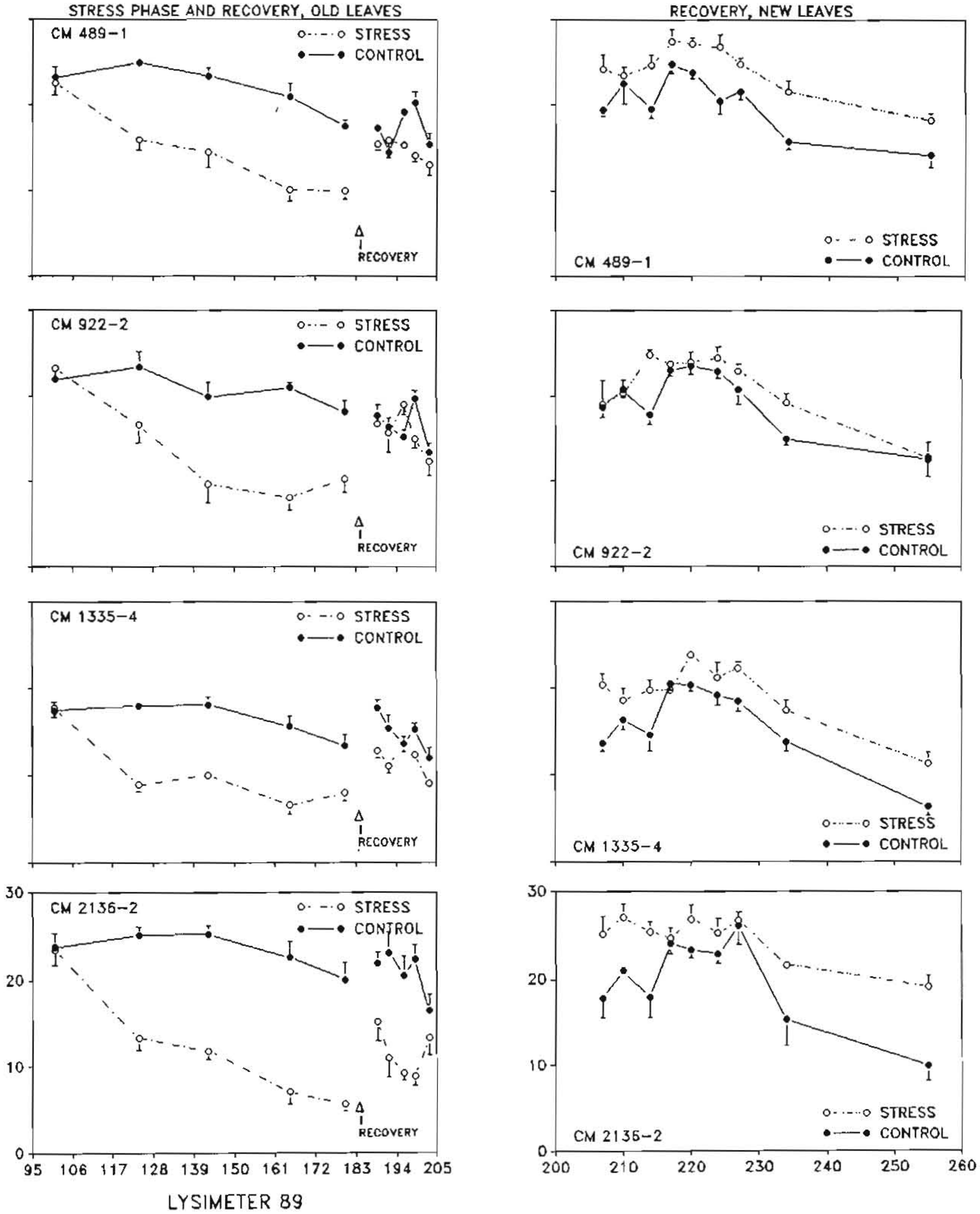


Figure 5.4 Leaf photosynthetic rates of 4 cassava clones as affected by prolonged mid-season water stress.

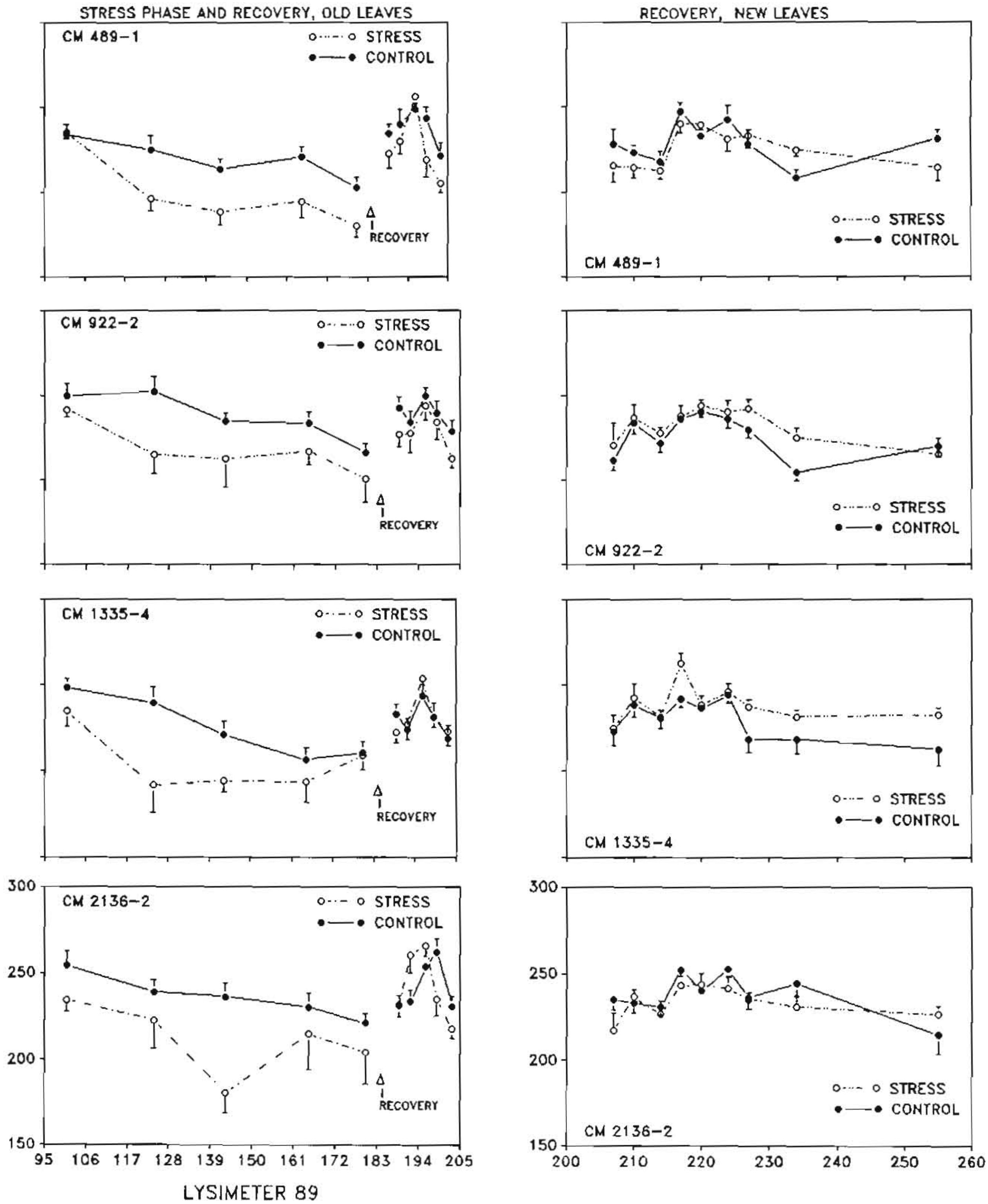


Figure 5.5 Intercellular CO_2 concentration of 4 cassava clones as affected by prolonged mid-season water stress.

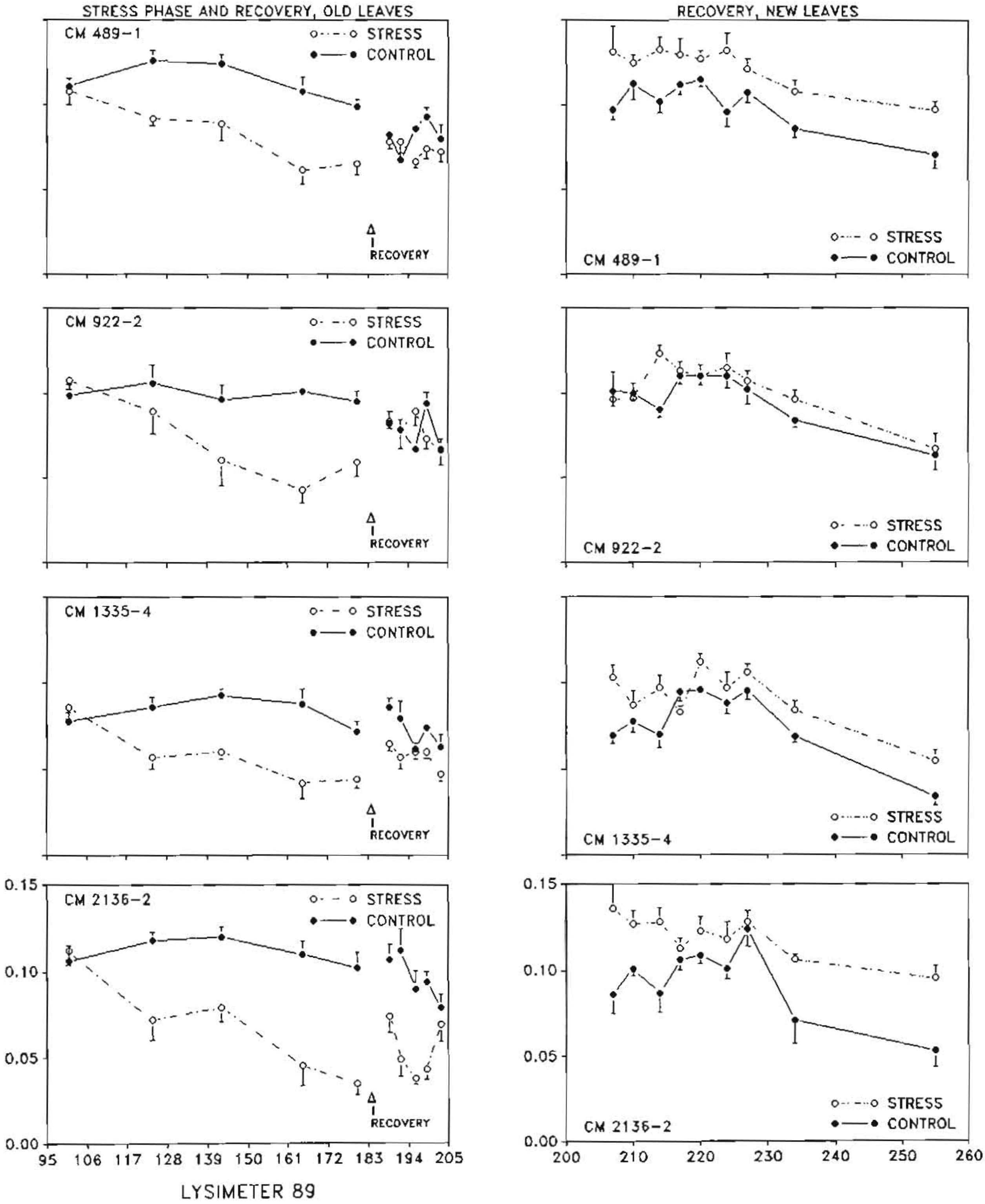


Figure 5.6 Mesophyll conductance of 4 cassava clones as affected by prolonged mid-season water stress.

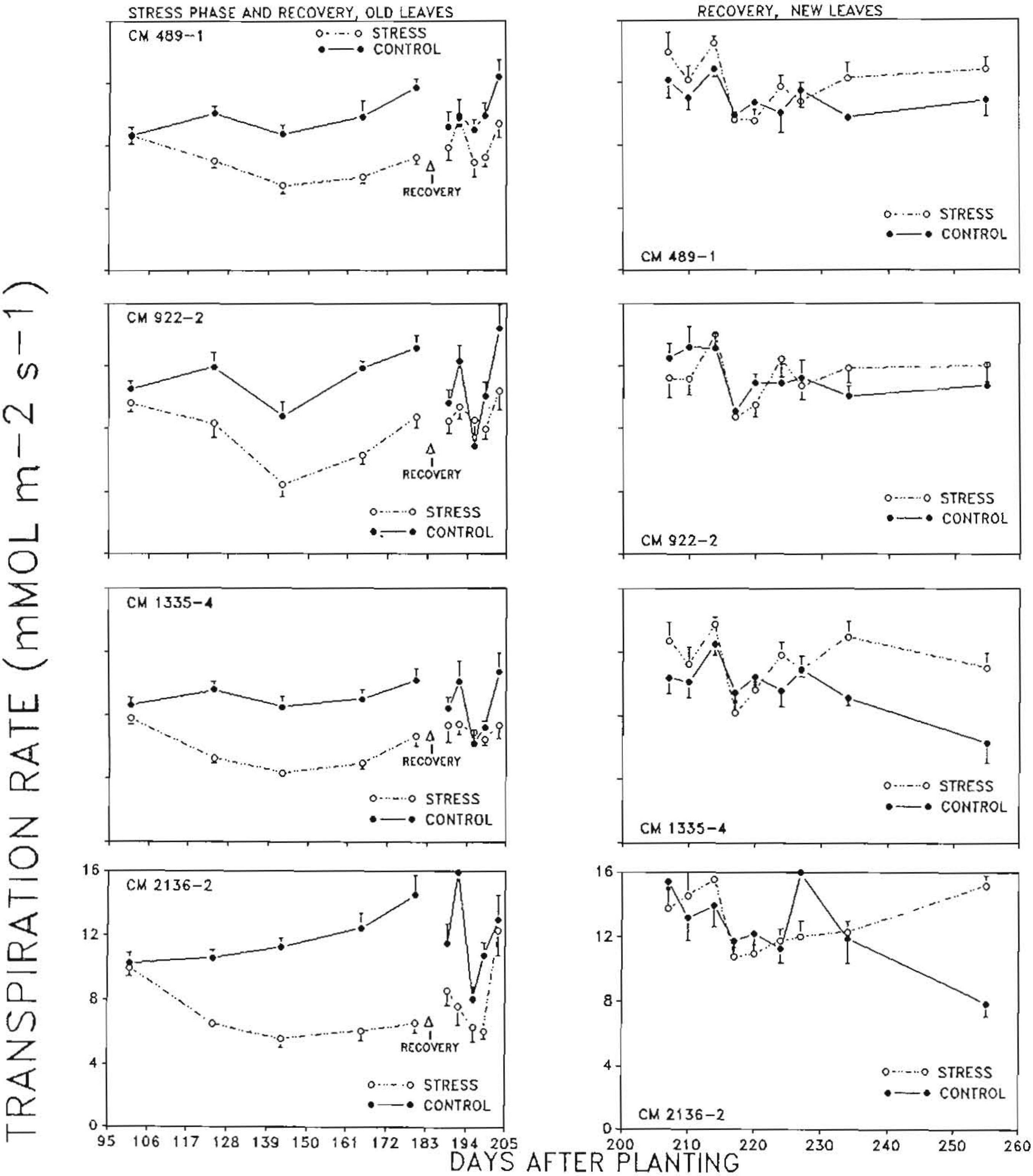


Figure 5.7 Transpiration rate of 4 cassava clones as affected by prolonged mid-season water stress.

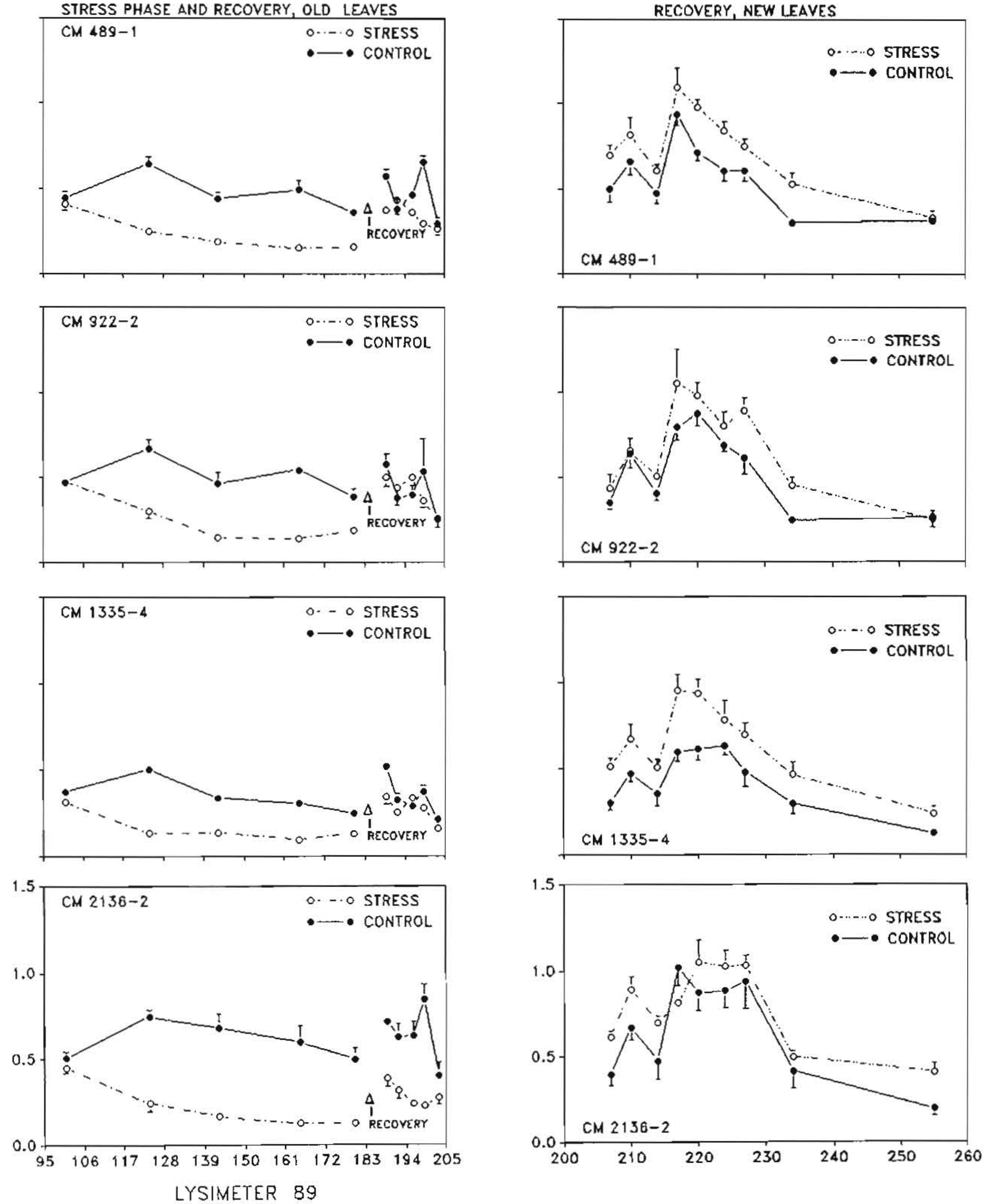


Figure 5.8 Stomatal conductance of 4 cassava clones as affected by prolonged mid-season water stress.

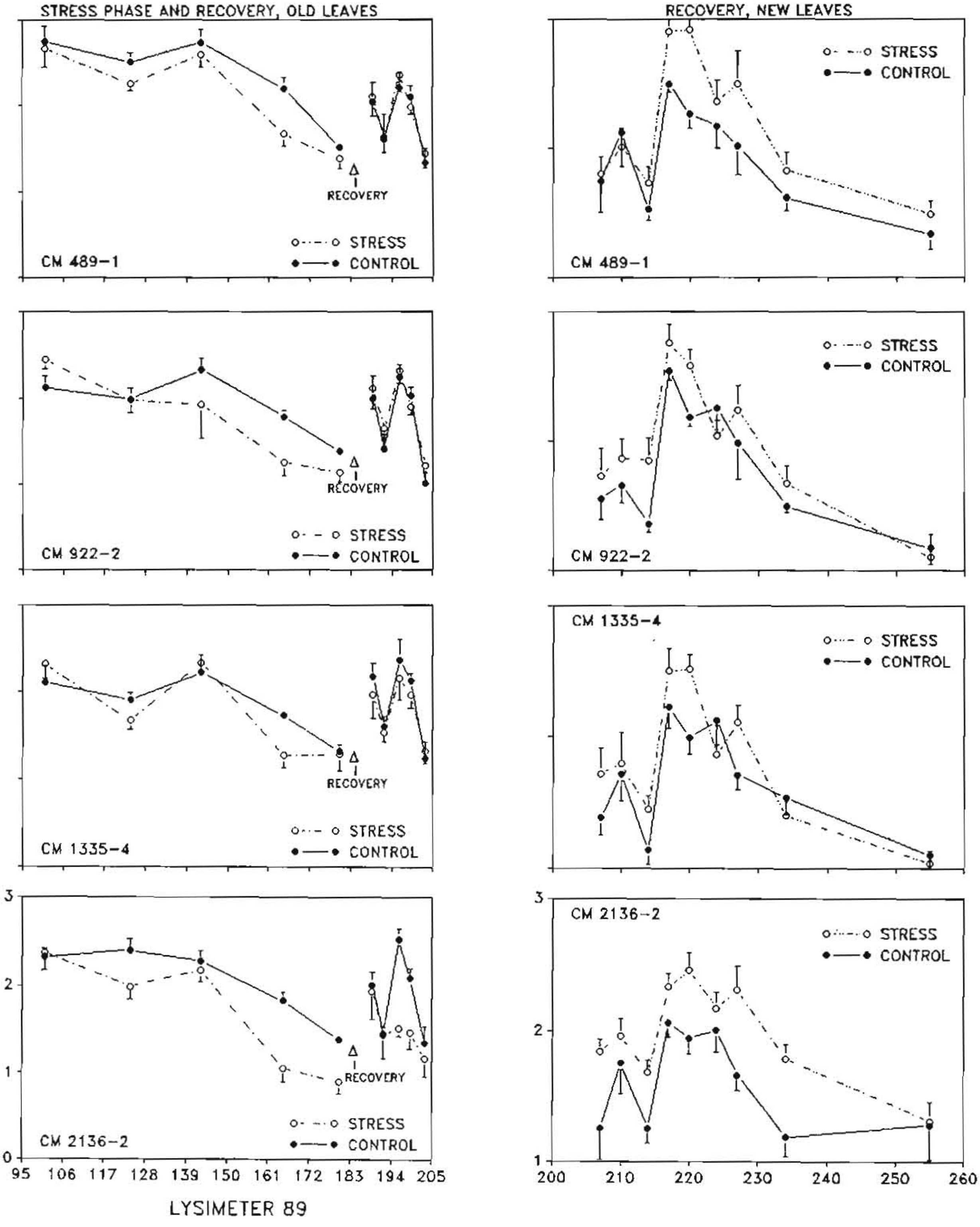


Figure 5.9 Water-use efficiency of 4 cassava clones as affected by prolonged mid-season water stress.

Table 5.1 Yield, biomass, HI and percent starch of four clones of cassava as affected by 3-mo stress period commencing 100 days after planting; final harvest at 11 mo after planting; stressed plots allowed to recover for rest of cycle (1989).

Clone	Unstressed					Stressed				
	Dry Roots	Dry Tops[1]	Total Biomass[1]	HI	% Starch[2]	Dry Roots	Dry Tops[1]	Total Biomass[1]	HI	% Starch[2]
	t/ha					t/ha				
CM 489-1	19.3	6.8	26.1	0.74	23.0	18.5	4.8	23.3	0.79	25.0
CM 922-2	12.7	7.2	19.9	0.64	33.3	12.9	2.9	15.8	0.82	35.0
CM 1335-4	16.2	6.1	22.3	0.73	31.2	13.9	2.6	16.5	0.84	33.4
CM 2136-2	17.6	7.6	25.2	0.70	25.3	13.7	4.2	17.9	0.77	27.2
Avg all clones	16.5	6.9	23.4	0.70	28.2	14.8	3.6	18.4	0.81	30.2
% change due to stress						-10	-48	-21	+16	+7.1

[1] Excluding fallen leaves.

[2] On fresh wt basis.

(CIAT Annual Reports 1988-1989) have shown significant positive correlations between leaf photsynthesis and both yield and total biomass for a wide range of cassava varieties when grown under stress in the Patía Valley (Cauca State), Colombia.

The highest reduction in RY among this group of genotypes was 22% (CM 2136-2); whereas CM 922-2 showed no change in yield due to stress. CM 1335-4 and CM 489-1 showed 14% and 4% reduction, resp. HCN content remained at low levels (140-220 ppm DM basis) under stress for the two clones, CM 1335-4 and CM 922-2; whereas they were elevated (ca. 330-440 ppm DM basis) in CM 2136-2 and CM 489-1. Maintaining low HCN under stress is of paramount importance when cassava is used for human consumption in drought-prone regions such as NE Brazil and Sub-Sahelian Africa.

5.1.2 Screening cassava germplasm for tolerance to low-P soils at Santander de Quilichao

In the effort to characterize cassava germplasm for tolerance to low-P soils, a new group of advanced breeding lines and clones were screened during 1989-90 at the Quilichao station. The screened accessions were planted (10,000 pl/ha) in plots with low available P (<4 ppm), which had received no P for 8 yr. Half the plots received 75 kg P/ha annually for 8 yr (4 reps). Adequate levels of N and K were applied at planting to the whole experimental area; P fertilizer in the form of triple superphosphate was banded around the stakes at planting. Table 5.2 shows DMY at 10 mo after planting along with the calculated P adaptation indices. At both levels of P, there were significant differences in yield among genotypes. The overall avg yield of all genotypes at low P (8.8/t ha) was significantly lower than with adequate P (12.5 t/ha). These yields are comparable to those obtained on these plots over the last few years (CIAT Annual Reports 1986-89). Reasonable yields without P application may indicate that native P uptake by cassava was effective. Cassava is highly dependent on mycorrhizal associations for P uptake; thus it is possible that cassava roots were effectively colonized by efficient VAM strains.

Based on the low-P adaptation indices, this group of cassava genotypes varied widely in their tolerance to low-P soils (ranging from 0.35 for M Col 2215 to 2.05 for the CIAT advanced line CG 996-6). The highly adapted genotypes, with low-P adaptation indices greater than 1.65 included 3 new CIAT lines (CG 996-6, CM 305-41, CM 1374-2) and two traditional clones from Brazil (M Bra 383 and M Bra 191). There were 3 very low adapted genotypes, with low-P adaptation indices under 0.5, which included 2 CIAT clones (CM 2774-11 and SG 250-3) and a traditional variety from the North Coast of Colombia (M Col 2215). The remaining accessions showed either intermediate (indices from 1.49 to 1.06) or low adaptation levels (indices from 0.99 to 0.56). Considering that cassava was cultivated continuously at this site for the last 10 years, the moderate level of productivity maintained without P application suggests that acid soils with low available P, but with high OM, can support sustainable yields. Nevertheless, the significant response to a moderate level of P fertilizer, observed in these trials as well as in previous ones, indicates that cassava still benefits from applied fertilizer. The genotypes highly adapted to low-P soils should be considered as genetic resources for breeding new materials adaptive to low-P soils.

5.1.3 Relationships among leaf gas exchange, total biomass, RY and tolerance to low-P soils

Leaf gas exchange (CO_2 uptake and H_2O loss) was measured on upper canopy-exposed, fully expanded leaves of the 33 genotypes screened for low-P tolerance using portable infrared CO_2 analyzers. Measurements were conducted six times between 3 and 6 mo after planting with a total of 24 leaves measured/genotype/P treatment when incident sunlight

Table 5.2 DMY and low-P adaptation index of 33 cassava clones at Santander de Quilichao (1989-90); values are means of 4 reps.

Clone	DMY (t/ha) Zero P	DMY (t/ha) 75 kg P/ha	Low-P Adaptation Index[1]	
CG 996-6	13.1	16.9	2.05	
CM 305-41	13.9	14.6	1.86	
CM 1374-2	11.9	16.2	1.78	HA[2]
M Bra 383	10.9	16.9	1.67	
M Bra 191	12.6	14.1	1.65	
CM 2718-1	10.1	16.5	1.49	
CM 4864-1	11.4	14.1	1.45	
CM 3750-5	11.5	12.8	1.35	
CM 4711-2	9.6	14.0	1.27	
CM 3401-2	9.0	15.4	1.27	IA[2]
CM 4830-3	9.4	13.9	1.24	
CM 3654-3	11.3	11.9	1.23	
SG 455-1	9.8	12.7	1.16	
M Pan 51	9.1	13.1	1.08	
CM 3456-3	8.5	13.4	1.06	
SG 106-59	9.3	11.6	0.99	
CM 3667-1	9.4	11.4	0.98	
CM 4701-1	7.6	13.6	0.95	
SM 414-1	7.7	13.1	0.92	LA[2]
CM 3285-7	9.8	10.0	0.91	
SG 104-284	6.5	13.5	0.84	
SG 545-7	8.1	10.5	0.79	
CM 4793-1	7.6	10.3	0.75	
CM 4617-1	7.5	10.6	0.73	
CM 4575-1	7.0	11.0	0.71	LA[2]
SG 104-264	6.6	10.9	0.66	
CM 4716-1	6.4	11.2	0.66	
CM 4145-4	6.4	10.0	0.59	
SG 302-1	5.1	11.9	0.56	
CG 927-12	6.6	9.3	0.56	
CM 2774-11	5.0	10.1	0.47	
SG 250-3	6.7	7.4	0.45	
M Col 2215	4.8	7.9	0.35	VLA[2]
Avg all clones	8.8	12.5	-	
LSD 5%	1.9	2.1	0.43	

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

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

[2] HA = High adaptation; IA = Intermediate adaptation; LA = Low adaptation; VLA = very low adaptation.

was greater than 1000 μ mol $m^{-2}s^{-1}$ in the photosynthetic active range. Gas exchange data (avg for measurement period) were correlated with RY and total biomass at 10 mo after planting. Low-P adaptation index and other growth parameters were also included in calculating simple correlations. Among this group of genotypes, leaf photosynthesis was significantly correlated with RY, total biomass, top weight, storage root no. and low-P tolerance index (Table 5.3). Mesophyll conductance, but not stomatal conductance, was also significantly correlated with these yield and growth parameters. These correlation patterns confirm earlier findings at CIAT that a direct, positive relation exists between single-leaf photosynthesis and cassava yield (CIAT Annual Reports 1988-89). This relation is related more to variations in mesophyll characteristics (i.e., enzyme systems and leaf anatomy) than stomatal conductance. Another important finding is the significant positive relation between RY and both top wt and storage root no. It appears that when HI is high (in this group of genotypes, HIs were > 0.6), improvement in yield could be achieved by improving the crop photsynthetic capacity through higher leaf area and higher leaf photosynthetic rate (carbon assimilation source) and by increasing storage root no. (sink strength). Tolerance to low-P soils also appears to be directly related to both assimilation capacity and storage root no. High assimilation capacity and high sink strength would probably lead to higher P use efficiency, particularly in soils low in P (see section 5.2).

5.1.4 Long-term response of cassava to NPK fertilizer in acid soils

For the last 7 years cassava was grown at two experimental sites in the acid soil at Santander de Quilichao to assess the effect of this permanent production system on cassava productivity and its response to applied fertilizer.

One site was initially fertile (fertile plot) while the second was very low in fertility (exhausted plot). Two cassava clones (M Col 1684 and CM 91-3) were planted at the two sites annually. Fertilizer treatments consisted of three levels of NPK (0, 50, 100 kg/ha each of NPK). Each of the three elements was also varied independently at three levels (0, 50, 100 kg/ha) while the other two elements were kept constant at 100 kg/ha. The treatmentsH (4 reps) were allocated in a complete randomized block design within each site. All fertilizer treatments were applied at planting. Harvesting was at 11 mo after planting.

Figures 5.10 and 5.11 illustrate cassava yield response to the combined fertilizer applications at the two sites for 6 yr. For both varieties, first-year yields in the fertile plot were higher than in the exhausted plot, indicating the

Table 5.3 Correlation coefficients among leaf gas exchange characteristics, RY, biomass and low-P tolerance index of 33 clones[1].

	Leaf Conductance (H_2O)	Mesophyll Conductance (CO_2)	DMY	Top Dry Wt	Total Biomass	No. Storage Roots	Low-P Tolerance Index	HI
Leaf photosynthesis	0.81**	0.97**	0.48**	0.39*	0.49**	0.37*	0.51**	0.12 ns
Leaf conductance (H_2O)	-	0.69**	0.29 ns	0.25 ns	0.31 ns	0.11 ns	0.30 ns	0.03 ns
Mesophyll conductance (CO_2)	-	-	0.53**	0.40*	0.56**	0.49**	0.57**	0.08 ns
DMY	-	-	-	0.58**	0.96**	0.62**	0.99**	0.33 ns
Top dry wt	-	-	-	-	0.76**	0.50**	0.58**	-0.52**
Total biomass	-	-	-	-	-	0.65**	0.96**	0.09 ns
No. storage roots	-	-	-	-	-	-	0.67**	0.07 ns
Low-P tolerance index	-	-	-	-	-	-	-	0.31 ns

[1] Mean of the two P levels.

ns = Not significant at 5%; * = Significant at 5%; ** = Significant at 1%.

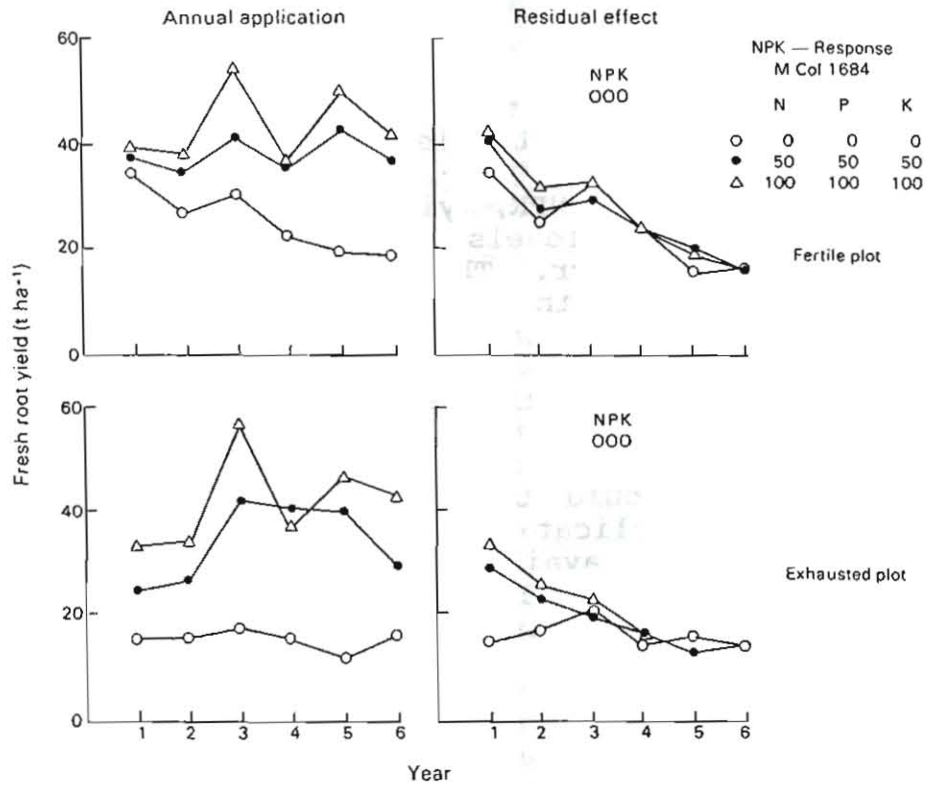


Figure 5.10 Long-term responses to NPK fertilizer application in acid soils, Santander de Quilichao, Clone M Col 1684.

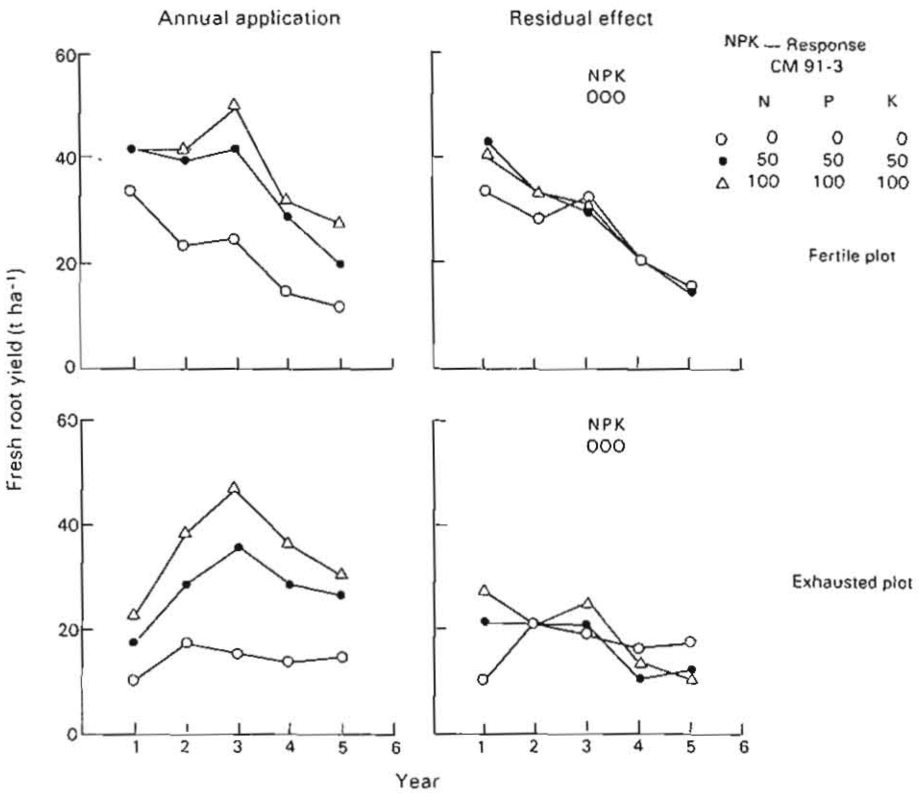


Figure 5.11 Long-term responses to NPK fertilizer application in acid soils, Santander de Quilichao, Clone CM 91-3.

extremely low fertility in the latter. This enhancement in yield was apparent despite the level of applied fertilizer.

In absence of applied NPK, yields in the fertile plot decreased from initial levels of about 38 t/ha to around 15-20 t/ha by the sixth yr. The rate of yield reduction was greater in CM 91-3 than in M Col 1684. On the other hand, the level of productivity in the exhausted plot without NPK fertilizer remained almost stable (ca. 15-18 t/ha) for both varieties, which was equivalent to the lowest yields achieved in the fertile plot by Yr 6 of cassava production. This mimimun level of productivity clearly illustrates that sustainable yields could be obtained in infertile soils without fertilizer application, provided that the soil OM is adequate to release available nutrients. Furthermore, annual application of fertilizer can ensure higher levels of productivity when cassava is continuously cultivated in the same site without fallow or crop rotation. These data contradict the long-held views that cassava cultivation causes soil depletion and degradation in the tropics. It has been documented that cassava produces more biomass per unit nutrients removed from the soil or from applied fertilizer than most other annual grain and root crops. Nevertheless, the long-term concern of soil fertility dictates that reasonable levels of fertilizer application be practiced irrespective of the kind of crop produced. Cassava should not be considered an exception in this case. For resource-poor farmers, who are the main growers of cassava, alternative means for improving soil fertility should be sought. Perhaps by seeking better patterns of land uses and crop production systems, soil fertility could be maintained to levels capable of sustaining reasonable productivity.

In soils similar to those at Quilichao, long-term cassava production appears to be more limited by the level of K than of N and, to certain extent, of P. Figures 5.12-5.17 illustrate the long-term response of cassava to NPK. It is clear that cassava is highly responsive to K, particularly when the soil is poor in this element (Figs. 5.12 & 5.15); 50 kg K/ha almost doubled the yield of cassava. Moreover, in the absence of adequate K levels, no benefit in productivity is achieved by supplying the crop with high levels of N and P. This conclusion is further substantiated by the lack of large responses to N and P when K levels were high (Figs. 5.13-5.17). In cassava a large portion of absorbed K (>60%) is removed with the harvested roots; whereas significant amounts of absorbed N and P are recycled to the soil through fallen leaves and crop residues. It is known that a crop of cassava can return to the soil from 3 to 6 t of dry leaves during its growth cycle of 10-12 mo. In addition to the native OM in the soil, this relatively large amount of crop residue can serve as a source for nutrients.

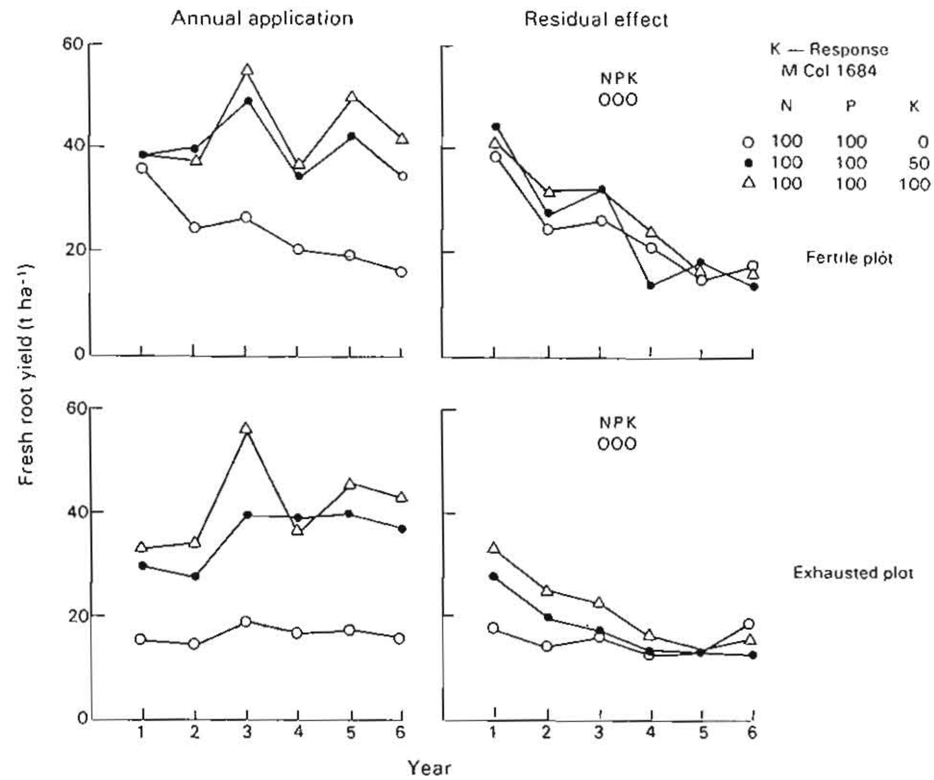


Figure 5.12 Long-term responses to K application in acid soils, Santander de Quilichao, Clone M Col 1684.

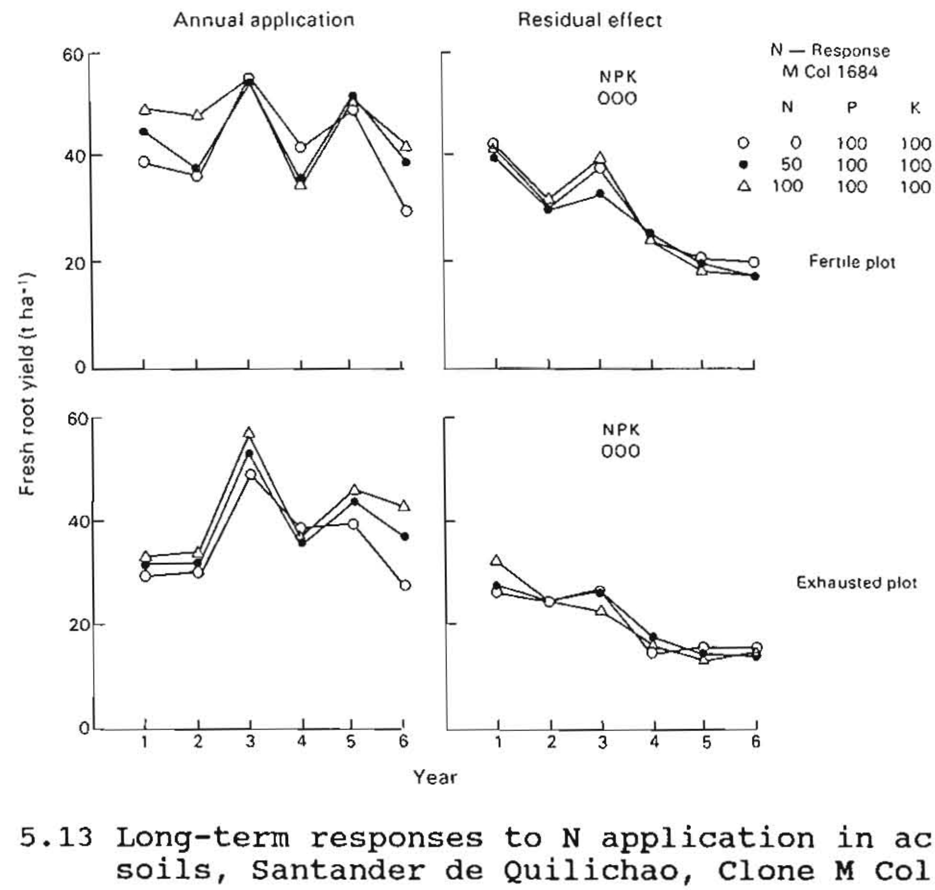


Figure 5.13 Long-term responses to N application in acid soils, Santander de Quilichao, Clone M Col 1684.

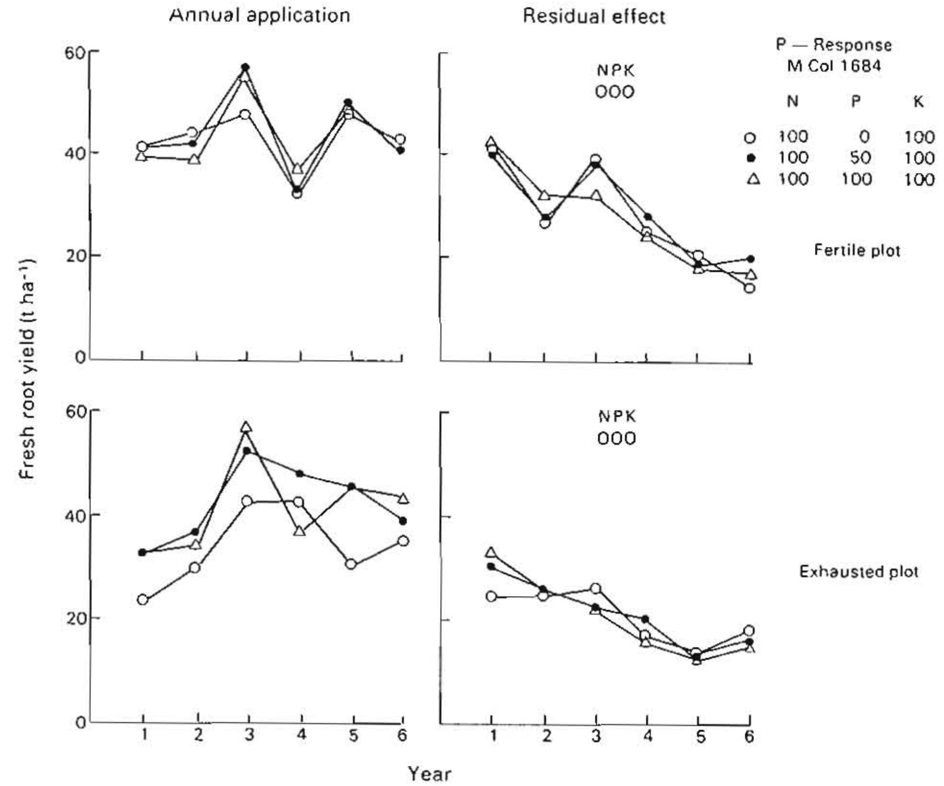


Figure 5.14 Long-term responses to P application in acid soils, Santander de Quilichao, Clone M Col 1684.

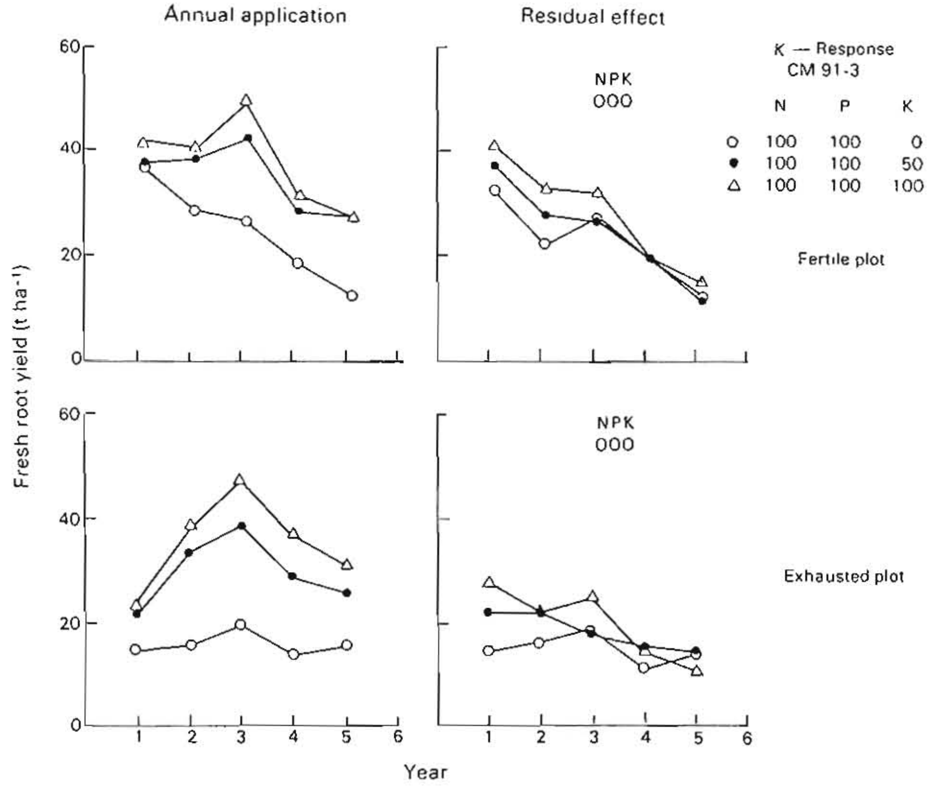


Figure 5.15 Long-term responses to K application in acid soils, Santander de Quilichao, Clone CM 91-3.

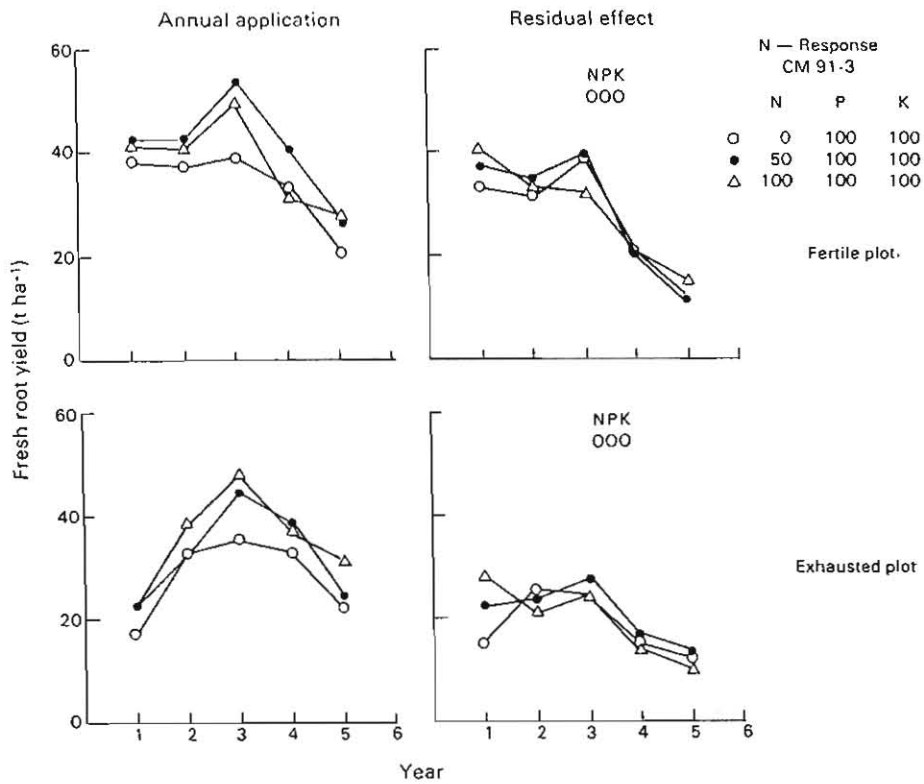


Figure 5.16 Long-term responses to N application in acid soils, Santander de Quilichao, Clone CM 91-3.

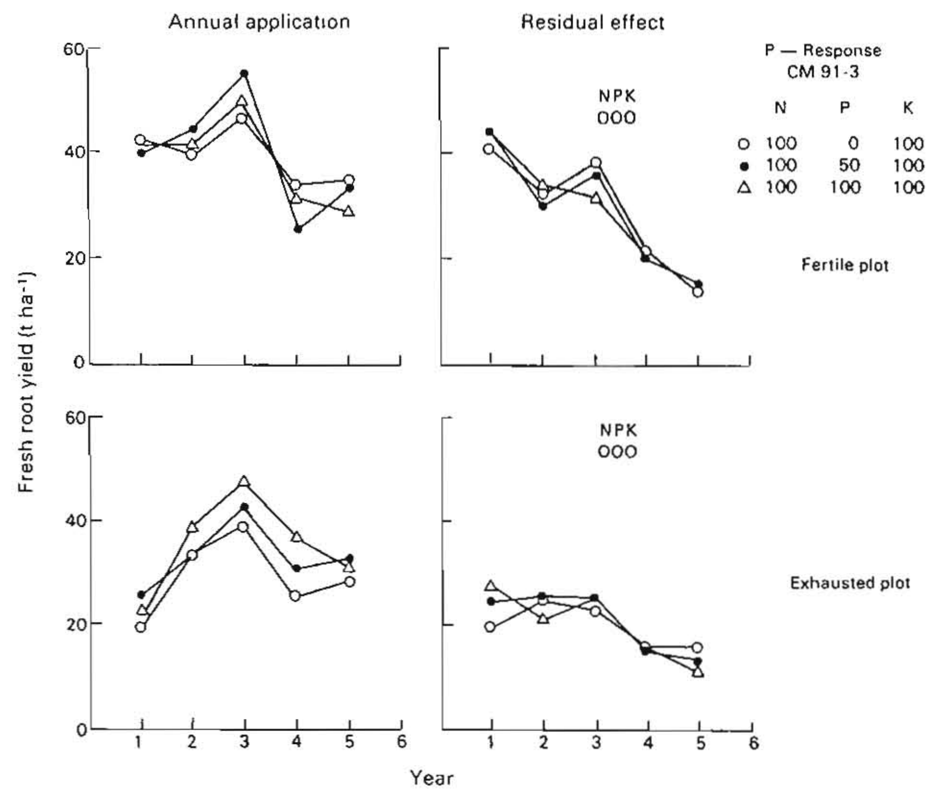


Figure 5.17 Long-term responses to P application in acid soils, Santander de Quilichao, Clone CM 91-3.

In conclusion, it can be stated that long-term cassava productivity can be maintained at a reasonable level in acid soils high in OM provided that moderate levels of K fertilizer are applied to compensate partially for the removed soil K in the harvested roots. However, when soils are poor in OM or sandy, other nutrients such as N and P would limit productivity.

5.1.4 Response of cassava to NPK fertilizer in sandy soils

In contrast to the Quilichao soils, the Media Luna soils (Magdalena State, Colombia) are sandy with extremely low OM and nutrient contents (CIAT Annual Report 1988). Yields of cassava in that region have declined rapidly in the last few years. One of the more obvious reasons (see Pathology section, Chap. 4) is the disappearance of the traditional "fallow system" due to pressure on the limited land available to local farmers. In addition, the resource-poor farmers rarely apply fertilizer. Field trials were initiated in the last two years to assess the value of applying a moderate level of NPK fertilizer (50 kg/ha NPK or 330 kg of 15-15-15 compound fertilizer), which is equivalent in cost to the price of one ton of fresh cassava (ca. Col.Ps. 28,000).[1] Trials were conducted on a private farm using 15 cassava clones including local varieties as well as some CIAT advanced lines. Split applications of the fertilizer were made at 30 and 60 days after planting.

Table 5.4 contains data on DMY and biomass production for the 1989-90 season. The experimental site was the same for the 1988-89 trials, but with a new group of cassava clones. Average increases for all clones due to fertilizer application were 103%, 136% and 116% for DMY, top growth and total biomass, resp. These differences in yield and biomass due to fertilizer application are more than twice the increases in the 1988-89 trial (ca. 47% increases, CIAT Annual Report 1989). This indicates that by continuously growing cassava in this poor sandy soil, productivity decreases and the need to fertilize the soil becomes more crucial.

Among this group of genotypes, the increase in RY ranged from 38% for M Ven 25 to 275% for CG 1411-1 (a CIAT clone). As a result of the fertilizer, the three local var. (M Col 1505, M Col 2215 and M Col 2216) showed yield increases of 124%, 81% and 171%, resp. Beside these substantial increases in RY, top growth was also greatly increased. This is of paramount importance to cassava growers as production of sufficient good-quality stakes is critical in that

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1 Avg exchange rate for 1989-1990 season, Col. Ps. 433.73 = US$1.00.

Table 5.4 Response of cassava to moderate levels of NPK fertilizer application in sandy soils at Media Luna (Magdalena, Colombia), 1989-90 season; values are means of 4 reps (DMY, t/ha) and % increase due to fertilizer in parentheses.

Clone[1]	50 kg NPK/ha			Unfertilized		
	Roots	Tops[2]	Total	Roots	Tops[2]	Total
M Bra 191	7.8	4.9	12.7	3.5	2.6	6.0
M Bra 383	7.9	4.6	12.5	5.0	2.5	7.5
<u>M Col 1505</u>	4.7 (124%)	5.6	10.3	2.1	3.0	5.1
<u>M Col 2215</u>	5.8 (81%)	4.1	9.9	3.2	1.9	5.1
<u>M Col 2216</u>	6.5 (171%)	6.9	13.5	2.4	2.5	4.9
M Cub 18	3.8	5.0	8.7	1.8	1.4	3.2
CG 912-8	7.1	5.8	12.9	3.0	2.4	5.4
CG 1220-2	5.9	6.6	12.5	2.5	1.8	4.3
CG 1355-2	8.9	4.3	13.2	4.9	3.5	8.4
CG 1372-5	7.6	4.7	12.3	2.5	2.4	4.9
CG 1411-1	4.5 (275%)	3.5	7.9	1.2	1.0	2.2
CM 507-37	5.7	7.3	12.9	3.3	1.7	5.0
CM 3320-4	7.5	3.0	10.4	3.3	1.5	4.8
CM 4181-1	5.0	4.0	9.0	2.3	1.6	3.9
M Ven 25	9.1 (38%)	7.0	16.1	6.6	3.0	9.6
Avg all clones	6.5	5.2	11.7	3.2	2.2	5.4
% increase due to fertilizer	103	136	116	-	-	-

[1] Underlined entries are local varieties.

[2] Fallen leaves not included.

region. The cost of added fertilizer is insignificant compared to the large gains in yield and the supply of planting materials. There was also a reduction in labor costs for weeding as fertilizer enhances cassava growth and results in reduced weed populations.

5.1.6 <u>Soil erosion in cassava-based cropping systems</u>

The Cassava Program has been conducting research on production management practices effective in minimizing soil erosion in erosion-prone hilly lands, both in Latin America and Asia (see Section 5.3). Results of these research efforts indicated some useful practices that can sustain cassava productivity and also help in soil conservation. Table 5.5 summarizes data on soil loss as affected by various production practices along with cassava yield at Quilichao station. Similar results were obtained on private farms with steeper slopes (20-30%) at Mondomo (Cauca State). Annual soil loss from bare soils ranged from 50 to 200 t/ha at Quilichao (≈ 12% slope) and from 50 to 300 t/ha at Mondomo (≈ 25% slope). A major portion of this loss can occur in a very short time because of water runoff during high-intensity rains (CIAT Annual Report 1989). This suggests that in less than a decade, the thin top soil of those regions can completely disappear and the land will become unproductive. The findings also point to the high risk in growing cassava on vertical ridges where soil loss is very high as compared to other more effective practices. Growing cassava in association with annual grain legumes (e.g., common beans, cowpeas, peanuts) also results in more soil loss than growing cassava alone. Some of the most effective practices in minimizing soil erosion are growing cassava on contour ridges with live barriers of native grasses or with elephant grass. Cassava in association with some forage legumes (as live ground covers) also appears to be effective; nevertheless, the feasibility of the latter practice has to be determined because of the difficulties inherent in establishing and managing the legumes in association.

Table 5.5 Soil loss at Santander de Quilichao (10-15% slope) and cassava RY as affected by production systems and cultural practices; clone CM 507-37 planted in 1 x 1 m arrangement (10,000 pl/ha).

Treatment	Soil Loss 1989/90	Cumulative Soil Loss (1987/90)	Fresh RY 1989/90
		t/ha	
Clean-tilled fallow (control)	165	411	-
Cassava planted on flat	4	26	28.5
Cassava planted on contour ridges	4	17	28.4
Cassava/kudzu + mulch	3.5	-	23.4
Cassava/Zornia + mulch	4.3	-	30.5
Cassava/grain legumes	5.0	42	22.1
Cassava/grass barriers	5.6	26	24.4
Cassava (CM 523-7) planted on vertical ridges (1987-1989)	-	98	27

Research on soil erosion control has been strengthened by a joint project with the University of Hohenheim, funded by the Federal Republic of Germany.

5.2 Cassava Varietal Response to P

Generally in the tropics, particularly in Latin America, the cassava-growing areas are characterized by a strong acid, P-deficient soil. Low P levels can limit cassava yield. CIAT germplasm is currently being characterized for tolerance and adaptation to low-P soils at Santander de Quilichao. Since 1980, more than 1500 clones have been evaluated, several of which have been found to be tolerant to low-P soils (CIAT Annual Reports 1982-87).

A collaborative research project between CIAT and the Swiss Federal Institute of Technology and funded by the Swiss Development Cooperation (SDC) was initiated in 1988 to study varietal response to P and to elucidate possible mechanisms underlying this response.

Two crop cycles (1988-89 and 1989-90) have been conducted on a private farm near CIAT's Quilichao station. The experimental site was under tropical pasture grass for several years, and soil-P was about 2.5 ppm--lower than the critical level required for optimum cassava growth. The experiment was laid out in a split-plot design with three reps; and the following fertilizer treatments (P as triple superphosphate, K as KCl, N as urea) were assigned to the main plots: (1) unfertilized; (2) 100 0 100 kg NPK/ha; (3) 100 50 100 NPK/ha; and (4) 100 100 100 kg NPK/ha.

The same treatments in the same plots were maintained in the second crop cycle. Before planting the second crop, 500 kg/ha of dolomitic lime were incorporated in all plots. Cassava var. CM 523-7 (released in 1989 under the name ICA-Catumare for the Llanos Orientales de Colombia), CM 489-1, M Col 1684 and CMC 40 were planted as subplots at a population density of 10,000 pl/ha. Sequential harvests of 8 protected pl/plot were made every 2 mo (up to 10 mo) to determine the pattern of growth over time. The plants were separated into 7 "parts": youngest leaf blades (nonfully expanded leaves), mature leaves, petioles, stems, storage roots, original stakes and new formed tissues at this level (which is neither root nor stem), fallen leaves (with fallen petioles), collected between two harvests. In the second crop cycle, flowers and fruits were collected separately.

P content was determined for each plant part, and total P uptake was estimated as the sum of P accumulated in the different plant parts. This was obtained by multiplying P concentration in each plant part by its dry weight.

Soil samples (taken to a depth of 20 cm at 2-mo intervals) were analyzed for available P and exchangeable K (Bray II extraction method). For fine root density determination, 12 soil samples per plot were taken at the mid-distance between two plants by hand auger (433 cm3) in the 0-20 cm soil layer. Rootlets were separated from soil by flotation, and length was estimated using the grid line method. Vesicular-arbuscular mycorrhiza (VAM) infection of fine roots was determined under stereoscopic microscope after Trypan blue staining.

Single-leaf gas exchanges (CO_2 uptake and H_2O loss) were measured on the 5-7th upper canopy leaves 2, 3, 4 and 5 mo after planting, using a portable infrared gas analyzer. Measurements were always made from 0800 to 1300 h with a solar irradiance over 1000 μ mol $m^{-2}s^{-1}$ in the active photosynthetic range.

5.2.1 Soil analysis

P and K fertilizer application increased soil nutrient availability (Fig. 5.18). N application had no effect (data not shown). In the first crop cycle, at 2 mo after planting and applying NK fertilizer, there was very low availability of P in the control treatment (0 kg P/ha)--the only one under the critical level (6 ppm).

During the second cycle (1989-1990), soil P in the control treatment ranged from 2.5 to 5.3 ppm. Comparing these levels with that at the beginning of the experiments in 1988 (2.5 ppm), cassava caused no apparent P depletion after two crops. Two consecutive applications of 100 kg P/ha/yr induced a dramatic buildup of P to 25 ppm in the second cycle. With intermediate P applications (50 kg P/ha/yr), P availability reached an optimal level for cassava growth.

The yearly application of 100 kg K/ha maintained exchangeable K above the critical level (0.15-0.17 meq/100 g soil) after two cycles (Fig. 5.18). In plots without fertilizer application, soil K contents fell from 0.15 meq K at the beginning of the first cycle to 0.10 meq K 6 mo after planting during the second cycle, stressing the importance of K fertilization to sustain cassava production (see Section 5.1).

5.2.2 Root yield, leaf canopy, sink-source relationship and photosynthesis

Figure 5.19 illustrates fresh RY and its evolution over time after planting for each of the two crop cycles. Clone CM 489-1, which had the highest yield at any given P level, showed a significant response to P in both years. M Col 1684 did not show any significant response to P at final

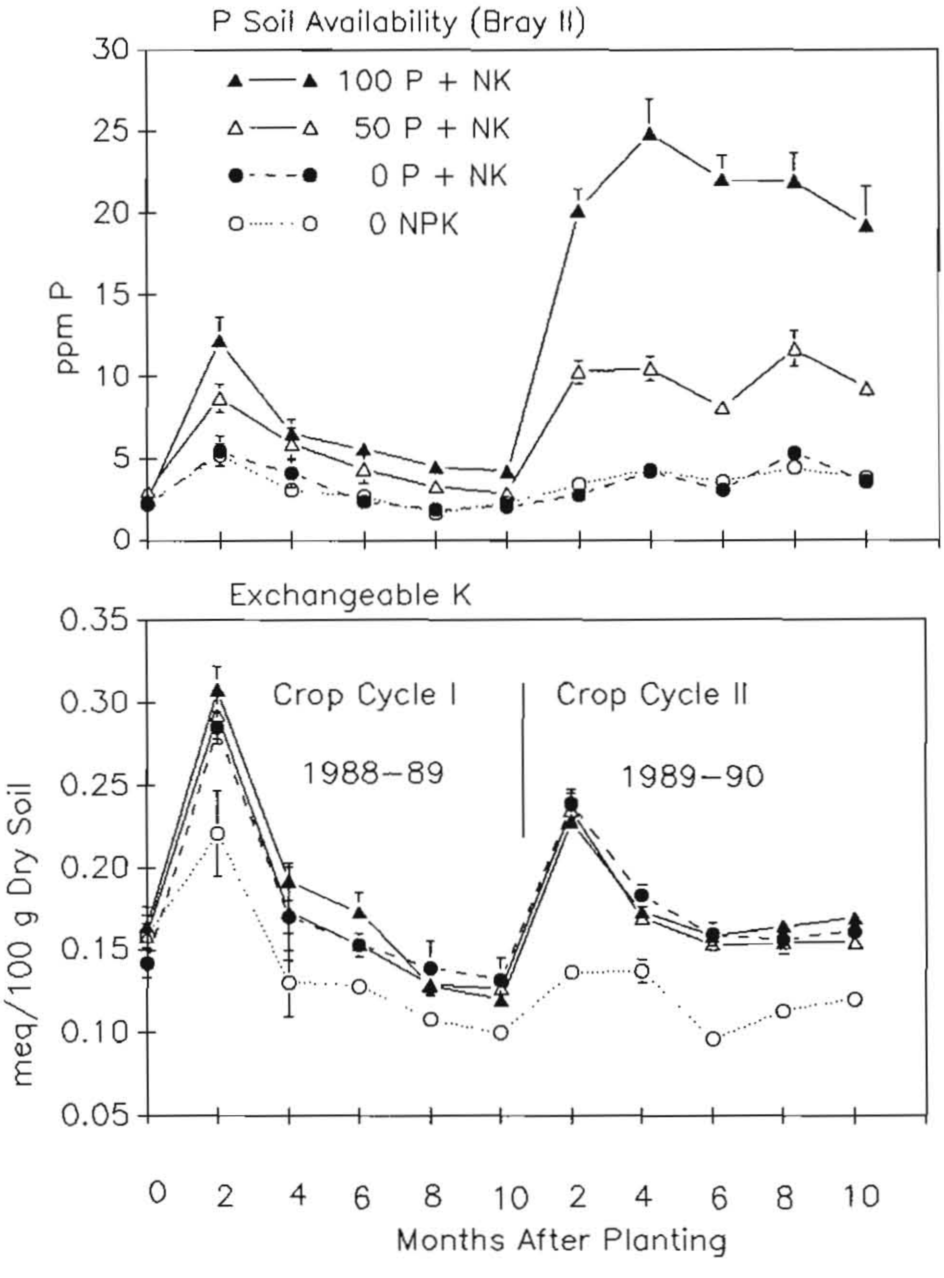


Figure 5.18 Evolution of P and K soil availability over time according to fertilizer treatments, during a 2-yr field trial; vertical bars represent SE of the mean (n=3) if greater than symbols.

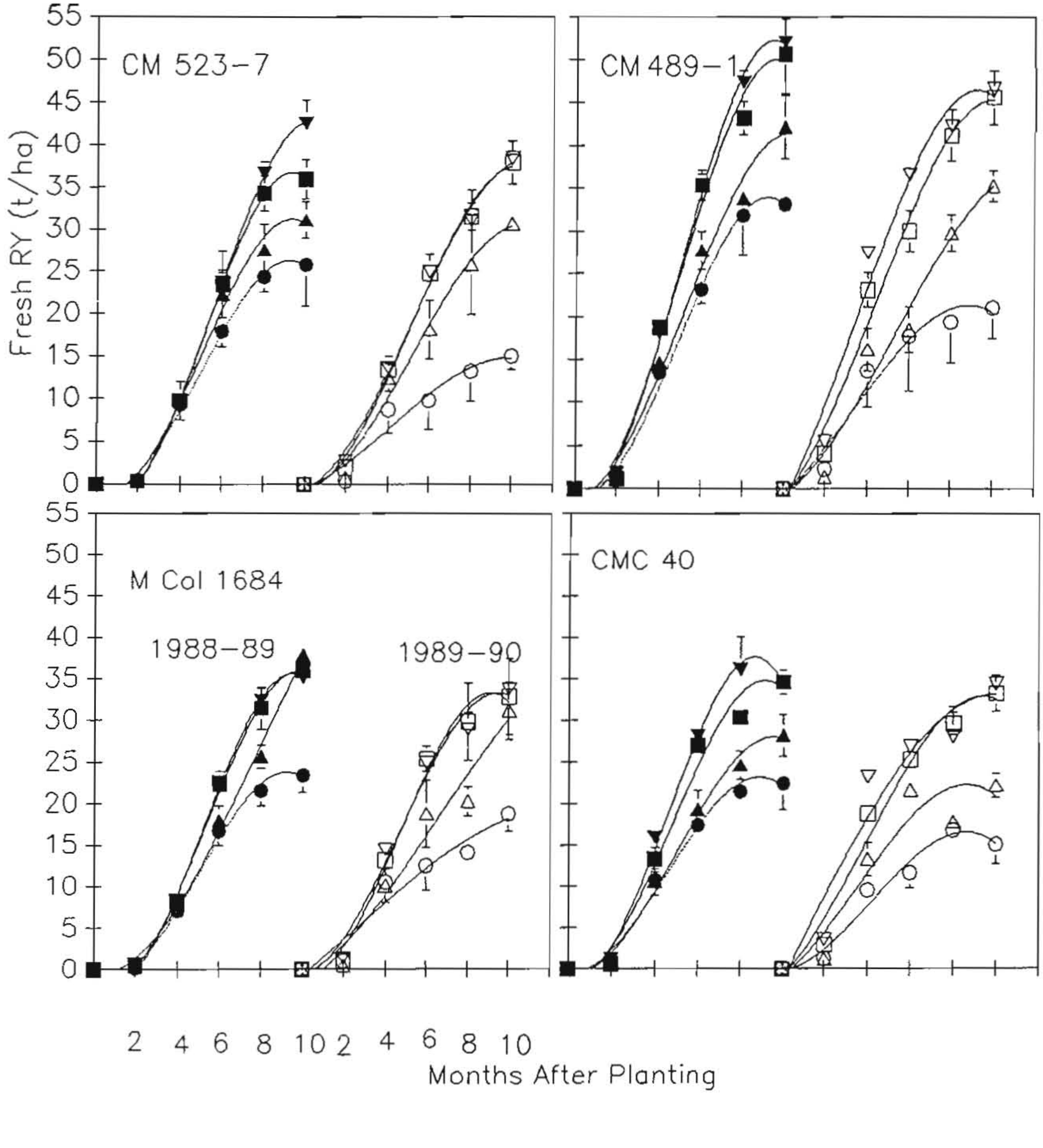


Figure 5.19 Response of fresh RY to P application: filled symbols for first crop cycle (1988-89), open symbols for second cycle (1989-90); vertical bars represent SE of the mean (n=3).

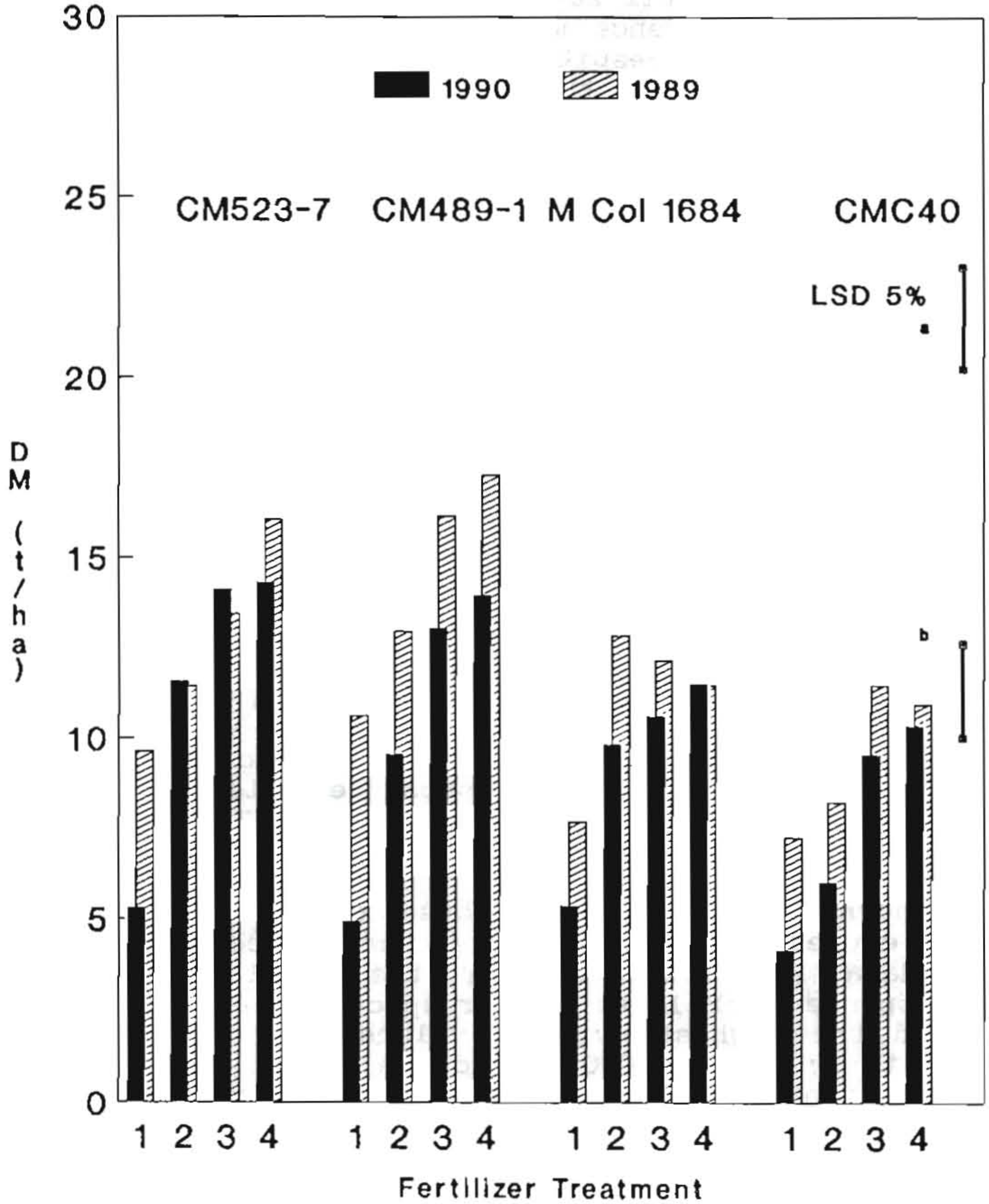


Figure 5.20 Influence of fertilizer treatment on final DMY of 4 cassava clones in 1989 and 1990.

harvest either year. CM 523-7 and CMC 40 showed intermediate response to P. In the second year, yield of unfertilized plants decreased compared to the first crop cycle, partly because of K stress.

Figure 5.20 shows DMY at final harvest for both crop cycles. Generally, yields were higher in 1989 than in 1990, particularly in the zero fertilizer treatment. In the second cycle no significant difference was noted between 50 and 100 kg P/ha for any clone despite large differences in soil P availability, confirming the optimal fertilizer rate of 50 kg P/ha/yr. Differences between the two cycles could be due to changes in climatic factors (storm with some plant lodging in 1990) and canopy development (see below); however, the differential clonal response to P was consistent across both years. The two most contrasting clones (CM 489-1 and M Col 1684) maintained different behaviors over the years; i.e., a significant response to P application in CM 489-1 but not in M Col 1684. Under P stress, however, these two clones had similar yields both years.

Figure 5.21 illustrates the effect of fertilizer treatment on LAI evolution over time during the two crop cycles. In 1990 LAI reached higher values in all clones than in 1989. The rapid leaf area development was already evident at 2 mo after planting, reaching its maximum at 4 mo. At that point, M Col 1684 showed the highest response to P; CM 523-7, the least. The LAIs in CM 489-1 and CMC 40 were significantly increased by P application. In 1989, LAI reached its maximum from 4 to 6 mo after planting, but with lower values and less response to P than in the 1990 crop. In 1990, leaf fall was very marked just after reaching maximum values. Excessive shading due to large canopy enhanced rapid senescence and subsequent leaf fall. The apparently large leaf regrowth in CM 523-7 and CM 489-1 might partly explain the decrease in RY as compared to 1989.

It is known that cassava response to soil fertility is markedly expressed in leaf canopy changes (confirmed by the present data, Fig. 5.22); however, the varieties differed in their response to P level with respect to leaf canopy. CM 523-7 had the highest avg LAI values with no significant response to P; whereas CMC 40 had the lowest avg LAI values and significant response to P. The two contrasting clones CM 489-1 and M Col 1684 had very similar LAI values and response to P. M Col 1684 could not transform its leaf canopy increase into economic yield increases because of a poor HI at high P rates (HI = 0.65 at high P and 0.77 at 0 P); while the HI of CM 489-1 did not change much with P rates (HI = 0.68 at high P and 0.7 at 0 P). M Col 1684 is known to have a high HI (HI = 0.71 avg for all treatments), higher than CM 489-1 (HI = 0.68 avg for all treatments). As varieties with comparable HI may respond differently to

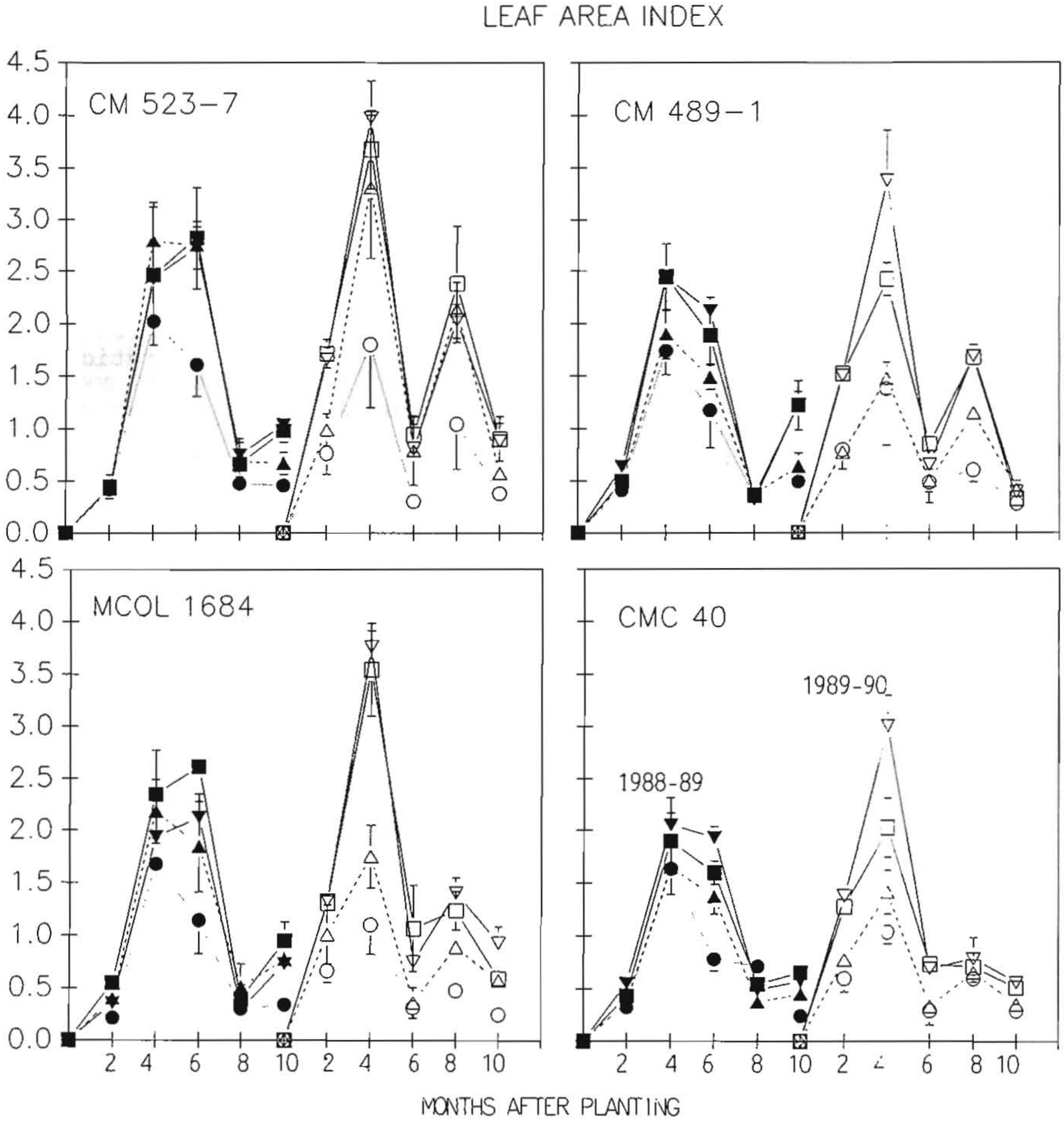


Figure 5.21 Response of LAI to P application: filled symbols for first crop cycle (1988-89), open symbols for second cycle (1989-90); response of LAI to fertilizer application; vertical bars represent SE of the mean (n=3).

increased soil fertility, HI is not a good parameter for predicting cassava reactions in this regard.

Figure 5.22 also shows the influence of fertilizer treatments on no. of storage roots. All varieties showed a significant response to P. As in 1989, Clone CM 489-1 reached the highest values. No. of storage roots was significantly correlated with final DMY ($r=0.70$, $P<0.001$). This confirms results of the first year, suggesting that no. of storage roots could be an indicator of "sink" capacity of cassava. Moreover, recent findings showed the additive effect of leaf area duration and leaf photosynthesis on RY. These facts suggest that cassava yield depends on both "source" and "sink" capacity. Figure 5.22 presents the avg value of "sink-source" ratio for each variety (taken as root no./avg LAI). M Col 1684 had the lowest sink-source ratio (8.1 and 6.6 for 0 P and high P, resp.) and the lowest DMY increase due to P; CM 489-1 with high sink-source ratio (18.6 and 16.4 for 0 P and high P, resp.) gave the highest DMY increase. This suggests that sink/source relationship may be a better indicator than HI alone to characterize varietal response to soil fertility.

Figure 5.23 illustrates single-leaf photosynthesis over time according to P treatment for four genotypes in 1990. Maximum photosynthetic rates were reached 3-4 mo after planting, with enhanced rates at high P compared to 0 P by CM 489-1 and CM 523-7 (Figs. 5.23 & 5.24). Across all measurements and treatments, clone CM 489-1 had the highest avg rate; M Col 1684, the lowest (32.13 ± 0.6 and 29.74 ± 0.6 umol $CO_2.m^{-2}s^{-1}$, resp.). Leaf photosynthesis might be influenced by sink-source ratio (feedback effect). Enhancement of leaf photsynthesis by P application was consistently related to nonstomatal factors (biochemical or anatomical) as indicated by the level of internal CO_2 concentration. Internal CO_2 tended to decrease with increases in photosynthesis (e.g., compare net photosynthesis with internal CO_2 of CM 489-1 at different treatments).

5.2.3 P uptake, plant reaction to P, P-use efficiency

Figure 5.25 represents total P uptake or total P accumulation over time by four different varieties as affected by fertilizer levels (crop cycle 1988-89). From these data (see Table 5.6), it is obvious that all varieties accumulated more P at high P fertilizer levels (50 and 100 kg P/ha) compared to the control (0 kg P/ha). This response was apparent from 4 to 6 mo up until 10 mo after planting (8 mo for M Col 1684). The observed decrease in uptake between 8 and 10 mo for var. 523-7 and M Col 1684 was due to dieback and senescence of aerial parts. The lack of RY response of M Col 1684 to P is thus not related to limitation in P uptake or acquisition.

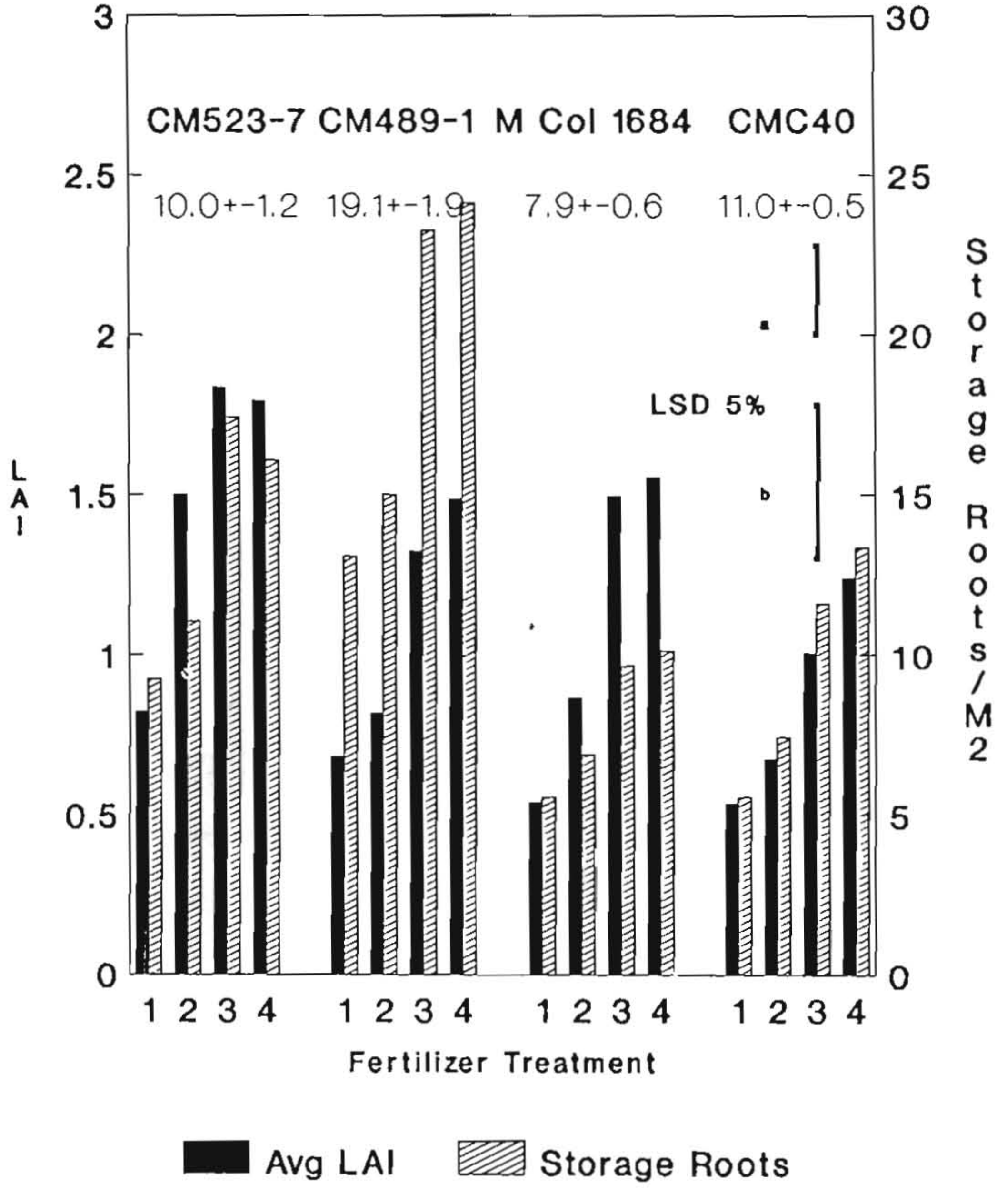


Figure 5.22 Influence of fertilizer treatment on LAI and storage root no. in 1990 (a = LSD 0.05 for storage root no.; b = for avg LAI).

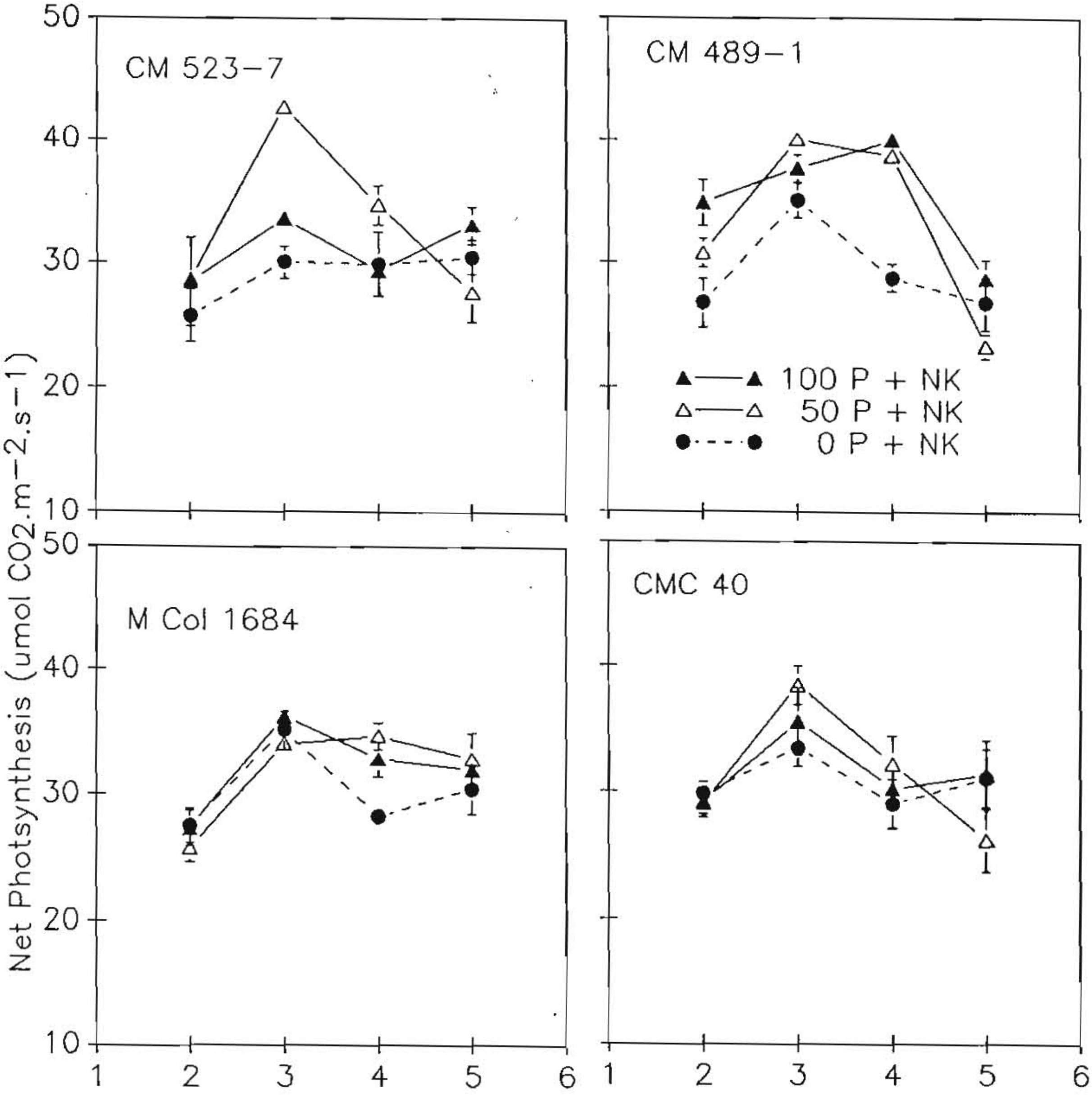
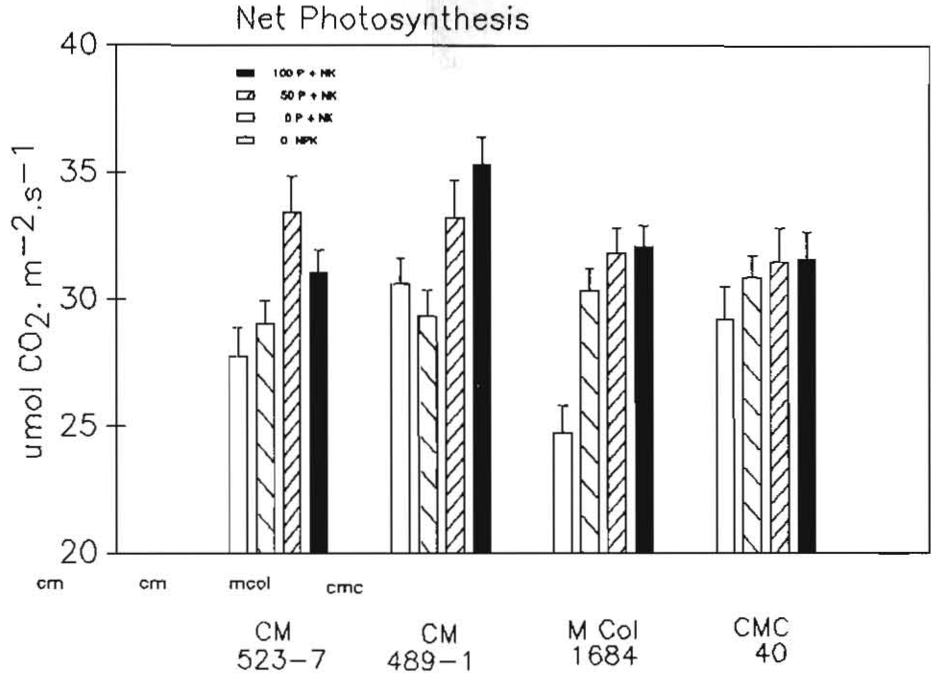


Figure 5.23 Influence of P application on single-leaf CO_2 uptake over time by 4 cassava genotypes in 1990; vertical bars represent SE of the mean (n=3 reps x 2 readings).



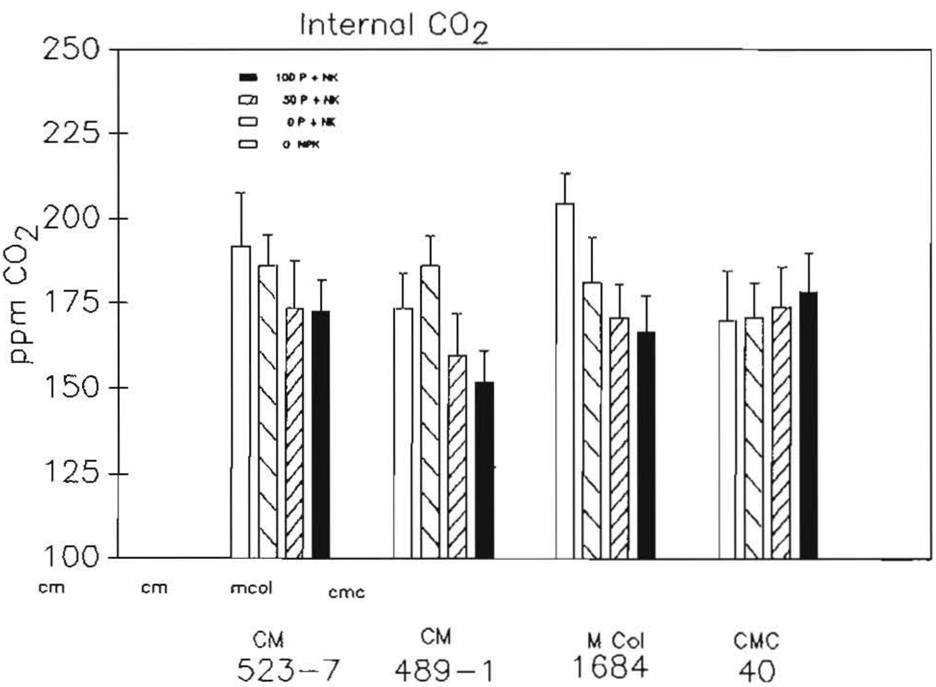


Figure 5.24 Influence of fertilizer treatment on avg single-leaf CO_2 uptake rate and intercellular CO_2 over all measurement periods by 4 cassava genotypes; vertical bars represent SE of the mean (n=4 measurements x 2 readings x 3 reps).

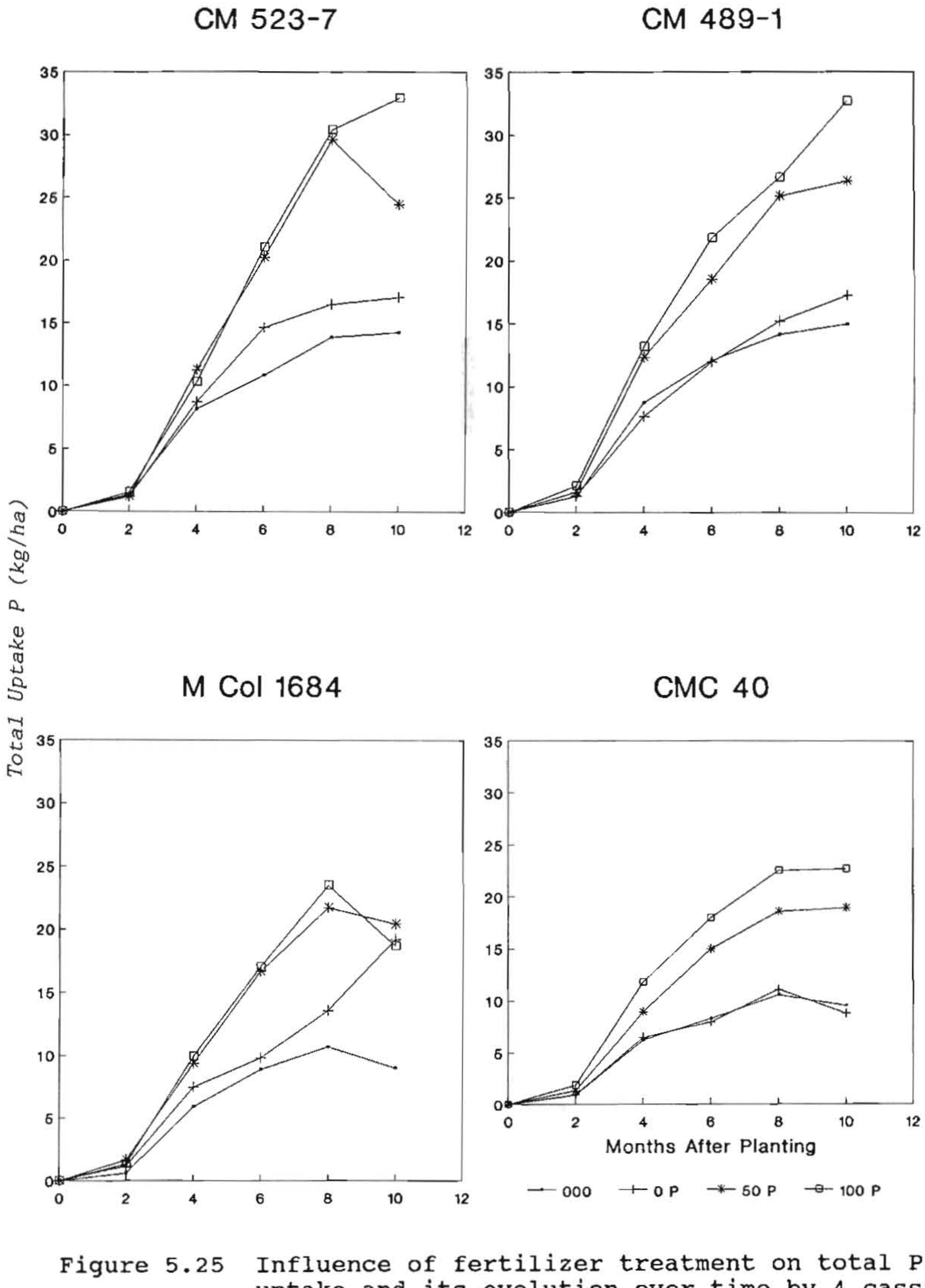


Figure 5.25 Influence of fertilizer treatment on total P uptake and its evolution over time by 4 cassava varieties in the first crop cycle; vertical bars represent SE of the mean (n=3).

Table 5.6 Varietal and fertilization effect on total P uptake and their evolution over time (during first crop cycle 1988-89).

Cassava Variety[1] or Fertilizer Treatment[2]	Total Uptake P (kg P/ha)				
	Months after Planting				
	2	4	6	8	10
Varieties					
CM 523-7	1.37	9.64	16.69	22.60	22.19
CM 489-1	1.65	10.48	16.10	20.27	22.82
M Col 1684	1.24	8.18	13.10	17.39	16.83
CMC 40	1.32	8.39	12.33	15.72	15.00
LSD (0.05)	0.25	1.36	1.80	2.27	1.80
Fertilizer Treatment					
0 NK	1.08	7.29	10.04	12.33	11.97
0 P + 100 NK	1.21	7.60	11.11	14.10	15.59
50 P + 100 NK	1.52	10.50	17.61	23.77	22.54
100 P + 100 NK	1.79	11.31	19.46	25.78	26.76
LSD (0.05)	ns	1.97	4.26	5.30	4.24

[1] Each value is the avg over all treatments.

[2] Each value is the avg over all varieties.

This is confirmed by data on absolute P uptake rates, calculated over the entire growth period in the first crop cycle (Fig. 5.26, Table 5.7). Across all clones, there were higher uptake rates at adequate P supply (50 and 100 kg/ha) as compared to the control (0 P). At 0 P, uptake rates of the different clones were very similar, indicating that VAM efficiency was similar in the four genotypes, even in the presence of slight differences in VAM root infection (data not shown).

Figure 5.27 shows the influence of fertilizer treatments on apex no./plant, dry storage RY, total biomass, and total P uptake 6 mo after planting in the first crop cycle. As mentioned, all varieties showed marked responses in P accumulation to P fertilization (compare treatments 1-3).

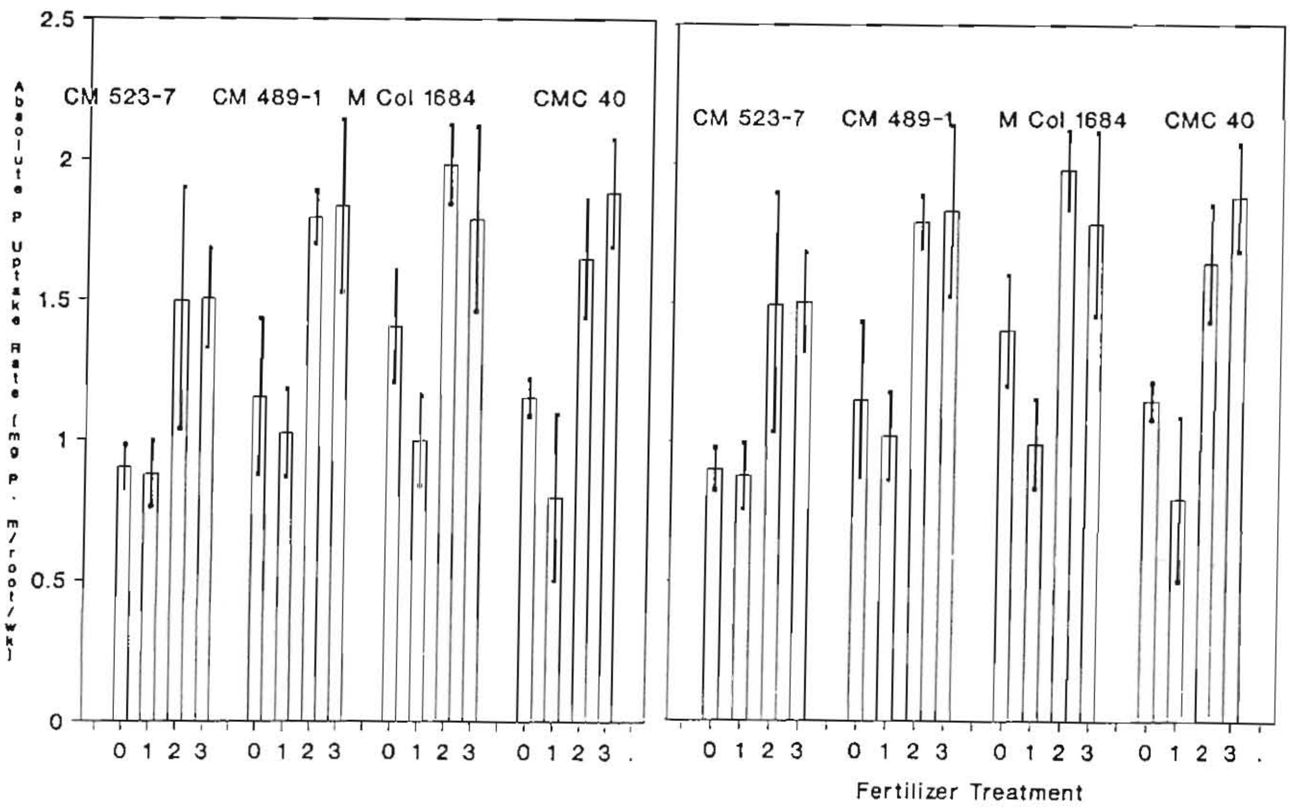


Figure 5.26 P uptake rates related to (a) VAM-infected root length and (b) total root length. Values calculated from 2 and 8 mo after planting of the first crop cycle; vertical bars represent SE of the mean (n=3).

CM 523-7 and M Col 1684 had more apices and showed a marked increase in apice no./plant due to P application, but showed no or low increases in dry root and biomass (higher P concentrations were observed in the stems of these two varieties; data not shown). On the other hand, CM 489-1 and CMC 40 had a low no. of apices, which did not change with P fertilization, but showed high DMY and total biomass responses to P. Varietal response to P was not related to absolute P uptake; CMC 40 accumulated less P than CM 523-7 at 6 mo (Table 5.6 and Fig. 5.25) but had a greater absolute yield increase than CM 523-7 at that stage (Fig. 5.27).

Table 5.7 Varietal and fertilization effect on mean fibrous root length, VAM infected mean fibrous root length, mean absolute P uptake rate, related to fibrous root length and VAM infected fibrous root length (during first crop cycle 1988-1989).

Cassava Variety[1] or Fertilizer Treatment[2]	Mean Root Length (m.m-2)[3]	VAM-Infected Mean Root Length (m.m-2)[3]	Mean Absolute P Uptake Rate[4] Root Length (mg P .m-1 root.wk-1)	VAM-Infected Root Length (mg P.m-1.wk-1)[4]
Varieties				
CM 523-7	189.9	71.8	0.444	1.194
CM 489-1	139.3	52.8	0.539	1.450
M Col 1684	110.6	43.1	0.605	1.541
CMC 40	101.5	44.5	0.595	1.369
LSD (0.05)	19.0	11.1	0.101	ns
(0.01)	25.8	15.5	ns	
Fertilizer Treatment				
0 NPK	122.8	41.5	0.393	1.152
0 P + 100 NK	139.9	57.4	0.378	0.923
50 P + 100 NK	143.3	55.2	0.647	1.728
100 P + 100 NK	135.4	58.1	0.766	1.751
LSD (0.05)	ns	ns	0.189	0.509
(0.01)			0.287	ns

[1] Each value is the avg over all treatments.

[2] Each value is the avg over all varieties.

[3] Measured in the 0-20 cm soil layer; avg of measures 4 to 8 mo after planting.

[4] Calculated for time period 2 to 8 mo after planting.

P-use efficiency 6 mo after planting (first crop cycle) in terms of biomass and dry root production (kg DM/kg P concentrated in total biomass), differed significantly among clones; CM 489-1 and CMC 40 had higher P-use efficiency than CM 523-7 and M Col 1684 (Table 5.8). The latter clones produced more apices and tissues high in P concentration but low in biomass. It is suggested that formation of large no. of apices might be related to lower P-use efficiency. The same patterns of apex formation were observed in the second year at 4 mo after planting (Fig. 5.28). CM 523-7 and M Col 1684 had more apices and high response to P as compared to CM 489-1 and CMC 40. Flower production also varied among clones, with M Col 1684 showing the strongest response to P and the highest production of flowers (note the high production of flowers and fruits in treatments without fertilizer). These data indicate the importance of K for translocation of assimilates. Fruit production was not closely related to P fertilization. It is interesting to note that M Col 1684, with the smallest sink-source ratio and least RY response to P, used more assimilates to produce flowers--organs high in P (0.5 to 0.6 % P) and very low in biomass.

5.2.4 Conclusions

The present study supports the following conclusions:

-- Differential varietal response to P was observed in two consecutive crop cycles.

-- One clone (M Col 1684) with the lowest DMY response to P was characterized by a low sink-source ratio and a marked response in apices and flowers production.

-- The clone with the highest sink-source ratio (CM 489-1) had high DMY response to P, the highest CO_2 uptake rates and response to P fertilization. It is a late-branching variety with a low no. of apices and few reproductive organs.

-- Yield response to P was not related to P uptake, and no specific mechanism of P acquisition was identified to explain differences in P response between genotypes.

-- Genotypic differences in response to P are related to P-use efficiency in terms of yield and total biomass production.

-- P-use efficiency differed significantly among this group of 4 clones, with CMC 40 and CM 489-1 showing the highest rate.

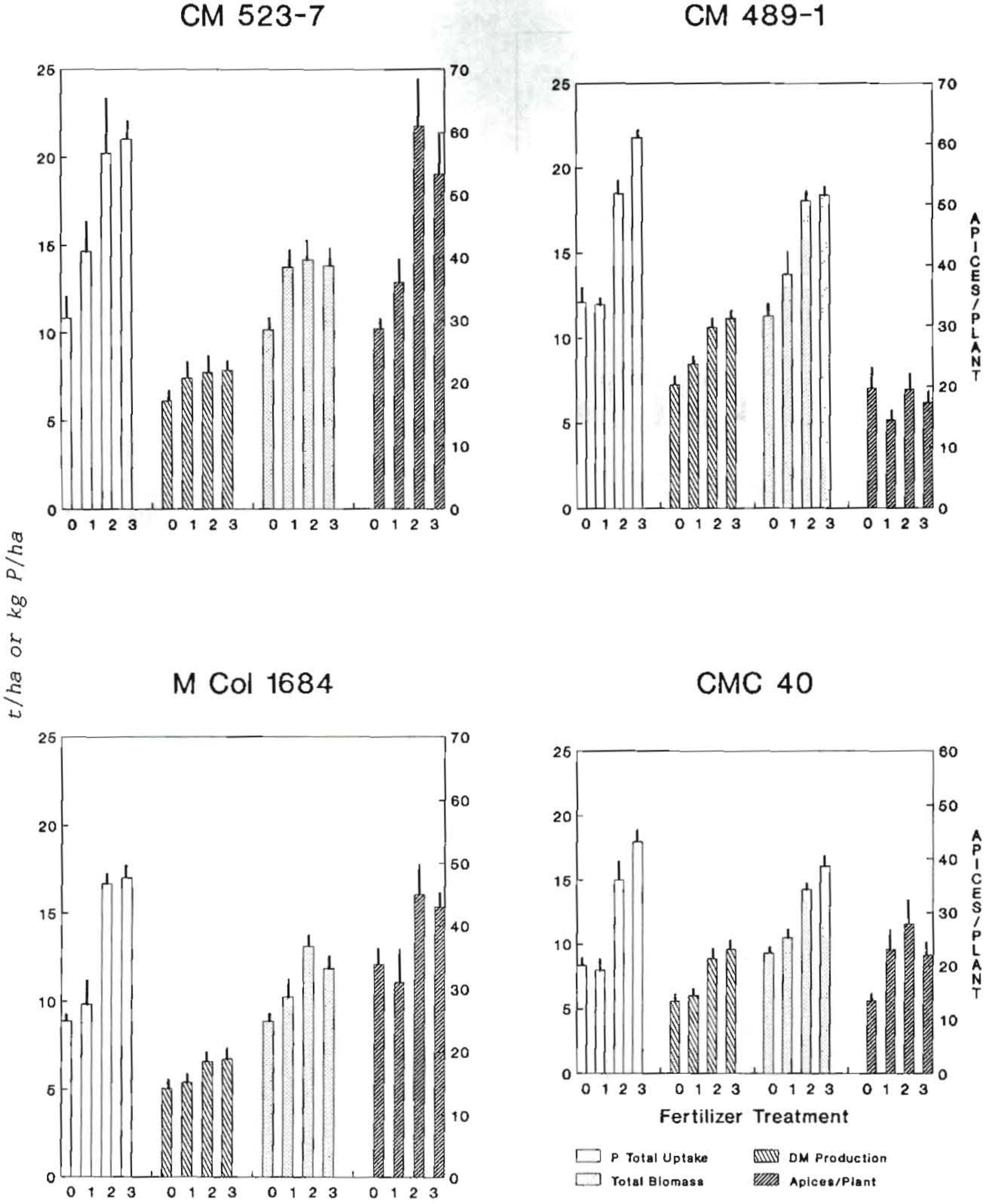


Figure 5.27 Influence of fertilizer treatment on different yield and phenological parameters of 4 cassava varieties, 6 mo after planting (1989); vertical bars represent SE of the mean (n=3).

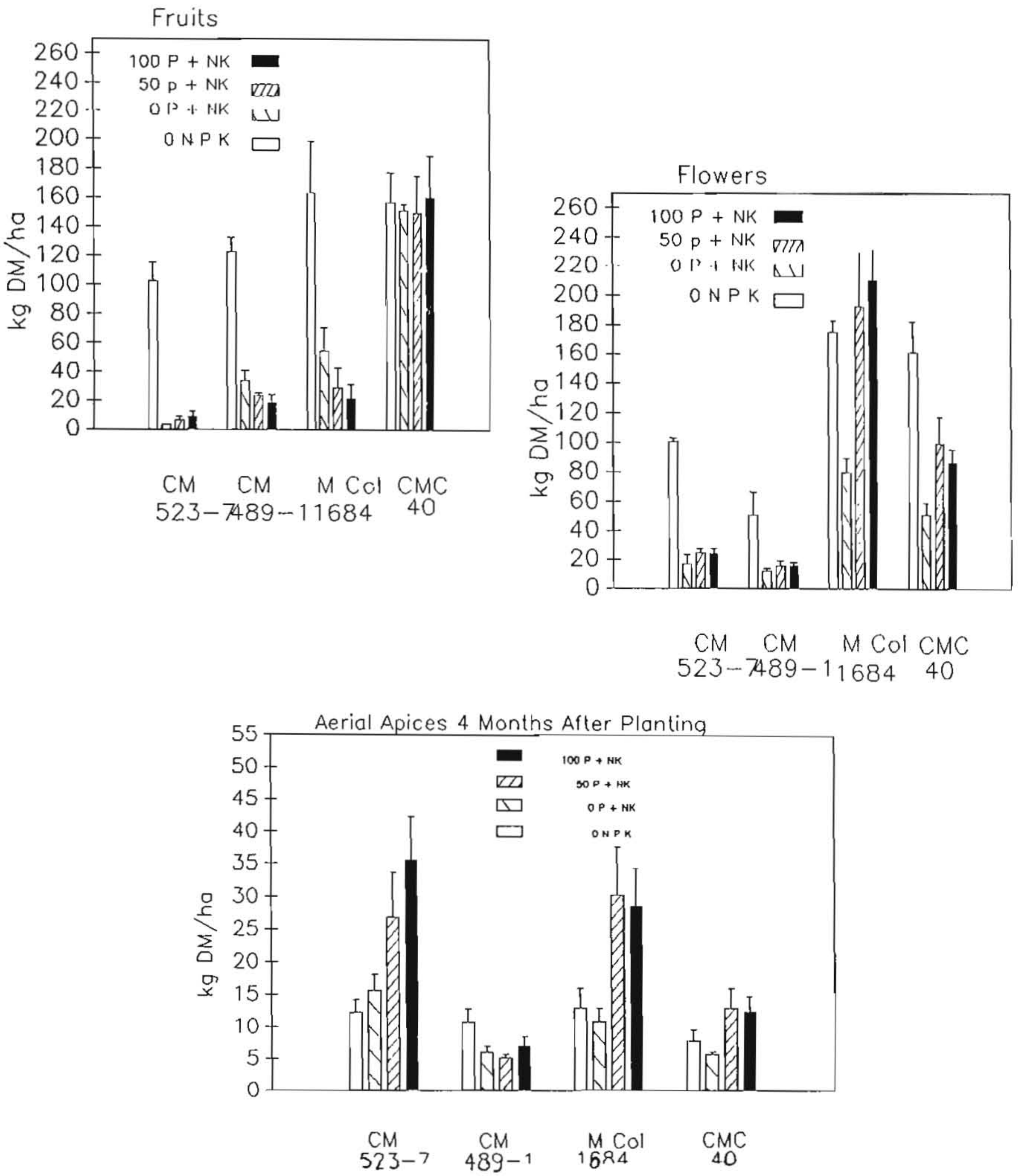


Figure 5.28 Influence of fertilizer treatment on fruits, flowers and aerial apices production in the second crop cycle (1989-1990); vertical bars represent SE of the mean (n=3).

Table 5.8 Varietal and fertilization effect on P-use efficiency for total biomass and bulked root production, 6 mo after planting (during the first crop cycle, 1988-89).

Cassava Variety[1] or Fertilizer Treatment[2]	P-Use Efficiency for: Total Biomass Production, kg DM/kg P[3]	P-Use Efficiency for: Bulked Root Production, kg DM/kg P
Varieties		
CM 523-7	821.8	465.1
CM 489-1	975.9	598.9
M Col 1684	895.1	491.7
CMC 40	1083.2	645.6
LSD (0.05)	61.6	46.7
(0.01)	83.4	63.3
Fertilizer Treatment		
0 NPK	1012.1	612.0
0 P + 100 NK	1131.6	643.2
50 P + 100 NK	858.9	492.5
100 P + 100 Nk	773.2	453.5
LSD (0.05)	246.3	ns
(0.01)	ns	

[1] Each value is the avg over all treatments.

[2] Each value is the avg over all varieties.

[3] Kg of total biomass (including fallen leaves) produced by kg of P absorbed in total biomass.

[4] Dry bulked roots.

5.3 Sink-Source Relationships in Cassava

Previous findings (see above and CIAT Annual Report 1989) showed that cassava yield was highly correlated with total no. of storage roots and, to a lesser extent, with individual storage root wt. It was suggested that no. of storage roots could be a reliable indicator of sink capacity or sink strength in cassava. In the same trials, varietal ranking on the basis of both leaf photosynthesis and sink-source ratio (as root no./LAI) were similar. Thus leaf photosynthesis might be influenced by the sink-source relation (i.e., feedback effect), warranting further research to test this possibility. Two contrasting clones--M Col 1684 with a low no. of storage roots and early-branching, and CM 489-1 with many roots and late branching--were reciprocally grafted and planted in the fields in Palmira, along with control plants and self-graftings. Woody stems were used for grafting by cutting both the scions and stocks at 45° and then tying them with plastic tape. All planting materials were treated with fungicide-insecticide solution prior to planting. The field experiment was laid out in a randomized block design with four reps at a population density of 10,000 pl/ha. Three sequential harvests of 6 protected plants each were made 3, 5 and 9 mo after planting. There were six treatments:

1 - M Col 1684	(control)	MCO
2 - M Col 1684/M Col 1684	(self-grafting)	MCO/MCO
3 - M Col 1684/CM 489-1	(reciprocal grafting)	MCO/CM
4 - CM 489-1	(control)	CM
5 - CM 489-1/CM 489-1	(self-grafting)	CM/CM
6 - CM 489-1/M Col 1684	(reciprocal grafting)	CM/MCO

M Col 1684 produced flowers intensively while CM 489-1 produced very few flowers; thus flowers were eliminated as they appeared to avoid forming alternative sinks.

5.3.1 No. of storage roots

Figure 5.29 illustrates the evolution of storage root no. (roots thicker than 1 cm in diameter). Plants with M Col 1684 as root stock had fewer storage roots than the reciprocal graftings with CM 489-1 as stock. Storage root no. was nearly constant from 5 mo until final harvest. Although self-graftings had fewer storage roots than the controls, the effect of the clones was more evident than that of self-grafting. It appears that grafting was effective in manipulating root no.; hence the sink strength of the combined clones.

5.3.2 Fresh and dry RY

Fresh RY as a function of harvest time and treatments are presented in Figure 5.30 and the final DMY in Figure 5.31. The effect of self-grafting was not significant (compare control and self-graftings). RY was significantly increased when CM 489-1 was used as stock for M Col 1684; whereas when M Col 1684 was used as stock for CM 489-1, RY decreased significantly. These data suggest that sink capacity is limiting yield in cassava, and storage root no. might be a

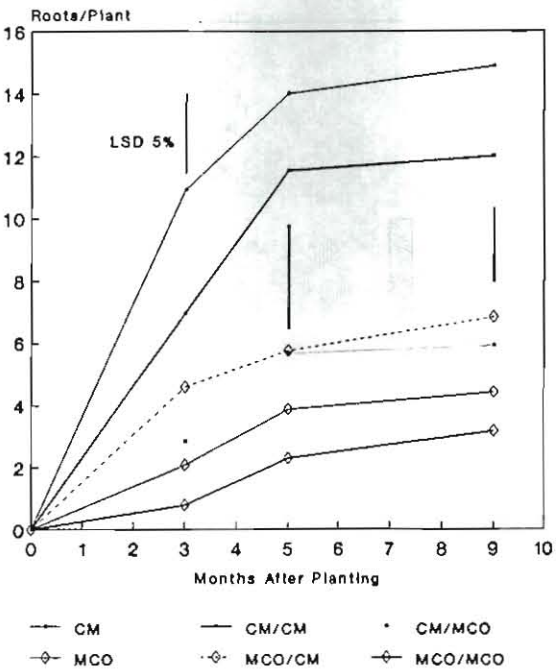


Figure 5.29 Evolution of no. storage roots/plant according to clone and reciprocal graftings.

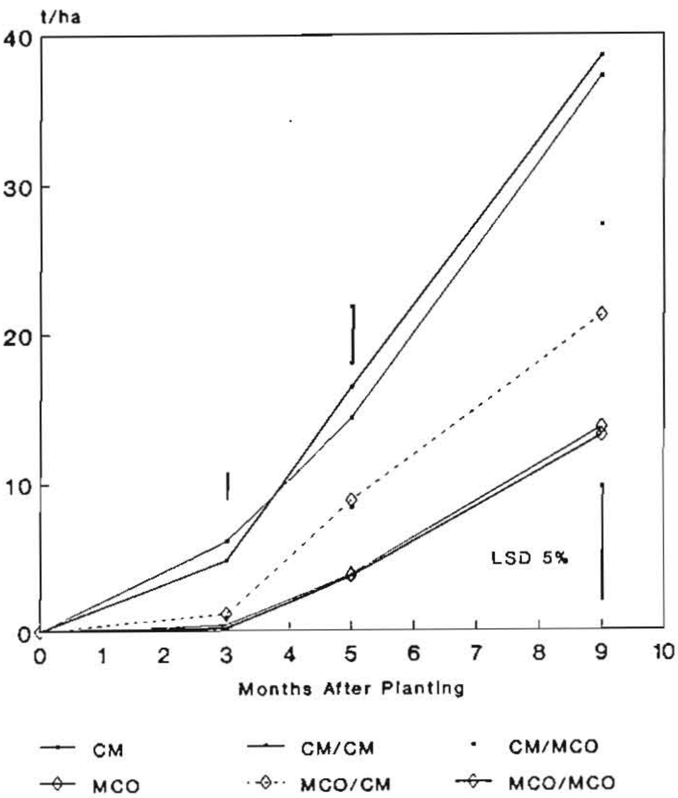


Figure 5.30 Influence of grafting treatment on fresh RY and its evolution over time.

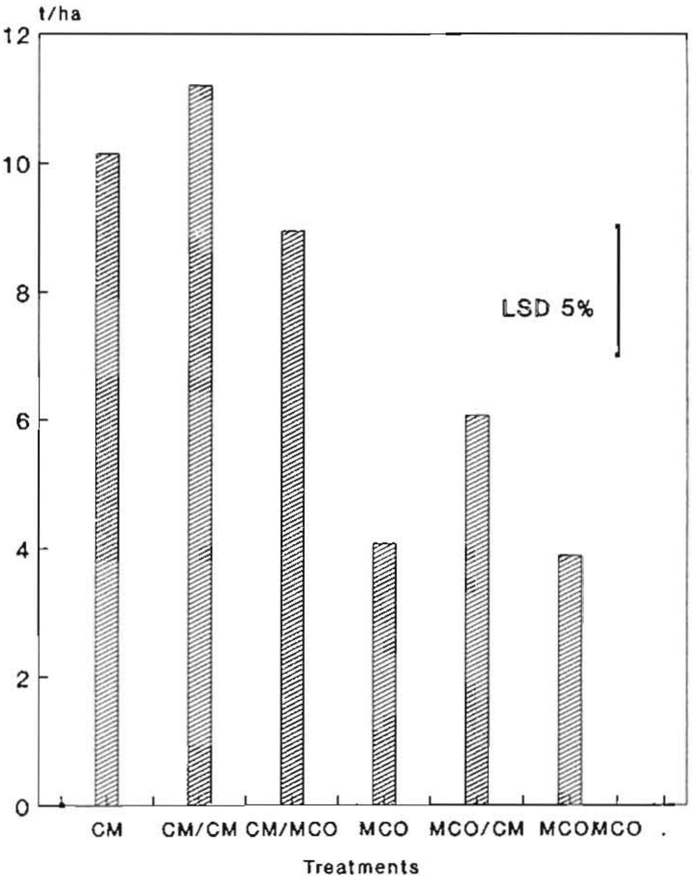


Figure 5.31 Influence of grafting treatments on DMY at final harvest 9 mo after planting.

useful criterion for evaluating progenies with better sink capacity and hence higher RY. In Figure 5.31, the source effect can be observed comparing grafts with the same root stock and different scions. In boths cases the effect of scion on final RY was much greater than that of stock. This indicates, as already known, that leaf area duration and photosynthesis are of paramount importance in cassava and should be considered as selection criteria for high yield potential.

5.3.3 Sink-source ratio, HI

Sink capacity in terms of root no. was used to determine the sink-source ratio (no. storage roots/LAI). This ratio as well as HI (root wt/total biomass) are indicators of assimilate partitioning between top and root growth. At 5 mo after planting, sink-source ratio and HI showed similar trends in biomass partitioning (Fig. 5.32). Grafts and control plants with M Col 1684 as stock had significantly

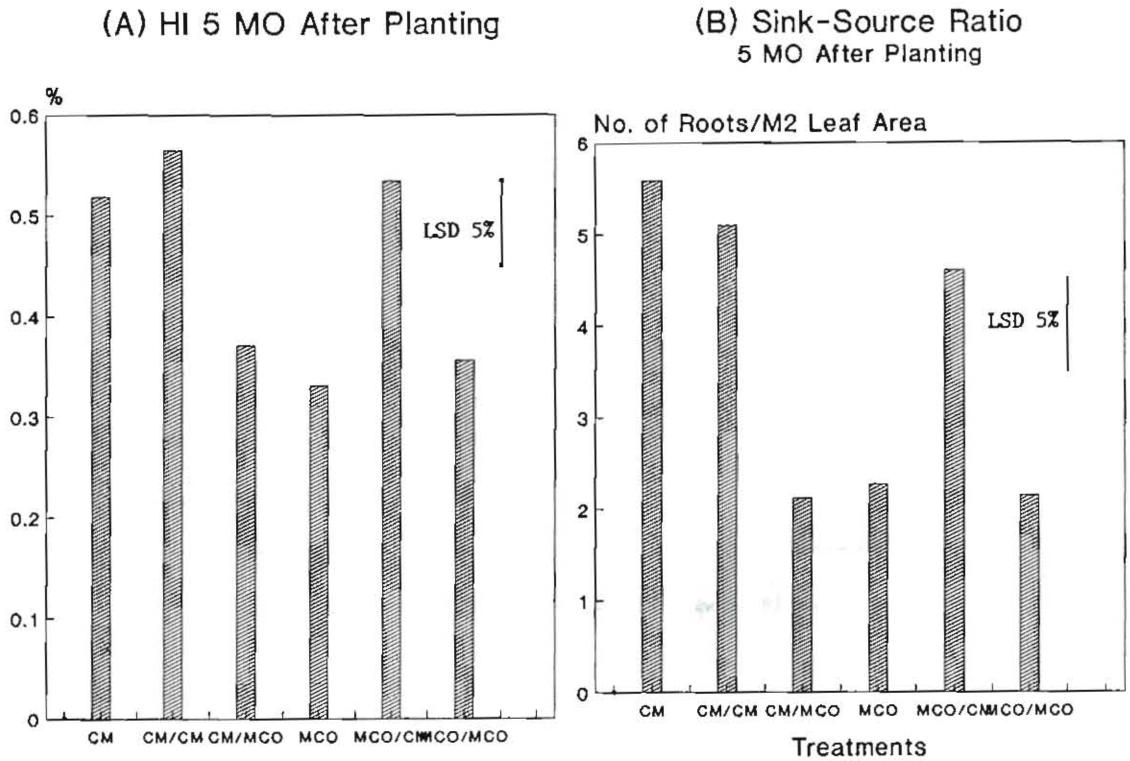


Figure 5.32 Influence of grafting treatments on HI and sink-source ratio (LAI/no. storage roots) 5 mo after planting.

lower HIs and sink-source ratio than plants with CM 489-1 as stock. This suggests that sink capacity is important in biomass partitioning. This also means that the distribution of assimilates in this trial was controlled mainly by the stock.

5.3.4 Photosynthesis

Table 5.9 presents data on leaf gas exchange as measured at 3 and 4 mo after planting. Higher rates of net photosynthesis were observed in CM 489-1 leaves (avg of scions and controls of CM 489-1) than in M Col 1684. Differences were due more to mesophyll characteristics of clones than to stomatal differences.

Grafts of CM 489-1/M Col 1684 did not show any decrease in photosynthetic rates compared to the self-graft of CM 489-1, despite reduction of sink capacity (root no.). In the

Table 5.9 Influence of scions and reciprocal grafting on gas exchange characteristics.

Overall Avg	Net Photosynthesis $\mu mol/m^2/s$	Internal CO_2 ppm CO_2 [2]	Stomatal Conductance $mmol/m^2/s$
CM 489-1	26.85 a	197.19 b	713.27
M Col 1684	23.46 b	212.31 a	709.70 ns
Graft Treatments			
CM 489-1 control	26.58 b	199.4 d	721.15
CM 489-1/CM 489-1 self-graft	26.99 a	195.93 e	720.37
CM 489-1/M Col 1684 recipprocal graft	26.97 a	196.22 e	698.30
M Col 1684 control	23.30 d	212.4 b	705.5
M Col 1684/M Col 1684 self-graft	22.60 e	216.33 a	716.37
M Col 1684/CM489-1 reciprocal graft	24.50 c	208.19 c	707.23 ns

[1] All values are avg of 5 measurements between 92 and 134 DAP.

[2] DMRT, $P = 0.05$.

grafts with M Col 1684 as stock, a significant increase in aerial biomass compared to self-graft (data not shown) offered an alternative sink in the absence of large root no. On the other hand, leaf photosynthesis was enhanced in the graft of M Col 1684/CM 489-1, compared to self-grafting of M Col 1684 and M Col 1684 control, suggesting a possible effect of large root no. on leaf photosynthesis. In this case, the enhancement in CO_2 uptake was associated with lower internal CO_2 concentration, suggesting nonstomatal regulating mechanisms.

The hypothesis of a "feedback" effect of sink-capacity on photosynthesis appears to be confirmed partially. Final DMY was significantly correlated with avg leaf photosynthetic rate ($r=0.65$, $P<0.001$), with avg LAI ($r=0.75$, $P<0.001$) and with final no. of storage roots ($r=0.77$, $P<0.001$). On the other hand, no significant correlations were observed between RY and avg wt of individual storage roots or with DM content at final harvest.

5.3.5 Conclusions

Number of storage roots seems to be a good indicator of sink capacity. Yield was affected by sink capacity of the different root stocks. Root sink capacity affected biomass partitioning between top growth and roots. A feedback effect of no. of storage roots on photosynthesis was detected. To determine in greater detail the sink strength of cassava clones, sink capacity should be complemented with parameters describing sink activity.

5.4 Soil Fertility Maintenance and Erosion Research in Asia.

From October 22 to 27, the Third Asian Cassava Workshop was held in Malang, Indonesia, at which researchers from national programs presented results of the agronomy trials conducted from 1987-90. Most of this research was conducted in collaboration with, and with small financial contributions from, CIAT. An across-country overview of this research, highlighting the most important results, was also presented. Thus this report will be limited to the principal results obtained during 1990 in the area of soil fertility maintenance and erosion control in Asia.

5.4.1 Soil fertility maintenance

5.4.1.1 **Fertilizer response.** Short-term fertilizer trials conducted with cassava in many Asian countries have usually shown a marked response to N and an occasional response to K, but seldom a significant response to P. This is in sharp contrast to similar trials conducted in Latin America, where cassava often responds principally to P, especially in the low-fertility Oxisols, Ultisols and Inceptisols, where cassava is principally grown. In Asia, however, it is estimated that 55% of the cassava is grown on Ultisols, 18% on Inceptisols, 11% on Alfisols, 9% on Entisols and only 7% on Oxisols, Mollisols, Histosols and Vertisols combined. Although Ultisols have relatively low levels of OM, P, K, Ca and Mg, they are not nearly as infertile as many of the Oxisols and Inceptisols on which cassava is often grown in Latin America. For that reason, fertilizer responses in Asia tend to be less pronounced than those obtained in Latin America, and the responses tend to be limited to NPK, very seldom to the secondary or minor nutrients.

While short-term trials in Asia have usually shown a major response to N, several long-term fertility trials have invariably shown a major response to K. As cassava extracts large amounts of K in the root harvest, it is expected that continuous cassava cultivation on the same soil will eventually lead to K exhaustion and a significant response to K. To determine both the short-term fertilizer response and the long-term nutrient requirements for cassava, simple long-term fertilizer trials were initiated at 13 locations in 7 countries. Most of these trials had a standard design of 12 treatments, in which 4 levels of NPK were combined in an incomplete factorial design. The levels and sources of the nutrients varied among locations, depending on the native soil fertility and the type of fertilizers available.

Table 5.10 shows the soil characteristics and the relative response to the application of NPK at the various locations. As expected, the major first year response was to the application of N, while only in two locations in E. Java was there also a significant response to P or P and K. The soil analyses data in Table 5.10 indicate that at most locations soils are intermediately acid (pH 5-6) and relatively low in OM, P and K. But even at very low soil P and K levels, there was seldom a response to the applied nutrients. Only in the trial at Thai Nguyen in Vietnam, was it possible to observe (not yet harvested) a marked first-year response to K because of the very low level of exchangeable K in these soils. It is expected that after several years of continuous cropping in the same plots, cassava will start to respond mainly to the application of K.

Figure 5.33 shows the response to NPK in Guangzhou, China and in Tarokan, Kediri district of E. Java. In Guangzhou there was a significant response only to the application of N; while in Tarokan there was also a significant response to P. In both locations there was a very marked response to the application of NPK combined, which nearly doubled yields in Guangzhou and tripled yields in Tarokan. Figure 5.34 shows the response of a similar trial conducted in Jatikerto of Malang district in E. Java, in which cassava was intercropped with maize, as this is the standard practice in E. Java. Although in this case there was a significant response to all three nutrients, it is also clear that there was a marked negative response of cassava to the highest level of application. This is because the intercropped maize responded markedly to the highest level of application of N, thereby creating an increasing level of competition for light and water with cassava, which resulted in decreased cassava yields at the highest level of fertilizer application. These examples illustrate that fertilizer recommendations obtained in monoculture are not always correct when the crops are grown in intercropping systems.

5.4.1.2 **Effect of green manures.** A trial on the effect of green manures on cassava yield and soil fertility was initiated in Pluak Daeng, Thailand in 1988 and replanted in 1989. In 1989 the green manures were planted in the early rainy season (June) and cut after two months. The tops were left as a mulch on the soil surface and cassava was planted without further soil preparation.

Table 5.11 shows the dry weight and nutrient content of the green manures at time of cutting. <u>Canavalia ensiformis</u> and <u>Crotalaria juncea</u>--the two most productive legumes--absorbed the greatest amounts of N and K. They also resulted in the

Table 5.10 Soil characteristics and the first-year relative response of cassava to application of NPK fertilizers in various locations in Asia.

	Soil Characteristics					Relative Response(1) (%)		
	Texture(2)	pH	% OM	ppm P	meq/100g K	N	P	K
China								
Guangzhou, Guangdong	cl	5.6	1.2	3.9	.09	74*	95	93
Nanning, Guangxi	cl	5.0	2.4	15.7	.14	68*	91	98
Vietnam								
Thai Nguyen, Bac Thai(3)	scl	5.2	1.6	15.1	.08	-	-	-
Hung Loc, Dong Nai	c	5.0	2.1	5.0	.28	98	99	95
Philippines								
Bay Bay, Leyte	c	5.1	2.8	1.7	.15	90	100	73
Ubai, Bohol	l	5.7	1.8	9.1	.08	95	95	99
La Carlotta, Negros Occ.	c	5.4	1.7	2.5	.16	74*	94	95
Indonesia								
Jatikerto, Malang(3)	c	5.9	1.0	1.6	1.16	75*	79*	82*
Tarokan, Kediri	-	5.8	1.6	4.8	0.13	51**	80*	100
Umas Jaya, Lampung	scl	4.6	2.1	4.0	0.19	61*	87	94

* = significant at 5%; ** = highly significant at 1%.

(1) Relative response = cassava yield without nutrient applied divided by the highest yield when the nutrient is applied.

(2) c = clay, l = loam, cl = clay loam, scl = sandy clay loam.

(3) Soil analysis data from field near NPK trial; others in check plots of NPK trials.

highest cassava yields. Unlike the previous year, when incorporation of nearly all green manures increased cassava yields, the application of green manure mulch this year increased cassava yields only in the case of three species. C. juncea was among the most effective species in both years, increasing cassava yields even above those obtained with chemical fertilizers. Sesbania rostrata, which was the most effective species last year, had no significant effect this year.

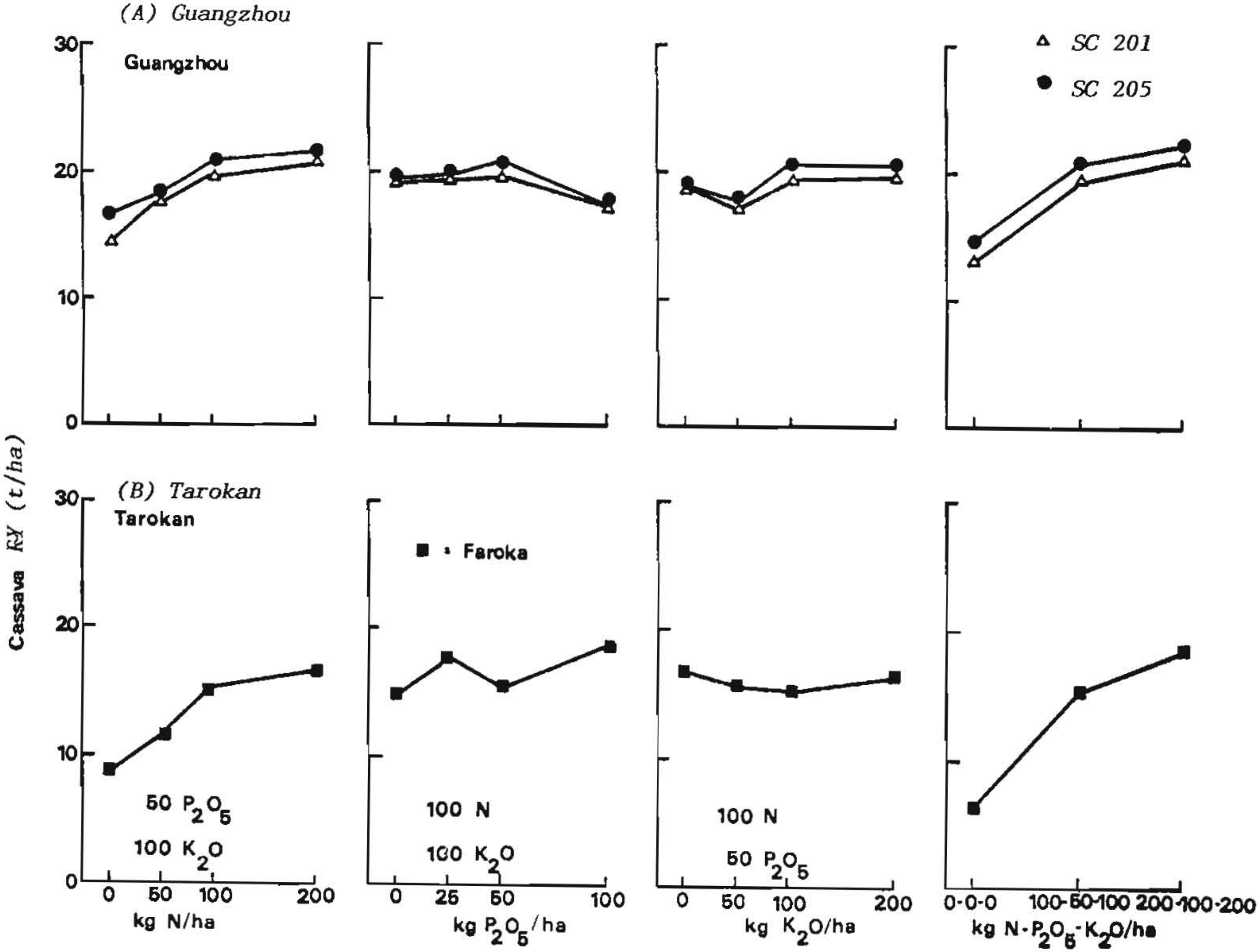


Figure 5.33 Response of cassava to NPK application in the first year of cropping in Guangzhou, China (A) and Tarokan, Indonesia (B) in 1988-89.

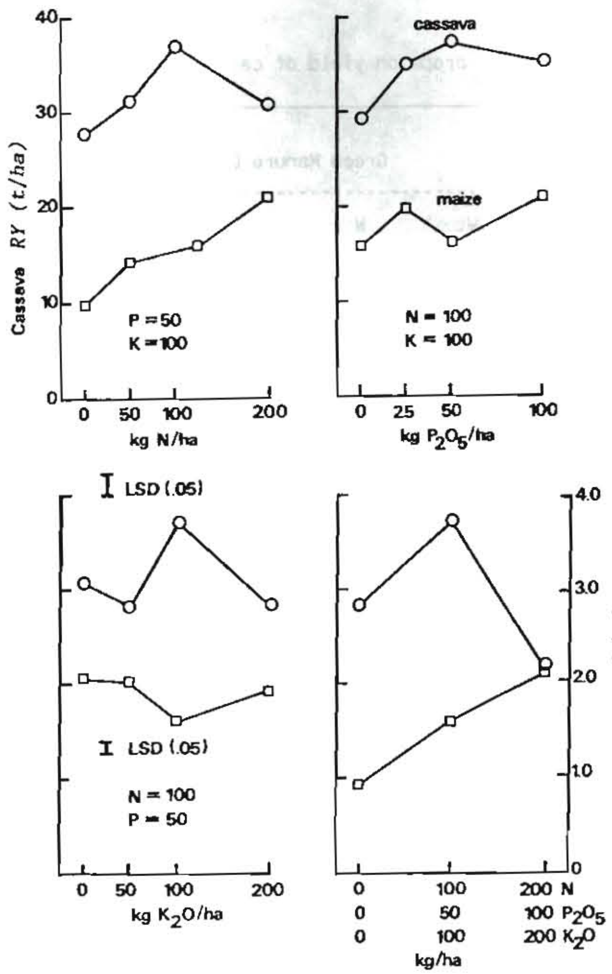


Figure 5.34 Response of intercropped cassava (Faroka) and maize to the application of various levels of NPK in the first year of cropping in Jatikerto, Malang, Indonesia in 1988-89.

It can be seen (Table 5.11) that cassava yields were low even when fertilizers were applied because cassava could only be planted in August (i.e., toward the end of the wet season) and had to be harvested at 9 mo, 5-6 mo of which were very dry. Thus the growing of a green manure crop before planting cassava may not be feasible in areas with only one relatively short wet season because much of the wet season will be used for growing the green manure and little is left for cassava. Green manuring may be a more attractive alternative in areas with a bimodal rainfall distribution or in those that have a longer wet season. In Thailand it may be useful only if cassava can be left in the ground for 15-18 mo and grown in a 2-yr cropping cycle.

Table 5.11 Effect of green manure crops on yield of cassava at Rayong, Thailand in 1989.

Treatment	Green Manure Crops(1) Dry Wt (t/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Cassava RY (t/ha)
No fertilizer	-	-	-	-	5.75 bcd
Sesbania speciosa	2.15 b	61.31 c	2.54 abc	40.38 b	4.46 cd
Sesbania rostrata	3.46 b	57.11 c	4.56 a	55.29 b	5.37 bcd
Sesbania aculeata	2.54 b	56.94 c	3.67 ab	40.96 b	4.42 cd
Indigo	3.21 b	101.73 bc	2.25 ab	41.06 b	5.08 bcd
Canavalia ensiformis	6.96 a	183.54 a	2.36 bc	93.58 a	7.00 abc
Mucuna fospeada	2.70 b	74.33 c	3.25 ab	39.77 b	6.08 abcd
Crotalaria mucronata 7790	2.86 b	65.81 c	0.67 c	37.14 b	5.17 bcd
Crotalaria spectabilis	2.98 b	153.83 ab	1.61 bc	51.36 b	3.96 d
Crotalaria juncea	6.88 a	209.08 a	3.38 ab	97.14 a	8.83 a
Pigeon pea (ICRISAT)	3.46 b	86.23 bc	1.81 bc	45.48 b	4.50 ab
Fertilizer (94-0-50 kg/ha)	-	-	-	-	7.71 ab
F-test	**	**	**	**	*

(1) Dry wt and nutrient content of green manure crops at time of cutting.

*,** - Means within a column, followed by the same letters are not significantly different at 5% and 1% levels, resp., DMRT.

5.4.1.3 **Effect of cover crops.** One alternative to green manuring is to grow a legume crop together with cassava, with the purpose of protecting the soil from erosion, controlling weeds and contributing N to the cassava crop.

Thus in 1988 and 1989 several legume species were grown as cover crops under cassava in Pluak Daeng, Thailand. In 1988 the cover crops were seeded in rows at the time of planting cassava. All cover crops competed with cassava, causing a reduction in cassava yields (1989 Annual Report). In 1989 each legume plot was split in two; in one half, 30-cm wide strips for planting cassava were prepared mechanically with a hand tractor, while in the other half the strips were prepared by spraying an herbicide (Gramoxone = paraquat) to kill the cover crops. Cassava was planted at 110 x 90 cm distance in the prepared strips. Table 5.12 shows the number of plants harvested and the cassava RYs obtained for both methods of plant bed preparation. The cover crops had no significant effect on cassava establishment, but significantly decreased cassava yields due to competition for

Table 5.12 Effect of cover crops on stand and yield of cassava at Pluak Daeng, Thailand in 1989.

Treatment	No. Plants at Harvest ('000/ha)		Cassava RY (t/ha)		
Land preparation (M)					
- Mechanical land preparation (A)	9.85 a		6.44 a		
- Herbicide spray (B)	9.59 b		5.46 b		
F-test	*		**		
	A	B	A	B	X
Cover crops (S):					
Monoculture cassava	10.10	10.10	7.79	7.19	7.49
Indigo	9.89	10.10	6.36	6.56	6.46
Centrosema pubescens	10.10	8.84	5.60	2.99	4.29
Centrosema acutifolium	9.68	9.26	6.69	3.41	5.05
Macroptillium atropurpureum	9.47	9.05	7.70	4.46	6.08
Mimosa envisa	9.89	10.10	6.48	8.04	7.26
Stylosanthes hamata	9.47	10.10	3.91	4.71	4.31
Stylosanthes guianensis	9.89	9.45	6.56	5.26	5.91
Arachis pintoi	10.10	9.68	6.56	6.06	6.31
Desmodium ovalifolium	9.89	9.26	6.78	5.85	6.31
F-test	NS		*		
LSD(0.05) for interaction (MxS)	-		2.13		

*,** - Means within a column, followed by the same letters are not significantly different at 5% and 1% levels, resp., DMRT.

light, water and nutrients. As the cover crops were cut at a 30-cm height at regular intervals to prevent excessive light competition, cassava yield reduction was less pronounced in the second year than in the first when the growth of cover crops was not controlled. Nevertheless, cassava yields were significantly reduced by the cover crops of Centrosema pubescense and C. acutifolium, as well as by siratro (Macroptillium atropurpureum) and Stylosanthes hamata when the strips were prepared by herbicide spraying (there was much less yield reduction when a hand tractor was used). Given its relatively slow establishment, S. hamata was the least competitive cover crop in the first year; however, in the second year it was among the most competitive cover crops, causing a significant reduction in cassava yield with both methods of plant bed preparation. Mimosa envisa, Arachis pintoi and Desmodium ovalifolium were among the less competitive cover crops. Soil analyses after every cassava harvest indicate that the cover crops had no significant effect on soil fertility and could not prevent a significant reduction of the level of OM, from 0.93% before planting the first cassava crop to 0.57% at harvest of the second. Thus, while cover crops may be effective in reducing erosion, they seem to contribute little to the maintenance of soil fertility and can cause severe competition for cassava, especially during periods of drought. For that reason, it is unlikely that farmers will find this a useful practice.

Table 5.13 shows the results of a similar trial conducted at the South China Academy of Tropical Crops (SCATC) on Hainan Island. Four rows of cassava were alternated with one row of pasture species, four grasses and four legumes, with the objective of establishing a pasture after the cassava harvest. Brachiaria dictyoneura and B. humidicola were the most competitive grasses; Setaria anceps, the least competitive. Among the legumes, Stylosanthes guianensis and S. hamata were less competitive than the two Desmodium spp., mainly because of their slower rate of establishment. Brachiaria decumbens was most productive in terms of DM production. The strip cropping of pasture species within a cassava stand seems to be a promising way of establishing pastures without seriously affecting cassava yields.

Table 5.13 Effect of intercropping cassava(1) with various pasture legumes and grasses on cassava RY and pasture production at SCATC, Hainan, China, 1989.

	Cassava RY (t/ha)	Pasture Yield (t DM/ha)
1. Cassava + Brachiaria decumbens	20.5	8.53
2. Cassava + Brachiaria dictyonuera	16.5	5.53
3. Cassava + Brachiaria humidicola	19.4	5.33
4. Cassava + Setaria anceps	21.5	3.47
5. Cassava + Stylosanthes guianensis	22.1	0.72
6. Cassava + Stylosanthes hamata	22.0	0.63
7. Cassava + Desmodium ovalifolium	20.9	3.33
8. Cassava + Desmodium gyroides	19.8	0.85

(1) 4 rows of cassava var. SC 205, alternated with 1 row of pasture spp.

5.4.1.4 **Effect of intercropping.** Intercropping cassava with grain legumes will establish a rapid soil cover and reduce erosion; and the crop residues of the intercrops, if left in the field, can contribute nutrients to cassava and help maintain soil fertility.

During 1988-89 a trial was conducted in Rayong, Thailand to determine the best spacing of peanuts, mung beans and soybeans intercropped between cassava rows. Cassava was planted at 180 x 55 cm at a population of 10,100 plants/ha. Table 5.14 shows that cassava RY was not significantly reduced by the mung bean intercrop, but was reduced by intercropping with 3 rows of peanuts or with 2-3 rows of soybeans. Cassava RY was always higher when the intercrops were planted at 60 rather than at 45 cm from the cassava row, but the intercrop yields were generally slightly higher at 45 cm. Although intercropping always increased the land equivalent ratio (LER), the various spacing treatments had no significant effect on the LER. Gross income was significantly increased only by intercropping with peanuts, while soybeans or mung beans had no positive effect on income.

Another intercropping trial was conducted in Hung Loc Centre, South Vietnam, where cassava was intercropped with seven grain legumes and maize. Table 5.15 shows that cassava RY was slightly increased by intercropping with soybeans and mung beans, which produced very low grain yields, but decreased by intercropping with winged beans, peanuts, cowpeas and maize. Net income was greatest for cassava monoculture or when intercropped with peanuts. All other crop combinations were less profitable.

5.4.2 <u>Soil erosion control</u>

Because of its slow rate of early growth, cassava normally takes several months for complete canopy closure. For that reason cassava cultivation can cause serious problems of soil erosion. However, once the crop is well established, the foliage is quite effective in protecting the soil from the direct impact of rain drops. To be effective in reducing soil erosion, cultural practices should therefore aim at rapid canopy closure, minimum disturbance of the soil, or provision of barriers to slow down water runoff. To determine the most effective soil and crop management practices that reduce erosion and increase cassava yields, simple erosion control trials were conducted at 10 locations in 5 countries. Different management practices were established on relatively large plots with a uniform slope; a contour channel was built below each plot to catch the eroded soil sediments, which were weighed at monthly intervals. In most locations the channels were lined with plastic sheets that had little holes to let the runoff water seep out; but at a few locations the channels were lined with a tightly woven

Table 5.14 Effects of spatial arrangement of intercropping cassava with peanuts, mung beans and soybeans on their yields in Rayong, Thailand (combined 2 years, 1988-89).

Cassava + Intercrops cm/row#(cm) (1)	Intercrop Yield (t/ha)	Cassava RY (t/ha)	LER	Gross Income (US$/ha)
Cassava 180 x 55	-	22.69 a	1.00 b	623 de
Peanuts 45 x 11.1	1.64 a			473
Cassava + peanuts				
180x55+45/2(5.5)	0.96 b	19.49 abc	1.48 a	800 abc
180x55+60/2(5.5)	0.84 b	20.77 abc	1.47 a	801 abc
180x55+45/3(8.3)	1.16 b	18.37 bc	1.55 a	829 ab
180x55+60/3(8.3)	1.01 b	22.04 ab	1.60 a	881 a
	**			
Mung beans 45+11.1	0.61 a			241
Cassava + mung beans				
180x55+45/2(5.5)	0.44 a	18.99 abc	1.60 a	704 bcde
180x55+60/2(5.5)	0.40 a	21.24 abc	1.70 a	771 abcd
180x55+45/3(8.3)	0.61 a	18.82 abc	1.87 a	765 abcd
180x55+60/3(8.3)	0.46 a	21.33 abc	1.77 a	764 abcd
	NS			
Soybeans 45 x 11.1	0.49 a			158
Cassava + soy beans				
180x55+45/2(5.5)	0.28 a	17.70 c	1.53 a	574 e
180x55+60/2(5.5)	0.30 a	19.79 abc	1.68 a	638 de
180x55+45/3(8.3)	0.26 a	17.66 c	1.50 a	584 e
180x55+60/3(8.3)	0.35 a	19.63 abc	1.80 a	660 cde
	NS			
F-test	-	*	**	**

*,** - Means within a column, followed by the same letters, are not significantly different at 5% and 1% levels, resp., DMRT.

(1) 45/2 and 45/3 refers to planting 2 or 3 rows of the intercrops at 45 cm from cassava row; 60/2 and 60/3 is same at 60 cm from cassava row; no. in parentheses is plant distance (cm) within the intercrop row.

plastic mesh or with bricks and cement to improve durability. In one location a special splitter system was installed to measure runoff water as well.

Minimum or zero tillage usually produced a low level of erosion (Table 5.16); at Pluak Daeng (Thailand) it also produced the highest cassava RY. However, in many other locations such as on Hainan Island (Table 5.17), RY decreased as a result of soil compaction or inadequate weed

Table 5.15 Economic evaluation of intercropping cassava with grain legumes and maize at Hung Loc Centre, South Vietnam, 1989-90.

Treatments	Yield (t/ha) Cassava	Yield (t/ha) Intercrops	Cost	Gross Income	Net Income
			(US$/ha)		
1. Cassava + winged bean	17.97	0.58	345.9	346.8	0.9
2. Cassava + peanuts	22.57	0.86	363.9	496.9	133.0
3. Cassava + soybeans	25.92	0.00	313.4	388.8	75.4
4. Cassava + lab-lab	21.98	0.00	313.4	329.7	16.3
5. Cassava + mung beans	23.34	0.27	378.5	440.1	61.6
6. Cassava + Canavalia	21.17	0.00	313.4	317.5	4.1
7. Cassava + cowpeas	21.02	0.31	378.5	413.5	35.0
8. Cassava + maize	20.02	2.23	345.9	430.4	84.5
9. Cassava monoculture	21.95	0.00	190.5	329.2	138.7

Table 5.16 Effect of soil and crop management on cassava RY and losses due to erosion in Pluak Daeng, Thailand, 1989.

	Root Yield (t/ha)
3 disc plow + 7 disc harrow; no ridging	10.8
3 disc + 7 disc; contour ridging	12.4
3 disc + 7 disc; up-and-down ridging	12.7
cassava harvester	11.8
No tillage	14.3
3 disc + 7 disc; no fertilizers	11.2
3 disc + 7 disc; closer spacing (0.8x0.8m)	11.3
3 disc + 7 disc; cassava (1x1m) + peanut intercrop	9.5
LSD (0.05)	3.18

control. The localized preparation of planting holes with a hoe (Table 5.17) further reduced erosion and gave better RY. Contour-prepared strips alternated with unprepared strips, was not effective in reducing erosion in either Thailand or Hainan (Table 5.17); it also resulted in low yields.

Normal plowing followed by harrowing always resulted in high soil losses in Thailand, Indonesia, China and the

Table 5.17 Effect of method of land preparation on dry soil losses due to erosion and on fresh RY of cassava (1) planted on 25% slope at SCATC, Hainan, China, 1989.

	Soil Loss (t/ha)	Cassava RY (t/ha)
1. complete preparation:2 plowing, 2 discing, contour ridging	71	26.3
2. 2 plowing, 2 discing, no ridging	141	26.0
3. 1 plowing, no ridging	91	21.3
4. 4 m wide plowed strip alternated with 1 m strip without prep.	145	23.5
5. 2 m wide plowed strip alternated with 0.5 m strip without prep	82	22.6
6. preparation of planting hole with hoe	38	25.5
7. no preparation	60	22.6

* cultivar SC 205

Philippines unless this practice was followed by contour ridging. Contour ridging was consistently effective in reducing erosion and usually resulted in high yields (Figs. 5.35 & 5.36; Table 5.17).

Planting intercrops or live barriers of grasses, legumes or hedgerow trees generally reduced erosion, but tended to reduce cassava RY because land was occupied by the barrier species or there was direct competition for light, water and nutrients. In Thailand (Table 5.16) intercropping with peanuts reduced erosion but also seriously reduced cassava RY. In Lampung Province of Indonesia, intercropping cassava with maize, rice or peanuts also reduced erosion (Fig. 5.37) but seriously reduced cassava yields (Table 5.18). Gross income was highest when cassava was first intercropped with peanuts, followed by mung beans.

In E. Java it was found that live barriers of elephant grass (Pennisetum purpureum) or setaria grass (Setaria anceps) were more effective in reducing erosion than those of peanuts or hedgerows of Leucaena or Gliricidia (Fig. 5.38). Elephant grass, when regularly cut, is a highly promising live barrier. On Hainan Island of China, a live barrier of Brachiaria decumbens was generally more effective in reducing erosion than one of Stylosanthes guianensis.

Application of dry grass as a mulch was found to be highly effective in the Philippines, reducing erosion and increasing cassava RY, probably through the release of some nutrients. Althouth application of chemical fertilizers reduced erosion consistently in various trials in China, the

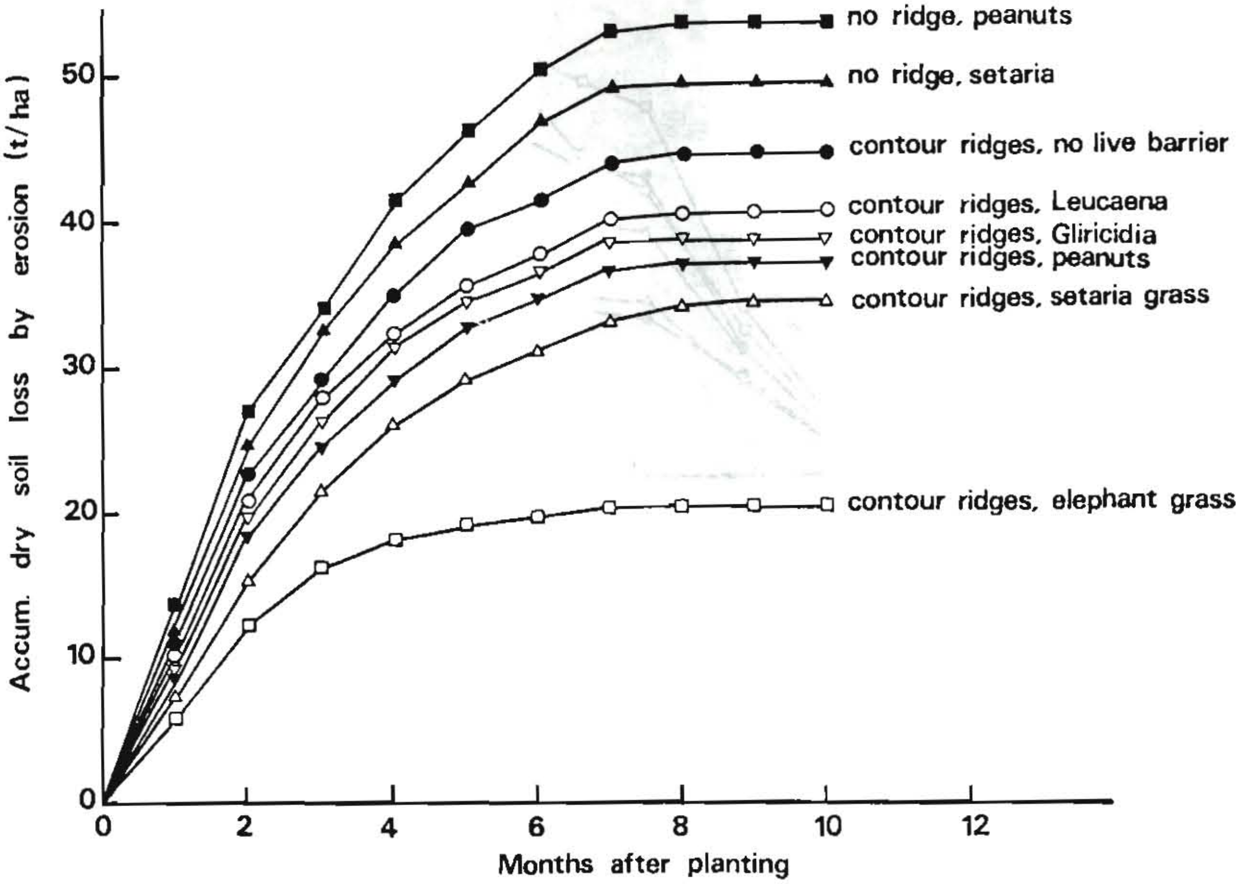


Figure 5.35 Effect of various agronomic practices on accumulated dry soil loss due to erosion in a farmer's cassava field with 8% slope in Sri Racha, Thailand in 1988-89.

Philippines and Thailand (Figs. 5.35 & 5.36; Table 5.16), it increased erosion at some locations in China, probably due to the loosening of soil during application; moreover, the fertilizers had no significant effect on growth and yield. It is mainly on very poor soils that fertilizer application will increase yields and reduce erosion through a more rapid canopy closure. The latter can also be achieved by closer plant spacing, which was very effective in Thailand in reducing erosion and increasing yield (Table 5.16). A spacing of 80 x 80 cm could be recommended. In Lampung, Indonesia, square planting (100 x 100 cm) reduced erosion markedly when compared with single (200 x 50 cm) or double (273 x 60 x 60 cm) row planting even when these rows were grown along the contour (Fig. 5.37; Table 5.18).

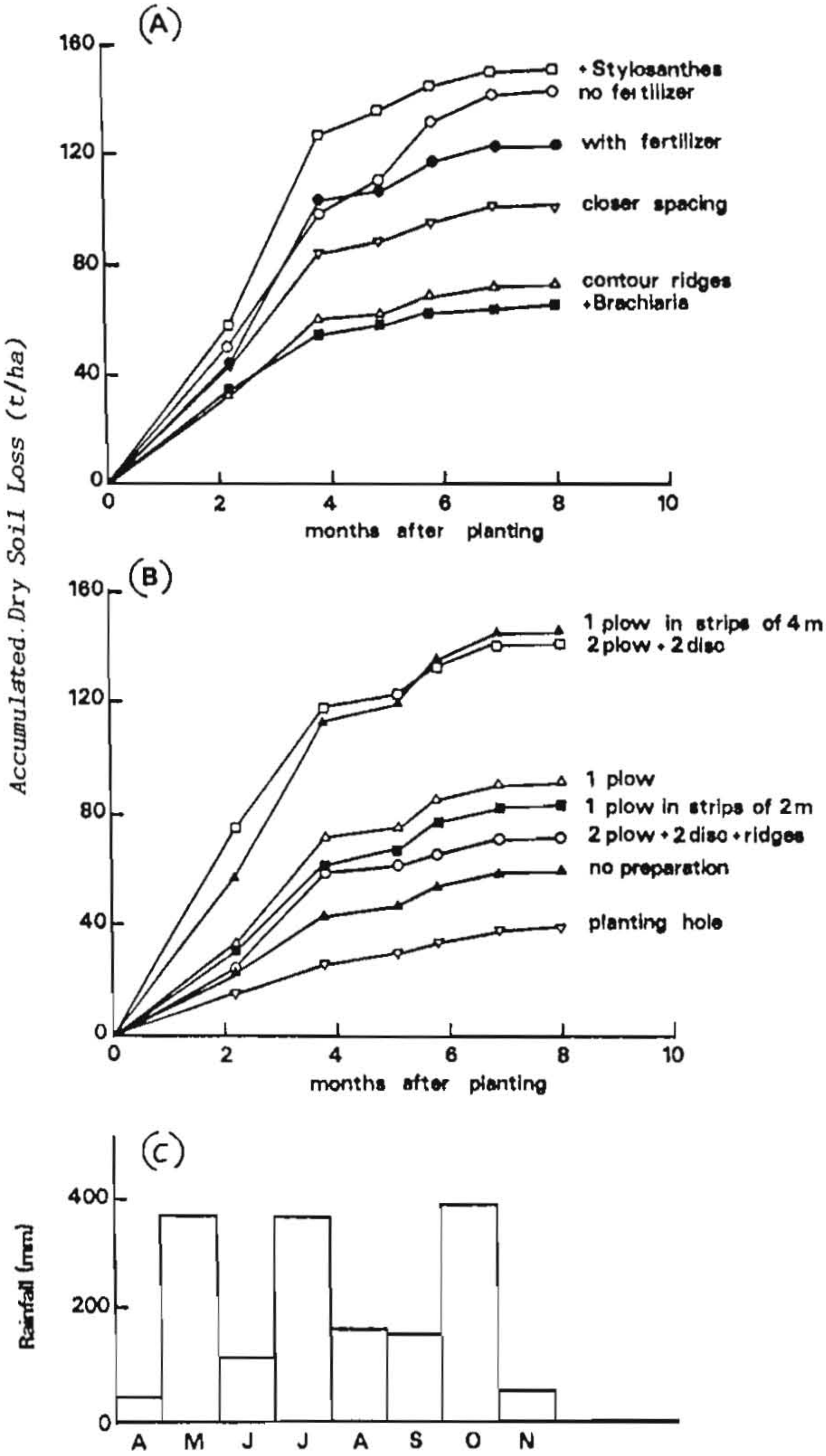


Figure 5.36 Effect of various cultural practices on accumulated soil loss due to erosion in cassava planted at SCATC, Hainan, China, 1989.

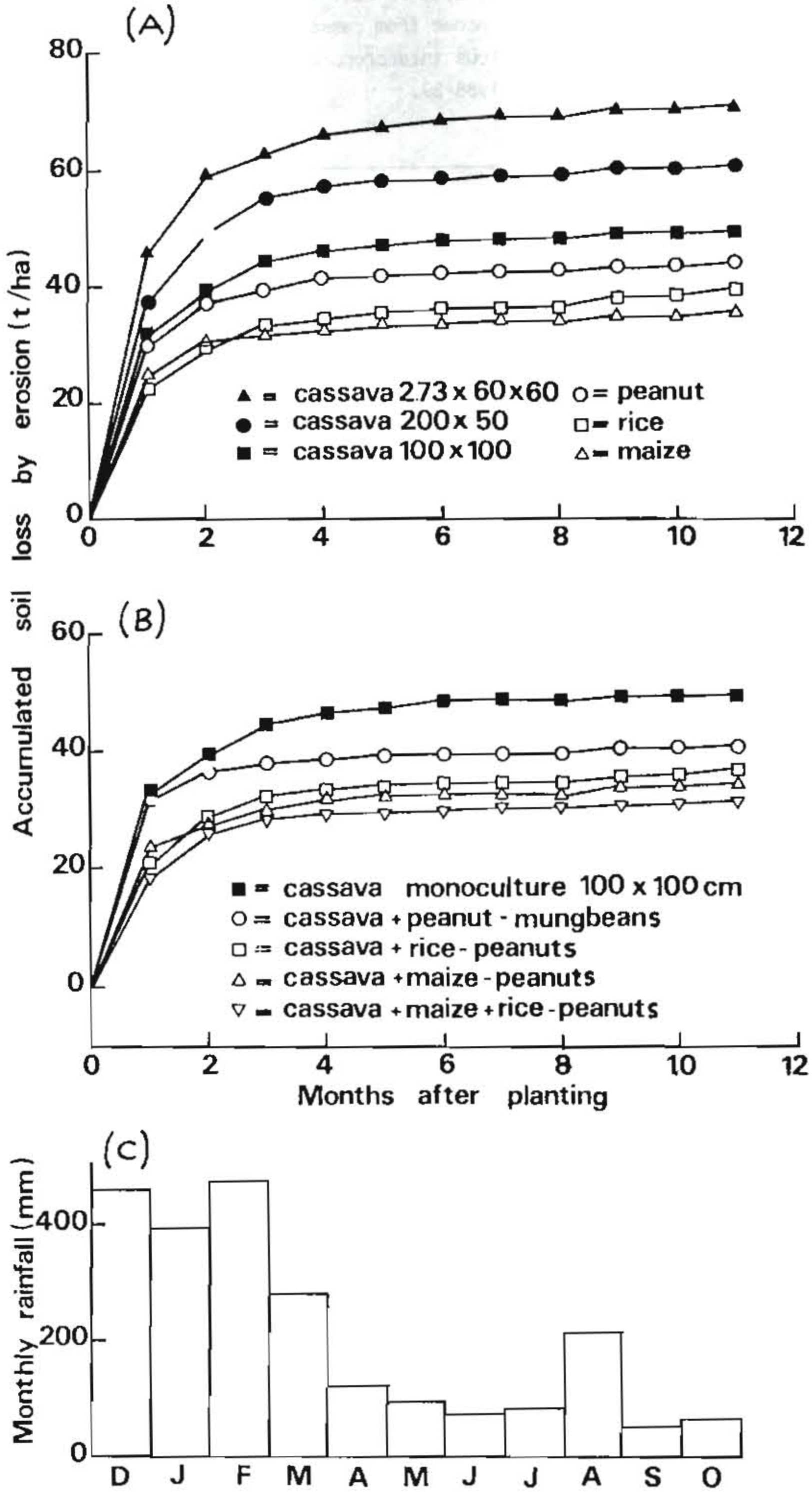


Figure 5.37 Accumulated dry soil loss by erosion in various monocrop (A) and intercropping (B) systems during an 11-mo cropping cycle in Tamanbogo, Lampung, Indonesia in 1988-89; rainfall distribution is shown in (C).

Table 5.18 Effect of planting arrangement on soil losses by erosion as well as on the yield and gross income from cassava, rice, maize, peanuts and mung beans grown in various intercropping systems in Tamanbogo, Lampung, Indonesia, in 1988-89.

Cropping System	Cassava Spacing (cm)	Yield (t/ha) Cassava	Rice	Maize	Peanuts	Mung Beans	Gross Income(1) ('000Rp/ha)	Dry Soil Loss (t/ha)
A-1 C+M+R-P	100x100	21.73	1.79	0.83	0.232	-	1596.3	31.52
-2 C+M-P	"	30.91	-	2.18	0.226	-	1766.8	34.22
-3 C+R-P	"	31.95	1.94	-	0.177	-	1864.1	36.30
-4 C+P-Mu	"	32.53	-	-	0.809*	0.078	2091.7	40.86
B-5 C+M+R-P	200x50	21.41	2.21	0.49	0.247	-	1638.4	41.25
-6 C+M-P	"	23.54	-	1.97	0.349	-	1551.2	41.88
-7 C+R-P	"	28.30	2.59	-	0.232	-	1910.6	32.81
-9 C+P-Mu	"	31.73	-	-	0.816*	0.065	2003.6	41.97
C-9 C+M+R-P	273x60x60	22.44	2.04	1.11	0.173	-	1668.6	40.55
-10 C+M-P	"	22.79	-	2.21	0.349	-	1557.2	34.07
-11 C+R-P	"	29.90	1.88	-	0.325	-	1902.1	33.27
-12 C+P-Mu	"	36.08	-	-	0.553*	0.095	2016.9	38.40
D-13 R-C	100x100	18.83	3.63	-	-	-	1551.8	39.28
-14 M-C	"	22.31	-	1.77	-	-	1157.9	35.34
-15 P-C	"	16.89	-	-	1.055*	-	1625.1	44.56
E-16 C monocult	100x100	43.57	-	-	-	-	1742.8	49.58
-17 C "	200x50	42.54	-	-	-	-	1701.6	60.66
-18 C "	273x60x60	44.05	-	-	-	-	1762.0	70.95

(1) Crop prices: Cassava (C) Rp 40/kg fresh roots
Rice (R) 220/kg paddy
Maize (M) 150/kg dry grain
Peanuts (P) 900/kg dry pods
Mung Beans (Mu)800/kg dry grain
Avg exchange rate for 1988-89, US$ = Rp1800

* First intercrop of peanuts, others second intercrop.

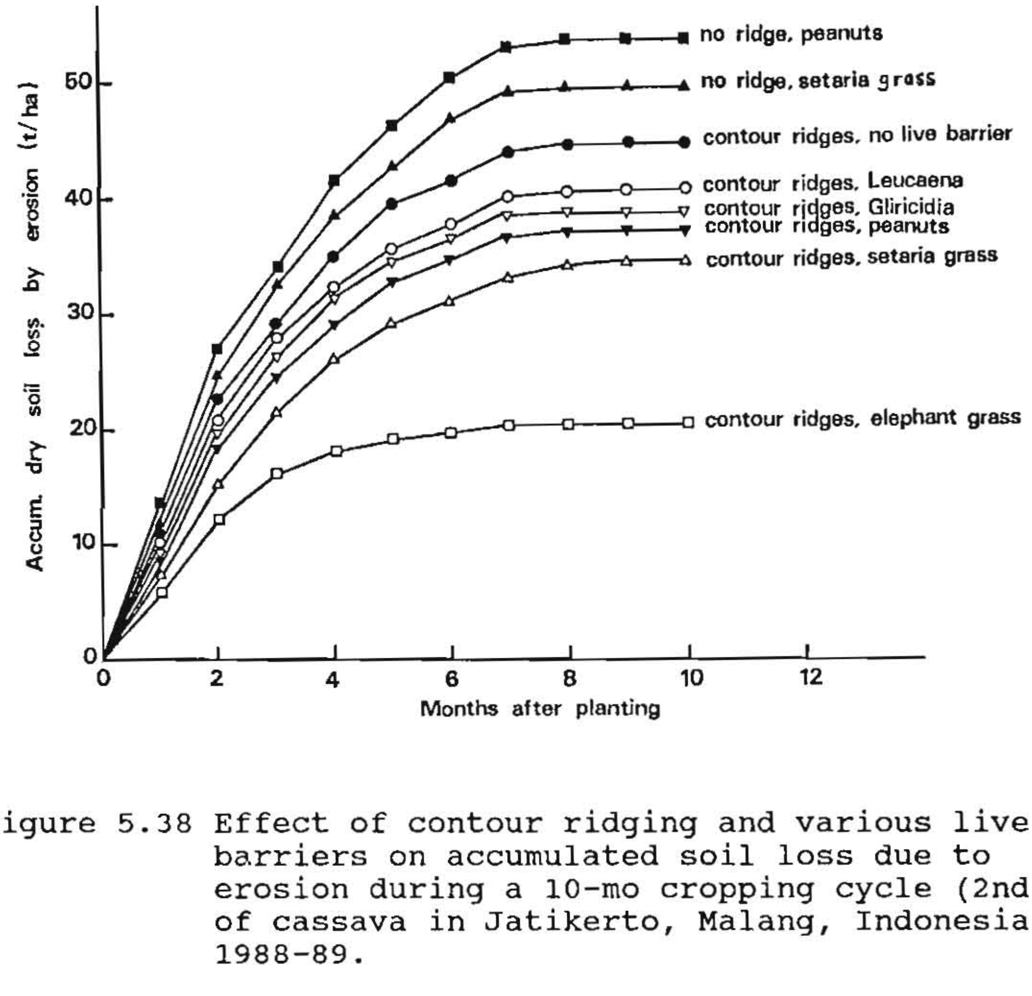


Figure 5.38 Effect of contour ridging and various live barriers on accumulated soil loss due to erosion during a 10-mo cropping cycle (2nd yr) of cassava in Jatikerto, Malang, Indonesia in 1988-89.

From these experiments it may be concluded that soil erosion can be greatly reduced by (a) simple agronomic practices that result in a rapid canopy closure, such as fertilizer application, closer spacing and square planting arrangements; (b) establishing a soil cover such as application of mulch, intercropping, and minimum tillage with crop residues left on the soil surface; or (c) by barriers that slow down the runoff water, such as contour ridges or banks, live barriers of closely spaced tillering grasses and even rock barriers along the contour. Fertilizer application, mulching and closer spacing will often also increase cassava RY, which make these practices most attractive to farmers.

5.5. Cassava Intercropping Systems

During 1990 the Agronomy Section of the Cassava Program conducted outreach activities, mostly OFR in several countries of Latin America. Support research, mostly in intercrop systems with cassava, was conducted both at HQ and on the North Coast of Colombia, the results of which are presented here.

5.5.1 Performance of the cassava/maize intercrop across different environments on the North Coast of Colombia

In most countries where maize and cassava are intercropped, the number of new maize varieties released by national institutions is larger than the number of new cassava varieties. Improvements in the coverage of extension services and the efforts of private seed companies are also contributing to better availability of new maize varieties to farmers.

Adoption of improved varieties depends mainly on their availability on the local market and on the farmers' economic conditions. Most of the recently released maize varieties have been developed for intensive production in monoculture, with improved HI as the main breeding objective; however, small farmers cultivate maize using traditional management practices, treating improved varieties exactly like traditional ones: intercropped with other species, planted at similar densities and stored in the same facilities. Such production practices modernize slowly as the new varieties become more and more familiar to farmers.

The inclusion of new maize varieties in the cassava/maize intercrop represents a technological innovation with several management implications. National research and extension teams of Colombia, Ecuador, Paraguay, Ecuador and, more recently, Brazil are conducting OFR to adapt this new technology better to their specific production conditions.

Several diagnostic studies conducted by CIAT and ICA on the North Coast of Colombia since 1985 indicate that farmers intercrop cassava mainly with traditional maize varieties. The low market availability of seed was given as the main reason for not using new maize varieties more frequently. At the time, two new varieties (V-156 and V-109) were released on the North Coast, based on their performance as a monocrop in farmers' fields. It was expected that as more seed became available, new maize varieties would replace the traditional ones in the intercrop with cassava. Similar situations were developing in other countries where the cassava/maize intercrop is commonly cultivated.

Since 1985 a series of studies of the agronomic implications of new maize varieties for the maize/cassava intercrop have been conducted jointly by CIAT and ICA-Regional II. This ICA unit is responsible for the Colombian North Coast states of Córdoba, Bolívar, Sucre and Atlántico. Several diagnostic studies were conducted, and different experimental procedures were tested in the field. Training in field evaluation methods and data analysis was provided to improve the ability of the national team to conduct OFR on intercrop systems. Similarly linked research and training efforts have been pursued with national institutions of other countries. The following summary of findings is based on 4 years' research.

Venezolana, the most commonly grown cassava variety on the North Coast, was used in all on-farm trials. Three to five new maize varieties were tested during the experimental phase reported here; however, ICA var. V-156 and V-109 and the local maize variety were always included. Maize and cassava were intercropped in alternate rows at 1.2 x 1.2 m in a split-plot design with **cropping system** (maize and cassava in monoculture and the maize/cassava intercrop) as the main plot and **maize variety** as the subplot. Selection of planting material, protective stake treatment, application of preemergence herbicide and planting were done jointly by researchers and farmers; however, crop management was the responsibility of each farmer.

Statistical analyses were based on 479 plots grown on 19 farms with at least two reps per farm. Half the plots were planted to maize or to maize associated with cassava, and the other half to cassava as a sole crop or associated with maize. Cassava was intercropped with improved maize varieties on 189 plots and with the traditional maize variety on 51 plots.

Intercropping with improved maize varieties increased cassava yield by ca. 1.0 t/ha over the association with traditional varieties (Table 5.19). Cassava yield reduction, when intercropped with either traditional or improved maize varieties, was small (2-3 t/ha) compared to the cassava monocrop, and was compensated by the additional yield from the maize component (Table 5.20). This may explain why North Coast farmers rarely plant cassava in monoculture. The avg yield of 13 t/ha for cassava as a sole crop was very close to the avg yield for the area, as reported in surveys conducted by ICA and CIAT; but lower than expected given the consistent use of stake selection and treatment, and preemergence herbicides.

Significant differences in yields of all cropping systems were found between years ($P \leq 0.05$), which is a characteristic of rainfed, small-scale agricultural systems and is an

Table 5.19 Avg yields of cassava as sole crop and intercropped with improved and traditional maize varieties on the North Coast of Colombia, 1985-88.

Cropping Systems	Yield (t/ha)	No. of Plots
Cassava sole crop	13.15 a [1]	239
Cassava + improved maize	11.07 b	189
Cassava + traditional maize	10.07 c	51

[1] Means followed by different letters are significantly different ($P \leq 0.05$, DMRT).

Table 5.20 Yields of improved and traditional maize varieties in sole crop and intercropped with cassava var. Venezolana; avg. of four years (1985-88) of on-farm trials.

Cropping Systems	Yield (t/ha)	No. of Plots
Improved variety as sole crop	2.57 a [1]	189
Improved variety + cassava	2.40 a	189
Traditional variety + cassava	2.01 b	51
Traditional variety as sole crop	1.93 b	50

[1] Means followed by different letters are statistically different ($P \leq 0.05$, DMRT).

important factor in farmers' decisions to plant intercrops rather than sole crops as part of their risk-aversion strategy.

Significant differences in all cropping systems ($P \leq 0.05$) were found among farms. This variability is related to physicobiological characteristics of the farm itself, as well as to differences in management. In addition to the variability in rainfall distribution from year to year--which is probably the main cause of differences in yields between years--the environment changes continuously as the farmer rotates from one plot to another within the farm. A progressive decrease in soil fertility from one cropping season to the next occurs if a crop is cultivated on the same piece of land. Variations in management were expected even though several activities including planting were standardized through the participation of the researcher; and several cultural practices were common among the farmers included in the study.

No differences in yield were found among cropping systems for improved or traditional maize varieties; however, improved varieties were always superior in yield to traditional ones (Table 5.20). Yield of improved maize was calculated as the average of at least three varieties and was compared with only one traditional variety. The traditional variety is similar in origin and general agronomic performance throughout the North Coast although some variation in performance between farms occurred, as is characteristic of landraces. This variability was not studied.

Comparing yields of cassava and maize in monoculture and in association, the LERs were 1.77 with traditional varieties and 1.72 with improved maize. These high LER values, in an area where access to land is very limited, clearly explain the farmers' preference for intercropping.

Although both interactions were significant, the level of significance of the interaction between year and cropping system was greater than for the interaction between farmer and cropping system. This could be interpreted as an indication that variations in environmental conditions (e.g., rainfall distribution) affect yields of maize and cassava in all cropping systems tested, more than the variability between farms as production units (e.g., soil fertility, water holding capacity, crop management).

When cassava's reaction to intercropping with improved and traditional maize varieties is evaluated without including the cassava monocrop as a check, cassava yields when intercropped with traditional or improved maize varieties are not statistically different. As the improved maize var. V-109 was included in the field experiments from 1986 onward, comparisons between the yields of cassava intercropped with traditional and improved maize varieties were based on data from 1986-88 (Table 5.21).

A one t/ha difference between the yields of cassava intercropped with traditional and with improved varieties of maize would not be detected by an analysis with a 26% coefficient of variance; however, for intercropped maize varieties, the sensitivity of the analysis was 0.38 t/ha.

Neither traditional nor improved maize varieties suffered significant yield reductions as a consequence of intercropping with cassava. These data for maize corroborate

Table 5.21 Yields of cassava var. Venezolana and maize varieties in intercrop; avg of on-farm trials from 1986-88.

Crop Association	Cassava	Maize	No. Plots
Cassava + maize V - 156	10.9 a [1]	2.49 a	44
Cassava + maize V - 109	10.9 a	2.35 a	44
Cassava + traditional maize	9.9 a	1.97 b	44

[1] Means followed by different letters are statistically different ($P \leq 0.05$, DMRT).

earlier results from other sites in Colombia, but are quite different from what is generally reported in the literature. Based on analyses of three consecutive cropping seasons, the main effects of year and farm on yield of the cassava/maize association were highly significant. The interactions of year x farm, and among year x farm x cropping system were also highly significant, suggesting that the cassava/maize association will perform similarly regardless of the maize variety planted; but it will vary as a whole depending upon the environmental conditions prevailing in a given cropping season, the specific conditions of the farm or locality and/or farmers' management.

Differences due to year and farm were the main sources of variability for the improved maize (V-156, V-109)/cassava (var. Venezolana) intercrop (bivariate analysis; $P \leq 0.01$). Cassava/maize V-156 was the best combination in terms of yield across the localities tested (DMRT, $P \leq 0.05$). No interaction was found for year and cropping system, indicating that the same results should be expected over time despite yearly variation in factors such as weather.

Given the yield increases that can be attained with improved maize varieties with no negative consequences for cassava production, adoption of improved maize varieties would be expected to proceed more rapidly if there were an increase in the relative price of maize. A survey of 360 farms on the North Coast showed that 37% of the farmers were already planting new maize varieties. In Córdoba, where maize monocropping is more common than in the other North Coast states, the proportion of farmers' planting improved varieties was even higher.

The stability of different cropping systems across different environments was tested, and the sensitivity of cropping systems to various environments was estimated. For purposes of this analysis, environments refer to a series of farms with characteristic physical, biological and management properties. The environmental favorability of farms was based on relative comparisons within the range of farms selected as experimental sites. At present, the available regional information on the spatial variability in physico-biological characteristics is inadequate; therefore, the analyses of environmental sensitivity provided in this report should be considered as preliminary.

As a sole crop, cassava is less sensitive (Fig. 5.39a) to different environments than any of the maize varieties tested (Fig. 5.39b). Cassava yield estimates varied between 10 and 14 t/ha across the environments tested. From this analysis cassava would be expected to yield over 10 t/ha even in the least favorable environment although it does not respond very positively to more favorable environments.

The reaction of maize to different environments is very unlike that of cassava. The improved and traditional varieties respond positively to better environments but do not perform very well in the less favorable ones. Contrary to what was expected, the traditional maize variety did not perform better than the improved varieties in the less favorable environments; but as expected, its performance in the most favorable environments was inferior to that of improved varieties (Fig. 5.39b). V-109 is claimed to be more drought resistant than V-156. This observation is consistent with the superior yields obtained with V-109 in less favorable environments; however, the performance of V-156 was superior in more favorable environments.

The general performance of maize as sole crop and in association with cassava is similar in terms of environmental sensitivity. The behavior of each variety under intercropping can be predicted from its behavior in monoculture; however, the expected yields in intercrops are lower than in sole crop (Figs. 5.39a & c).

From the standpoint of cassava, association with maize increases its sensitivity to different environments as the cassava/maize performance is inferior to that of cassava as sole crop in less favorable environments and much better than cassava monoculture in more favorable environments.

5.5.2 <u>Effect of fertilization on the cassava/maize intercrop</u>

Deciding upon fertilizer recommendations for intercrops is difficult because the components generally differ in their requirements for nutrients and in the manner and timing of

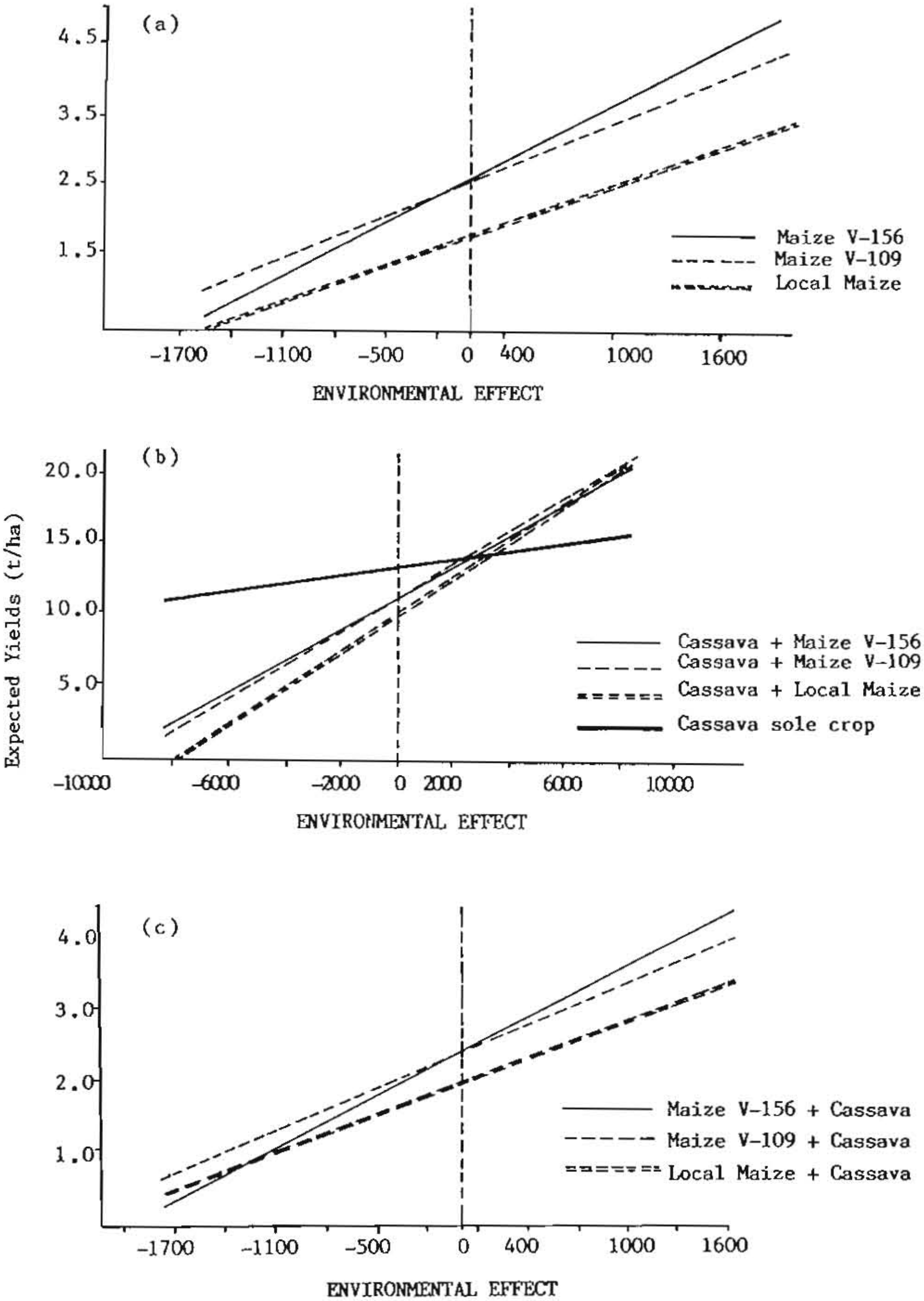


Figure 5.39 Sensitivity analysis for (a) cassava sole crop and intercropped with a regional and two improved maize varieties; (b) three maize varieties as sole crop; and (c) three maize varieties intercropped with cassava. Environments to the left and right sides of the perpendicular divisory lines are less and more favorable, resp. (analysis of incomplete data from experiments on the North Coast of Colombia, 1985-88.)

application. Furthermore, the relative ability of a given species to take up a specific nutrient while competing with the root systems of other species is not well understood. When cassava is intercropped with maize, the latter will probably respond positively to increases in N applications up to a level that depends on variety and soil type. Cassava, on the other hand, will increase its HI at N levels that are still adequate for increased maize yield. Similar relationships occur with other nutrients and other crop combinations. In practice, farmers will decide whether to fertilize a given intercrop based mainly on the probable return on investment in fertilizers by either or both crops.

Improved maize varieties have outperformed traditional varieties in association with cassava at several experimental sites, without negatively affecting cassava yields. New maize varieties perform even better in an intercrop with cassava if small amounts of fertilizers are applied.

If the tendency to replace traditional with improved maize varieties continues, farmers will eventually be faced with the decision of whether to fertilize the maize planted in association with cassava in order to benefit fully from the use of improved maize varieties, which allocate more photosynthates to the grain than traditional varieties. Consequently, soil nutrient depletion will proceed at a faster rate as new varieties replace the traditional landraces. In most regions where the cassava/maize association is found, production systems rely on fallow periods for the restoration of soil fertility. As improved maize replaces traditional varieties, the duration of the fallow phase will have to be increased, or fertilization of the new maize varieties will be required if soil fertility is to be maintained. Possible benefits of fertilization to the cassava/maize intercrop include higher maize yields in the short term and greater sustainability of production in the long run.

Few recommendations for fertilization of the cassava/maize association are available in the literature; however, positive responses to small amounts of fertilizers were obtained with new maize varieties intercropped with cassava in preliminary experiments at a few sites on the Colombian North Coast. Direct application of fertilizer (in bands) to maize, approx. 10 days postemergence, rather than to the two crops simultaneously at planting gave the best results in small-scale trials. As the improved maize varieties were developed for cultivation in monoculture but performed better than traditional ones in association, the existing technical recommendations for fertilizing maize as sole crop could presumably be used for intercropped maize.

On-farm trials were planted in order to verify these preliminary results and test the performance of intercropped maize when fertilized according to the recommendations for maize as a monocrop. Based on soil analyses, three farms were selected with high, medium and low soil fertility levels (Table 5.22). Farms were chosen from a single state in order to minimize differences in rainfall, planting dates and management practices. A completely random block design of three blocks and four fertilizer levels (low, medium, high and no fertilizer; see Table 5.23) was used (3 reps within each farm). Except for the fertilizer treatments, management decisions were taken by the farmer.

The effects of fertilizer treatment (Table 5.24) and farm fertility level on yield were highly significant, and the interaction between these factors was also highly significant. The low level of fertilization resulted in an increase in maize yields of ca. 1.0 t/ha. Yields obtained with the medium and high fertilization rates were not statistically different.

Cassava plant height was significantly higher at high levels of fertilization; however, the total weight of the aerial part was not significantly affected by the fertilization treatments. Yield of marketable cassava roots was not affected by the level of fertilization applied to the maize. Cassava HI was not affected by the fertilization treatments; however, there was a significant interaction between localities and fertilization level for this variable.

Given that cassava yield was not affected by fertilization level, a cost/benefit analysis of fertilization was made based on maize yields only (Table 5.25). The low application rate resulted in the largest marginal net return (5.68) per unit of money invested in fertilization (cost of the fertilizers plus cost of the labor used). The maximum marginal benefit, however, was realized with the medium level of fertilization.

Yields of maize intercropped with cassava were increased significantly using relatively low levels of fertilization. The results demonstrate that the fertilization recommendations for maize in monoculture are appropriate for intercropped maize. The application of fertilizer in bands, directly to the maize rows of the intercrop, 10 days post-emergence, appears to be an effective practice.

The statistical significance of the interaction between localities and levels of fertilization suggests that better characterization of agricultural environments (soils in this case) can improve the relevance of technical recommendations for specific cassava-producing regions.

Table 5.22 Soil characteristics of three farms on the North Coast of Colombia with low, medium and high fertility conditions.

Locality According to Soil Fertility	% OM	P ppm (BrayII)	K meq/100 g
Low	1.2	4.1	0.21
Medium	3.4	4.0	0.47
High	4.6	3.1	0.57

Table 5.23 Rates of NPK applied to maize intercropped with cassava at three localities on the North Coast of Colombia.

Low-Fertility Locality	N	P2O5	K2O
Low rate	50	50	15
Medium rate	75	75	25
High rate	100	100	35
Medium-Fertility Locality			
Low rate	25	50	0
Medium rate	50	75	15
High rate	75	100	25
High-Fertility Locality			
Low rate	0	50	0
Medium rate	25	75	15
High rate	50	100	25

Table 5.24 Effect of fertilization on maize yields.

Fertilization Level	Maize Yields (t/ha)
Low	3.03 b[1]
Medium	3.68 a
High	3.65 a
No fertilization (check)	1.89 c

1 Means followed by the same letter are not statistically different ($P. \leq 0.05$, DMRT).

Table 5.25 Total cost (x 100) of fertilizer application, maize yields (t/ha), total value of production/ ha (x 1000), marginal net benefit (x 100) due to fertilizer applied and marginal net return per unit of money invested in fertilizers applied at different rates on the North Coast of Colombia.

Fertilization Level	Total Cost	Maize Yield	Total Value	Marg.Net Benefit	Marg.Net Return
Low	23.5 [1]	3.03	354.0	330.5	5.68
Medium	37.9	3.68	429.3	391.4	5.50
High	51.5	3.65	426.1	374.5	3.98
No Fert.	0	1.89	220.4	220.4	0

1 The cost/kg of the fertilizers applied (in Colombian pesos) were: urea = $93.8; triple phosphate = $130.4 and potassium chloride = $89.8. The price of one kg of maize was $116.5 (US$1 = 463.42 Col. 15 Mar. 1990).

5.5.3 Biomass partitioning and nutrient uptake by the cassava/maize intercrop

The replacement of traditional maize varieties will accelerate the depletion of nutrients from soils in areas where the maize/cassava association is commonly cultivated. Improved varieties allocate more photosynthates to the grain than traditional ones; therefore, more nutrients will be exported from production units as grains. Consequently, the recirculation of nutrients within farms will be modified.

To gain more knowledge about biomass partitioning in traditional and improved maize varieties intercropped with cassava, nutrient uptake and recirculation were studied at at Palmira. Maize clone H-211 and ICA var. V-258 were used as improved varieties and the regional materials, Limeño and Clavo represented traditional varieties. These varieties were planted in association with the cassava clone CMC 40 at a density of 20,000 pl/ha. As a sole crop, maize was planted at 20 and 50,000 pl/ha, the densities used in crop association (AD) and the commercial density (CD), resp. Cassava was also planted as sole crop at densities of 8300 and 10,000 pl/ha. The first planting density was also used in the intercrop (AD) with maize, and 10,000 pl/ha is the recommended planting density (CD) for the region. As differences in the performance of the cassava/maize association due to spatial arrangement had been reported previously, two spatial arrangements were used: intercrop of maize and cassava in alternate rows (AR) and intercrop on the same row (OR). A split-plot design was used with spatial arrangement as the main plots; cropping system, the subplot; and maize varieties, the sub-subplots.

The total biomass produced by cassava was not affected by the association with maize or the maize variety with which it was associated (Table 5.26). CV values for cassava biomass were relatively high (ca. 30%); consequently, the analysis could not detect a 4.0 t/ha difference between total biomass values.

Uptake of nutrients by cassava was not affected by the type of maize with which it was associated (Table 5.27). As the sole crop cassava data (Tables 5.26-27) are an avg of AD and CD planting densities, in general terms the biomass accumulation and nutrient uptake of cassava are similar, whether monocropped or associated with different maize varieties. Total biomass and nutrient uptake by cassava as a sole crop (10,000 pl/ha) was higher than in the other treatments, but this difference was not statistically significant.

The total biomass accumulation of the two improved and two traditional maize varieties was similar, but a significant difference between variety types was observed in the allocation of photosynthates to product (grains) biomass. Traditional varieties allocated more biomass to vegetative parts of the plant than improved ones (Table 5.28). Allocation of photosynthates to grains was different in the two traditional maize varieties (Table 5.29); however, no difference between the two improved ones was found as to total biomass or biomass allocated to grains. In the traditional varieties, the difference in biomass allocated to grains was

Table 5.26 Biomass production by cassava var. CMC 40 in monoculture and in association with different types of maize.

Intercropped Maize	Biomass (t/ha) Total	Leaves	Stems	Roots
H-211	18.90	0.68	8.63	9.68
V-258	17.48	0.44	7.19	9.85
Clavo	17.54	0.64	6.90	9.99
Limeño	20.48	0.55	7.75	12.18
Cassava monoculture	22.07	0.72	9.12	12.23

Table 5.27 Uptake of nutrients by cassava in monoculture and in association with different maize varieties.

Varieties	Nutrients (kg/ha) N	P	K	Ca	Mg	S
H-211	111.9	19.6	118.6	82.2	63.7	14.6
V-258	101.8	17.3	94.0	72.6	58.1	13.7
Clavo	102.6	17.5	104.0	72.2	57.2	13.4
Limeño	124.4	20.3	121.6	80.8	66.0	15.2
Cassava monoculture	130.9	21.1	128.6	98.8	83.0	18.5

Table 5.28 Total biomass and biomass allocated to grains by traditional and improved maize varieties; avg of sole crop and intercropped with cassava.

Maize Variety	Biomass (kg/ha) Total	Grains	% to Grains
Improved	10083	4312	42
Traditional	9662	2113	21

Table 5.29 Total biomass and biomass allocated to grains by traditional maize varieties; avg of sole crop and intercrop with cassava.

Maize Variety	Biomass (kg/ha)		
	Total	Grains	% to Grains
Clavo	10364	1963	18
Limeño	8959	2261	25

statistically significant (Table 5.29), suggesting that they have distinct origins and, consequently, differ substantially in agronomic performance. The exact origins of Limeño and Clavo were not known to farmers, but both are considered local varieties in the Valle del Cauca.

Maize intercropped with cassava yielded less biomass than maize as sole crop (Fig. 5.40a). There was interaction between total biomass and spatial arrangement of the intercrop (Fig 5.40b). As expected, more total biomass and more leaves plus stems were produced at 50,000 plants regardless of maize variety, cropping system or spatial arrangement (Fig. 5.41). In terms of total biomass, traditional maize varieties yielded more than the improved ones at the 50,000 density, but this difference was not statistically significant. At 33,000 density the improved varieties yielded significantly more total biomass than the traditional ones (Fig. 5.42); however, most of the total biomass was allocated to vegetative parts in the latter.

There was an interaction between the improved maize varieties and spatial arrangement. H-211 yielded considerably more total biomass in association with cassava in the AR than in the OR spatial arrangement. In monoculture there was no interaction between maize type and spatial arrangement (Table 5.30). A larger proportion of photosynthates was allocated to grains by H-211 regardless of spatial arrangement. It is not known if higher yields in alternate rows is a general characteristic of hybrids or specific to H-211. The higher yields of maize hybrids in ARs have been mentioned in the literature, but no systematic research has been conducted to test this hypothesis.

In either spatial arrangement, association with cassava (CMC 40) did not affect the ability of improved maize varieties to allocate a large proportion of biomass to the grains.

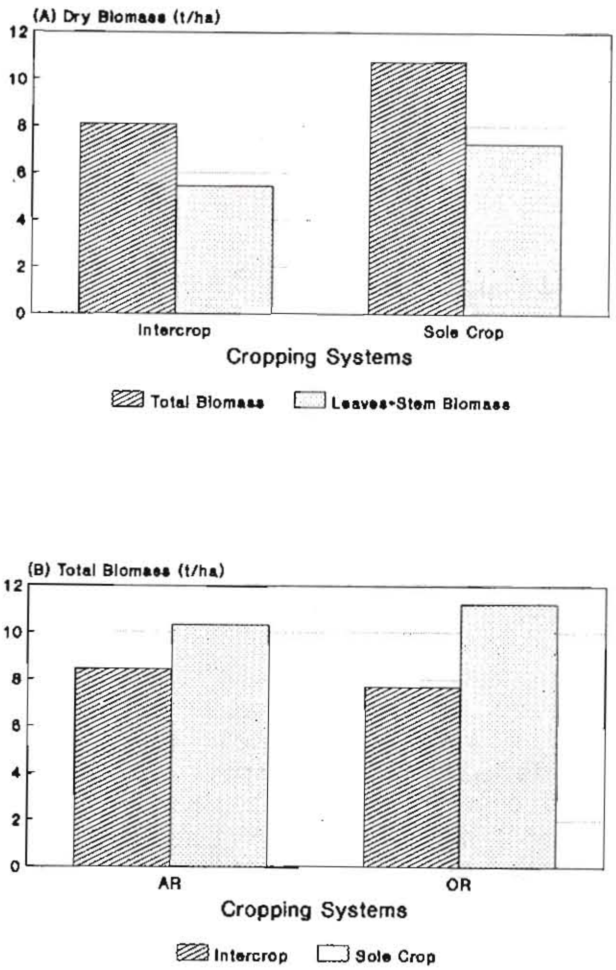


Figure 5.40 Biomass yield of maize in sole crop and associated with cassava.

The efficiency characteristics of improved maize varieties are particularly evident in H-211.

Nutrient uptake by cassava was not affected by spatial arrangement or maize type. The traditional maize varieties used more nutrients than improved ones (Table 5.31). More nutrients were allocated to leaves and stems in traditional

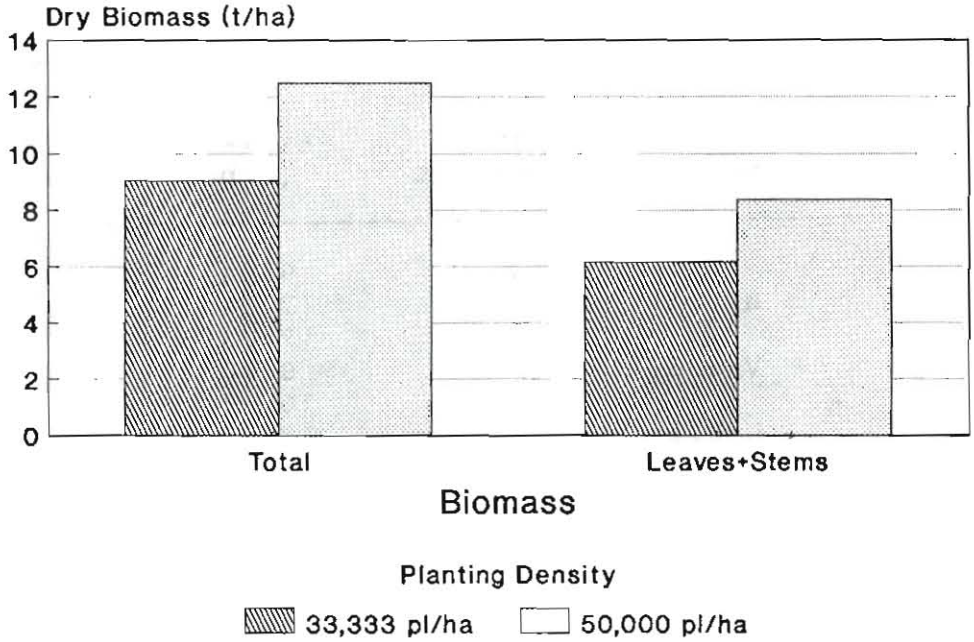


Figure 5.41 Biomass yields of maize as sole crop at two planting densities.

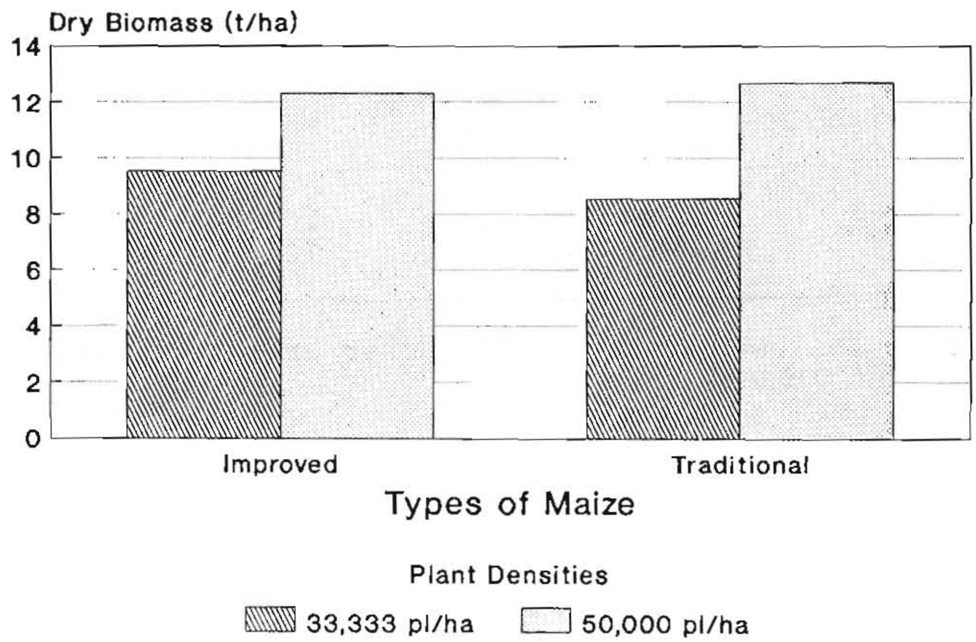


Figure 5.42 Total biomass yields of two types of maize at two planting densities.

Table 5.30 Total biomass and % biomass allocated to the grain by improved maize varieties in sole crop and associated with cassava in two spatial arrangements.[1]

Cropping System	Var.	Spatial Arrangement[1]	Total Biomass (t/ha)	% to Grain
		AR[1]	9.64	50.3
	H-211	OR	7.51	46.8
Intercrop		AR	7.73	36.1
	V-258	OR	8.70	38.0
		AR	10.23	50.5
Sole crop	H-211	OR	12.99	43.4
		AR	11.19	39.8
	V-258	OR	9.26	36.5

[1] AR and OR correspond to maize interplanted with cassava in alternate rows and in the same row, resp.

Table 5.31 Nutrient uptake by traditional and improved maize varieties; avg of intercrop with cassava and sole crop.

	Nutrients (kg/ha)				
Type of Maize	N	P	K	Ca	S
Improved	72 a[1]	14 a	101 a	21 a	10 a
Traditional	195 b	21 b	124 b	27 b	13 b

[1] Figures followed by the same letter are not statistically different (DMRT, $P = 0.05$).

varieties and to the grains in the case of improved varieties. If leaves and stalks of traditional varieties are left standing in the field after harvesting the cobs, more efficient recirculation of nutrients is expected than if the residues are removed to feed animals.

Association with cassava affected the amount of nutrients used by maize. Intercropped maize always extracted fewer nutrients than maize alone, not only because it yielded less total biomass in the intercrop, but because the percent of each nutrient in the tissues, except Mg, was always less in the intercrop than in the monocrop (Table 5.32).

Uptake of K, Ca and Mg in intercropped maize varies significantly between spatial arrangements (Fig. 5.43). Regardless of maize type, cropping system or spatial arrangement, heavier nutrient use by maize occurred only as the no. of pl/ha was increased (Table 5.33) from 33,000 to 55,000 (CD).

In monoculture, improved maize varieties used more N than traditional varieties, but this difference was not statistically significant. Monocultures of traditional maize varieties extracted significantly more P, K and Ca than improved varieties (Table 5.34). It appears that traditional varieties cultivated at relatively high densities tend to use nutrients, particularly P, K and Ca rather inefficiently, at least in favorable environments such as Palmira.

Clone H-211 extracted significantly more nutrients (particularly N) than the improved variety. The two traditional maize varieties also differed in nutrient uptake (Table 5.35).

5.5.3.1 **Efficiency in nutrient use.** Two indices were used to compare the efficiency of nutrient use by maize, cassava and in the intercrop of these. Biomass Efficiency Index (BI) is the quantity (kg) of a given nutrient required to produce 1000 units of dry total biomass of either maize or cassava. Production Index (PI) is the amount (kg) of a given nutrient necessary to produce 1000 units of either dry maize grain or dry cassava roots. The smaller the value of the index, the more efficient the biomass production. Table 5.36 gives values for the BI and PI indices for the cassava monocrop (mean of two plant densities), the cassava/maize intercrop and maize as a sole crop at two plant densities.

Cassava is more efficient than maize in production of both total biomass and per unit of nutrient extracted. The data for cassava in Table 5.36 were averaged over 8300 and 10,000 pl/ha as no significant difference was found between the nutrient uptake efficiency at these densities. With maize there was a difference in nutrient use efficiency between 33,000 and 50,000 densities; therefore, the results for these densities are presented separately.

Cassava was a more efficient user of NPK and S than maize at any plant density. Maize was more efficient than cassava in production of stems and leaf biomass per unit of Ca and Mg.

Table 5.32 Nutrient uptake by maize in association with cassava and as a sole crop; avg of two improved and two traditional maize varieties.

Cropping System	Nutrients (kg/ha)				
	N	P	K	Ca	S
Intercropped	117 a [1]	22 a	102 a	21 a	14 a
Sole crop	158 b	32 b	142 b	27 b	19 b

[1] Figures followed by the same letter are not statistically different (DMRT, P = 0.05).

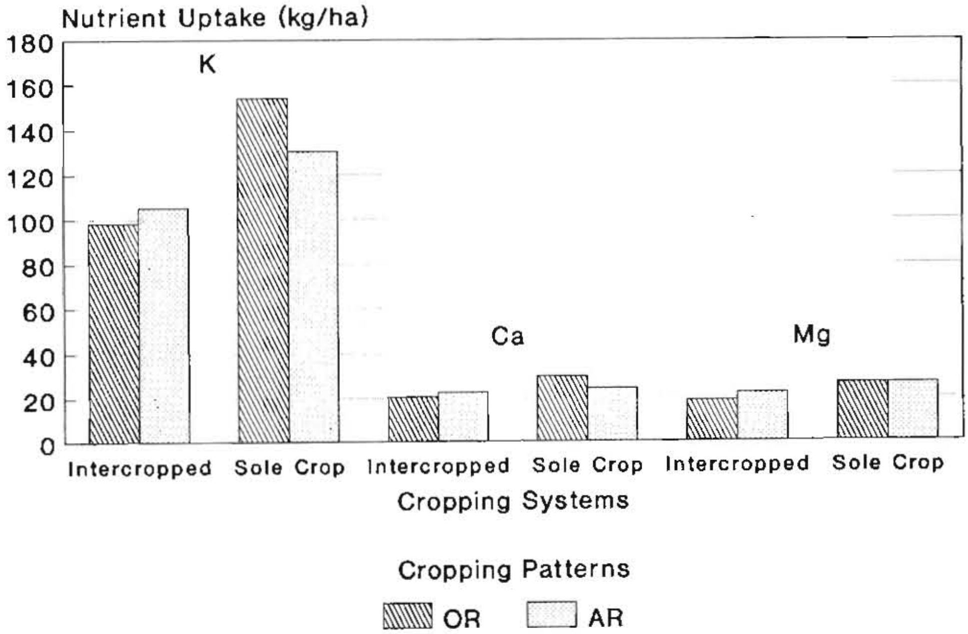


Figure 5.43 K, Ca and Mg uptake in maize as sole crop and intercropped with cassava in two cropping patterns.

Table 5.33 Uptake of nutrients by maize as sole crop at two plant densities.

Plants/ha	Nutrients (kg/ha) N	P	K	Ca	Mg	S
33,000	117 a [1]	22 a	119 a	22 a	21 a	16 b
50,000	178 b	37 b	166 b	32 b	32 b	22 b

[1] Figures followed by same letter are not statistically different (DMRT, P = 0.05).

Table 5.34 Nutrient uptake by traditional and improved maize varieties as sole crop and at two planting densities.

Plants/ha	Var.	Nutrients (kg/ha) N	P	K	Ca	Mg	S
33,000	Improved	151	27	121	21	21	17
	Local	125	25	116	23	21	15
50,000	Improved	183	33	146	26	31	21
	Local	173	41**	185**	36**	33	23

Table 5.35 Nutrient uptake by two traditional and two improved maize varieties as sole crop.

Type of Maize	Maize Var.	N	P	K	Ca	Mg	S
Local	Clavo	145	32	151	38	27	19
	Limeño	128	26	121	26	22	16
Improved	H-211	165	29	129	22	25	18
	V-258	139	26	114	23	24	17

Table 5.36 Efficiency of nutrient use by maize and cassava as sole crops and in association.

	Biomass Index (BI)							
	YM	Y	M1	M2	YM	Y	M1	M2
Maize	----- Nitrogen -------				---- Phosphorus ---			
Clavo	8.5	6.0	13.8	14.3	1.58	0.9	3.0	3.4
Limeño	8.4		15.4	13.1	1.5		2.8	3.2
H-211	8.6		16.4	15.4	1.6		2.7	2.9
V 258	8.8		14.9	14.1	1.6		3.0	2.6
	----- Potassium -----				----- Calcium ------			
Clavo	8.7	5.9	14.7	14.8	3.7	4.5	2.5	3.0
Limeño	7.9		12.6	13.9	3.8		3.0	2.8
H-211	7.7		13.0	12.4	3.6		2.0	2.1
V 258	7.7		12.0	11.7	3.6		2.4	2.2
	----- Magnesium -----				------ Sulfur -----			
Clavo	3.0	3.8	2.6	2.7	1.1	0.8	1.7	2.0
Limeño	3.0		2.5	2.6	1.0		1.8	1.7
H-211	3.0		2.2	2.6	1.0		1.7	1.7
V 258	3.0		2.3	2.6	1.1		1.8	1.8
	Production Index (PI)							
	----- Nitrogen ------				----- Phosphorus ---			
Clavo	19.8	11.5	81.6	81.7	3.7	1.8	17.6	19.7
Limeño	16.7		64.3	59.0	3.0		11.6	14.2
H-211	17.5		37.3	32.4	3.2		6.0	6.0
V 258	17.6		40.5	38.2	3.2		8.3	7.0
	----- Potassium -----				----- Calcium -----			
Clavo	20.1	11.2	88.4	85.3	8.6	8.7	15.6	18.6
Limeño	16.0		53.5	60.6	7.6		12.6	12.5
H-211	15.8		30.0	27.2	7.3		4.8	4.7
V 258	15.4		33.0	32.0	7.2		6.5	6.3
	----- Magnesium -----				----- Sulphur ----			
Clavo	7.0	7.3	15.9	15.8	2.6	1.6	10.3	11.4
Limeño	6.0		10.1	12.5	2.0		7.7	7.6
H-211	6.2		4.9	5.4	2.2		3.8	3.5
V 258	6.2		6.3	7.2	2.3		4.8	4.8

1 YM = Cassava/maize intercrop; Y = Cassava; M1 = Maize sole crop planted at 33,000 pl/ha and M2 = Maize sole crop planted at 50,000 pl/ha.

The efficiency of biomass production in maize is improved by intercropping with cassava.

BI was similar in improved and traditional maize varieties; but improved varieties were significantly more efficient in nutrient use and allocation of resources to the grain instead of the leaves and stems. H-211 was by far the most efficient user of N for grain production in association with cassava (Table 5.37). Intercropping cassava and maize resulted in efficiency values slightly above those of the cassava as a sole crop, but significantly different from maize as a sole crop.

No significant differences were found between the indices in maize or cassava as sole crops or in association for most of the nutrients studied. This means that maize and cassava will be equally efficient in nutrient uptake whether monocropped or in association. Phosphorous was an exception, used more efficiently for biomass production when maize was planted in association with cassava. The BI index was 2.71 for associated maize and 2.93 for maize as sole crop. Significant differences in PI were found between the traditional maize varieties. Limeño was more efficient than Clavo for most of the nutrients tested.

To compare the production efficiency (PI) of a crop combination (cassava/maize) vs. the sum of its components (cassava + maize), Table 5.38 was constructed. Only K, Ca, Mg and S are shown as no difference were found in PI values for N or P.

A difference in favor of the crop association in comparison with the sum of the components can be observed for the selected nutrients included in this table.

5.5.3.2 **Nutrient content and export by a cassava/maize system.** A model of nutrient content that includes the percentage of each nutrient in different plant parts is presented in Figure 5.44. Maize roots were not included although they constitute ca. 5% of total maize biomass. The model does not include soil, which is the main source of nutrients.

The export of nutrients from the crop system is represented by maize grains and cassava roots. In reality, the export of nutrients by maize could be greater if the leaves and stems leave the farm system. If the leaves are consumed by the animal subsystem on the farm, recirculation may take place in other plots within the farm. Cassava roots are always taken out of the plots, but most of the aboveground biomass returns to the soil in the form of planting material or is left in the borders of the fields to decompose. The model is based on management practices common on the North

Table 5.37 Values of Biomass Index (BI) and Production Index (PI) for nutrient use by improved and traditional maize varieties. Avg of intercrop with cassava and maize as a sole crop.

Maize Var.	Index[1]	Nutrients (kg/ha)					
		N	P	K	Ca	Mg	S
Local	BI	14.2	3.0	13.8	2.9		1.8
	PI	74.1	15.7	73.9	15.7	14.0	9.5
Improved	BI	15.0	2.7	12.0	2.3		1.7
	PI	36.8	6.7	30.2	5.7	6.1	4.3

1 BI = Biomass Index; PI = Production Index.

Table 5.38 Production Index (PI) for nutrient use by cassava associated with maize and avg for cassava and maize as sole crops.

Nutrient	Crops	Clavo	Limeño	H-211	V-258
N	YM	19.8	16.7	17.5	17.6
	Y+M	20.0	19.3	19.2	17.8
K	YM	20.1	16.0	15.8	15.5
	Y+M	20.2	17.3	16.8	16.0
Ca	YM	8.6	7.6	7.3	7.2
	Y+M	9.1	9.0	7.4	8.1
Mg	YM	7.0	6.0	6.2	6.2
	Y+M	8.0	7.6	6.5	7.0
S	YM	2.6	2.0	2.2	2.3
	Y+M	2.6	2.5	2.3	2.3

1 YM = Cassava and maize intercropped; Y+M = avg value of PI for cassava and maize as sole crops.

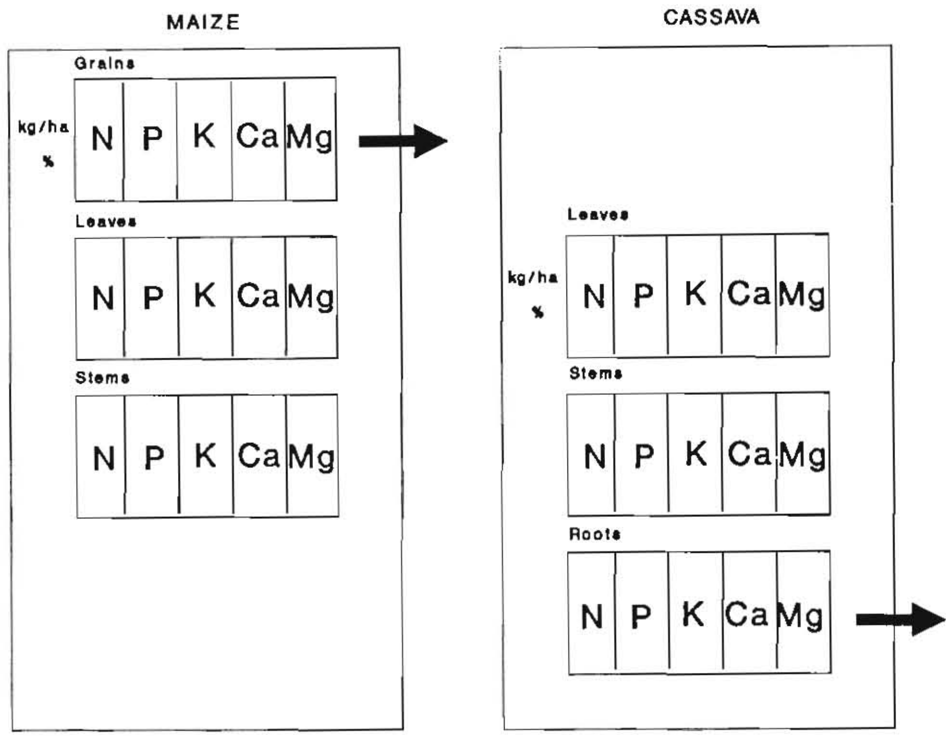


Figure 5.44 Nutrient distribution model of a cassava/maize intercrop.

Coast of Colombia, where maize leaves and stems are not consumed by the animal component of the system, but are left in the field until decomposition. Recirculation in the model assumes decomposition and mineralization at similar rates for all biomass components and for each nutrient.

In Figures 5.45a-d, the amounts and percentages of each nutrient in different plant organs are represented for the four maize varieties under study. The amounts of NPK vary between the organs and the maize varieties. Cassava contains approx. 73% of the total Ca and 72% of the total Mg of the crop system. As only 10 and 20% of Ca and Mg, resp., are exported by the system, cassava is the component that recirculates most of these elements to the environment (ca. 87 and 80% for Ca and Mg, resp.). Recirculation in the model assumes the composition and mineralization at a similar rate for all the biomass and each nutrient in particular (Figs. 5.46-5.48). The cropping system with maize (H-211) exports ca. 45% of the NPK out of the system, while an intercrop that includes a traditional maize var. such as Clavo exports only 35% of the same nutrients. This

(A)

MAIZE

Grains					
kg/ha	35.4	6.3	9.1	0.3	2.1
%	34.0	32.1	9.9	1.3	12.0

Leaves					
kg/ha	34.5	4.9	24.8	12.5	6.2
%	33.1	24.9	26.8	59.3	36.0

Stems					
kg/ha	34.3	8.4	58.4	8.3	9.0
%	32.9	43.0	63.3	39.4	52.0

CASSAVA

Leaves					
kg/ha	5.4	1.0	5.9	17.7	6.8
%	6.6	5.0	4.9	21.9	10.3

Stems					
kg/ha	54.4	8.1	28.2	63.0	45.0
%	51.8	40.1	23.2	65.5	68.1

Roots					
kg/ha	51.6	11.1	87.5	10.2	14.3
%	41.6	54.9	71.9	12.6	21.6

(B)

MAIZE

Grains					
kg/ha	33.8	6.2	10.0	0.2	2.2
%	28.7	26.4	8.3	0.8	10.0

Leaves					
kg/ha	40.5	6.8	31.4	13.9	8.4
%	34.5	28.9	26.0	62.5	40.4

Stems					
kg/ha	43.4	10.5	79.3	9.4	11.0
%	36.9	44.7	65.7	36.7	49.6

CASSAVA

Leaves					
kg/ha	11.4	1.2	5.2	17.3	8.4
%	11.1	6.6	5.0	24.0	14.7

Stems					
kg/ha	58.1	7.7	24.0	46.6	37.3
%	56.5	43.9	23.1	63.5	65.3

Roots					
kg/ha	33.2	8.7	74.8	9.0	11.4
%	32.4	49.5	71.9	12.5	20.0

Figure 5.45 Nutrient distribution in a cassava (var. CMC 40) intercrop with (a) maize var. Limeño and (b) var. Clavo.

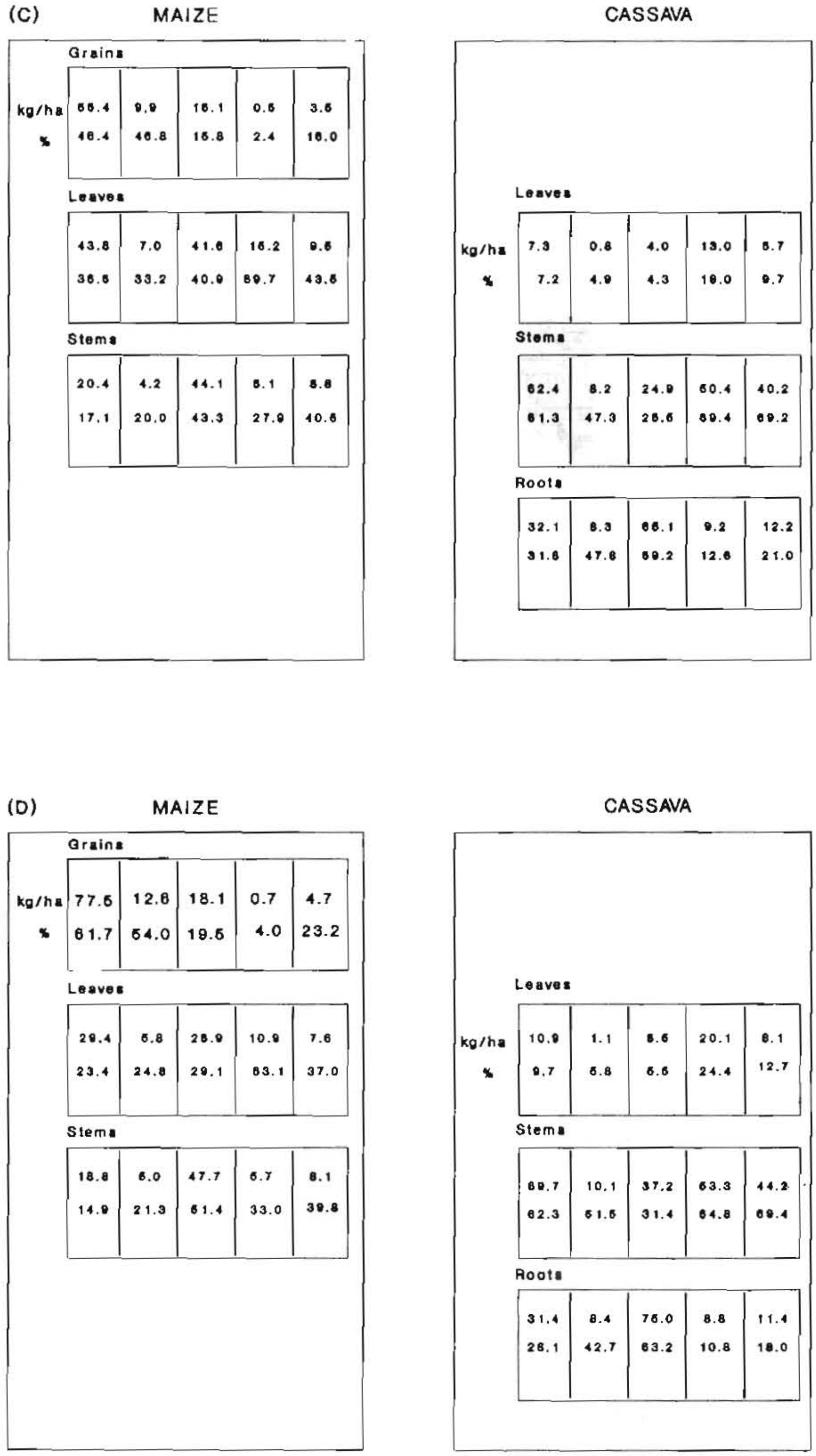


Figure 5.45 Nutrient distribution in a cassava (var. CMC 40) intercrop with (c) maize var. V258 and (d) maize var. H-211.

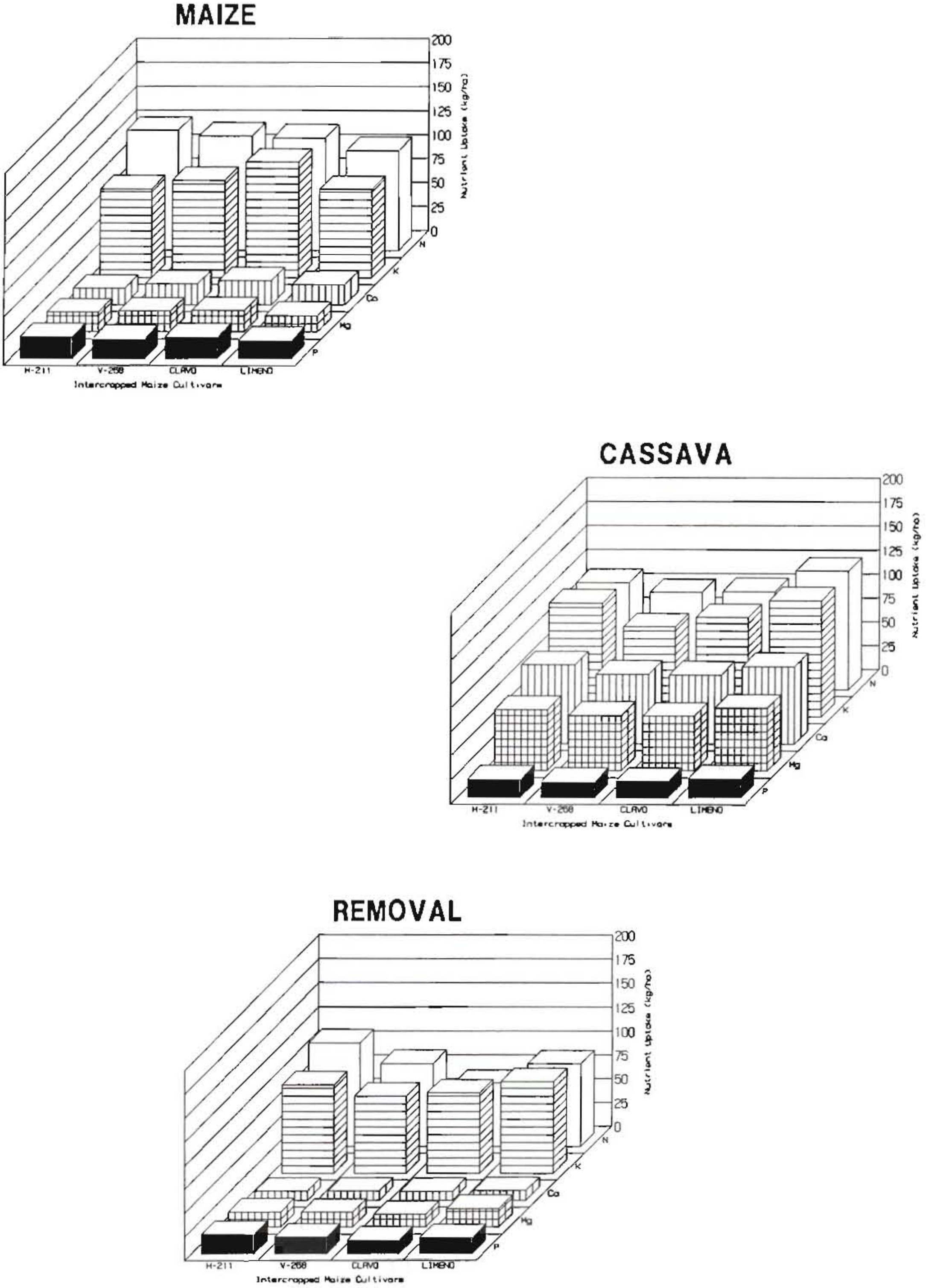


Figure 5.46 Nutrient uptake and removal from a cassava/ maize intercrop.

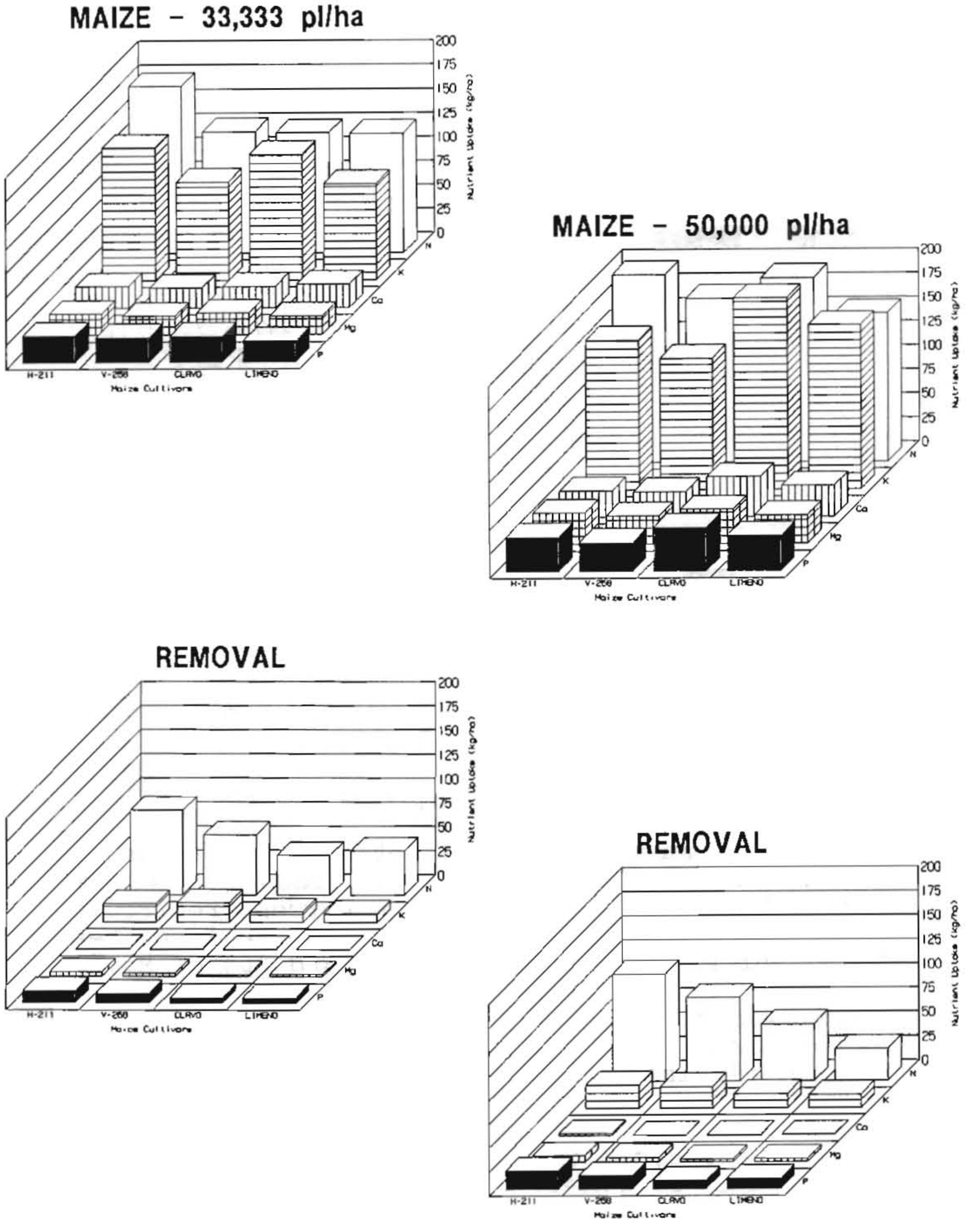


Figure 5.47 Nutrient uptake and removal from a maize sole crop at two plant densities.

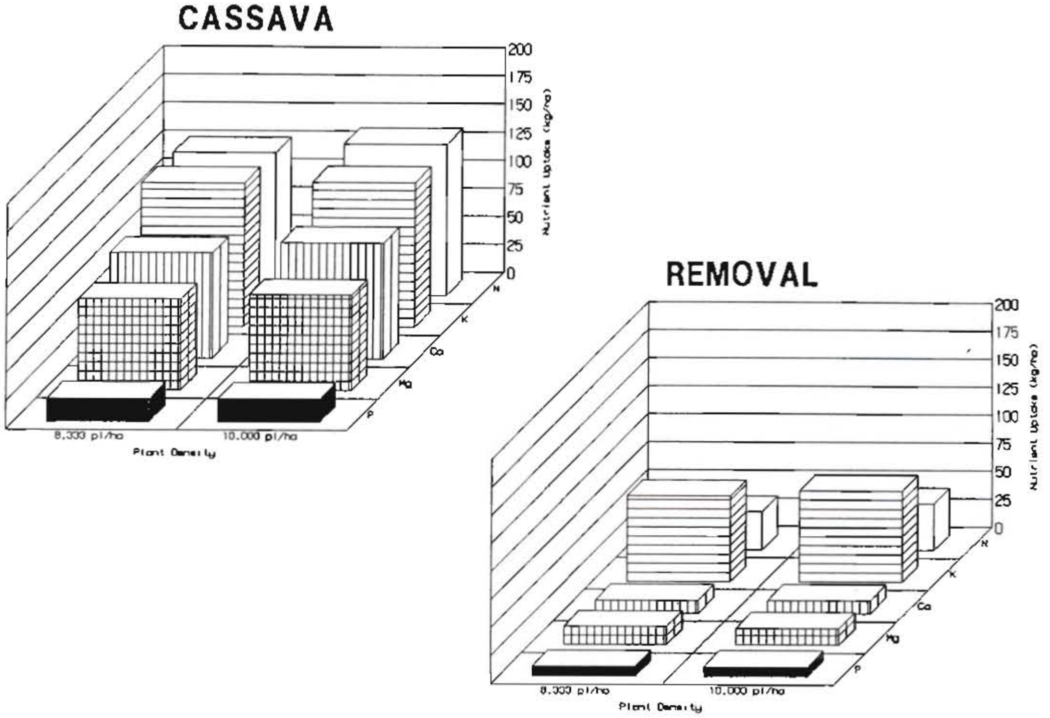


Figure 5.48 Nutrient uptake and removal from cassava sole crop at two plant densities.

difference is due to the heavy allocation of biomass to the grain in the improved maize varieties.

Improved maize varieties in monoculture recirculate ca. 50% of N and P, while traditional varieties recirculate 70%. The inclusion of improved maize varieties in a cassava/maize intercrop will slightly increase the percent of N that is recirculated, but it will decrease the percent recirculation of other nutrients. Cassava as a sole crop recirculates ca. 70% of N, 55% of P, 39% of K, 87% of Ca and 80% of Mg.

When cassava was associated with maize, recirculation of K was decreased by ca. 30% compared with each component as a sole crop. A similar pattern was observed with P although the decrease in recirculation was aprox. 13%.

As a result of the dynamics of K in the soil, a decrease in recirculation due to intercropping should not affect the performance of the system in the long run. A similar situation is anticipated for the P in soils that are deficient in this element.

Improved maize varieties in association with cassava increased the recirculation of N by 7% in comparison with traditional varieties, while maintaining tne same level of recirculation for P.

In general terms, considering cassava and maize as sole crops as well as in association, the recirculation of nutrients was always above 50%. These amounts are sufficient to replace the quantities exported outside the system in the form of maize grains and cassava roots. The nutrient loss by percolation and surface runoff should probably be replaced by fertilizers or other soil management practices. A summary of the dynamics of nutrient recirculation is presented in Table 5.39.

5.5.4 Performance of different cassava varieties intercropped with maize, cowpeas, yams and sweet potatoes

Worldwide, most cassava is grown in association with other species; therefore, the characterization of cassava germplasm for its ability to grow as an intercrop component is important for both cassava breeding and agronomy.

Several studies carrried out at CIAT HQ have indicated that not all cassava varieties perform similarly when intercropped with other species, particularly maize. Cultivars with less foliage and high HI tend to yield less in inter-

Table 5.39 Percent nutrients recirculated to the farm in a cassava/maize intercrop and in maize as sole crop.

Cropping System	Maize Var.	N	P	K	Ca	Mg
Intercrop	H-211	54.2	51.2	56.0	90.4	80.8
Sole crop		49.8	52.0	80.2	97.2	77.9
Intercrop	V 258	60.5	53.0	58.5	90.0	80.3
Sole crop		51.1	57.8	80.3	93.9	79.6
Intercrop	Clavo	69.6	63.7	65.2	90.6	90.6
Sole crop		67.3	77.0	92.0	98.5	90.1
Intercrop	Limeño	62.0	56.3	54.9	90.0	80.4
Sole crop		63.3	70.0	91.0	98.6	88.0

crop with maize than tall varieties. It has also been suggested that more erect and late-branching cassava types tend to yield more when intercropped with other species, particularly maize.

To continue with the study of the reaction of different cassava varieties to intercropping, an experiment was conducted at HQ with seven representative cassava varieties in association with maize, cowpeas, sweet potatoes and yams. The cassava clones selected for this experiment and their plant characteristics are presented in Table 5.40.

Maize (H-211), the new yam var. CDC-18, the sweet potato var. S-2 (El Carmen de Bolívar collection), and the S-5 cowpea (ICA's collection in Palmira) were each intercropped with cassava. These crops were planted simultaneously as monocrops and in alternate rows with cassava at 33,000; 100,000; 8300 and 40,000 pl/ha, resp. Cassava was planted at 8300 pl/ha both as a sole crop and in association with other species. Treatments were arranged in a split-plot design where the main plots were the species intercropped with cassava and the cassava clones were the subplots. Four reps were planted.

The performance of the maize clone H-211 intercropped with different cassava varieties is presented in Figure 5.49a. Maize yielded significantly more when intercropped with medium-height cassava clones, but the differences in the yield of maize intercropped with short and tall cassava varieties of cassava were not significant (Table 5.41).

Table 5.40 Growth characteristics of cassava varieties selected for intercropping with other species.

Cassava Clone	Plant Height	Branching Habit
CMC 40	Medium	Erect
CM 1223-11	Low	Erect
CM 523-7	Tall	Erect
CM 849-1	Medium	Branched
SG 107-35	Tall	Erect
CM 1918-3	Low	Branched
M Ven 218	Medium	Branched

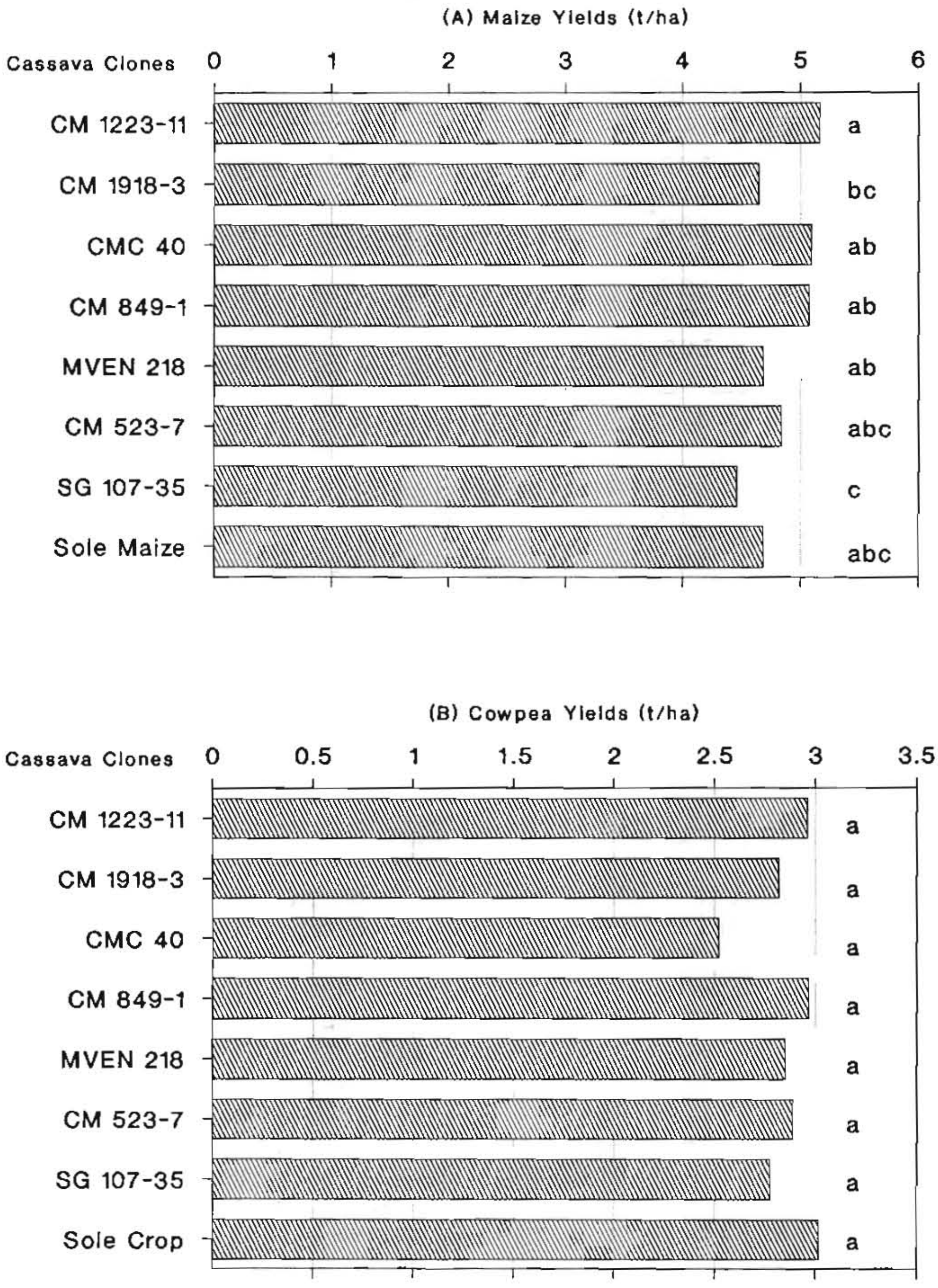


Figure 5.49 Yields of (a) maize (H-211) as sole crop and (b) cowpea var. S-5 intercropped with different cassava varieties; bars followed by the same letter are not significantly different (DMRT, P = 0.05).

Table 5.41 Relative yields (% of sole crop) of maize, cowpeas, sweet potatoes and yams intercropped with selected cassava varieties.

Clone	Maize	Cowpeas	Sweet Pot.	Yams
CMC 40	109	84	52	95
CM 1223	110	98	43	109
CM 523-7	103	96	40	129
CM 849-1	108	98	41	113
SG 107-35	95	92	46	76
CM 1918-3	99	94	46	79
M Ven 218	109	95	52	80

Cassava branching habit did not significantly affect the performance of maize; however, there was a tendency for higher maize yields in intercrops with erect types of cassava. This tendency was more evident as the size of the cassava plants decreased. Apart from dry (14% MC) grain yield, other variables such as total biomass, no. of cobs/plant and no. pl/ha were not affected by the cassava clone. Maize as a sole crop registered one of the lowest yields, corroborating results from previous studies.

Cowpea yields were not affected by cassava clone (Fig. 5.49b); moreover, there were no differences between the yields of cowpeas intercropped with cassava and as a sole crop. Other variables recorded for cowpeas such as no. of pods/plant; no. of grains/pod; no. of grains/100 g and total cowpea biomass, were not affected either by cassava type or by cropping system. The S-5 cowpea variety performed similarly with all cassava varieties tested; this may be due to its relatively short growing cycle (80 days).

As shown in Figure 5.49c, sweet potato yields were significantly lower in the intercrop than in the monocrop. The no. of roots/plant (2.14 vs 1.21), mean weight of marketable roots (0.5 vs 0.4 kg); aerial biomass (4.0 vs 2.7 t/ha) and HI (0.4 vs 0.3) were all higher when sweet potatoes were grown as a sole crop than in association with cassava. The cassava clones tested did not affect sweet potato yields differently. There was no significant effect of cassava clone on the other sweet potato variables that were evaluated.

The new yam var. CDC-18 was severely affected by foliar pathogens, and some plots were negatively affected by root

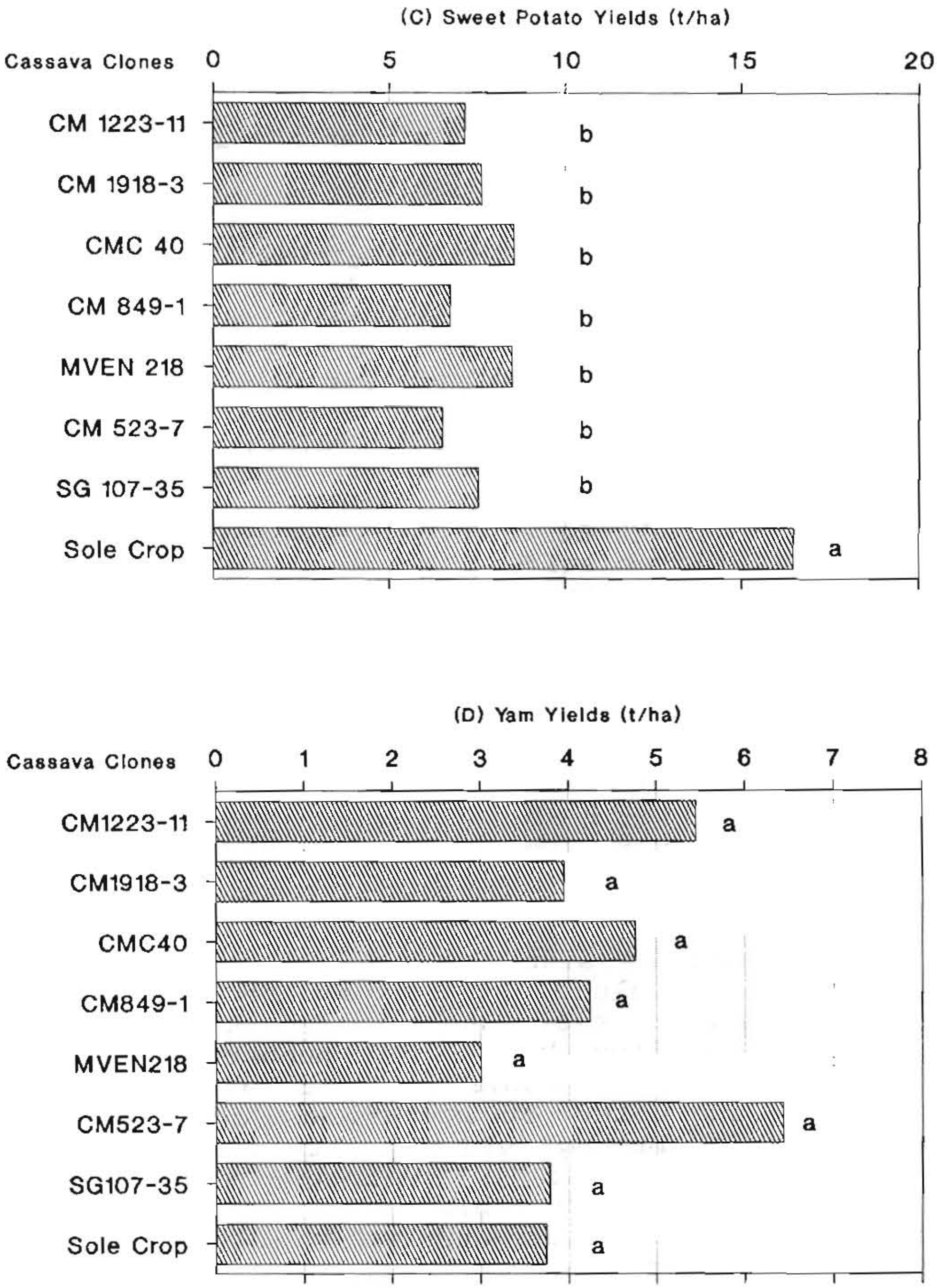


Figure 5.49 Yields of (c) sweet potato var. V2-CIAT and (d) yam var. CDC-18 as sole crop and intercropped with different cassava varieties; bars followed by the same letter are not significantly different (DMRT, P = 0.05).

rot pathogens. As a result of this highly variable yam growth, the CV values for yields were very high (46%); and the avg yield (6 t/ha) (Fig. 5.49d) was much lower than obtained in previous experiments (ca. 30 t/ha) with other yams varieties in Palmira. Under these experimental conditions, differences as large as 2.6 t/ha between treatments were not registered as significant. A summary of the yield reductions in cassava due to intercropping with maize, cowpeas, sweet potatoes and yams is presented in Table 5.42.

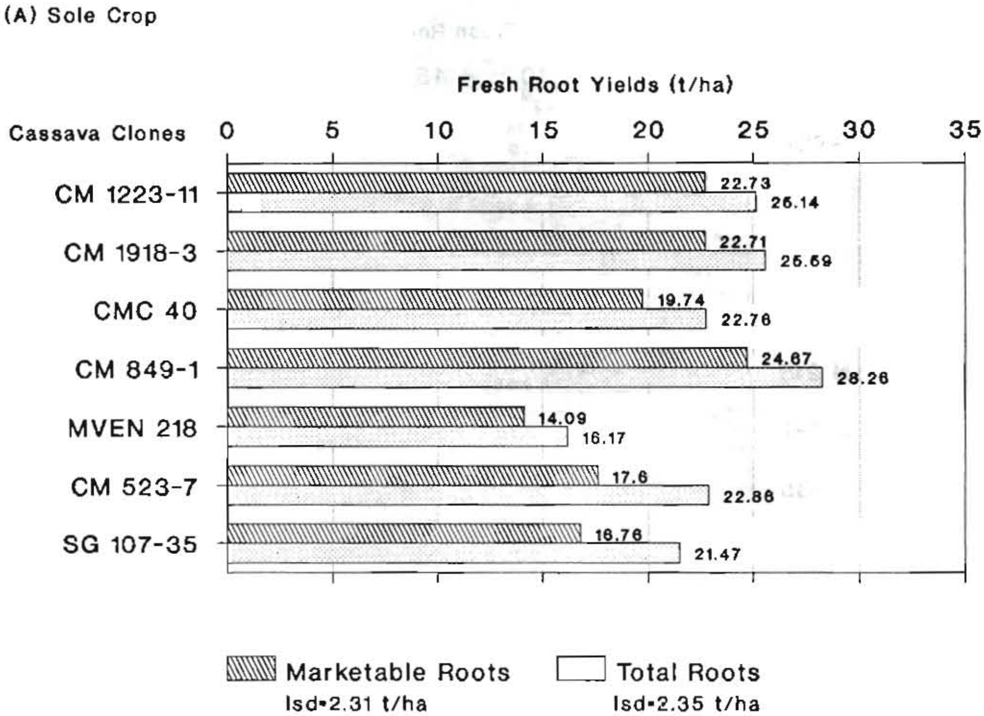
The medium-height, moderately branched cassava var. CM 849-1 outyielded other varieties in monoculture, but this was an exceptional case. Generally the highest yields were obtained in the short cassava varieties (Fig. 5.50a). CM 849-1 also yielded more than the other clones in association with cowpeas, sweet potatoes and yams, and performed relatively well in association with maize (Fig. 5.50b-e). Cassava clone CM 523-7 performed relatively well as an intercrop component. Only CM 849-1 performed better in association with cowpeas, sweet potatoes and yams, and CM 523-7 outperformed CM 849-1 in the intercrop with maize. Shorter cassava clones suffered greater yield reductions as a consequence of intercropping than the other varieties. M Ven 218 yielded poorly both as an intercrop and as a sole crop. Fresh yield in tall, erect cassava types was less affected by intercropping than medium and short types (Table 5.42).

In an analysis of correlations between plant height, stem diameter, no. of stems/plant, no. of leaves/pl, stem diameter multiplied by stem height and fresh RY, only no. of leaves/pl, plant height and stem diameter were correlated with fresh RY (Table 5.43).

The largest number of significant correlations were found between variables evaluated 141 days after planting. The number of positive correlations diminished significantly for the subsequent sampling dates. The number of significant correlations between the above variables and yield did not vary with sampling date. No significant correlations were obtained for any sampling date for some clones such as CM 849-1 and SG 107-35 (Table 5.44). In general, the correlations between the above variables and the yield of marketable fresh roots were lower and less frequent than in the case of total fresh roots.

5.5.5 Effect of cropping systems on the quality of cassava planting material

A number of surveys indicate that the majority of small farmers use their own cassava stakes as planting material year after year. Since cassava is primarily grown in association with other crops, the stakes that are used as



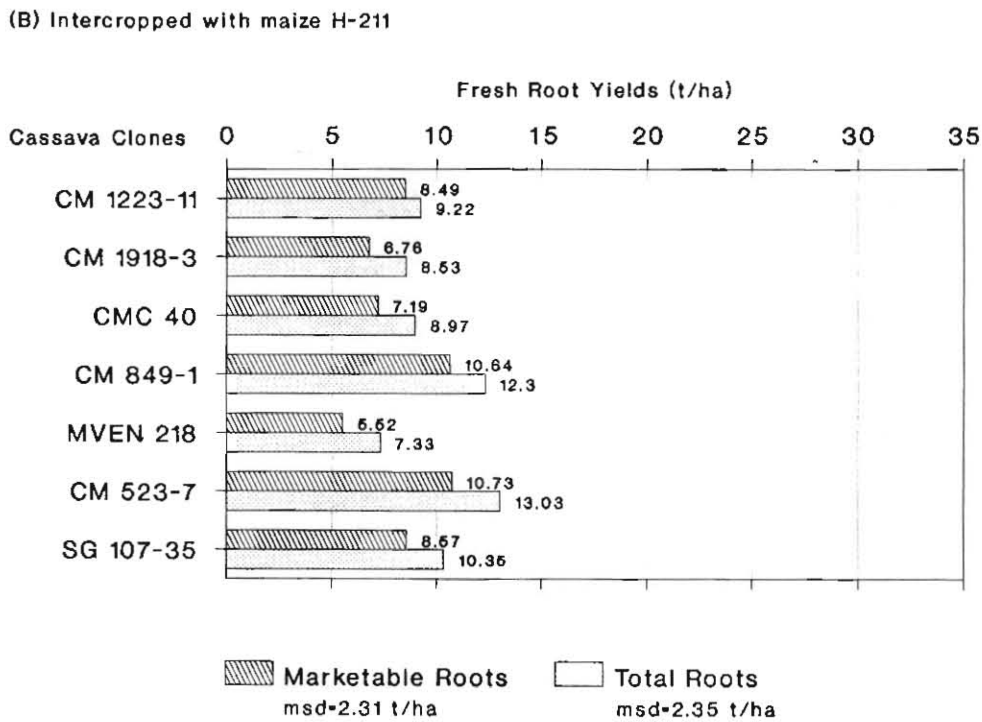
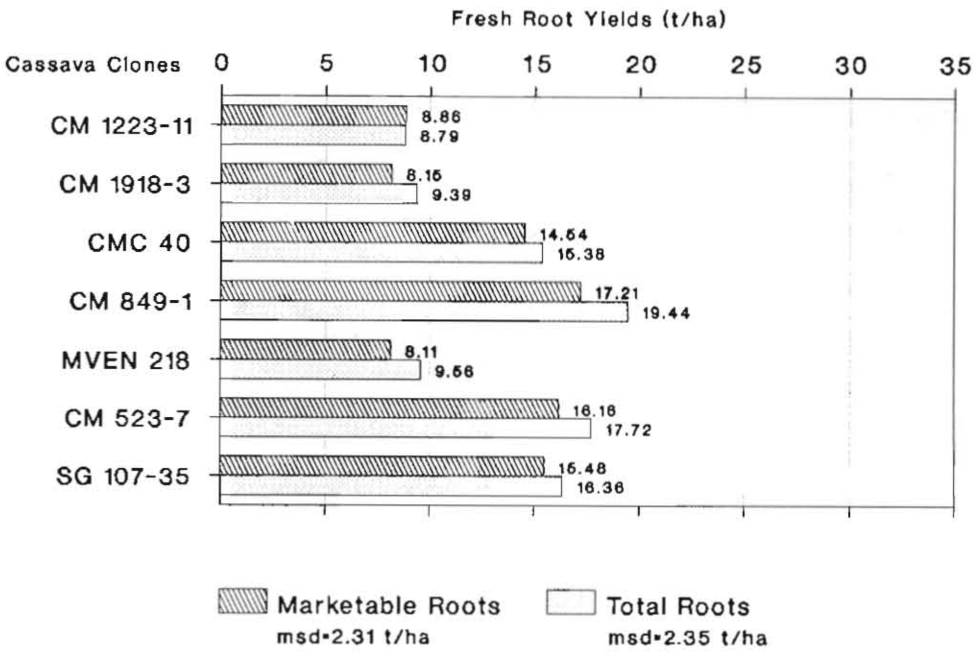


Figure 5.50 Total and marketable fresh root weights of different cassava clones (a) as sole crop and (b) intercropped with maize (H-211).

(C) Intercropped with cowpea



(D) Intercopped with sweet potatoes

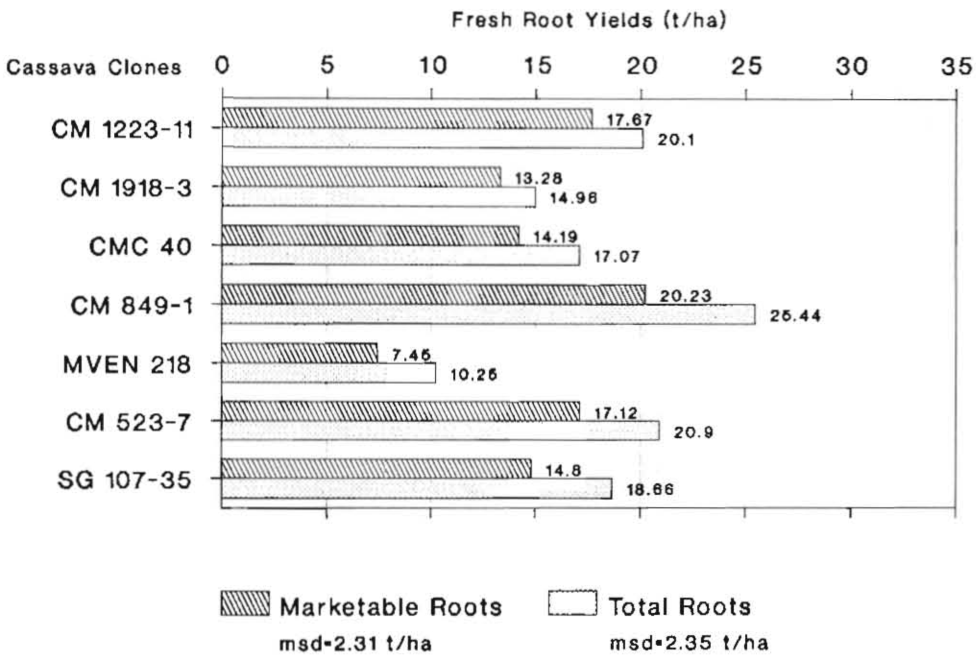


Figure 5.50 Total and marketable fresh root weight of different cassava clones intercropped with (c) cowpeas (S-5) and (d) sweet potatoes (V-2 CIAT).

(E) Intercropped with yams.

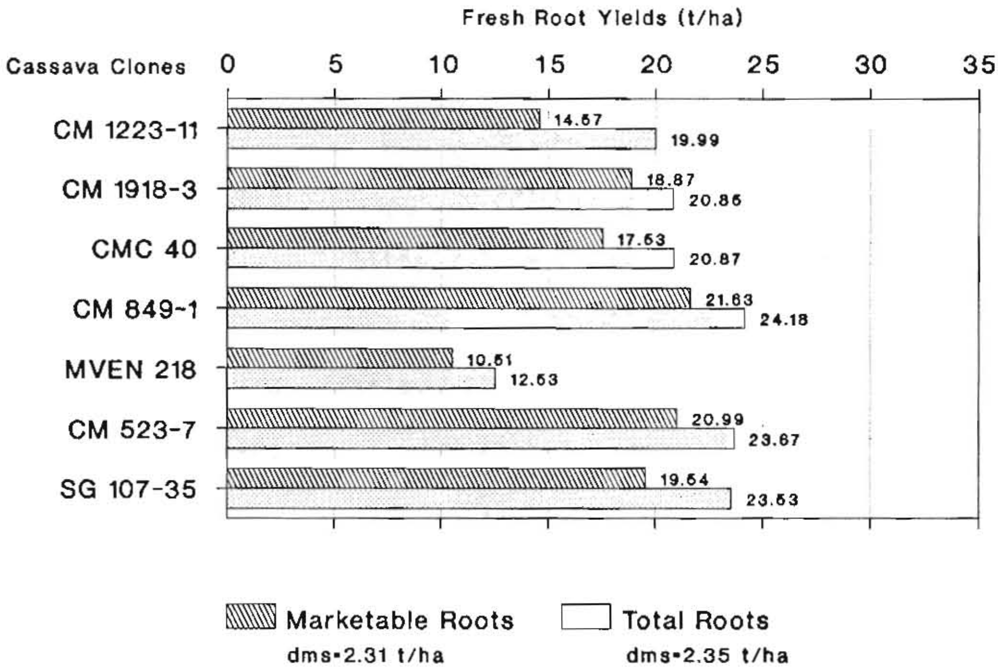


Figure 5.50 Total and marketable fresh root weight of different cassava clones intercropped with (e) yams (CDC-18).

Table 5.42 Yield reduction in cassava clones intercropped with maize, yams, sweet potatoes and cowpeas.

Cassava Clone	Yield (t/ha)	Yield Reduction (%) Maize	Yams	Sweet Pot.	Cowpeas	Mean Avg
CM 1223	25	63	20	20	65	42
CM 1918-3	26	67	18	41	?6	47
CMC 40	23	61	8	25	32	31
CM 849-1	28	56	14	10	31	28
M Ven 218	16	55	22	37	41	39
CM 523-7	23	43	3	8	22	18
SG 107-35	21	52	9	13	24	20

Table 5.43 Correlation coefficients for total fresh RY, no. leaves/pl (leaves), plant height (height) and stem diameter (diam.) for seven cassava varieties.

DAP[1]	Var.	CMC 40	CM 1223	CM 523-7	CM 849-1	SG 107-35	CM 1918-3	M Ven 218
77	leaves	.79**	.84**		.76**		.88**	
	height							
	diam.	.82**	.79**	.76**		.81**	.80**	.75**
106	leaves	.87**	.91**	.84**	.83**		.93**	.81**
	height							
	diam.	.87**	.89**	.79**			.89**	.76**
141	leaves	.85**	.80**	.82**	.84**	.81**	.89**	.86**
	height	.79**						.83**
	diam.	.88**	.84**	.79**		.78**	.88**	.80**
169	leaves	.82**	.75**	.77**			.75**	
	height	.81**						.83**
	diam.	.84**	.87**		.79**	.76**	.86**	.76**
198	leaves	.83**						
	height	.77**						.83**
	diam.	.87**	.85**	.77**		.77**		.82**
230	leaves	.83**	.82**					
	height	.76**						.80**
	diam.	.83**	.79**				.85**	

[1] DAP = Days after planting.

planting material come from mother plants that were intercropped with one or more species. Competition with other species usually reduces the aerial biomass of cassava plants. As a result, planting material coming from intercropped plants tends to be less vigorous than the planting material from plants grown in monoculture. If stakes obtained from intercropped cassava are planted year after year, a progressive decline in quality coupled with lower yields is to be expected.

A study of the effect of the origin of cassava planting material was conducted over a period of three years. Stakes originating from intercropped cassava grown in alternate rows, from mother plants grown continuously in monoculture,

Table 5.44 Correlation coefficients for weight of marketable roots, no. of leaves/pl (leaves), plant height (height) and stem diameter (diam.) for seven cassava varieties.

DAP	Var.	CMC 40	CM 1223	CM 523-7	CM 849-1	SG 107-35	CM 1918-3	M Ven 218
77	leaves		.79**				.86**	
	height							
	diam.	.76**					.80**	
106	leaves	.81**	.86**	.72*			.91**	
	height	.83**						
	diam.		.85**				.88**	
141	leaves	.82**	.78**		.85**		.88**	.78**
	height	.77**						.77**
	diam.	.85**	.80**				.87**	
169	leaves	.82**						
	height	.78**						.78**
	diam.	.81**	.83**				.86**	
198	leaves	.84**						
	height	.76**						.79**
	diam.	.86**	.82**				.89**	
230	leaves	.80**	.81**					
	height							
	diam.	.82**	.76**					.77**

and from cassava grown in association with other crops in alternate years, were included in the experiment. The eight treatments are summarized in Table 5.45.

Cassava (CMC 40); yams (CDC-18) and maize (H-211) were used in the experiment. Cassava mother plants were randomly selected from the center plots of either cassava grown in association or as a sole crop. Immediately before planting, a random selection of cuttings was made.

There was a significant difference between the yields of cassava grown in monoculture and in association with maize and yams; but within cropping systems, no differences in yield due to stake origin were registered. Cassava yields corresponding to the different treatments are presented in Figure 5.51. Maize tended to yield more when it was inter-

Table 5.45 Origin of planting stakes.

Treatment No.	Cycle 1987-88	1988-89	1989-90
1	Sole crop	Sole crop	Sole crop
2	Sole crop	Sole crop	Maize/yams
3	Sole crop	Maize/yams	Sole crop
4	Sole crop	Maize/yams	Maize/yams
5	Maize/yams	Sole crop	Sole crop
6	Maize/yams	Sole crop	Maize/yams
7	Maize/yams	Maize/yams	Sole crop
8	Maize/yams	Maize/yams	Maize/yams

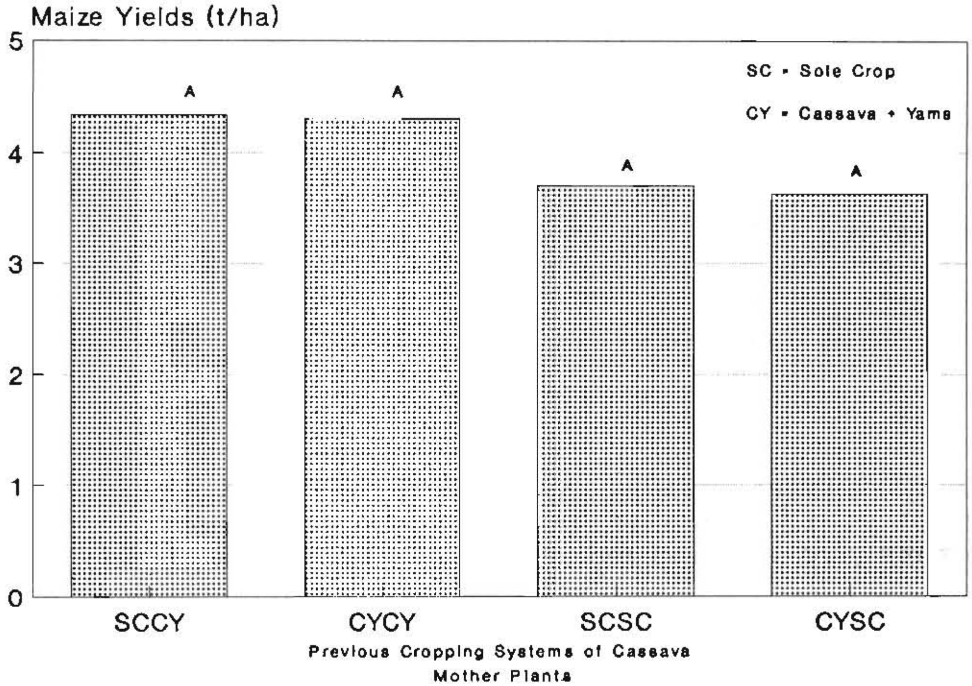


Figure 5.51 Yields of maize (H-211) intercropped with cassava and yams; planting stakes of the cassava plants were obtained from mother plants cultivated in different cropping systems during the two previous cropping seasons; bars with equal letters are not statistically different (DMRT, P = 0.05).

cropped with cassava grown from stakes of mother plants intercropped continuously (Fig. 5.52); however, this difference was not statistically significant with a 10% value for CV. Maize intercropped with cassava plants from continuously intercropped mother plants produced more cobs/plant than maize intercropped with cassava from stakes of plants grown continuously in monoculture.

Cassava grown from stakes from mother plants continuously intercropped probably has a slower initial growth than when grown from stakes of other origins and therefore competes less strongly with the intercropped maize; however, initial growth rates of cassava and maize were not recorded.

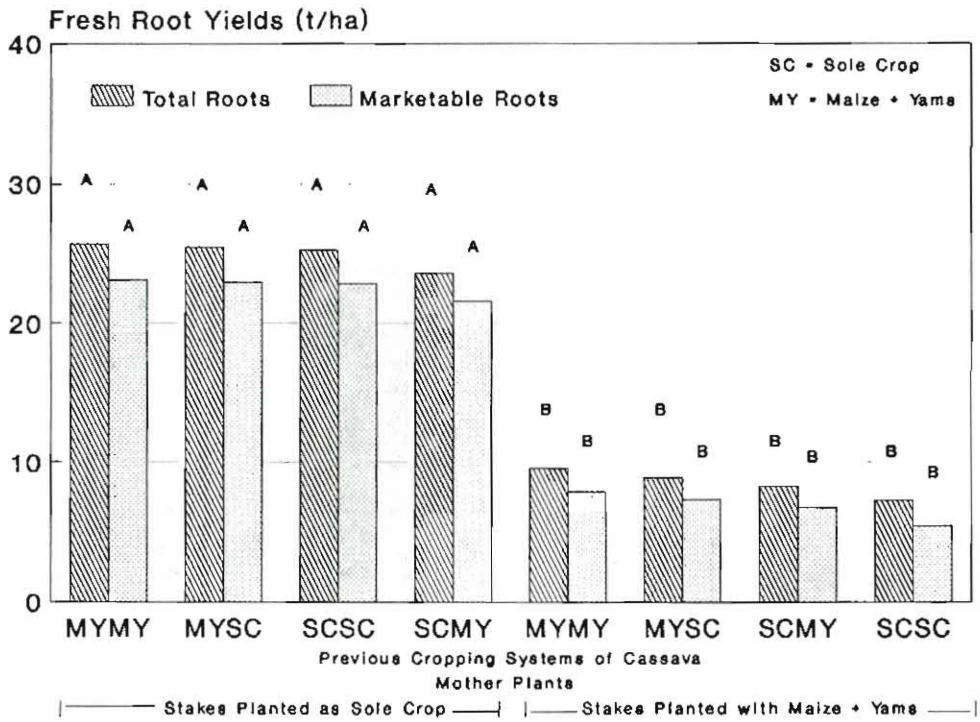


Figure 5.52 Total and marketable fresh root weight of cassava (CMC 40) obtained using planting stakes from mother plants cultivated in different cropping systems during the two previous cropping seasons; bars with equal letters are (DMRT, P = 0.05).

No significant differences were found between the yields (fresh root weight) of yams intercropped with cassava planted from stakes of mother plants previously intercropped or grown in pure culture (Fig. 5.53). Yams intercropped with cassava from stakes in continuous monoculture yielded significantly more roots/plant than than yams from other treatments (Table 5.46). Cassava plants from stakes grown continuously as a sole crop had vigorous initial growth, which provided yam vines with good physical support, resulting in more yam roots/plant.

Treatments 1 and 8 are considered the two extremes for this experiment. In Table 5.47 differences in no. of leaves/ plant and plant height are presented for these two extreme treatments.

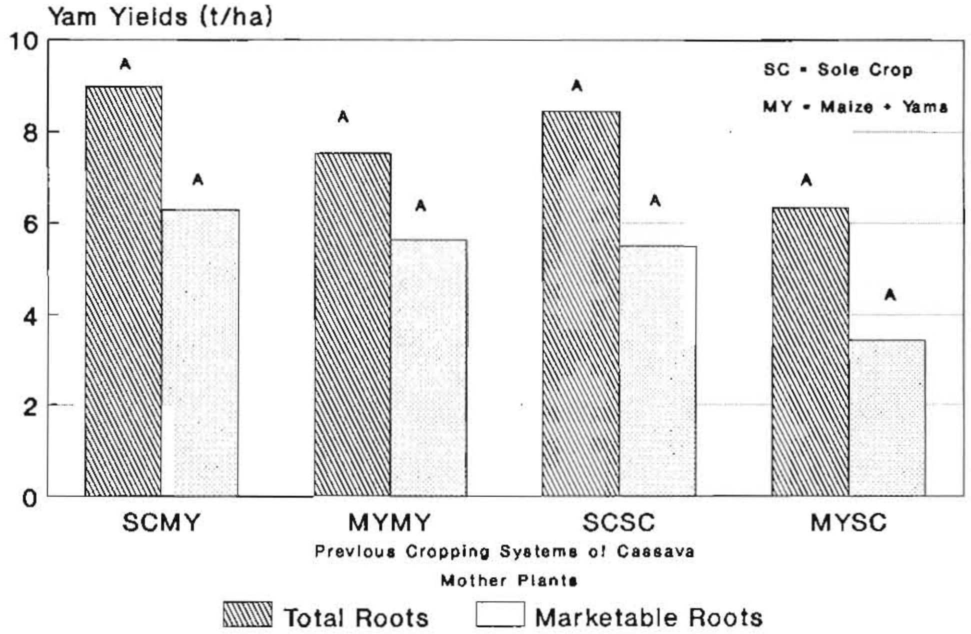


Figure 5.53 Yields of yams (CDC-18) intercropped with maize and cassava; planting stakes of the cassava plants were obtained from mother plants cultivated in different cropping systems during the two previous cropping seasons; bars with equal letters are not statistically different (DMRT, P = 0.05).

Table 5.46 Effect of origin of cassava planting stakes on no. of roots/plant of yams intercropped with cassava.

Treatment No.	Roots/Plants
2	2.27 a [1]
4	1.77 b
8	1.77 b
6	1.73 b

[1] Amounts followed by the same letter are not statistically different (DMRT, P = 0.05).

Table 5.47 Plant height and no. of leaves/pl of cassava grown as a sole crop from stakes of mother plants continuously intercropped for three consecutive years and continuously grown in sole crop for three consecutive years.

Sampling DAP	Plant Height		No. of Leaves/Plant	
	From Intercrop	From Sole Crop	From Intercrop	From Sole Crop
79	91a [1]	88a	62a	53a
126	128a	125a	82a	68b
159	172a	164a	151a	129b
186	188a	185a	194a	166b
216	210a	201a	202a	160b
247	228a	215a	212a	160b

[1] Means followed by the same letter in the same sampling period are not significantly different ($P \leq 0.05$, DMRT).

Plant height and no. of leaves/pl were higher for cassava monocultures planted from stakes originating from continuously intercropped plants. The no. of leaves/pl in plants grown from stakes that were always intercropped increased until the last sampling date while the no. of leaves/pl remains constant after 181 days for cassava grown from stakes originating from continuous monoculture.

Heights of intercropped cassava plants from stakes of mother plants continuously intercropped and plants from stakes continuously grown as a sole crop were not statistically different (Table 5.47); but the no. of leaves/pl in cassava plants from stakes of continuously intercropped mother plants was significantly higher than in cassava plants grown from stakes continuously grown as a sole crop (Table 5.48).

In other experiments with cassava associated with maize, with yams, and with maize and yams simultaneously, a higher no. of leaves/pl and, consequently, a higher leaf area were recorded immediately after harvesting the associated crops than in cassava of the same age but grown as a sole crop.

Table 5.48 Plant height and no. of leaves/pl of cassava grown in intercrop with maize and yams from stakes of mother plants continuously intercropped for three consecutive years and continuously grown in sole crop for three consecutive years.

Sampling DAP	Plant Height		No. of Leaves/Plant	
	From Intercrop	From Sole Crop	From Intercrop	From Sole Crop
79	109a[1]	108a	38a	30a
126	123a	123a	32a	29a
159	139a	127a	46a	33b
186	150a	148a	57a	41b
216	162a	165a	65a	43b
247	183a	183a	103a	57a

[1] Means followed by the same letter in the same sampling period are not significantly different ($P \leq 0.05$, DMRT).

6. CASSAVA ECONOMICS

The Economics Section of the Cassava Program at HQ has the responsibility for conducting research within a three-dimensional framework. As such, it has to work in an integrated fashion across disciplines within the Program. The Section also identifies and analyzes issues within its own discipline. Not only does the Section work in Latin America but also in Asia and Africa. Given the presence of IITA in Africa, the Section plays a minor role there. In Asia, on the other hand, cassava production and consumption developments have been dynamic, thus requiring an increasing amount of economics resources given the absence of a CIAT cassava economist stationed in the region.

To assist in optimizing the efficient development and diffusion of improved cassava technologies, the Economics Section allocates its resources among five major work areas (within the above framework):

-- Collection of regional and country data to monitor production and consumption of cassava (products) and related commodities

-- Generation of primary farm- and household-level data to identify and analyze cassava production, processing, marketing and consumption problems and opportunities

-- Ex-ante analyses of potential technologies in order to assess priorities, feasibility and probability of success

-- Collaboration in evaluating and diffusing improved technologies

-- Ex-post analyses of technology diffusion and impact

6.1 Past Emphasis

In 1984 the External Program Review recommended that CIAT undertake studies to assess the future demand for cassava and cassava products. Since then the Cassava Economics Section has focused its efforts almost entirely on cassava demand studies in Latin America and Asia. With support from the Rockefeller Foundation (RF), IITA, CIAT, NRI and several other institutions initiated a baseline survey on cassava production, processing, marketing and consumption in Africa under the name of COSCA (Collaborative Study of Cassava in Africa) in 1988.

The studies for Latin America and Asia were completed in 1987. The results clearly demonstrated that cassava products have a significant potential for the developing world, depending on the area; that for various processed cassava products there exists a strong and growing demand; that these products will continue to serve as an important source of relatively inexpensive calories for the very poor; and that on-farm or rural processing of cassava intermediate products (e.g., chips, starch, flour) can significantly improve incomes of the resource-poor, small farmer in the developing world.

Besides this major effort on the cassava demand studies, the Economics Section has allocated limited resources over the last 5 years, to supportive research on technology development and diffusion, as well as the ex-post measurement of technology adoption and impact, almost exclusively in Latin America.

6.2 Current Priorities

Given the adjustment of CIAT's research goals and objectives to meet the ever-evolving demands in a developing world, the Section's current research agenda includes the following major activities:

-- Adoption and impact studies of already diffused technologies, both in Latin America and Asia

-- Assessment and analysis of alternative cassava-based products markets in Latin America and Asia

-- Updating and expansion of the socioeconomic database for cassava products and related commodities for Latin America and Asia

-- Readjustment of the methodology and use of monitoring activities for Cassava Integrated Projects in Latin America

-- Coordination of the setting up of benchmark studies on cassava in Asia

-- Provision of economics input in technology development.

The Economics Section works on these topics together with a wide range of partners and under different institutional, organizational and financial conditions; e.g., networking, thesis work, contract research and training. In addition, a major emphasis for the next two years will be placed on adoption and impact studies. Table 6.1 lists the Economics Section's major projects and activities during 1990.

Table 6.1 Cassava Economics Section's major projects and activities in 1990.

Title/Objective	Topic	Collaborators	Country	Time Table
Organization/analysis of UAPPY's monitoring database	Regional impact	UAPPY, FUNDAGRO	Ecuador	Jan.-May
CIAT's commodity portfolio revisited; indicators of present and future importance	Ex-ante potential	CIAT economists	HQ	April-Dec.
The agroindustrial development of cassava on the Colombia Atlantic Coast	Thesis	Cornell University, USA	Colombia	June-Nov.
History, current status and potential of cassava use in Asia	Market potential	CGPRT Centre Bogor, Indonesia	Asia	June-Aug.
Ex-post impact of cassava technologies in Colombia	Ex-post impact	ICA, ANPPY, DRI	Colombia	July onward (ongoing)
Cassava study in Vietnam	Benchmark survey	MFI, IAS, INSA	Vietnam	Feb. onward (ongoing)
Adoption of Rayong-3: Beneficiaries	Ex-post adoption	Dept. of Extension, MAE	Thailand	Dec. onward (ongoing)

6.3 Research Results

Of this year's activities, two sets of research results will be discussed: a reevaluation by CIAT's economists of the Center's commodity portfolio and a study of the rapid development of Integrated Cassava Projects in Latin America and how monitoring activities can be a strategic device to refocus project strategies, while at the same time measure regional impact of an improved technology.

6.3.1 Quantifying the relative importance of cassava

The criteria used to assess the current importance or future potential of a crop reflect the user's objectives and goals. International agricultural research centers may have criteria that differ from those of developing country decision makers (in the short run); and the relative weights of criteria shift over time. In addition, especially in the case of cassava, the crop production system, production area, intensity of cropping, methods of processing, cassava-based product range and consumption patterns, change. These dynamics can, to a large extent, change the outlook of a crop.

In order to reexamine CIAT's commodity portfolio, a range of commodities (including CIAT's mandate crops) were evaluated on the basis of four sets of criteria: economic growth, equity, conservation of the natural resource base, and institutional considerations. The methodology developed for the analysis combines several different approaches. An initial hierarchical screening process was followed by a multiple-criteria model, based on a cost-benefit analysis using estimates derived from consultations with commodity experts. To establish the relative importance of cassava, this analysis focuses on only a small sample of the initial set of 18 commodities--cassava, beans, rice and sorghum--in Latin America. In the case of cassava, Asia is also included (for the original study, see Janssen et al. 1990).

6.3.1.1 **Economic growth**, as the principal aim of technology development, is by far the most widely used criterion. It is generally interpreted as the direct effect of increased production per unit of land or labor. Nevertheless, as the increased supply of a commodity can indirectly influence demand for other commodities (or goods and services) in nonrelated sectors, a linkage effect was introduced in the model to capture this indirect effect. Other economic growth criteria included present value of production, expected demand growth and potential foreign export earnings including import substitution.

The direct effect of potential technological impact on a commodity's supply and demand from 1990-2025 was estimated in a partial equilibrium framework. Estimates on commodity productivity increase, cost reduction, lag time and adoption rate were obtained through an expert-opinion survey. Benefits from research were calculated at net present value (NPV), applying a 10% discount rate (for model specifications, see Janssen et al. 1990). The indirect effect was estimated in a general equilibrium framework, and a distinction was made between tradeable and nontradeable commodities.

When commodities are evaluated (Table 6.2) for the criterion of monetary benefits from research only, rice technology can generate (direct and indirect) research benefits of well over US$5 billion. Cassava benefits at US$738 million are comparable to the other crops; however, it should be noted that cassava benefits are considerably higher when Asia is included.

When looking at the criteria of potential foreign export earnings and future demand growth, it becomes clear that cassava benefits in Asia and sorghum benefits are the

Table 6.2 Economic growth parameters for selected commodities in Latin America.

Parameter	Cassava LA	Cassava Asia	Beans	Rice	Sorghum
NPV of research benefits at 10% (millions US$).	419	1,076	594	2,957	619
NPV of multiplier effect (millions US$).	319	902	241	2,319	454
Potential foreign exchange earning[1]	*	***	*	*	***
Future demand growth[2]	≤	≥	=	=	>
Current value of production (millions US$)	1,461	1,767	2,459	4,070	1,237

1 *** = high; ** = medium; * = low (includes import substitution).

2 <, =, > than population growth.

winners. The last criterion--current value of production--to a large extent reflects a similar relative importance of rice. Thus, if the commodity's importance is measured by the foregoing economic growth criteria alone, rice technology presents the best picture. Nevertheless, cassava technology generates a relatively better pay-off than either beans or sorghum.

6.3.1.2 **Equity criteria**, as related to income improvement, have become increasingly important as the primary mechanism for reducing poverty and malnutrition. Agricultural commodities play a dual role: as food crops for small farmers and as generators of economic development. Development in Latin America has been characterized by intensive use of capital, with low labor absorption and labor displacement. Large producers benefit more than small ones from public policies, farm mechanization and input subsidies, resulting in increased urbanization, landless labor and increased poverty. Moreover, small farmers have often been pushed to less fertile or marginal lands. Therefore, equity criteria need to include benefits for small farmers and poor consumers, generation of labor and direct nutritional contributions.

For purposes of this analysis, measurement of the benefits to poor consumers was based on the results of the partial equilibrium model for the NPV of research benefits. The second criterion of benefits to small farmers was captured by using the share (%) for small farmers (i.e., earning a family income of < US$3000) among total farmers. The criterion of labor generation was introduced in the form of a technology-derived employment effect, which was measured using the general equilibrium model. The employment effect is comprised of (a) the direct effect, which measures employment changes within the commodity sector as influenced by technological changes; and (b) the indirect effect, which captures employment changes outside the subsector and is calculated through the linkage effect of the model. Total calories and proteins make up the last two equity criteria.

The results for the equity criteria are shown in Table 6.3. When considering benefits to poor consumers, rice technology can generate more than US$ 2.5 billion to this group; while cassava and beans can contribute US$ 461 and 415 million, resp. The contribution of sorghum to poor consumers is rather low. The picture changes dramatically, however, when inspecting the share of small farmers who benefit from technology. It can be seen that benefits are targeted to more than half the cassava and bean farmers; whereas for rice and sorghum, only 18 and 13%, resp., of the small farmers will profit from improved technology. Hence the largest proportion of rice and sorghum technology benefits will make intermediate and large farmers better off. In the case of cassava and beans, a relatively larger group of small farmers will benefit. Moreover, when considering derived benefits to Asian cassava producers, improved cassava technology automatically translates into improved incomes for the rural poor as 90% are small farmers.

The effect of employment shows relatively higher values for rice and cassava in Asia. This is in line with the knowledge that cassava products in Asia and rice employ a considerable labor force during the processing stage. Total calories and proteins are high for rice and beans; but it should be noted that these values are expressed for direct human consumption. If the amount of cassava used in animal feed to produce animal protein (direct human consumption) were calculated, the calorie and protein values for cassava would be significantly higher. The same reasoning applies for cassava starch used in human food products.

6.3.1.3 In the past little consideration was given to **natural resource preservation** in assessing the relative importance of agricultural commodities research. Economic growth, equity and natural resource management interact and

Table 6.3 Equity parameters for selected commodities in Latin America.

Parameter	Cassava LA	Cassava Asia	Beans	Rice	Sorghum
Technology-derived benefits for poor consumers (millions US$)[1]	461	280	415	2,595	62
Small farmers benefiting from new technology (%)[2]	58	90	55	18	13
Technology-derived employment effect ('000 person-yr)	60	111	-63	98	59
Total calories for human nutrition (millions kcal/day)	229.8	56.7	38.8	106	2.3
Total proteins for human consumption ('000 kg/day)	187	355	2,393	2,100	60

[1] For consumers of two lowest income quintiles (lowest 40%).

[2] Farmers with incomes of less than US$3000/family.

link in such a manner that a negative effect of one of the them will have a negative impact on the combined outcome in the long run. Together they have to be sustainable for beneficial results in the future.

Although one can identify suitable parameters that would incorporate or at least approximate sustainable resource management criteria, their quantification is a serious bottleneck for lack of "hard" data, which if they exist, are often too general and too rough. Hence in the current analysis an attempt was made to qualify the relative contribution of commodity technology to the conservation of the natural resource base in specific ecozones of Latin America. CIAT's Agroecological Unit recently defined three ecozones, which in line with future Latin American development will benefit most from agricultural research in an integrated resource management/germplasm development framework. These are (1) the hillsides, (2) the savannas and (3) the seasonal forest transition zones.

There are no significant differences among the commodities for this criterion (Table 6.4). Cassava technology may have an intermediate contribution for all zones, while rice may have a large contribution for the savannas (based on integrated rice/legume pastures technology). Sorghum contributes the least to natural resources preservation. Although somewhat inconclusive, the scoring of these criteria (based on commodity expert opinion) may serve in a decision-making process when weights are attached to each.

6.3.1.4 The last set of criteria--**institutional considerations**--is of great importance to agriculture research. Without a viable institutional research capacity the potential of a crop may never be realized. In this analysis, three criteria were used to incorporate institutional aspects. Of prime importance is current investigation by national programs. To score this, an attempt was made to evaluate national program presence, capacity, effectiveness and sustainability. Especially this last parameter is often rather questionable. National program human and capital resources are very dependant upon the country's economic and political performance, which do not tend to be very stable in Latin America. The second criterion lists other international research efforts. The last criterion is the lead time of research, which to a certain extent measures the difficulty in developing improved technology for a commodity.

From the results in Table 6.4, it can be observed that cassava has weak national program investigation; while beans, rice and sorghum have intermediate scores. Nevertheless, this needs some clarification. The intermediate score for bean research is based on the real strength of the

Table 6.4 Conservation of natural resources and institutional parameters for selected commodities in Latin America.

Parameter	Cassava LA	Cassava Asia	Beans	Rice	Sorghum
Conservation of natural resources[1]					
Hillside zones	**	-	**	*	*
Savanna zones	**	-	**	***	**
Seasonal forest transition zones	**	-	*	**	*
Institutional					
Current research of national programs[2]	*	*	**	**	**
Current research international centers	IITA	IITA	CRSP	IRRI, WARDA	INTSORMIL, ICRISAT
Lead time of research (yr)	8	6	4	4	7

[1] Relative contribution of commodity technology to the conservation of the natural resource base in specific Latin American ecozones.

[2] Weak and strong: * ; intermediate: **

national programs. In the case of rice and sorghum, the intermediate score is more a reflection of relatively strong producer organizations and commercial companies. With regard to other international research efforts, work is being done on all commodities; in most cases, however, this research is conducted under different agroclimatic conditions. The last criterion shows that both cassava and sorghum have long lead times for research, implying that research benefits will accrue at a longer horizon than that for rice and beans.

6.3.1.5 What major <u>conclusions</u> can be drawn from this analysis? Basically two. First of all, the importance of cassava has been demonstrated, both quantitatively and qualitatively, for several sets of criteria. Current value of cassava production is US$1.46 and 1.76 billion in Latin America and Asia, resp. The NPV of research benefits from improved technology (including the multiplier effect) amount to US$738 and $1.978 million for LA and Asia, resp. It has also been shown that cassava in Asia enjoys strong growth in future demand and a high potential for foreign exchange earnings. From the standpoint of equity, it has been demonstrated that technology-derived benefits to consumers in the lowest 40% income groups amount to US$460 and $280 million in Latin America and Asia, resp. Because of improved cassava technology, 60,000 and 111,000 person-years of labor can be generated on these two continents. Moreover, it is primarily the small, resource-poor farmer who is the ultimate beneficiary.

From a natural resources preservation perspective, it was noted that cassava research can have an intermediate contribution to the conservation of the natural resource base in several Latin American ecozones. From an institutional standpoint, it was shown that cassava research at the national level is weak in general. Benefits from improved technology have a 6- to 7-year research lag time.

The second major conclusion that can be drawn from this analysis is that the relative importance of a commodity vis-a-vis others can significantly change depending on the criteria that are used. Table 6.5 gives a summary of the four sets of criteria used in the analysis. If the decision maker uses only the criterion of economic growth to assess the importance of a crop for research investment, rice would

Table 6.5 Summary of scores for four sets of criteria for evaluating the relative importance of commodities.

Criteria	Cassava LA	Cassava Asia	Beans	Rice	Sorghum
Economic growth		*	**	*	*** *
Equity		**	***	**	** *
Natural resources preservation	*	**	*	**	**
Institutional considerations		*	*	***	** ***

be the obvious choice. However, if the decision is based on equity alone, cassava research (in Asia) would be the clear winner. Similar contradictory conclusions can be drawn when reviewing the other two sets of criteria. Hence, if decision makers have clearly defined their goals and objectives, they are able to place weights on each criterion, covering all the different aspects that need to be considered. Depending on the objectives, the outcome would probably be a portfolio of commodities whose potential technology would influence a broad range of essential criteria positively, within the decision maker's multi-objective decision framework.

6.3.2 Growth and monitoring of integrated cassava projects

The following short analysis not only quantifies the dynamic adoption of a cassava technology but also demonstrates the value of monitoring. The integrated cassava project concept was initially developed in the Atlantic Coast region of Colombia in the early 1980s. Small cassava farmers' associations using small-scale processing methods started to produce chips for the animal feed industry as an alternative to selling for the fresh market. Over the last 9 years this methodology has been rapidly adopted throughout Central and Latin America (Fig. 6.1). By 1990, there were four other major cassava-producing countries, besides Colombia, with integrated cassava projects. While the no. of cassava drying plants on the Colombia North Coast increased by 11% annually, in Ecuador the rate was almost twice that (20%). In Brazil (state of Ceará) the no. of plants remained constant until the start-up of a special project funded by the W.K. Kellogg Foundation, after which the no. of plants increased by 23%. It must be noted here that in Colombia and southern Brazil, additional plants have sprung up (for which no official data exist), so the total no. of drying plants in these countries exceeds the figures presented.

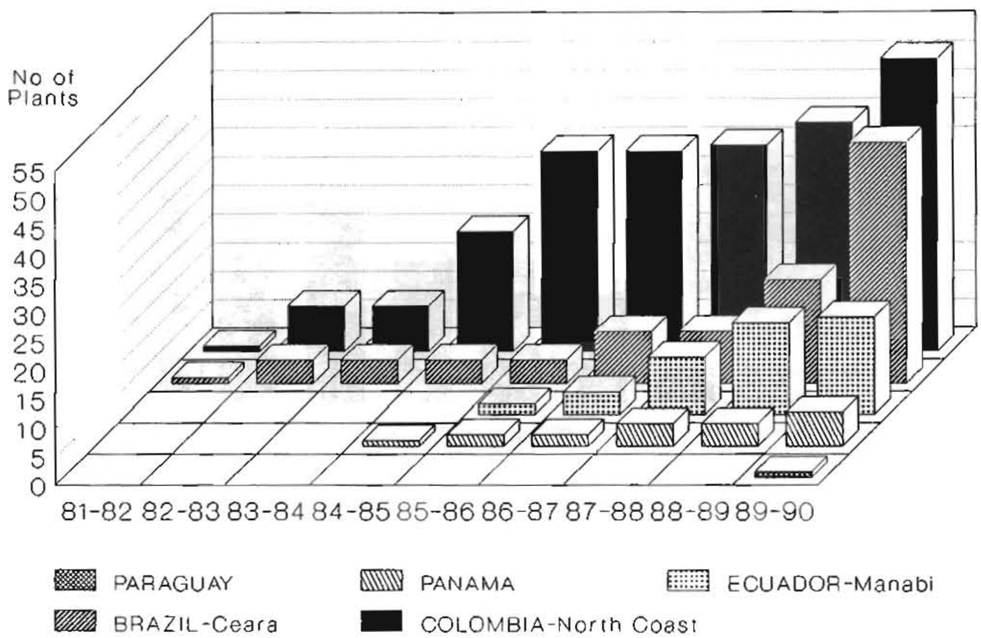


Figure 6.1 Expansion of cassava drying plants in selected countries of Latin America (1981-90).

Cassava drying production estimates are given in Figure 6.2. It can be seen that drying plant production in Colombia increased from 38 t in 1982 to almost 10,000 t in 1990. Figure 6.3 shows a similar increase for value of dried cassava production.

In addition to these aggregate results, it is of interest to analyze some of the monitoring data that each of the projects generates annually. With this information, project decision makers are able to verify long-term goals and objectives by adjusting short-term strategies. In addition, collaborating researchers can receive feedback for necessary changes in integrated research support.

For example, Figure 6.4 shows that in the Ecuadorian drying campaign of 1988-89, cassava flour/chip production decreased significantly. This was due to a slump in the demand for shrimp feed, for which cassava flour is an integral part. Although the demand strengthened the next year, the Ecuadorians realized that their output market was very limited and that alternative markets should be explored. As such, an increased production of cassava starch can be observed in 1990, which diversifies the market and lowers project risks.

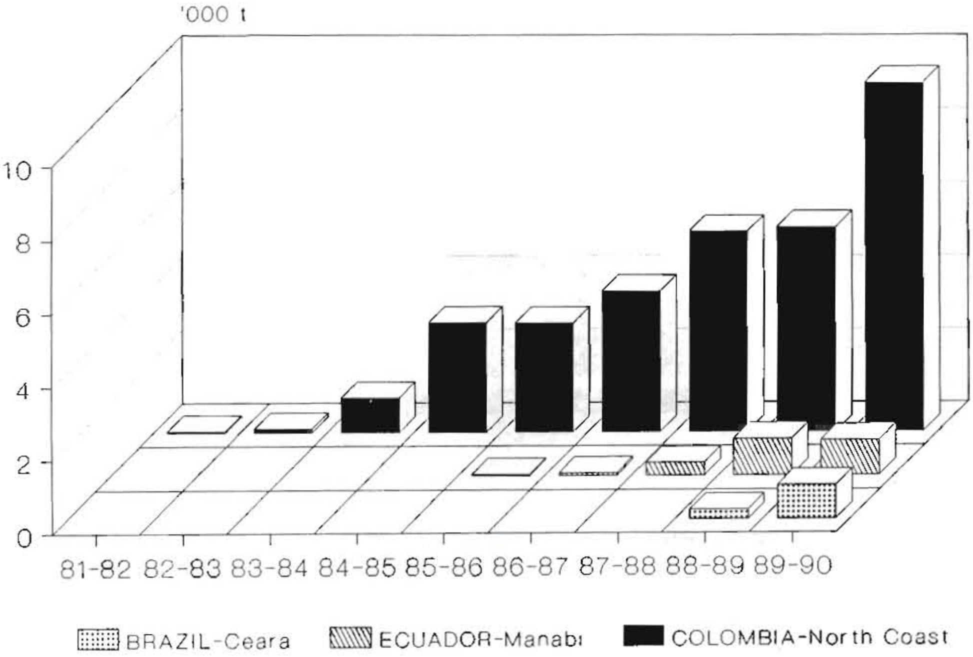


Figure 6.2 Cassava drying production in selected countries of Latin America (1981-90).

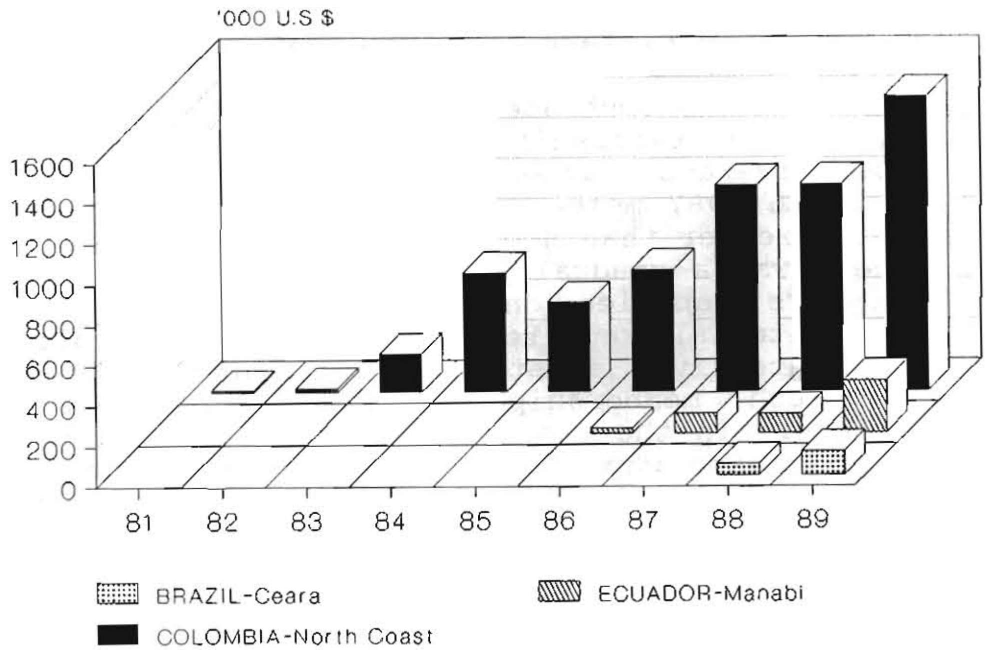
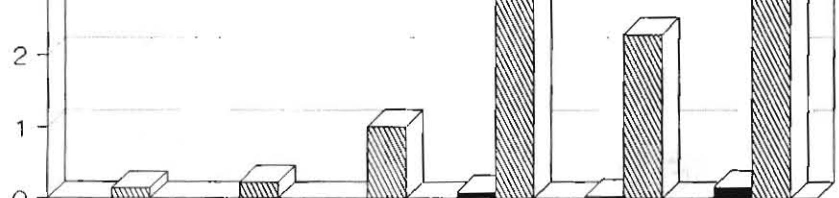


Figure 6.3 Value of production from cassava drying plants in selected countries of Latin America (1981-90).

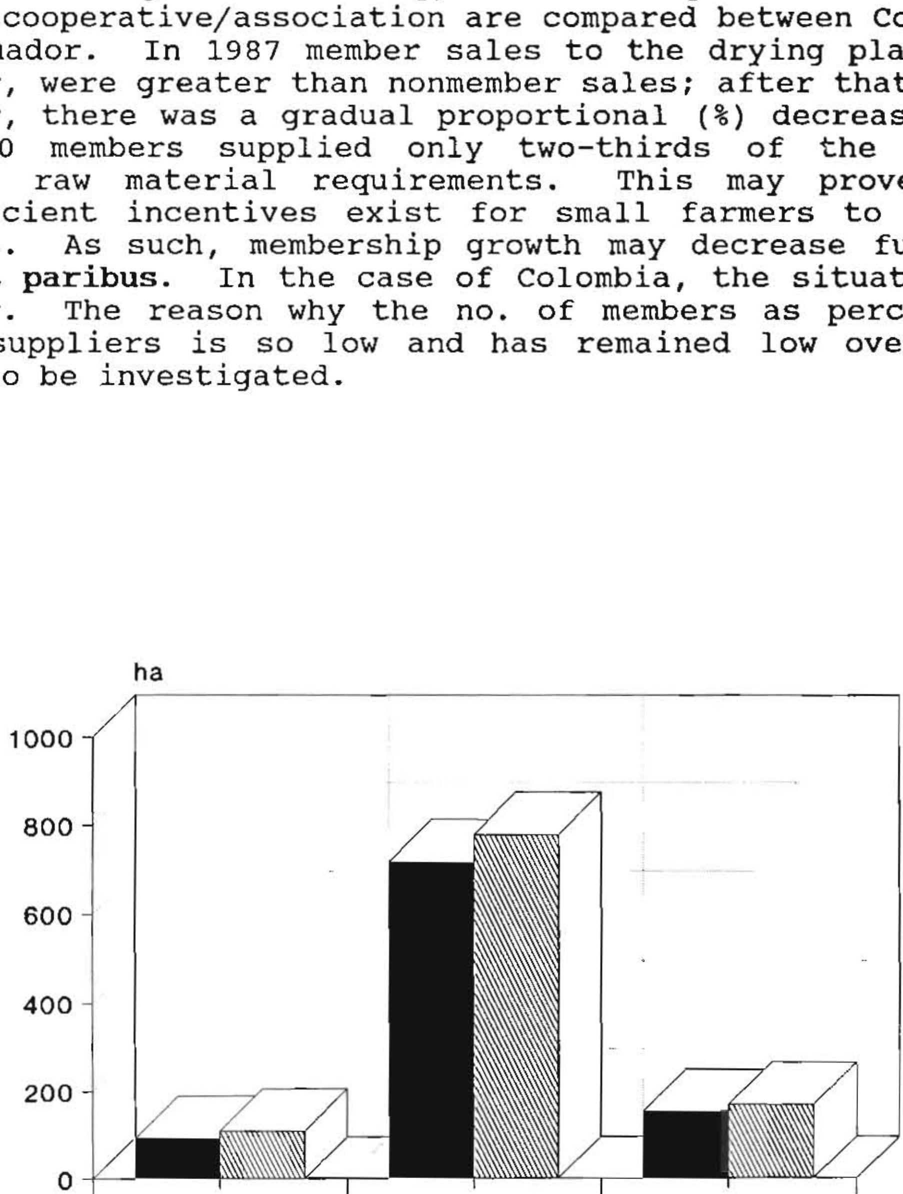


	84-85	85-86	86-87	87-88	88-89	89-90
Starch				0.09	0.03	0.162
Chips	0.142	0.228	1.006	2.85	2.28	5.027

Figure 6.4 Cassava utilization in integrated projects in Manabi, Ecuador (t fresh wt equivalent).

Other information from Brazil (Fig. 6.5) shows that most of the cassava grown for the drying plants is produced by smallholders. This information can, over time, shed light on technology impact on landholding systems. At the same time, it serves to verify the goals of the project with respect to what type of farmer the technology is benefiting.

A similar issue is demonstrated in Figure 6.6, where cassava sales according to membership/nonmembership in the farmers' drying cooperative/association are compared between Colombia and Ecuador. In 1987 member sales to the drying plants in Ecuador, were greater than nonmember sales; after that year, however, there was a gradual proportional (%) decrease; and by 1990 members supplied only two-thirds of the drying plant's raw material requirements. This may prove that insufficient incentives exist for small farmers to become members. As such, membership growth may decrease further, **ceteris paribus**. In the case of Colombia, the situation is similar. The reason why the no. of members as percent of total suppliers is so low and has remained low over time needs to be investigated.



	Sharecroppers	Smallholders	Renters
1988	92.6	717.49	152.3
1989	109.4	777.99	169.2

Figure 6.5 Hectares of cassava by land tenure in Brazil (Ceará Project).

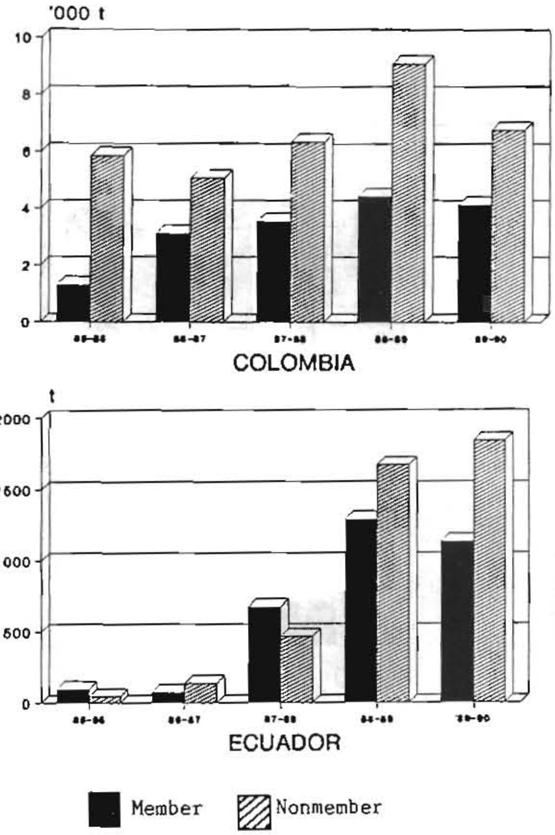


Figure 6.6 Cassava sales to drying plants by membership in Ecuador and Colombia.

Information of a different nature is shown in Figure 6.7, which compares the use of different cassava varieties over time, by suppliers to the drying plants in Manabí, Ecuador. The variety "Taurino", which in 1985 accounted for the largest share (41%) fell to only 11% in 1990. A similar trend was shown by "Chola." However, the reverse was true for "Tres Meses," whose share increased from 37% in 1985 to 88% in 1990. This very strong evidence of a variety that becomes dominant within 5 years and other varieties that virtually disappear needs to be studied by cassava breeders, processing specialists and economists to see whether it was caused by abiotic stresses, changing quality demand, starch content, etc.

This sample analysis of monitoring data demonstrates that if collected timely, analyzed properly and fed back to the right audience of project coordinators, supporting institutions and researchers, the information is of great value in helping cassava integrated projects become more efficient and effective in increasing employment and incomes of the rural poor.

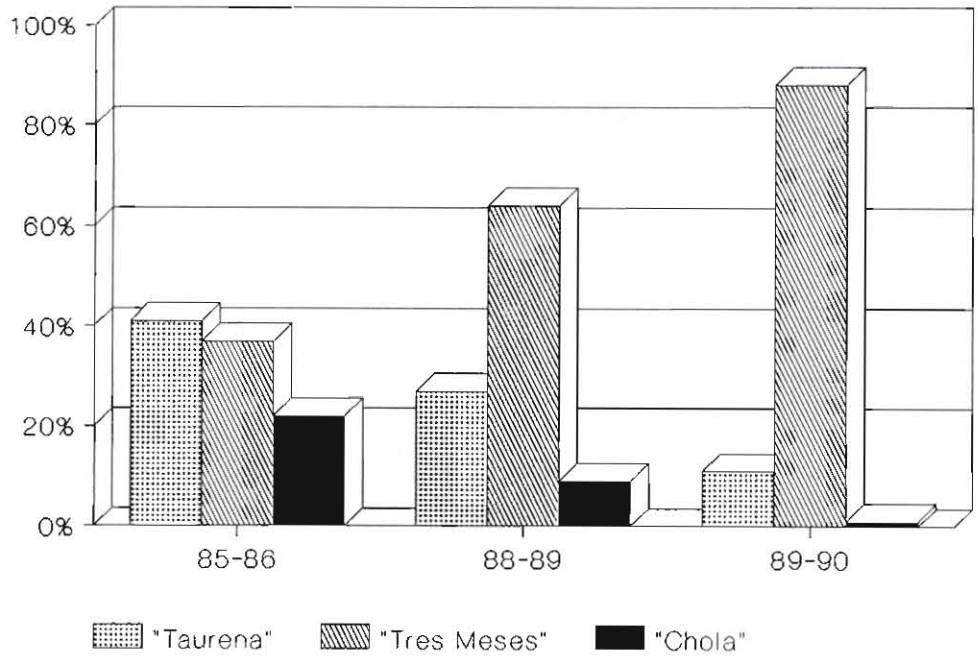


Figure 6.7 Cassava variety changes in drying plants in Manabí, Ecuador (Napoleón Chávez, INIAP).

6.4 References

Janssen, W., Sanint, L., Rivas, L. & Henry, G. 1990. Trends in CIAT Commodities (Working Document No. 74). Cali, CIAT.

7. CASSAVA UTILIZATION

During 1990 the Utilization Section continued research on cassava starch and flour for human consumption and on cassava quality for all end uses. In addition some research was conducted on improving the practicality of the fresh cassava storage technology based on the experiences of the pilot project on the Atlantic Coast of Colombia. The Section also devoted significant human and material resources to training and support of integrated cassava projects in Colombia, Ecuador, Paraguay and Brazil.

The Section actively pursues collaboration with relevant institutions in the developed and developing world in the areas of process and product development as a mechanism for allowing a greater proportion of core resources to be devoted to research on cassava quality issues. During this past year, collaboration was received from CEEMAT/CIRAD of France on research on fermented cassava starch; NRI of the UK on research on cassava flour and quality (especially HCN); and the financial support of IDRC, Canada for the pilot phase of the cassava flour project. Research collaboration with the Universidad del Valle (UNIVALLE) Cali on cassava flour and starch process and product development was intensified. An agreement with the University of the State of Sao Paulo (UNESP, Botucatu) will strengthen collaboration in the areas of cassava starch, eating quality and HCN research.

7.1 Cassava Quality

7.1.1 Cyanide analysis. The Utilization Section has used Cooke's (1978) enzymatic method for analyzing root cyanide content for the last 10 years. This method requires extracting free cyanide and cyanogenic glucosides into a stable medium (orthophosphoric acid). The subsequent enzymic hydrolysis of the cyanogenic glucosides uses exogenous linamarase and the determination of total cyanide is based on color reaction with piridine/pirizolone. This method was recently modified by the NRI. A different initial medium increases the time permitted between extraction and hydrolysis from 4 to 30 days. The amount of piridine used is also greatly decreased, reducing costs and the risks involved in handling this toxic chemical. This modified method also permits the quantification of cyanhydrin intermediaries in addition to the free and bound cyanide already possible. Cyanohydrins are an intermediary step in the breakdown of cyanoglucosides to free cyanide. Although unstable in fresh roots, cyanohydrins may be found in some processed products.

A third variation of the enzymatic method (Monroy, 1990) was also tested. The color reaction is carried out using barbituric acid, which requires only 4 min vs over 1 h for the piridine/pirizolone method. The faster reaction time is not a significant advantage, however, as fewer samples can be analyzed per batch. Moreover, use of barbituric acid, which is a restricted drug in many countries, may be difficult and supplies uncertain. The reduced use of piridine is an advantage, however.

Table 7.1 gives the differences among the three methodologies. The ability to store the extracted samples for up to 1 mo before analysis is a significant advantage, especially for those labs where only a small number of samples are collected on a daily basis, allowing accumulation of samples for analysis on a weekly or biweekly basis for more efficient use of reagents, etc. It also allows more time for samples prepared in the field to reach the lab.

Table 7.2 compares the three options tested for the enzymatic method, using root parenchyma tissues from three varieties. All three options produced similar results although the barbituric acid color reaction tended to give a lower value than the other two.

Research laboratories in Latin America use a wide range of methods for cyanide analysis of cassava, cassava products and waste water from cassava-based industries (pollution control). A workshop was organized between CIAT and UNESP with participants from Brazil, Paraguay, Ecuador, Colombia and Mexico, at which 5 methods were compared for a range of cassava products. The enzymatic method was the only one that gave consistent and reproducible results for all types of products. In particular, the widely used picrate color reaction was highly inaccurate for some of the products tested. This workshop has already resulted in greater standarization of research methodologies (using the enzymatic method) by many of the participants, and interest has been expressed recently by Asian countries in similarly standardizing the analytic methods used on that continent.

7.1.2 Starch analysis

The analysis of cassava root starch content is a basic need for any lab working on this root crop as it comprises over 80% of root DM content. The basic steps to follow for this analysis are hydrolysis of starch and quantification of the glucose liberated through hydrolysis.

The first step--hydrolysis--is the limiting one for all methods; and the precision of analysis depends greatly on the efficiency of this process. The Utilization Section had used the AOAC standard method of acid hydrolysis until

Table 7.1. Comparison of three enzymatic methods of cyanide analysis: methodological differences.

	Cooke (1978)	Cooke Modified (1990)	Monroy et al. (1990)
Extraction medium	Orthophosphoric acid	Same with 25% ethanol	Orthophosphoric acid
Stability of extraction medium (days)	4	30	4
Determination of cyanohydrins	No	Yes	Yes
Color reaction	Piridine/ pirozolone	Piridine/ pirozolone	Piridine/ barbituric acid
Color reaction time (min)	60	60	4

Table 7.2 Comparison of three enzymatic methods for cyanide determination in cassava fresh root tissues (mg/kg fresh wt).[1]

	Analytic Method		
Clone	Cooke (1978)	Cooke (modified 1990)	Monroy et al. (1990)
M Col 22	67.3 ± 17	67.7 ± 20	56.3 ± 16
CM 507-37	219.7 ± 22	244.7 ± 44	174.0 ± 45
M Ven 25	1020.9 ± 260	956.0 ± 174	916.2 ± 122

1 Value are means of 10 samples/clone ± SD.

recently when it was decided to compare this with an enzymatic method (based on Bate & Ryde, 1982). This involves the solubilization of starch with a thermostable enzyme (amylase) followed by enzymatic hydrolysis with amyloglucosidase.

For the second step, the glucose resulting from the acid hydrolysis method was quantified using a copper reagent, whereas for the enzymatic method glucose oxidase was used to determine glucose content.

Table 7.3 shows the percent starch found in each of the four varieties of cassava analyzed using the two methods. Values were lower for acid hydrolysis than for the enzymatic method, which also had smaller standard deviation values. Acid hydrolysis was probably less efficient at hydrolyzing all the starch than the enzymatic method, which is now standard in the Utilization Section. Another advantage is a 50% reduction in cost compared with the acid hydrolysis method.

7.1.3 Effect of preharvest variables on root quality

Continuing collaboration between the Physiology and Utilization sections has provided a wealth of information on the effects of the preharvest environment, especially fertilizer application and water stress, on root quality factors such as DM and cyanide contents and eating quality. Experiments were managed by the Physiology Section in Santander de Quilichao (Cauca) and Pivijay (Magdalena) Colombia (see Section 5.1 for production-related results).

The Utilization Section took root samples from relevant experiments for DM, starch, cyanide and eating quality evaluations. These show that many of the treatments used in the experiments do affect root quality. Cyanide content has proved especially variable in this respect.

Table 7.3 Comparison of two methods of starch content determination from cassava root tissues.[1]

Clone	Acid Hydrolysis	Enzymatic Hydrolysis
1	72.8 ± 4.0	80.2 ± 0.4
2	73.3 ± 2.6	80.8 ± 0.4
3	82.0 ± 3.8	87.0 ± 0.0
4	77.0 ± 9.1	86.3 ± 0.3

[1] Values represent means of 6 reps/clone ± SD.

Two experiments were carried out studying the effect of different levels of NPK application and annual vs. residual effect (Tables 7.4 & 7.5). Identical results were obtained in both experiments, in that those treatments with zero K produced roots with the highest cyanide and lowest DM contents. DM content was increased by annual applications, but cyanide content increased in one experiment and decreased in another. This may be a varietal effect.

Considering each element separately, N application (Table 7.6) increased root DM content and decreased cyanide content. There was also an effect on eating quality of roots from plants treated with progressively increasing levels of N, which improved in taste and texture. The source of N was also important in affecting DM content and eating quality.

Table 7.4 The effect of NPK applications on root DM and total cyanide contents of M Col 1684 and CM 91-3, harvested at Santander de Quilichao.

	Root Quality Factor	
Treatment	%DM	Total HCN (ppm, DM Basis)
Fertilizer Application		
Annual	34.1	519
Residual	33.8	335
Significance	NS	0.01%
NPK levels (kg/ha)[1]		
0-0-0	33.7 abc	449 ab
50-50-50	33.8 abc	427 b
0-100-100	34.0 ab	376 c
50-100-100	33.5 bc	407 bc
100-100-100	34.7 ab	422 b
100-0-100	34.1 ab	412 bc
100-50-100	34.7 a	422 b
100-100-0	32.8 c	475 a
100-100-50	34.1 ab	450 ab
Significance	1%	1%

1 Values followed by different letters are significantly (5%) different, DMRT.

Table 7.5 Effect of applying NPK on root DM and total cyanide content of M Col 1505 at Pivijay.

Treatment	% DM	Total HCN (ppm, DM Basis)
Fertilizer Application		
Annual	41.5	303
Residual	39.5	376
Significance	0.1%	0.1%
NPK level (kg/ha)[1]		
0-0-0	39.5 b	352 abc
50-50-50	40.6 a	345 abc
0-100-100	40.9 a	316 c
50-100-100	40.6 a	339 abc
100-100-100	40.9 a	323 bc
100-0-100	40.6 a	333 abc
100-50-100	40.8 a	328 abc
100-100-0	39.9 ab	363 a
100-100-50	40.6 a	357 ab
Significance	5%	5%

[1] Values followed by different letters are significantly (5%) different, DMRT.

P application at 75 t/ha decreased root DM content and increased HCN content significantly (Table 7.7). Considering individual varieties, there were some differences; for example, SM 414-1 significantly increased in DM with P application against the general trend. From the standpoint of root quality, varieties adapted to low P would appear to be valuable.

Applications of K, even at moderate levels, decreased root cyanide content significantly and tended to increase DM content although this was not significant (Table 7.8). This agrees with the results of the NPK trials (Tables 7.4 & 7.5).

Table 7.6 Effect of N source and level on root DM and total cyanide content, and eating quality of M Col 1505 at Pivijay.

Treatment	% DM	Total HCN (ppm, DM Basis)	Eating Quality[1] Texture	Taste
Source				
NH4SO4	33.3	179	2.1	2.4
Urea	33.9	172	1.9	2.1
Significance	1%	NS	5%	5%
Level (kg/ha)[2]				
0	33.1 b	187	2.5 a	2.6a
50	33.9 a	189 a	2.1 a	2.3ab
100	33.7 a	176 ab	2.1 a	2.3ab
200	33.8 a	149 b	1.5 b	1.8b
Significance	5%	5%	0.1%	5%

1 Taste and texture evaluated on scale: 0 = excellent to 3 = bad.

2 Values followed by different letters are significantly (5%) different, DMRT.

Considering all these NPK trials together, it is clear that root quality is greatly affected by the levels of application of each element, and that although K and N appear to improve quality and P to decrease it, considerable varietal differences exist that could be exploited to achieve high-quality roots at low levels of fertilizer application.

Table 7.9 reports an experiment combining fertilizer application treatments with water stress (irrigated vs. rainfed or stressed plots), in which fertilizer application decreased root cyanide content and water stress increased both DM and cyanide contents. Plants were harvested at 5, 7 and 12 mo of age. DM increased with age, and eating quality improved. Cyanide content showed great variation, being significantly lower at 7 mo than at 5 or 10 mo. Table 7.10 shows how cyanide content varies with age for both stressed and irrigated treatments. Cyanide content was higher in

Table 7.7 Effect of P application on root DM and total cyanide content of 33 clones harvested at Santander.

Treatment	(% DM)		Total HCN Content (ppm DM Basis)	
P Application (kg/ha)				
0	37.0		200	
75	35.8		241	
Significance	1%		5%	
Clone x P	0	75	0	75
CG 927-12	36.1*	33.8	187	206
CG 996-6	38.8*	34.3	131	163*
CG 1374-2	40.0	39.3	128	154
CM 305-41	32.0	31.8	286	411*
CM 2718-1	35.9*	35.1	286	360*
CM 2774-11	37.3	36.7	96	119
CM 3285-7	37.8*	35.3	139	192*
CM 3401-2	37.7*	36.3	172	208*
CM 3456-3	36.4*	34.7	158	219*
CM 3654-3	40.1*	37.7	138	154
CM 3667-1	37.1	37.2	251*	220
CM 3750-5	37.6	37.6	278*	249
CM 4145-4	37.1	36.9	124	177*
CM 4575-1	37.1	36.9	234	285*
CM 4617-1	35.8	35.5	424	477*
CM 4701-1	38.5	38.2	102	132*
CM 4711-2	37.6	37.2	418*	262
CM 4716-1	40.2	39.7	123	154*
CM 4793-1	38.7*	36.7	257	354*
CM 4830-3	35.0*	31.0	184	343*
CM 4864-1	38.3*	35.3	152	189*
M Bra 191	35.6	35.9	168	227*
M Bra 383	37.4	37.2	350*	305
M Col 2215	38.5*	34.9	291	382*
M Pan 51	36.6*	33.7	148	293*
SG 104-264	37.0*	35.7	193	260*
SG 104-284	35.3	34.7	125	253*
SG 106-59	33.6	35.8*	168	150
SG 250-3	37.5*	33.3	145	181*
SG 302-1	36.1*	35.2	232	270*
SG 455-1	39.5*	38.2	166	214*
SG 545-7	33.9	33.5	207	198
SM 414-1	33.7	37.0*	132	204*
	LSD = 0.8		LSD = 29	

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

Table 7.8 Effect of K application on root DM and total cyanide content (mean of 8 clones harvested at Pivijay).

Treatment	(% DM)	Total HCN (ppm, DM Basis)
Level of K (kg/ha)[1]		
0	34.5	350 a
50	34.2	286 b
100	35.0	277 b
200	35.3	256 b
Significance	NS	0.01%

1 Values followed by different letters are significantly (5%) different, DMRT.

stressed plants at 5 and 7 mo, but lower at 10 mo than in the irrigated plots.

In a final water stress experiment, stress greatly increased root total cyanide content of each of four varieties although some showed greater percent increases than others (Table 7.11). Harvests were carried out at 6 and 11 mo of age. Root DM content increased between 6 and 11 mo in stressed plants (i.e., following the removal of the water stress regime) whereas DM content in control plants decreased over the same period.

Considering varietal effects on root starch content (Table 7.12), CM 489-1 produced lower values in control plants at 6 mo, but by 11 mo this had reversed. On the other hand, CM 2136 had higher starch content in stressed plants at 6 mo, with the position reversed at 11 mo. The response of plants to water stress is thus highly dependent on genetic factors as regards DM and starch content. This leaves considerable scope for varietal development to obtain high-quality roots under adverse environmental conditions.

7.2 Fresh Cassava Conservation

Since 1987 the Colombian Integrated Rural Development (DRI)-CIAT pilot project has been functioning in Barrranquilla, using the fresh cassava conservation technology developed by CIAT/NRI and first field tested in Bucaramanga, Colombia (see Annual Reports 1983-1984 for experimental

Table 7.9 Effect of fertilizer application and water stress on root DM, total cyanide content and eating quality from plants of M Col 1684 and CM 507-37 harvested at three ages at Santander.

Treatment	(% DM)	Total HCN (ppm, DM Basis)	Eating Quality[1] Texture	Fiber
Fertilizer Application				
500 kg/ha 10-20-20	28.1	745	2.5	1.7
Control	28.1	891	2.8	1.6
Significance	NS	0.1%	5%	NS
Irrigation	26.9	747	2.7	1.9
Water stress	29.3	890	2.7	1.4
Significance	30.1%	0.1%	NS	1%
Age at Harvest (mo)[2]				
5	24.5 c	945 a	2.8 a	2.1 a
7	28.9 b	576 b	2.7 ab	1.6 b
10	31.0 a	934 a	2.5 b	1.2 c
Significance	0.1%	0.1%	5%	0.1 %

1 Texture and fiber evaluated on scale: 0 = excellent to 3 = bad.

2 Values followed by different letters are significantly (5%) different, DMRT.

Table 7.10 Effect of water stress on total root cyanide content at different plant ages.

Plant Age (mo)	Total HCN (ppm, DM Basis) Irrigation	Water Stress
5	779	1110
7	492	660
10	968	900
	LSD = 59	

Table 7.11 Effect of water stress on root DM and total cyanide contents of four clones harvested at two ages.

Treatment	(% DM)	Total HCN (ppm, DM Basis)
Water stress	32.3	326.5
Control	32.3	186.5
Significance	NS	1%

	(% DM)	Total HCN (ppm, DM Basis) Mean	Drought	Control
Variety				
CM 489-1	27.5 d	350 a	432	268
CM 922-2	36.3 a	210 c	259	161
CM 1335-4	35.0 b	179 c	218	127
CM 2136-6	30.4 c	294 b	398	191
Significance	0.1%	0.1%		

	(% DM) Mean	Drought	Control	Total HCN (ppm, DM Basis)
Age at harvest (mo)				
6	32.3	31.3	33.1	290
11	32.3	33.2	31.4	226
Significance	NS	LSD = 0.0.01%		

phase, 1985-1987 for Bucaramanga project and 1987-1989 for Barranquilla reports). The process was technologically satisfactory, and good acceptance of the stored product was obtained by retailers and consumers, which led to the placing of orders for storable cassava from many supermarkets and shops in Barranquilla and other markets. Scale-up of the volumes of fresh cassava treated and packed beyond the 10 t/wk maximum achieved to date has been frustrated by two bottlenecks--one in the area of the

Table 7.12 Effect of water stress on root starch content in four clones harvested at 6 and 11 mo of age.

	Root Starch Content (%, DM Basis)			
	6 mo		11 mo	
Clone	Water Stress	Control	Water Stress	Control
CM 489-1	70.5	79.3	81.0	77.5
CM 922-2	79.3	77.0	85.3	86.5
CM 1335-4	78.3	79.5	84.8	86.5
CM 2136-6	77.0	73.8	82.5	86.3

Note: Differences significant at 1% level, LSD = 1.9.

organization of fresh cassava supply and the other in the area of product distribution and promotion.

Cassava reaches the Barranquilla market from several production areas--all in the Atlantic Coast region but with differing planting and harvesting times. Thus a constant, reliable provision of good-quality fresh cassava is difficult to achieve. Numerous farmer groups had to be trained in the use of the technology (treatment and packing must be carried out at the farm level immediately after harvest). Cassava quality is highly variable; and at times it is necessary to move to new production areas for quality rather than availability considerations. The constant changing of farmer groups carrying out selection, treatment and packing operations has made quality control difficult. Consequently, experiments were carried out to develop a more flexible supply approach.

If the treatment could be delayed by 24 h, greatly simplifying the operations to be carried out in the field, greater flexibility could be achieved in changing production areas and hence in assuring good-quality cassava. An experiment using three cassava clones carried out at CIAT (Fig. 7.1) showed that treating the roots with thiabendazole could be delayed for 24 h after harvest with no negative results as regards the amount of physiological or microbial deterioration 12 days after storage. An additional delay between harvest and treating (2 days) did, however, cause elevated levels of both types of deterioration. Although thiabendazole treatment can be delayed 24 h, the roots must still be packed at harvest in bags that retain moisture if physiological deterioration is to be prevented.

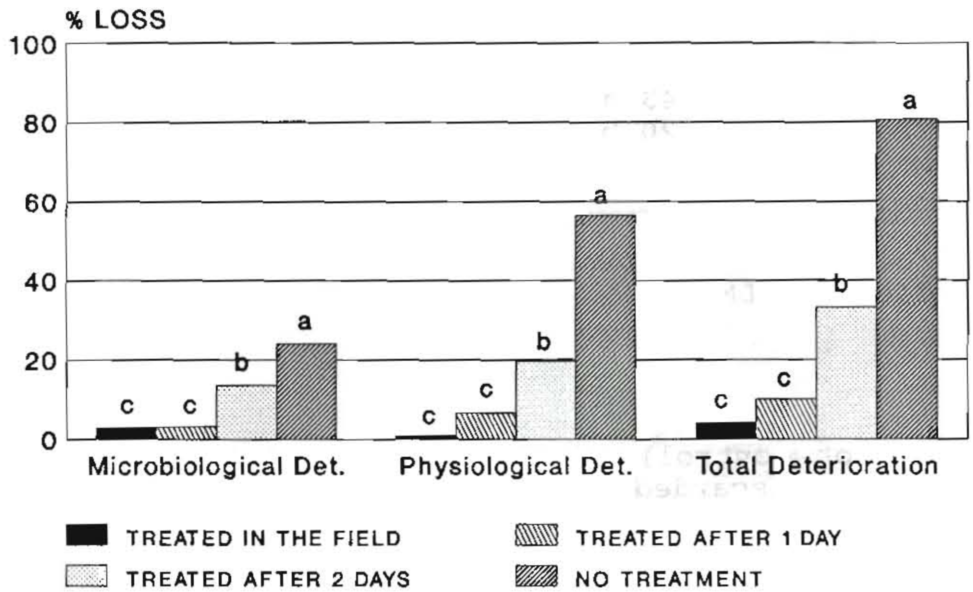


Figure 7.1 Fresh cassava conservation: mean of three varieties stored for 12 days after harvest.

When field treatment of the roots was practiced, roots were immediately packed into the 5- or 12-kg polyethylene bags in which they were to be commercialized. If treatment is delayed 24 h, roots can be selected, treated and packed in a central location, provided that they have been packed in the field into bags. These bags can be larger, and an experiment was conducted to see if reusable polypropylene sacks could replace polyethylene bags for this initial 24 h period only. Results (Table 7.13) suggest that although not as effective as polyethylene bags over a 3-day period, the polyethylene sacks were a significant improvement over the traditional sisal sacks used for cassava marketing in Colombia. The experiment shown in Figure 7.1 was carried out using root storage in polypropylene sacks for the 24-h period between harvest and treatment, with good results.

The economics of the process was improved by developing a means of using roots with high levels of mechanical damage. Such roots are cut cleanly to present a smooth surface and then a dessicant (e.g., $CaCO_3$) is applied to prevent the buildup of excessive moisture at the cut surface, effectively reducing the incidence of bacterial rotting (which thia-

Table 7.13 The effect of fresh root package material on physiological deterioration (%) after storage for 3 days after harvest.

	Mean[1]	M Col 22	CMC 40	CMC 76
Sisal sack	43 a	58	25	44
Polypropylene sack	20 b	31	6	22
Polyethylene bag	0 c	0	0	0

1 Values followed by different letters are significantly (5%) different, DMRT.

bendazole cannot control). This novel treatment means that all previously discarded damaged roots (10-20% of total roots harvested) can now be stored for two weeks.

Figure 7.2 compares the original and new fresh cassava storage processes. One major consequence of the new process is the transfer of treatment and packing operations from rural to urban areas. In practice, the process has been carried out as a small business in one of the marginal areas of Barranquilla, thus providing employment for the urban poor. The change has, however, resulted in a much greater flexibility in cassava root supply, with roots coming from cassava coops and/or individual farmers who need no training in treatment or root selection, only in the provision of high-quality fresh roots.

7.3 Cassava Flour

Previous reports (1984-88) detailed the experimental phase of the project to develop a high-quality cassava flour for human consumption. In 1989 IDRC funded the second phase, which contemplated the construction and operation of a pilot plant for producing the flour; the execution of in-depth market surveys to assess the demand for a cassava flour in the food industry; and the use of cassava production technology packages at pilot level to ensure sufficient cassava production to supply the plant. During the first year of the project (mid-1990), the following activities were carried out in collaboration with DRI and UNIVALLE.

TRADITIONAL		NEW SYSTEM
Harvest Select roots Pack into polyethylene bags (5, 12 kg roots/bag) Treat with Thiabendazole (Spray, 0.4%) Drain excess liquid Seal bags	Farm	Harvest Select initially Pack into polypropylene (sacks (50 kg/sack) Transport to treatment center
Transport to urban distribution center Distribute to retail outlets	Urban Center	Receive, store (<24 h) Wash Select Treat by immersion (thiabendazole 0.4%) Dry Pack into 5, 12 kg bags Distribute to retail outlets

Figure 7.2 Traditional and new processes for fresh cassava root storage.

7.3.1 Establishment of the pilot plant

The following criteria were used to select the site for the pilot plant: land availability, potential to increase cassava yield, availability of cassava, potential to harvest cassava throughout the year, infrastructure (electricity, water), proximity to final markets and wheat mills, institutional support/presence, socioeconomic importance of cassava. The region was the major cassava production area of Colombia--the Atlantic Coast--where farmer and institutional support for these activities is strong.

Six possible sites were selected by screening the entire region based on these criteria. The National Association of Cassava Farmers and Processors (ANPPY) was also involved in the planning process for site selection and in pilot plant operation. A detailed survey of each site was conducted to determine the best option. A site at Chinu (State of Córdoba) was selected, and the farmer organization of COOPROALGA (Cooperative of Farmers from Algarrobos) was chosen to participate.

A preliminary design for the pilot plant was given to architects to produce a final design (blueprints, electricity and water supply, quantities of material required and budget). However, the estimate for the initial design totaled US$80,000 (approved budget, US$35,000). Thus the capacity of the plant was reduced by 50% to 150 t/yr and other savings were identified for a final cost of US$52,000. Future capacity increases (e.g., increase in artificial drying bed capacity), following the economic feasibility of the pilot operation, will have a relatively low cost.

From among three bids for constructing the pilot plant, a local civil engineering firm was selected. The pilot plant was built between January and April 1990; and the following 3 mo were spent testing and adapting the equipment, organizing and training the coop members who are responsible for operating the plant. Personnel required are a plant head, a production chief and 3 workers.

The equipment was designed, adapted and improved in collaboration with UNIVALLE-Cali. The heat generation and transmission system (coke burner, fan, motor and ducts) were purchased from a firm in Bogota. Processing equipment was modified slightly on arrival at the plant as follows:

- root washer: sealed to prevent water leaks
- carts for chip transport: re-enforced
- drying chamber: improvement of finish to increase useful life

- pre-miller: re-enforced by soldering between screens and roller mills

- coke burner: additional grate to improve fuel-use efficiency

Equipment modification will continue during the trial operation of the plant as required.

A serious bottleneck developed with regard to the supply of water to the pilot plant. Although an aqueduct with sufficient supply passes close to the plant and an agreement had been reached with the local community for the plant to take its full requirement from this aqueduct, at a later date said agreement was anulled as a result of internal community conflicts. The efforts of DRI and other national agencies failed to persuade the local inhabitants to resume supply so a new source of water for the plant had to be found and additional funding sought to take advantage of this supply. This has resulted in the provision of an independant water supply for the pilot plant financed by a loan obtained by ANPPY. The delays encountered prevented operating the pilot plant until November 1990.

Despite this setback, the plant has been operating from June 1990 onward, producing cassava chips suitable for the animal feed market. These chips have been produced using the process for cassava flour production (i.e., strict root selection, artificial or mixed drying systems) and hence have suffered from higher costs than is usual for chips sun-dried for the animal feed market. Nevertheless, with careful cost control, good fuel-use efficiency and a reasonable price paid for the raw material, losses have been kept to a minimum. An unexpected result of this operation has been the tentative justification of mixed or artificial drying systems to produce a product for the animal feed market in Colombia. Conversion rates of fresh roots:dried chips as low as 2.42 were obtained. Coke requirements varied from 1600 to 670 kg per ton of chips produced, showing that as the workers become more practiced in plant operation, cost reductions can occur.

Although the cassava production component of this project is contained within the Agronomy section (see 5.5), it is interesting to note that no problems were experienced in obtaining a supply of raw material for the plant in the off season and that the local Venezolana variety had a higher root DM content than the introduced P-12 variety, which has significant implications for process economics. Future production trials will emphasize Venezolana rather than P-12.

7.3.2 Market development

Initial studies were carried out to detect potential markets for cassava flour in the food industry.

Market studies were carried out with food industries that use flours in their product formulations, in the following geographical regions of Colombia:

- National: Bogotá Medellín, Cali
- Atlantic Coast: Barranquilla, Cartagena, Santa Marta
- Area close to pilot plant: Montería, Sincelejo, Corozal, Chinu, etc.

All industries received samples of cassava flour in sufficient quantities for conducting their own product formulation trials, and they were interviewed on the results of these trials. The main conclusions were:

-- Preliminary estimate of potential demand in the food industry for cassava flour of 30,000 t/yr, for the substitution of other raw materials, principally wheat flour

-- The wide variety of both products and food industries is impressive. Products most suitable for substitution with cassava flour are:

- processed meats
- biscuits/cookies (all types)
- pastas
- cakes, bakery goods in general
- mixtures for starch-based drinks ("coladas")
- mixtures for soups
- for breading chickens, etc.
- ice cream cones
- sauce bases, spices, etc.

-- In some products cassava flour has clear functional and product quality advantages over other flours regardless of price; e.g., processed meats, biscuits/cookies, ice cream cones and mixtures for breading.

-- The main flour substituted by cassava flour is wheat (80%); others include rice, maize starch and cassava starch.

-- The industry requires 50-kg sacks of flour.

-- At a price 15-20% below that of wheat flour, cassava flour would be very attractive to the food industry. This price should be achievable by the pilot plant.

-- Of the major cities close to the pilot plant, Barranquilla and Medellín, the latter has a larger potential demand for the flour.

Subsequent actions will be to promote the use of cassava flours in those markets with greatest potential. This implies the development of market channels for the new product. Two possible market channels exist:

Pilot plant -- wheat mill -- industrial client

Pilot plant -- wheat mill -- wholesaler -- small volume client.

A third option--that of milling the chips to flour at the plant itself--will become available at a later date if a viable small-scale, efficient mill can be developed.

Wheat mills in Medellín and Barranquilla have milled 1-ton lots of cassava chips, with conversion rates of 70-95%. Both expressed great interest in milling the chips as a commercial proposition. Few modifications are necessary to achieve a consistent 90-95% conversion rate.

Product promotion activities will be concentrated in Medellín once the pilot plant is producing flour of an adequate quality.

7.3.3 Support research

In collaboration with UNIVALLE, research has continued in the following areas:

-- Product development using cassava flour for starch-based drinks ("coladas"), pastas/noodles for soups and "manjar blanco" (a typical Colombian milk-based dessert). Some changes in the process for producing the items are required to maintain product quality using cassava flour, but these are relatively easy to achieve with practice.

-- Processing equipment improvement: root washer, the coupling of washer to chipping machine, and the chipping machine itself.

-- Development of milling and grading equipment for in-plant production of cassava flour. A small-scale roller mill with a sifting/grading system that can function to mill pre-milled cassava chips is being evaluated. This system has a 200-300 kg/h capacity.

-- Storage studies. 900 kg samples of chips and flour were placed in 3 warehouses of IDEMA (Colombian state agricultural marketing organization) in Montería (Atlantic Coast), Bogotá and Cali. From February 1990 onward, monthly samples were taken; and the microbiological quality and physicochemical characteristics, evaluated. Initial results (Feb.-July) show that moisture content has remained stable (11.0-12.2%) as have protein, reducing sugar and fiber contents. The microbiological status of the samples has also been stable, with apparent reductions in fungal and yeast counts over this period. No Salmonella or E. coli bacteria have been found in those samples destined for human consumption.

-- Cyanide elimination studies. Cassava flour for human consumption must meet standards of 50 ppm HCN, yet the artificial drying system used to obtain flour with an acceptable microbiological quality also reduces the cyanide loss as compared to the sun-dried product. Flour samples from the pilot plant will be monitored for HCN content. Preliminary experiments at CIAT suggest that breaking the artificial drying time into two 4-6 h periods (with an overnight break) allows more time for enzymic release of free HCN, and has the potential to reduce the final level of HCN. This is also a practical operational procedure for the pilot plant.

7.3.4 Economic analysis

An economic feasibility study will be completed during 1991, using data and costs obtained from pilot plant operations. A model for calculating financial profitability (Financial Rate of Return, FRR) has been developed, which will be used for this analysis. Using the best information available at present, the costs of producing cassava chips for the food industry market are Col.$120,000/t: $74,000 for raw material, Col.$12,000 for transport and Col.$9,000 for coke.[1] The remaining costs relate mainly to labor and financial costs. A margin of Col.$28,000 is envisaged to produce a sale price in Medellín of Col.$140,000/t. This compares with a price for wheat in Medellín of Col.$159,000/t; i.e., cassava is 12% cheaper than wheat. Given these prices the FRR is highly positive (30%, twice the 15% needed to justify the project). Nevertheless the pilot plant operation will permit substitution of assumed prices/costs etc. by real commercially obtained data, thereby providing a true picture of the commercial viability of the process.

7.4 Production and Utilization of Cassava Starch

7.4.1 Background

In Latin America, many small-scale cassava starch industries exist where the product has specific food uses, typically for the production of "sour" starch (Brazil, Colombia). "Sour" starch is a naturally fermented starch whose characteristic functional properties are necessary for making traditional cheese breads: "pandeyuca", "pandebono" in Colombia or Ecuador, "biscoito", "pan de queijo" in Brazil. This traditional industry has a real socioeconomic importance for the local economy and for adding value to cassava production. Nevertheless, this sector presents many problems in terms of production, processing and comercialization, which limit its development. A collaborative CIAT-CEEMAT/CIRAD project on "Production and utilization of cassava starch" was initiated in 1989 to improve new technologies for this industry (see Annual Report 1989). For defining research priorities compatible with local needs, the following methodologies were used:

-- Analysis and diagnosis of the Colombian traditional process technology (see also biotechnology section)

-- Identification of the "bottlenecks" of the technio-economic system

-- Organization of workshops on this theme with the participation of researchers, producers and users

-- Constitution of multidisciplinary interinstitutional teams.

The following priority areas of research and development on cassava starch were established in 1989:

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[1] Exchange rate averaged Col. Ps.$501.10 to US$1 for the period June-July 1990.

- Standardization of analytical assays
- Characterization of sour starch
- Equipment technology
- Influences of raw material on product quality
- Mechanisms involved in natural fermentation

These themes have been developed in collaboration with national institutions: IIT, the Institute of Technological Research in Bogotá, SEDECOM, UNIVALLE (Section of Foods, Chemistry Dept., Dept. of Mechanical Engineering) and the Universidad Autónoma del Occidente (Depts. of Mechanical and Industrial Engineering) in Cali. Other national agencies are supporting this project in Colombia by providing technical assistance for cassava production through to commercialization, and farmer and starch producer organization.

7.4.2 Standardization of analytical methods

The analytical methods used by different institutions working on cassava products were compiled: NRI (England), CIRAD and ORSTOM (France), UNESP Botucatu (Brazil), ITNN (Paraguay), IIT and UNIVALLE (Colombia). Some of them have been evaluated; others adapted for cassava starch and used for research:

- Biochemical analysis (water content, starch determination by enzymatic assay,organic acids by gas chromatography, organic acids, ethanol, starch and glucose by high pressure chromatography)

- Physical parameters (color, granulometry)

- Functional properties of starch (amylograms, water absorption)

- Starch structure (degree of polymerization by gel permeation chromatography)

7.4.3 Characterization of sour starch

7.4.3.1 **Evaluation of sour starch quality.** Traditionally, only empirical tests are used (e.g., acidity, taste and rough sensation of starch granule in the mouth between the tongue and the palate, the color of a flame in the presence of starch dust, or the form and expansion of a starch ball made of sour starch and saliva put on the extremity of a lighted cigarette). No quality test with a scientific basis exists. The establishment of a simple method for evaluating sour starch quality has been a research priority. The main quality characteristic that sour starch users (small-scale bakeries or large companies) require is "expansion power." This is "the ability of a fermented starch to increase the volume of a dough containing that starch and submitted to a process of baking." The simplest parameter for determining expansion power is the specific volume of bread after baking. Nevertheless, this expansion power depends not only on the starch quality but also on the cheese quality (which is also very variable), product formulation, dough texture and consistency, bread form and baking conditions. For designing a reproducible and sensitive baking test, several assays using good- and bad-quality samples were carried out under different baking conditions and formulations (cheese, fat, salt, yeast, etc.) using a domestic electric oven.

The following protocol was standardized:

- Manual preparation of a dough made of sour starch (1 part), commercial white ("campesino") cheese (1 part) and cold water (0.5 part) at ambient temperatures
- Baking of 6 or 8 small round breads of 15 g at 450°F for 7 min.
- Determination of the average specific volume of the cheese breads by the method of seed displacement

This protocol has the advantages of using or having:

- A formulation similar to that of traditional products
- A sweet consistency of the dough
- A stable and homogeneous structure of the final product
- No variability with cheese quality
- The best differentiation between good and bad starch quality (Fig. 7.3)
- Good reproducibility (Table 7.14); the results obtained with this manual breading test (assay BTMan) were not significantly different ($p<0.001$, Student's test) from those assays carried out under stricter conditions: (dough prepared in a farinograph Brabender until a consistency of 200 BU and baking in a convection rotatory oven, assay BTFar).

This test can be used at the level of the lab to determine the influences of raw material or process steps on starch quality as well as in the extraction plants for process control and in product price negotiations.

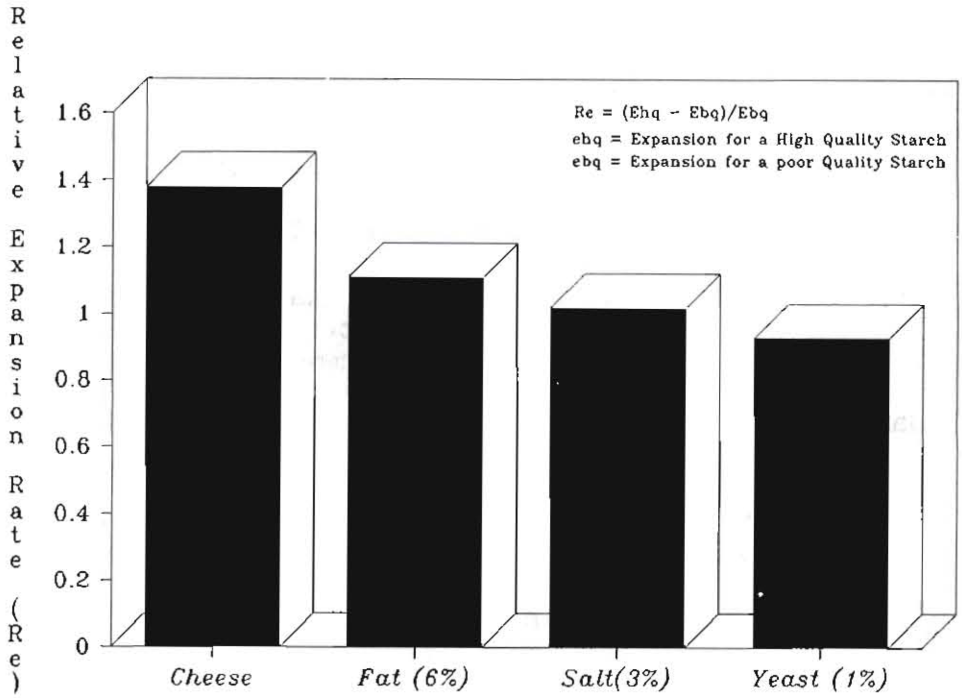


Figure 7.3 Relative expansion rate in function of different formulations with sour starch.

Table 7.14 Repeatibility of the breading test (10 reps) for two starch qualities.

	Specific Volume (g/ml)			
	Sour Starch N° 1		Sour Starch N° 2	
	Assay BTMan	Assay BTFar	Assay BTMan	Assay BTFar
Mean	3.81	3.88	3.39	3.31
SD	0.264	0.221	0.235	0.166
SE	0.084	0.070	0.075	0.053
CV	6.9 %	5.7 %	6.9 %	5.1 %

7.4.3.2 **Evaluation of different sour starches.** A series of 35 samples were collected and ranked with empirical criteria by users, into 3 groups: good, regular and poor quality. Another classification into 3 classes was made by clustering the values of the specific volumes determined by the breading test (Table 7.15). When the two classifications were compared, a correlation was observed between the qualitative one (empirical) and the quantitative one (specific volume value):

- Very good ($R = 1$, $p < 0.001$) for good-quality starches
- Not significant ($R = 0.79$, $p = 035$) for regular and poor-quality starches

Thus the traditional knowledge of the product permits identification of only the good-quality products.

Correlations between specific volume and starch character parameters (biochemical, physical and functional properties) were also studied. The following correlations were significant ($p < 0.05$):

- Total organic acids
- Lactic (+) and acetic (-) acids
- Color (brightness)
- Swelling power at 90°C
- Water absorption at 40 and 500 BU

These results show that acid lactic production and the modification of the functional properties of native starch during fermentation are important.

Table 7.15 Classes of a sour starch samples cluster (values with same letter are significantly different, $p < 0.05$).

Class	Starch Quality	Specific Volume Mean (SD)
1	Good	4.89 (0.05) a,b
2	Regular	4.21 (0.17) a,c
3	Poor	3.38 (0.15) b,c

7.4.4 Equipment technology

One of the main conclusions of the technological diagnosis made in 1989 was the very low efficiency of the traditional process, with starch losses of about 25%. To improve the extraction rate and the "sour" or/and "sweet" starch quality, some equipment modifications were proposed, looking at the possibilities of scale reduction of those used in advanced technology. The improved equipment was designed, built and is now being evaluated with the producers in some traditional starch-extracting operations ("rallanderias").

7.4.4.1 **Washing/peeling.** The presence of external peel affects the product color and increases the quantity of "mancha"; so, the modifications have been:

- Addition of 2 or 4 abrasive rollers
- Distribution of washing water from the central axle
- Direct power transmission by a moto-reductor

7.4.4.2 **Extraction.** The low efficiency of the process is due to a poor liberation of starch granules during rasping and a limited extraction of starch as shown by the values of the "rasping efficiency" (Re) and the "rasping effect" (R) of 83.6% (SD = 3.0) and 81.1 % (SD = 8.6) compared to those obtained in advanced technology of more than 95 and 90%, resp.

$$Re = 100 * (Sr - Swp)/Sr$$
$$R = 100 * (1 - Swp*Fr/(Sr*Fwp))$$

with Sr, Swp, Fr, Fwp (starch and fiber contents in the roots and the waste pulp, resp.).

The other problem is excessive fiber content in the final product. This can be overcome by:

- Grating with a system of root disintegration by cutting blades fixed on a plastic drum with a higher rotation velocity
- Extracting with water in a traditional cylindrical extractor equipped with four mixing screws to get better contact between water and cassava mash
- Refining of starch milk in a vibratory sifter with two sieves (80 and 120 mesh)

7.4.4.3 **Starch separation.** Natural decantation of starch milk in the settling tanks takes one day. To avoid removing starch on a daily basis, several successive sedimentations are carried out during one week. The natural fermentation that occurs modifies the functional properties of native starch; under these conditions, the final product does not respond to the general requirements for industrial uses of "sweet starch." Also, some starch is lost when the supernatant is removed. An improved system--sedimentation in settling tables--which is already used in India and Brazil, reduces starch losses and allows starch classification by purity and granule size.

7.4.5 Influence of raw material

A survey of starch producers was carried out in the municipalities of Santander and Caldono (97 rallanderias in Cauca, Colombia), to learn their opinion about the influence of cassava varieties on starch extraction yields and on sour starch quality. Ranking of the varieties using Friedman's test (Fig. 7.4) shows differences between quality and yield for the two main varieties used (Fig. 7.5). M Col 8 (Blanquita) gives the best yield but the worst quality; M Col 1522 (Algodona) the best quality but the worst yield.

A study of the suitability of cassava varieties for sour and sweet starch production was undertaken. Varieties were planted at CIAT and the starch production area in order to:

- Monitor the evolution of the raw material as a function of plant age and the preharvest environment
- Obtain precise data on extraction rate and on the sour starch quality for each variety
- Understand varietal differences in yield and quality by characterizing the native starch

7.4.6 Study of natural fermentation

7.4.6.1 **Physicochemical parameters.** The physicochemical parameters and functional properties of sour starch are highly variable from one processing plant to another and from one fermentation to another in the same plant. Factors such as ambient conditions, variety, water quality and traditional knowledge may be involved in this variability.

A study of several fermentations showed that natural fermentation is homolactic; that is, lactic acid explains 99% of the variation of total organic acids, but is in itself extremely variable (20-800 mg/100 g of starch DM basis). Nevertheless, a tendency can be shown for the evolution of pH and lactic acid production (Fig. 7.6). The process can be divided into three stages:

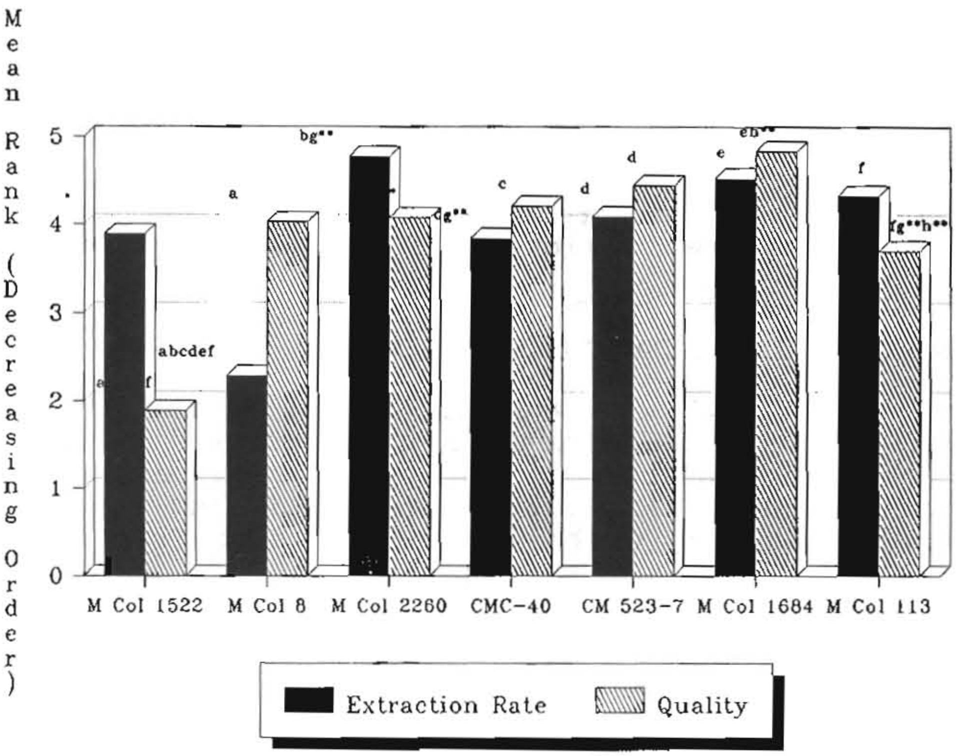


Figure 7.4 Mean order rank of some cassava varieties for extraction rate and quality parameters; values with same letters are significantly different (Friedman's multiple test, P<0.001 or P<0.01 or P<0.05).

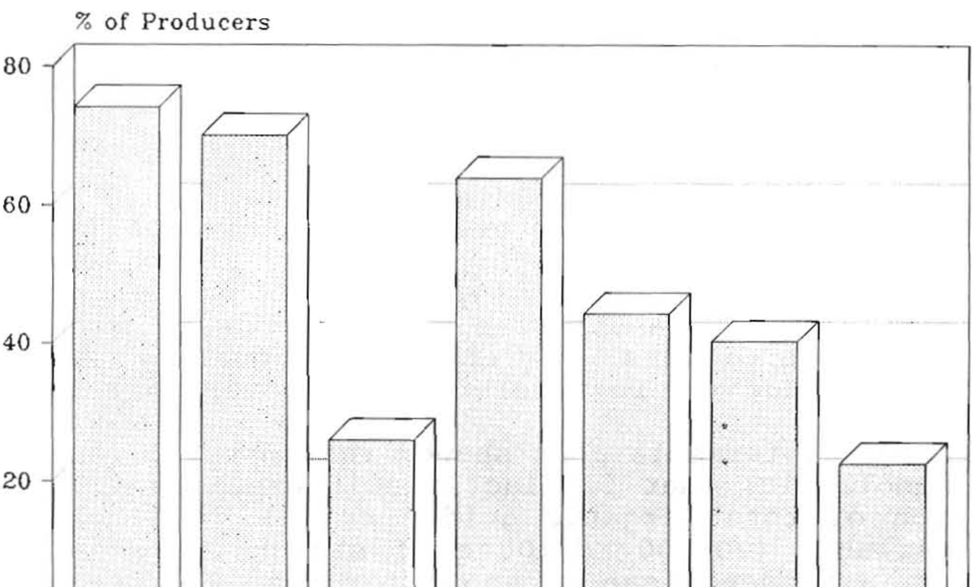


Figure 7.5 Main varieties used in sour starch process.

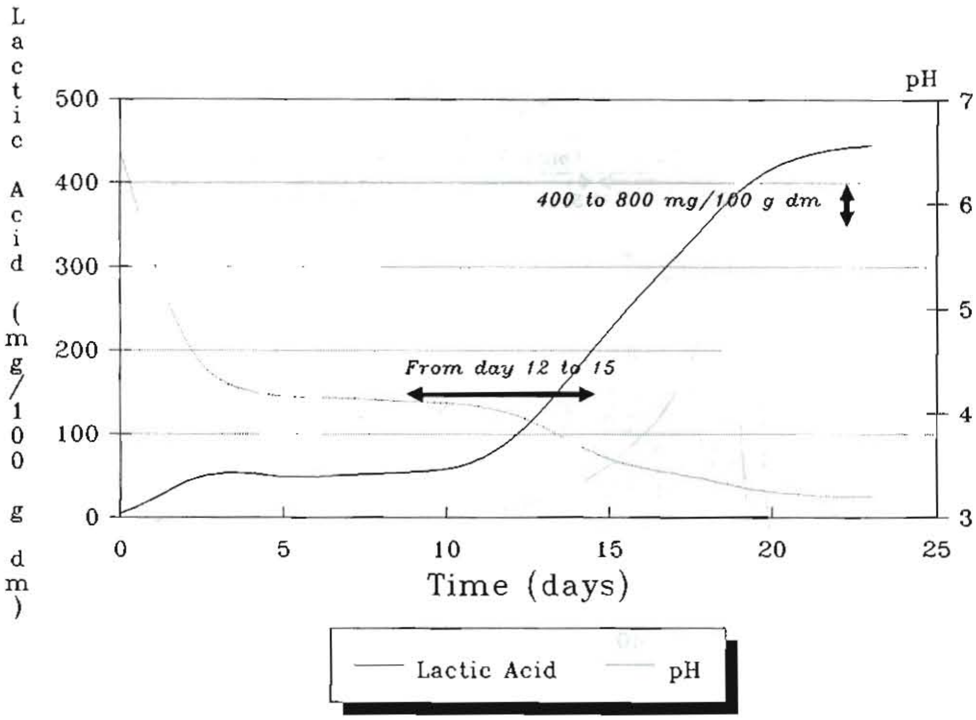


Figure 7.6 Evolution of pH and lactic acid during fermentation (case of good-quality sour starch).

-- Development of lactic fermentation during the first 3 to 5 days (pH 4-4.3) and production of organic acid (20-50 mg/100 mg of starch DM basis)

-- A stationary stage until day 15-20 when the microorganisms adapt to the difficult conditions of the medium, becoming anaerobic after day 3-4, with a temp of about 18-20°C, and a substrate composed only of starch

-- A renewed homolactic fermentation with great production of lactic acid (1000 mg/100 g starch DM basis) from day 20 onward; process does not always have time to develop fully before the starch is removed and dried, in which case final product quality is poor

7.4.6.2 **Functional properties.** During fermentation (increasing acidification of medium) and the subsequent modifications in starch structure, functional properties change (Fig. 7.7):

- Increased gelatinization temp (60 to 63/65°C)
- Lower viscosity values: maximum viscosity during heating (Vm), viscosity after 30 min at 90°C (Vr) and on cooling to 50°C (Ve)

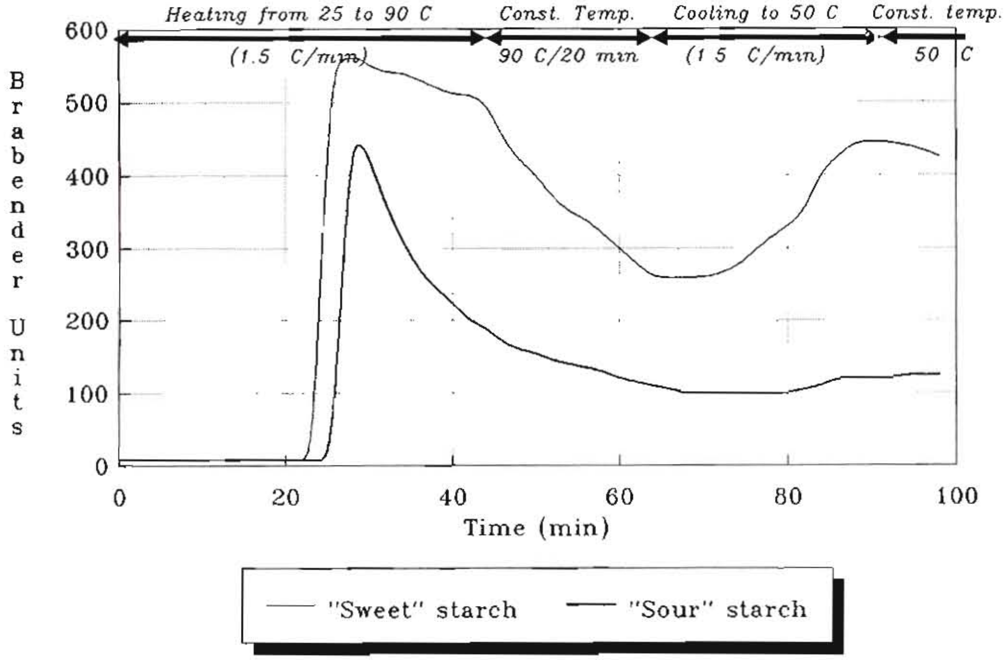


Figure 7.7 Effect of fermentation on starch paste (4%) quality.

- Different behavior of the starch paste: greater ease of cooking; i.e, time to reach the maximum viscosity starting from the beginning of the gelatinization phenomenon, a lower gelatinization index (Ve-Vr) and a greater setback value (Ve-Vm).

Screening the starch structure by SEM microscopy showed a selective decrease in the size of some starch granules, mainly during the last stage of fermentation. The evolution of the degree of polymerization using gel permeation chromatography will be studied to obtain more information on the changes in starch structure during fermentation.

7.4.6.3 **Microbial population.** Screening of the micro-organisms involved in natural fermentation of cassava starch showed the following characteristics (Fig. 7.8):

- A 10-fold increase in the anaerobic population between the extraction step and the beginning of fermentation

- A constant anaerobic microbial population of ca. 10^7 to 10^8 cells/g starch DM basis, (mainly bacteria)

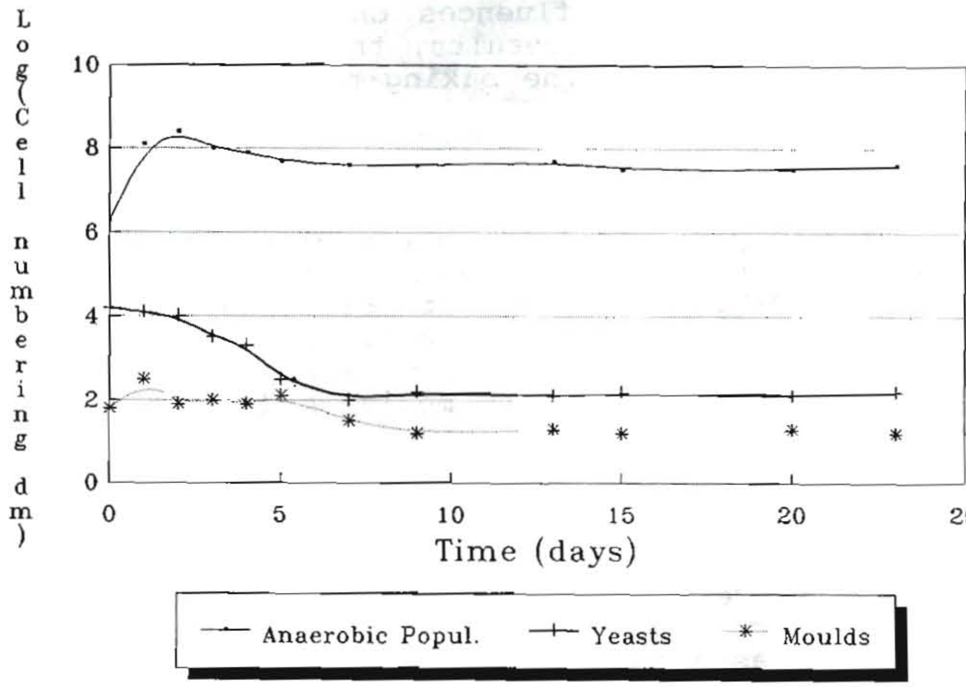


Figure 7.8 Evolution of the microbial population during fermentation (day 0 = extraction step; day 4 = beginning of fermentation).

- A small population of yeast and molds, more or less constant after the 5th day, about 10^2 and 10^1, resp.
- A progressive increase in the proportion of <u>Lactobacillus</u> (from 5% to 20% of the total population) during the entire fermentation

The microorganisms present in the medium have starch as their only carbon source. Oxygenation conditions change rapidly from aerobic to strictly anaerobic; thus selection of anaerobic amylolytic flora is important. For this, media progressively less rich in nutitive elements were used until one was obtained whose only carbon source is starch. It was found that in all the steps of the process, there are amylolitic microorganisms, some of which are producing a great quantity of gas, identified by mass spectrophotometry as CO_2.

Lactic bacteria (in MRS medium) with amylolytic activity, which play an important role in the process, were selected. Taxonomic characterization, metabolism and enzymatic system are being studied for the 20 isolates. Research on the amylolytic activity of the enzymes involved in microbial fermentation of cassava starch is reported in Section 2.6.

7.4.6.4 **Fermentation influences on sour starch baking power.** Based on previous results, the following hypothesis is presented to explain the baking power property of sour starch:

- Fermentation step. The amylolitic microorganisms (some are lactic bacteria) produce reducing sugars that are immediately consumed by lactic bacteria (the reducing sugar content in the medium has a zero value for the entire fermentation) to produce organic acids (mainly lactic acid) and carbonic gas. These may be absorbed by the starch; the attack by amylolitic enzymes and the acidification of the medium modify the functional properties of native starch.

- Baking step. During the heat treatment of baking, the dough moisture is volatilized (initial and final water contents are about 50 and 8-12%, resp.). Lactic acid and CO_2 produce the expansion power of the dough and the decreased gelling tendency, which together give the characteristic texture of the final product.

7.4.7 International cooperation

Contacts have been maintained in basic research with Brazil and Argentina, and technical assistance has been provided to national starch programs in the following countries:

Paraguay (SEAG)

- Technical diagnosis of the 3 technological levels (manual, semimechanized and mechanized) identified in the traditional process of strarch extraction

- Socioeconomical survey of this rural agroindustry

- Research for evaluating new technologies

Ecuador (FUNDAGRO, UAPPY)

- Technico-economic survey of cassava starch production in Manabi Province

- Determination of the biochemical, physical and functional properties of cassava-derived products commercialized by UAPPY (starches and flours)

- Definition of the requirements of products for some industrial uses in collaboration with these users

7.5 References

Bate & Ryde. 1982. Starch 34(4):125-128.

Cooke, R.D. 1978. An enzymatic assay for the total cyanide content of cassava. J. Sci. Food Agric. 29:345-352.

Monroy, J.A; Lebert, A; Marty, C; Bimbenet, J.J. and Muchnik J. 1990 (In preparation).

8. INTEGRATED CASSAVA DEVELOPMENT PROJECTS

8.1 Brazil: Cassava Development Project, Ceará

Through the establishment of a cassava-based agroindustrial development model, the CIAT Cassava Program will be in a position to formulate and implement a strategy aimed at supporting poverty alleviation and institution-building objectives. The project is expected to contribute to the development of a general methodology, technologies and expertise for implementing small farmer integrated rural development projects based on the specific characteristics of the cassava crop in other regions of Brazil and other countries of Latin America. CIAT is promoting the formation of a network of national agencies interested in cassava-based integrated rural development projects; and Brazil, as the largest cassava producer in Latin America, could be one of the principal actors.

Since 1979, Brazilian agricultural institutions have been trying to implement activities to promote the production of dry cassava chips for animal feed as an alternative commercial activity for the cassava farmers in NE Brazil. During the period 1980-86, efforts included the installation of the first dry cassava agroindustries in the State of Ceará (1981). These units were not very successful for various reasons, among these severe drought (1979-83), which substantially reduced crop production; and the agroindustrial model chosen relied on large farmer coops (400-500 members), which greatly diminished farmers' interest in participating in the administration of the agroindustries.

In 1986 the CIAT Cassava Program initiated closer collaboration with agricultural research and rural extension agencies of Ceará; and in 1987, during a training event held at CIAT, a group of technicians from NE Brazil did a diagnosis of the principal problems of the cassava crop in 7 states of the region. Production of dry cassava for animal feed was identified as a marketing alternative for the cassava farmers in the region. In 1988 the agricultural institutions of the State of Ceará formed a State Committee for Cassava (CCC) with the purpose of coordinating the work being implemented with this crop in the state. CIAT collaborated actively with the CCC in the formulation of this integrated development project, funded by the W. K. Kellogg Foundation as of May 1989.

8.1.1 The setting

The region of NE Brazil, considered to have the highest levels of poverty and underemployment in the country, is comprised of 9 states (Maranhao, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia) with a total area of ca. 1.5 million km^2 (18% of the country's total area). Negative national records are held in aspects such as absolute poverty, infant mortality rates, unemployment and underemployment, illiteracy and access to basic services. In 1990 the population of NE Brazil was approx. 43 million (28% of the country's population), 42% of whom live in rural areas. More than 50% of the work force is engaged in agriculture-related activities (IBGE, 1980).

More than 70% of the families live below the poverty line (i.e., cannot fulfill their own basic needs of food and basic services). Land distribution is greatly skewed; the no. of farms with fewer than 10 ha represent 70% of the total but account for less than 6% of the total farm area; whereas the no. of farms over 100 ha represent 6% of the total but occupy more than 40% of the total farm area (Fig. 8.1).

The NE's contribution to total Brazilian agricultural production represents about one fifth of the total value, and some of the most important agricultural commodities produced in the region (sugarcane, cotton, cassava) represent a significant share of national production.

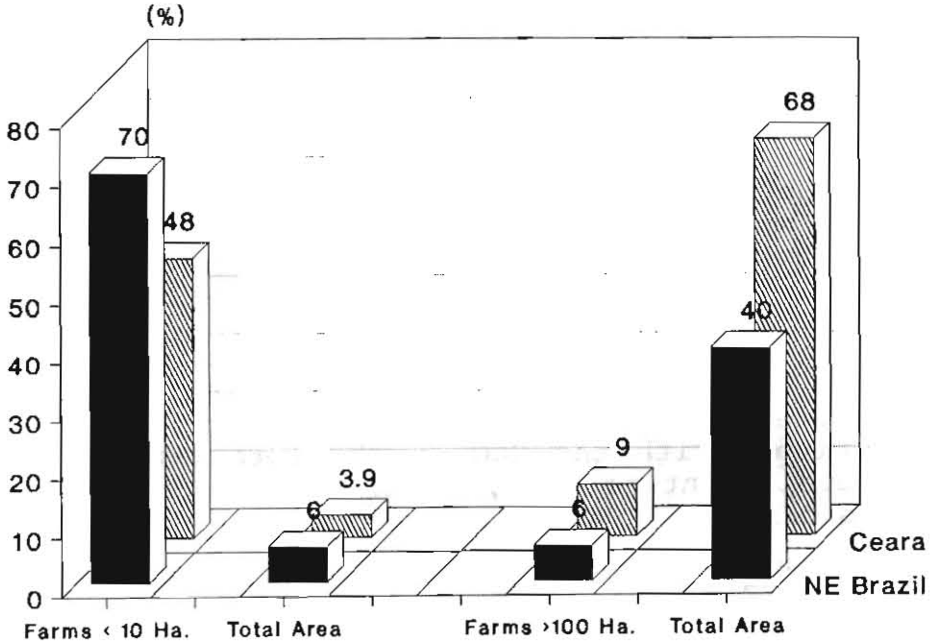


Figure 8.1 Land distribution in NE Brazil and the State of Ceará.

The State of Ceará is the fourth largest state in NE Brazil (148,000 km^2). Population projections indicate that by 1990, the total population of Ceará was about 6.4 million, 36% of whom will be living in rural areas. Agriculture is the main economic activity, employing 56% of the State's labor force (IBGE 1989).

Average per capita income in the rural areas is one of the lowest in the NE. Income distribution patterns are extremely skewed, with 50% of the population earning less than the minimum salary (US$75 in Oct. 1990), accounting for only 15% of the total income in the State. High rates of infant mortality (25/1000), malnutrition and illiteracy are major socioeconomic problems (IBGE 1989).

Land distribution in Ceará, as in the rest of NE Brazil, presents a highly skewed pattern, where farms with under 10 ha represent 48% of all farms but account for only 3.9% of the total farm area. Conversely, the no. of farms with areas over 1000 ha represents only 0.44% of the total no. of farms (20.5% of the total area available). Some 60% of the rural producers are classified as nonowners; and of those considered as owners, 40% have no legal title (IBGE, 1989) (Fig. 8.1). Cotton, beef, fruit, beans, maize, sugarcane and cassava are some of the State's most important agricultural products.

8.1.2 Importance of cassava production

Cassava is grown throughout Brazil. According to FAO, the area planted in 1989 was 1.9 million ha with a total production of 23.2 million t and an avg productivity of 12.5 t/ha. Brazil used to be the most important producer in the world, but recently this position was lost to Thailand. On a countrywide basis, cassava holds eighth place as regards total area planted and seventh place in monetary value (FAO, 199?).

Cassava, which is a major caloric source in Brazil, is consumed in two principal forms: "farinha" (toasted flour) and fresh. Per capita consumption of farinha (17,6 kg/year) is much more important than consumption of cassava in fresh form (6.1 kg/yr) (IBGE, 1989).

In the NE, cassava is produced mainly by small farmers. The climatic conditions in this area are much harsher than those of other cassava-growing areas of the country; consequently, yields are lower. In 1989 a total of 1.09 million ha of cassava were planted for a total production of 11.7 million t and an avg productivity of 10.7 t/ha.

Most of the cassava harvested in the region is used for making farinha, with smaller amounts sold fresh for human consumption and minimal quantities used for animal feed.

In the State of Ceará, cassava production is one of the main agricultural activities. From 1985-87, avg annual production was on 113,035 ha with avg productivity at 9.6 t/ha. This production ranked fifth statewide in terms of total crop area planted and second in terms of total monetary value. Cassava is mainly used in the form of farinha (64%), for animal feed at the farm level (25%), and minimal quantities are used in fresh form for human consumption (IBGE, 1989).

8.1.3 Project objectives and expected outcomes

The project is intended to improve the welfare of the rural poor involved in cassava production in communities throughout the State of Ceará, NE Brazil. This objective is to be achieved through the introduction and adoption of improved cassava production, processing and marketing technology.

Expected outcomes of the project are:

-- Generation and testing of a small-scale cassava-based agro-industrial development model

-- Institution building through a participatory management approach for implementing the project at the various levels and stages; development and strengthening of community-based organizations

-- Improved welfare through the simulation of economic development and generation of employment opportunities in the rural communities in the project area

8.1.4 Project activities

The work plan has involved the following activities:

-- Selection of site for developing a pilot project

-- Identification of local institutional capacity to implement the project, as well as local sources of financial support

-- Design and establishment of the pilot project: production technology, processing technology, commercialization, organization and training

-- Monitoring of operations and in situ modification of the modus operandum in accordance with local conditions

-- Monitoring of project performance and modification of project design

-- Expansion phase to semicommercial- and commercial-scale production

8.1.5 Progress toward project outcomes

8.1.5.1 **Selection of pilot project site.** The selection of the State of Ceará as the site for the pilot project was strongly influenced by prior involvement of some agricultural institutions in Ceará--especially the State Rural Extension Agency (EMATERCE)--in the promotion of activities related to small-scale cassava farming and processing. The concept of small-scale cassava-based agroindustries for producing dry cassava chips for animal feed, which had remained practically frozen in Ceará from 1981-86, was reactivated; and in 1987, five cassava agroindustries were installed across the State. However, the farmers' groups performed poorly once again as a result of the poor selection of areas and farmers' groups, the lack of credit for planting, and scarcity of planting material.

The formation of the CCC in 1988 facilitated the coordination of support activities in the state. With other sources of funding, nine new farmer groups were organized around dry cassava processing facilities that year. In May 1989 the coordinating activities of the CCC were strengthened; and during this reporting period (May 1989-Oct. 1990) 24 new producer groups were organized to install and operate dry cassava processing agroindustries. By December 1990 38 agroindustries will be installed (Table 8.1).

8.1.5.2 **Identification of local institutional capacity and financial support.** This objective is being pursued at four levels: State, regional, municipal and community. Identification of financial support at national and local level has been more difficult because of the prevailing economic situation in Brazil although the CCC has been able to obtain access to some development programs (PAPP-Support Program for Small Farmers; SUDENE-Superintendency for Development of the NE; BNB-Bank of NE Brazil), which are supporting farmer groups to install cassava processing agroindustries.

8.1.5.3 **Production technology.** Minimal adoption of improved agricultural technology and lack of good-quality planting material were identified as two of the main constraints in implementing the production technology component of the pilot project. Actions taken to overcome these constraints have included the setting up of (a) demonstration/preproduction trials and (b) seed production plots.

Table 8.1 Cassava drying plants in Ceará, 1981-90.

Period	No. of Agro-industries	Drying Plants Area (m^2)	Funding
1980-81	4	4,200	1
1986-89	5	2,070	1
1988-89	9	5,010	1-4
1989-90	24	22,179	1,2,3,5
TOTAL	42	33,459	

1. International Bank for Reconstruction and Development (IBRD)/EMBRATER
2. BNB/ETENE - Technical and Economic Studies for the NE
3. PAPP/FADA - Support Fund for Agriculture Development
4. Sao Vicente Rural Development Program
5. PAPP/ATER - Technical Assistance and Rural Extension

-- Demonstration/pre-production trials. In order to test and demonstrate improved cassava production technology generate feedback for the research and extension agencies, trials (0.25 ha) have been set up in the vicinity of each processing plant. During the first planting season (Jan-March 90), 16 of these trials were established; for the next planting season, a total of 35 pre-production plots will be installed.

The strategy for these trials is twofold: (a) Apply all the components of available improved technology in combination with those components of traditional technology for which no improvements have been developed in an area bigger than that used in classical experimental work; and (b) facilitate the integration of research and extension workers at field level through their active involvement and evaluation of the trials. If successful, these trials will form the basis for preparing local, regional and national production plans.

-- Cassava seed production plots. The expected impact of the project on the cassava production and commercialization systems in the State of Ceará, is likely to increase farmers' demand for improved, good-quality planting material. To meet this demand, seed production plots are being set up in collaboration with the farmers' groups.

During the first year 16 seed plots (1.0 ha) were installed; for the second year the goal is to establish 35. This work is being undertaken as communal enterprises so as to promote group cohesiveness and facilitate farmer participation and control of the production and distribution of the planting material.

8.1.5.4 **Processing technology.** Implementation of a dry cassava processing technology among small-scale farmers so that they can function as suppliers of raw material to the animal feeding industry, is faced with the problem of meeting large-scale demand on a continuous basis. The small farmers generally have difficulties maintaining consistency of price, quantity and quality.

The following parameters have been established to facilitate evaluation of farmers' groups performance in the adoption of the new processing technology and the new marketing alternative: efficiency of plant use and of processing, global efficiency, yields and conversion ratios. Some results obtained in assessing progress in this activity are as follows:

-- Efficiency of plant use. This parameter gives an idea of the availability of cassava in the area of influence of each agroindustry. In Ceará sun-drying can be carried out between August and December (24 wk). The climatic conditions prevailing during this period permit the drying of a lot of chips in two days (60 lots/yr). Where sun-drying is practiced on a day-to-day basis using only half the drying area each day, the no. of lots processed rises to 120/yr. Table 8.2 shows the efficiency of use of the drying plant for some of the groups that produced dry cassava the first year (1989). The values obtained were generally low, which is considered standard for the first year of operation. Data for the second year of processing are not yet available.

-- Efficiency of processing. This parameter gives an idea of the assimilation of the processing technology by the farmers. It compares the amount of cassava chips processed per unit of drying area with an optimum amount (10 kg/m^2). Values below 75-80% are considered low (Table 8.3).

-- Global efficiency. This parameter combines efficiency of plant use with that of processing. Values below 50% are considered low. Table 8.4 shows some rates obtained by farmers groups during the first two years of operation. Complete data for the second year are not yet available.

Table 8.2 Efficiency of use of cassava drying plants.

Organization	Processing Period (No. Wk)	No. Lots Processed Real	Theoret.[1]	Efficiency of Use (%)	System[2]
1989					
Poco dos Cavalos	11.5	40	70	57.1	A
Barreiro	14	19	42	45.2	B
Lagoa Grande	23	63	69	91.3	B
Queimadas	11	08	33	24.2	B
Jua dos Vieiras	18.5	52	110	47.2	A
1990					
Serra do Santana	14	25	42	59.5	B

1. The theoretical no. of processed lots of cassava was estimated on the basis of the actual no. of wk of operation in each agroindustry.

2. A = one lot/day with 50% of drying area occupied; B = one lot every two days with 100% of drying area occupied.

Table 8.3 Efficiency of processing of the drying plants.

Organization	Cassava Processing: No. Lots	Area (m^2)	Fresh Cassava Processed (kg)	Avg Loading Rate (kg/m^2)	Optimum Loading Rate (kg/m^2)	Efficiency of Processing (%)
1989						
Poco dos Cavalos	40	300	108,343	9.02	10.0	90.2
Barreiro	19	600	41,980	3.67	10.0	36.7
Lagoa Grande	63	210	120,000	9.07	10.0	90.7
Queimadas	08	500	16,148	4.03	10.0	40.3
Jua dos Vieiras	52	300	96,850	6.20	10.0	62.0
1990						
Serra do Santana	25	400	72,133	7.27	10.0	72.7

Table 8.4 Global efficiency of cassava drying plants.

Organization	Efficiency of Use of Drying Plants (%)	Efficiency of Processing (%)	Global Efficiency (%)
1989			
Poco dos Cavalos	57.1	90.2	51.5
Barreiros	45.2	36.7	16.6
Lagoa Grande	91.3	90.7	82.8
Queimadas	24.2	40.3	9.8
Jua dos Vieiras	47.2	62.0	29.2
1990			
Serra do Santana	59.2	72.7	43.0

-- Yields and conversion ratios. Table 8.5 presents the yields obtained during 1989-90 by the 12 farmer groups that participated in cassava processing activities. In 1989 the total output was 265 t of dry chips (702 t of cassava roots). During 1990 (23 groups and only 4 mo of processing activities, July-Oct.), total output was 932 t of dry chips (2438 t of cassava roots). This production represents an increase of 247% in relation to the first year. The conversion rates obtained in the two processing seasons--2.64 and 2.61 resp.--are considered acceptable.

8.1.5.5 **Commercialization.** This project activity operates under the basic assumption that as a result of the project's activities a new alternative market will be developed for the cassava crop through the cassava processing agro-industries, allowing small-scale farmers to sell dry chips to animal feed manufacturers for use as a partial substitute for cereals in feed rations. This assumption, which had proved to be valid in similar projects in Colombia and Ecuador, has not been fully realized in the Ceará Project thus far.

Most of the dried cassava produced in Ceará has been sold directly to dairy farmers in the vicinity of the drying plants. Of the 115 users for the dry cassava processed in 1989, only three were commercial manufacturers of animal feed although they purchased 30% of total output. Although only partial data are available for the 1990 processing

Table 8.5 Yields and conversion rates of cassava drying plants, 1989-90.

Organization	Cassava Roots(t) 1989	Cassava Roots(t) 1990	Dry Cassava(t) 1989	Dry Cassava(t) 1990	Conversion 1989	Conversion 1990
Folha Larga	92.5	171.8	34.0	71.5	2.72	2.41
Poco dos Cavalos	108.3	230.7	45.0	85.0	2.40	2.71
Jua dos Vieiras	96.8	152.6	38.9	59.8	2.48	2.55
Solidao	118.0	144.0	38.1	51.0	3.09	2.82
Lagoa Grande	120.0	182.0	44.4	67.0	2.70	2.72
Barreiro	41.9	74.2	16.7	31.1	2.50	2.38
Lagoa do Mato	47.5	67.2	17.4	24.0	2.72	2.80
Serra do Mondeu	35.0	90.9	13.8	38.1	2.53	2.38
Queimadas	16.1	36.0	6.9	14.4	2.33	2.50
Cacho. Boi Morto	17.3	77.1	6.8	31.4	2.54	2.45
Dourado	3.9	56.0	1.3	20.0	3.00	2.80
Serra do Santana	5.0	72.7	1.9	27.9	2.63	2.60
Pau da Bandeira		239.2		84.9	2.81	2.81
Sao Vicente		135.9		55.6	2.44	2.44
Carqueijo		138.2		50.4	2.74	2.74
Lagoa Mineiro I		161.8		67.8	2.38	2.38
Corrego do Brao		135.5		47.6	2.84	2.84
Iboassu Velho		49.2		20.8	2.37	2.36
Macajetuba I		54.5		22.0	2.48	2.47
Patos/Aruaru		64.0		23.7		2.70
Aroeiras		70.7		26.4		2.67
Gameleira						--
Marinheiros		18.3		6.9		2.65
Catanduba		15.9		4.7		3.38
Gurguri						--
TOTAL (25)	702.6	2,438.4	265.4	932.0	--	--
Avg					2.64	2.61

season, the tendency appears to be the same with a large number of low-volume consumers. This situation may be due to the fact that animal feed manufacturers are usually high-volume consumers throughout the year and the project is not yet sufficiently developed to stimulate their interest. Those who purchased more than 10 t accounted for 68% of the total production (Table 8.6).

Table 8.6 Commercialization of dry cassava in Ceará, 1989-90.

Year	No. Organizations	Total Output (t)	Total No. Consumers	No. Consumers/ Ton Purchased <1	1-10	>10
1989	12	265.4	115	68	41	6
1990	23	932.0	151	86	55	10

8.1.5.6 Organization

-- Institutions. The organizational structure proposed for the institutions participating in the Ceará Cassava Project is being implemented at various levels. The following results were obtained during the first 18 mo:

- State level: The Ceará State Cassava Committee (CCC) has been reinforced. It is composed of technical and administrative representatives from state agencies working with the cassava crop. Among these are EMATERCE, EPACE (State Agricultural Research Agency), CEPA (State Agricultural Planning Commission) and COOCENTRAL (Central Coop of Cotton Growers). The CCC is responsible for ensuring day-to-day planning and coordination of project activities and maintaining permanent communication with the offices of agricultural research and extension services located in the project's zones of influence. The CÇC has an executive leader chosen from one of the participating institutions.

- Regional level: The implementation strategy of the project at this level is pursued through the establishment of Regional Cassava Committees in each of the main areas of project influence. The purpose of these regional committees is to decentralize project administration and facilitate participation of local technicians and farmer groups in the decision-making process at state and regional levels. These Regional Committees function in close coordination with the CCC and have started to play important roles in project implementation in areas such as training, selection of new groups and technical assistance. During the first year only one Regional Committee was organized; in 1990 similar committees were formed in the other four areas of project influence.

- <u>Local level:</u> In each municipality where there are cassava processing groups, the goal has been to promote the formation of technical teams composed of agricultural extension agents, social extension personnel and subject-matter specialists drawn from EPACE, EMATERCE and other agricultural agencies. These teams are coordinated by the respective Regional Cassava Committee and are responsible for giving technical assistance to rural communities in the organization and administration of community-based groups around integrated cassava production and processing activities.

-- <u>Farmers</u>. Organization building among farmers participating in the project is been pursued through the establishment of small-scale farmers organizations who are responsible for the installation, operation and administration of the cassava-based processing agroindustries. Achievements in this area during the reporting period have been as follows:

- In 1989 twelve farmers' groups were reorganized and/or reactivated for cassava processing activities. Although the majority of these groups were established before the initiation of the project, they had no experience in operating cassava agroindustries under a commercial farmer-owned scheme, and most of their cassava-processing experiences had been under the community-owned scheme, which characterizes most of the communal cassava flour ("casas de farinha") production units existing in rural NE Brazil.

- During 1990 another 24 cassava farmers' groups were organized, and it is expected that by the end of 1990 a total of 36 groups will be engaged in producing dry cassava for animal feeding.

- The project is fomenting the organization of second-order groups at the regional level (Associations of Farmers' Groups) in order to improve their bargaining power and their participation in central project planning and implementation. This type of organization could play an increasing role in areas such as marketing, channeling of funding, farmer-to-farmer training and could also facilitate institutional work in the adaptation of cassava production and processing technology, as well as the implementation of agronomic, agroindustrial and social research activities.

- In 1990, in two of the regions where the project operates initial steps were taken toward forming Associations of Cassava Farmers' Groups (Ubajara and

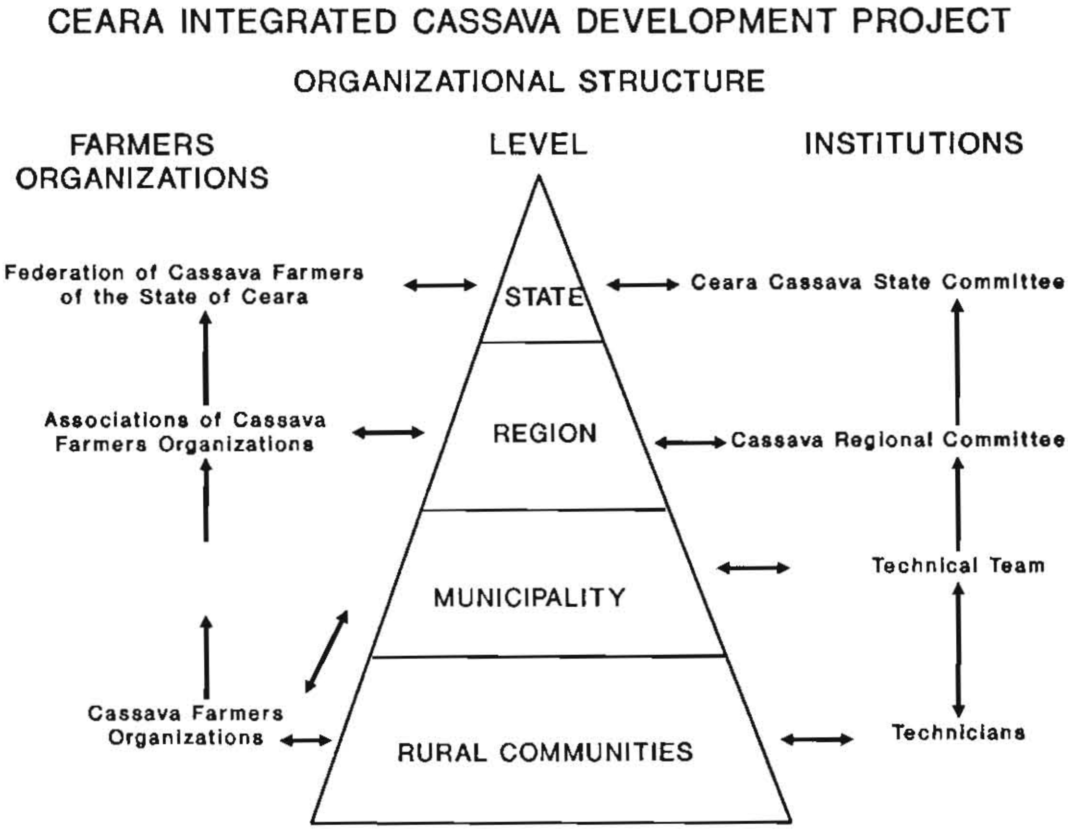


Figure 8.2 Organizational structure of the project.

Itapipoca). The organizational structure of the project is shown in Figure 8.2.

8.1.5.7 **Training.** During the first two years of the project, several important events related to training of technicians and farmers were accomplished (Table 8.7). In addition, excursions and special days are being utilized for training and information purposes (Table 8.8).

8.1.6 Monitoring and evaluation

Tracking progress toward achieving the project's specific objectives is being done through an evaluation strategy that includes the following monitoring activities:

-- Daily project functioning in the area of cassava processing

-- Project impact in relation to cassava production and productivity in Ceará

Table 8.7 Training events, 1989-90.

Event	Training Events Type	No.	Participants Tech.	Participants Farmers
1989				
Planing Meeting	Introduction	1	26	16
Course on Ceará Processing	Processing	1	30	-
Semminar on Community Organization	Organization	1	35	-
Course on Cassava Production	Production	1	38	-
I Annual Meeting of Farmers' Groups Mgers	Evaluation	1	14	17
1990				
Courses on Cassava Production	Production	2	30	-
Course on Organization of Farmers Groups	Organization	1	20	-
Courses on Cassava Processing	Processing	6	36	46
Semminars on Cassava Comercialization	Commercialization	5	35	26
II Annual Meeting of Farmers[1]	Evaluation	1	25	35[1]

1 Will be held in January 1991.

Table 8.8 Excursions and special days.

Type of Training Event	No. of Events	Participants Community	Participants Farmers
1989			
Excursions	15	15	123
Special Field Days	2	5	20
1990			
Excursions	11	11	82
Special Field Days	1	10	150

-- Distribution of project benefits among intended beneficiaries.

After the two cassava processing seasons, some preliminary information has been collected in the following areas:

8.1.6.1 **Characteristics of project participants**

-- Land tenure. Currently there are 38 active farmers' groups in the project. Members operate their holdings under three types of land tenure systems: owners, sharecroppers and renters (Table 8.9). The main difference between sharecroppers and renters is the land rental agreement, which in the case of the latter is often arranged for periods of more than one year.

-- Age of participants. The majority of the farmers are between the ages of 30 and 60, with fewer than 20% below 30 and 12% above 60 (Fig. 8.3).

-- Size of farmers' organizations. Most of the farmers' groups participating in the project have undergone a transition from community groups originally organized around communal activities such as farinha production units and communal wells. The dry cassava processing groups being formed within the Ceará Project are different in nature and organization, and their functioning has been initiated on the basis of farmer-owned and operated cassava agroindustries (Table 8.10).

Table 8.9 Land tenure of cassava farmers, 1990.

Type of Land Tenure	Frequency	%	Cumulative %
Owners	694	73.4	73.4
Sharecroppers	64	6.8	80.2
Renters	188	19.8	100.0
TOTAL	946	100.0	
Valid Cases	946		
Missing Cases	0		

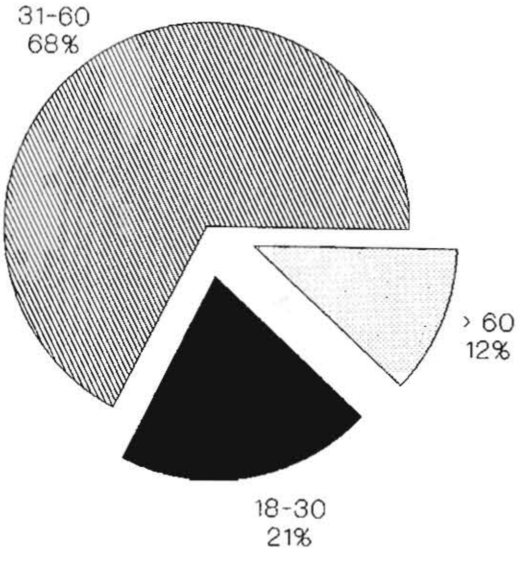


Figure 8.3 Age of members, 1990.

8.1.6.2 **Cassava production.** A basic assumption of the project is that small-scale cassava farmers will increase their production if there are alternative markets. Two production factors are being monitored to test this assumption: (1) size of cassava plots planted by project beneficiaries, and (2) the relationship between cassava plot size and land tenure system.

-- Size of cassava plots (1988-89). Preliminary analysis of baseline data collected on size of cassava plots planted by project beneficiaries indicates that 80% of the plots are from 1.0 to 2.0 ha and that fewer than 15% exceed 3.0 ha in size (Table 8.11).

-- Cassava plot size and land tenure system (1988-89). Initial data suggest a similarity in size of plots planted by sharecroppers and renters and a significant difference between these two groups and smallholders, whose plantings are generally larger (Table 8.12).

8.1.6.3 **Results of the first two processing seasons (1989-90).** The following information was collected during the first two seasons of processing activities:

-- Cassava sales. During the first processing season (July-Dec. 1989), 53% of the cassava roots processed were from nonmembers near the processing units and 47%

Table 8.10 Size of cassava farmers' groups, 1990.

Region	Community	Municipality	No.Members
ITAPIPOCA	Marinheiros	Itapipoca	19
	Maceio/Coqueiro		36
	Poco dos Cavalos	Trairi	21
	Gurguri		27
	Solidao	Cruz	16
	Lagoa Grande	Acarau	20
	Catanduba		34
	Lagoa do Mato	Bela Cruz	19
	Lagoa do Mineiro	Itarema	12
	Gameleira		22
	Lagoa Mineiro II		45
LIMOEIRO	Patos/Aruaru	Morada Nova	49
	Dourado		31
	Fradinho	Russas	12
	Aroeira	Aracati	19
	Siriema	Quixada	19
CARIRI	Sao Vicente	Araripe	11
	Serra de Monde	Araripe	07
	Serra do Santana	Assare	16
	Cajueiro	Santana do Cariri	28
	Pau da Bandeira	Salitre	17
CRATEUS	Cabea de Ona	Crateus	31
UBAJARA	Jua dos Vieiras	Viosa do Ceará	21
	Queimadas		15
	Macajetuba I		38
	Barreiros	Sbo Benedito	22
	Cachoeira B. Morto	Ubajara	21
	Nova Veneza		122
	Araticum		48
SOBRAL	Folha Larga	Granja	34
	Ibuassu Velho		41
	Angelim		18
	Carqueijo	Mucambo	18
	Pedra do Fogo		17
	Corrego do Brao	Camocim	21
	Tamboriu		29
	Alvaca/Goiabeira	Santana/Acarau	10
	Barroquinha	Lagoa do Mato	58
TOTAL	38	24	1024

Table 8.11 Cassava plot size (1988-89).

Cassava Area Planted (ha)	Frequency		Percentage	
	1988	1989	1988	1989
0.0 - 1.0	217	304	46.3	41.0
1.1 - 2.0	145	270	30.9	36.6
2.1 - 3.0	39	73	8.3	9.9
3.1 - 5.0	43	55	9.2	7.5
> 5.0	25	36	5.3	4.9
Valid Cases:	469	738	100.0	100.0

Table 8.12 Land tenure vs. cassava plot size, 1988-89.

Land Tenure	Mean Cassava Area Planted (ha)	
	1988	1989
Owners	2.31	2.33
Sharecroppers	1.45	1.70
Renters	1.65	1.48
Entire population	2.09	2.08
Valid cases:	477	738

from members. Partial information available on 1990 indicates that 56% of the raw material processed was from nonmembers and 44% from members (Fig. 8.4).

In relation to land tenure status of the farmers, during the first year 69% of the cassava sold to the processing units was from smallholders, 22% from renters and 9% from sharecroppers. Information on the 1990 processing season indicates that 66% of the raw material sold to the drying plants was coming from smallholders, 30% from renters and only 4% from sharecroppers (Fig. 8.5).

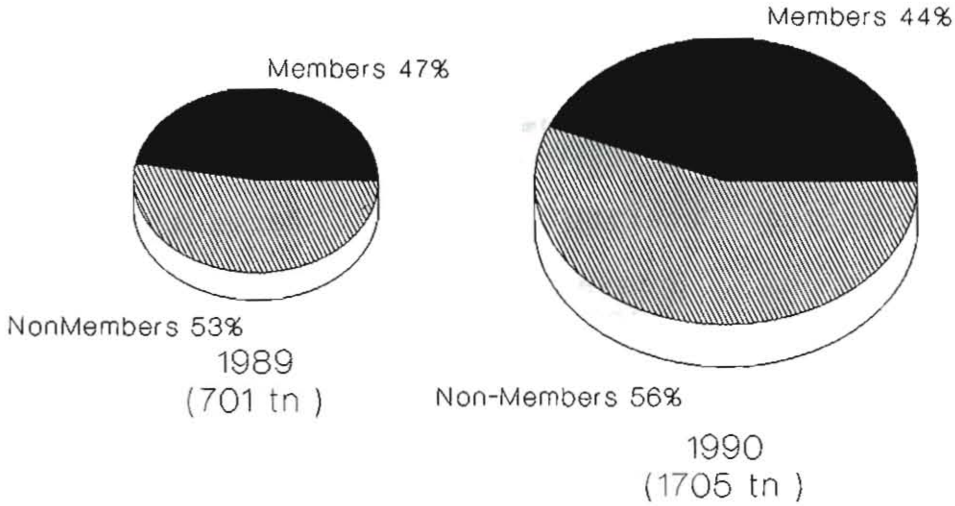


Figure 8.4 Cassava root sales by membership, 1989-90.

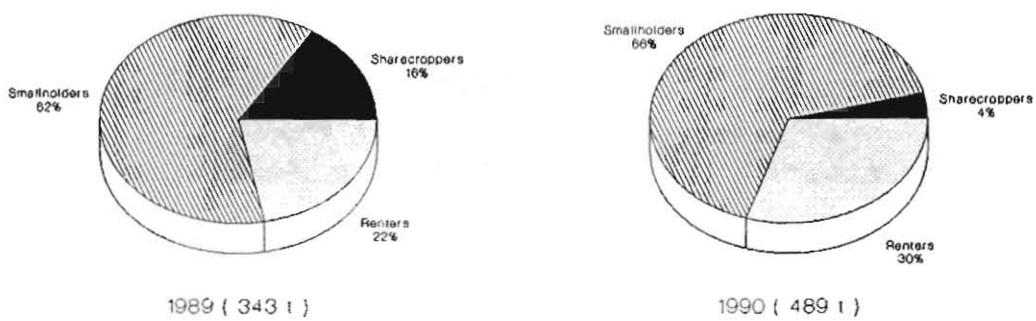


Figure 8.5 Cassava sales by land tenure, 1989-90.

-- <u>Cassava processing wages</u>. Besides selling the roots, another form of benefits gained by the farmer members of the cassava agroindustries is in the form of wages paid at the drying plants during the processing activities. During the first drying season (1989), the wages benefiting the farmers were distributed as follows: 52% to smallholders, 35% to renters and 13% to sharecroppers. Preliminary data for the second drying season (1990) show that 26% of the wages paid at the processing plants went to smallholders, 53% to renters and 21% to sharecroppers. (Fig. 8.6).

-- <u>Total incomes</u>. Benefits accruing to farmers' groups who participate in cassava processing activities include cassava sales, wages and the sharing of annual profits among members. During the first processing season, 58% of the total income earned by the processing groups went to smallholders, 32% to renters and 10% to sharecroppers. (Fig. 8.7). Total information about the second processing season is not yet available because some of the agroindustries will be processing dry cassava until December 1990. Preliminary data from 5 agroindustries indicate that 53% of the total incomes went to renters, 25% to smallholders and 22% to sharecroppers (Fig. 8.8).

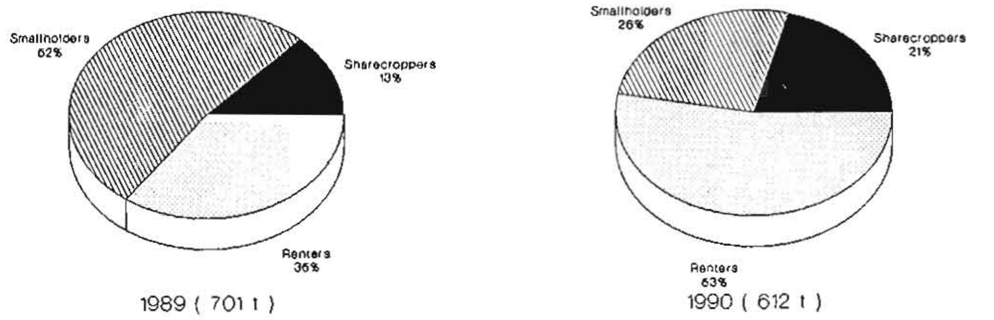


Figure 8.6 Wages (%) by land tenure, 1989-90.

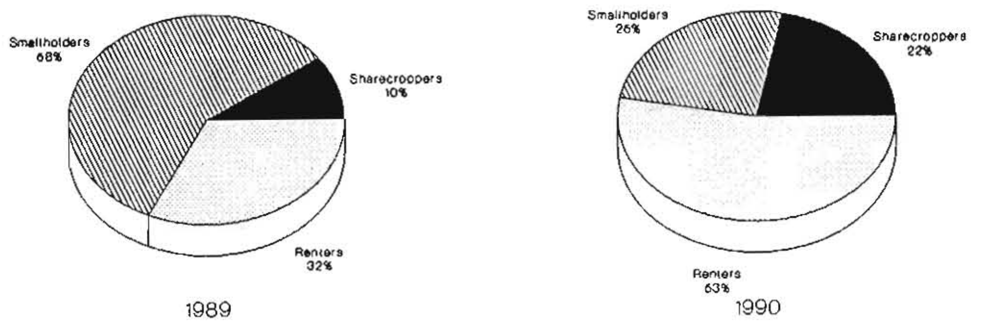
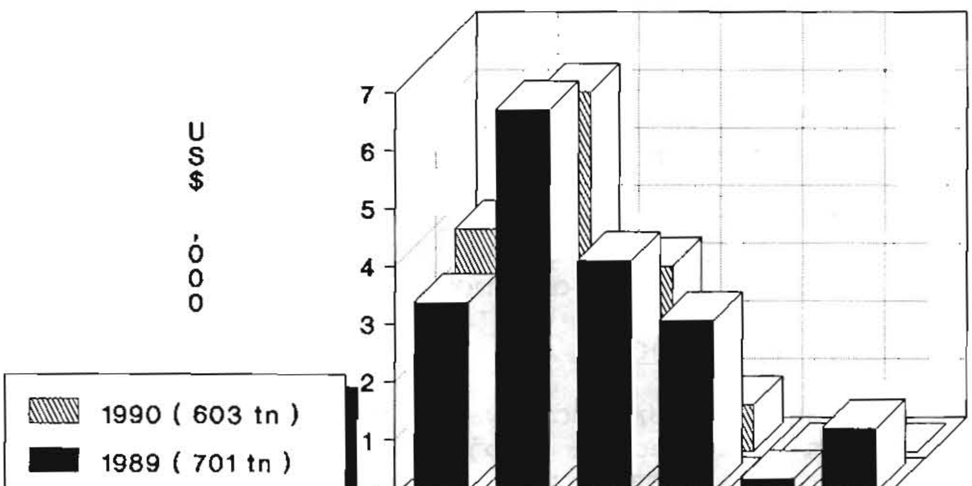


Figure 8.7 Total incomes (%) by land tenure, 1989-90.



	< 1.0	1.0-1.5	1.6-2.0	2.1-3.0	3.1-4.0	> 4.0
1990 (603 tn)	3.84	6.213	3.198	0.804		
1989 (701 tn)	3.271	6.618	4.006	2.967	0.231	1.109

Figure 8.8 Total incomes (1989-90) by cassava plot size (1990).

Additionally, the distribution of this total income according to the size of cassava plots planted in 1989, shows that more than 70% of the total income went to the farmers who planted between 1.0 and 2.0 ha of cassava and that farmers with more than 3.0 ha received less than 10% of total income. In 1990 the results of 5 agroindustries show that 94% of the total income went to farmers with cassava areas of up to 2.0 ha and that those farmers with more than 2.0 ha of cassava received less than 10% of total income (Fig. 8.8).

8.1.7 References cited

FAO.

IBGE. 1980. Agricultural Census.

IBGE. 1989. Anuario Estatístico do Brasil.

8.2 Ecuador: Cassava Development Project, Manabí

8.2.1 1985-89

The Ecuador Cassava Program was initiated in 1985. During the first phase of this project, the following achievements were accomplished:

-- Creation of a well-organized and effective farmer organization, the Union of of Cassava Producers and Processors Associations, UAPPY, with assured operational funding through the US Government PL-480 Program

-- Training of an experienced and qualified project coordinator supported by the National Foundation for Agricultural Development, FUNDAGRO

-- Development of an interinstitutionally supported cassava research and extension project with secure funding from USAID via FUNDAGRO for four more years.

8.2.2 June 1989-April 90

CIAT support for the project was then intermittent until April 1990 when the second project technical advisor arrived. This report summarizes activities until May 1989, the processing year from June 1989 to April 1990, and the current project situation.

With a good rainy season at the end of 1988-89 and greatly expanded drying space, UAPPY-Manabi and the collaborating sections in the Cassava Program fully expected an excellent production and processing season; nevertheless, the year fell short of expectations. No one factor or problem can be singled out; rather a constellation of related occurrences resulted in much lower processing and decreased benefits for UAPPY-Manabi members. However, experiencing a "bad" year may well have served good purposes for the long-term sustainability of both the UAPPY and the larger cassava program.

As a result of the good rains, cassava production in the region was good, and association members prepared for harvest. The cassava producer and processing associations (APPYs) began to demand operating funds for processing from the UAPPY. These were depleted, however, because of the investments made in drying patios; and the UAPPY was awaiting new PL-480 funds, which did not arrive. The only income was from the sale of flour to shrimp feed producers. As available UAPPY funds ran out, the APPYs turned to private lenders and borrowed operating capital at high rates of interest (8-10%/mo). The UAPPY moved quickly to turn around the milled flour to the feed factories to generate sufficient operating capital. As the year progressed, conditions for drying were optimal, but money became tighter.

In September Ecuador suffered a drop in the demand for exported shrimp due to strong competition from Asia. At the same time, national producers were faced with a growing shortage of larvae to stock their ponds. As their production declined, feed factories immediately stopped buying UAPPY cassava flour, traditionally used not only as a source of carbohydrate but as the natural agglutinant for the pellets used to feed the shrimp. UAPPY was faced with stores full of dried chips, no market, and still no funds from PL-480. APPYs with access to their own or privately borrowed resources continued to process; however, the majority simply stopped all work.

There were also problems of support from other participating institutions. The National Argicultural Research Institute, INIAP, continued with its program of varietal and agronomic work, but with reduced collaboration from CIAT HQ and decreasing attention to postharvest issues. An exception to this was a thesis on drying technology conducted by a university student who was subsequently hired by INIAP. The socioeconomics team conducted its fifth round of the farm-level production systems survey but did not complete the interviews. Funding from IDRC was somehow misplaced in ministerial circuits; and problems were compounded by a move of the IDRC regional office from Bogotá to Montevideo, leading to a halt in INIAP collaboration in the monitoring of the processing plants and preventing the final round of the farm-level production systems survey. This situation was further aggravated by the absence of direct socioeconomic support and participation from CIAT, as well as by delay in the analysis of the survey information. The end result was a growing gap between the work of the roots and tubers program at the local INIAP research station and the needs of the farmers associated with the UAPPY.

In the case of the Ministry of Agriculture, MAG, the person in charge of the cassava extension activities and activity involved with the UAPPY was transferred to another post in 1988. As his replacement did not have the same interests, collaboration was reduced, except in the area of accounting. Another problem directly affecting UAPPY was a virtual stalemate in the procedures within the MAG to legalize the APPYs. Uncertainty over legal status affects the APPYs' ability to obtain access to government resources that could be put to use in processing activities. It also affects APPY participation in UAPPY's electoral activities. UAPPY voted to revise its statues in order to ease the entry of rural workers' associations without legal ownership of land; however, MAG approval is still pending.

FUNDAGRO also underwent staffing changes that affected the Cassava Program. The position of Director of Programs was vacant for the entire year, and the Director of Research who resigned in late 1989 was not replaced until March 1990. The FUNDAGRO cassava coordinator was fully occupied with the problems of funding, commercialization and legalization of the UAPPY; and a shortage of professional staff reduced FUNDAGRO's capacity to monitor and support all programs, including cassava research.

Given the lack of money and market, as well as the decline in support from institutional collaborators, UAPPY could have virtually collapsed; but they resorted to several survival strategies. In order to conserve funds, half the administrative staff returned to their respective APPYs, and activities including training were put on hold. The jeep was stored to save on gasoline. Remaining UAPPY staff went on half salary, meetings of members were reduced, and the annual November get-together among members was cancelled. The UAPPY administrator and marketing committee--made up of older, experienced members--began an intense search for new markets for UAPPY products.

Problems with the UAPPY-Manabi also contributed to increasing organizational and operational problems in Esmeraldas. The coordinator, an expatriate volunteer, went on an extended funding trip and did not return for seven months. Given a certain lack of leadership and a lack of funding, the farmer groups were unable to sustain their processing activities. For lack of a local collaborating institutional environment and sustained contact with CIAT, the project is still in a state of reorganization and recovery.

When part (S./30,000,000) of the promised PL-480 funds finally arrived at the end of December, it was too late to process so this money was used to pay off debts and to complete the last of the processing. A study on the potential of cassava starch for industrial markets, commissioned by FUNDAGRO, pointed out the potential of the cardboard box industry. Samples of starch produced by the two women's groups were sent to a major box factory. As a result of the strong potential for this market, one of the larger APPYs invested money in the construction of starch processing facilities. Other explorations of potential markets began to yield tentative results, and further samples were sent for industrial experimentation. More importantly, the shrimp feed factories began to buy again. Slowly, UAPPY began to sell off its stored production, and funds were available again for operating at full capacity.

In the meantime new human resources were added to the project. FUNDAGRO made an agreement with the local technical university for agronomy students to do their required year of rural work with UAPPY in conjunction with INIAP's supporting research, training and extension activities. In October a doctoral student in nutrition from the Univsity of Arizona arrived to do research on the nutritional and consumption impact of the Cassava Program. She initiated a series of surveys that increased contact between the Cassava Program as a whole and the cassava farmer community. The CIAT socioeconomics input to the Ecuador project was revived, and the final step of the farm survey was initiated.

Although things were finally looking up, several hard lessons were learned. First and foremost was the recognition of the need to expand markets. This meant not only new markets for existing products but also for new products, implying new processing techniques and different marketing strategies. Second, UAPPY learned that it could no longer depend on one sole source of external funds but must make a concerted effort to locate more reliable sources of external funding in order to create sustained internal revolving funds for organizational growth.

8.2.3 The current situation

By the time the new project technical advisor had arrived (April 1990), UAPPY's situation had greatly improved. The remaining stores of cassava chips had been milled and sold. A new market was taking hold with a major plywood factory in Quito. UAPPY began sifting the unpeeled cassava meal to obtain a finer product equivalent to wheat flour for use by the plywood factory as a filler for the resins used to glue the sheets of wood together. Industrial experiments revealed that up to 40% cassava flour could be used to replace the wheat flour. In March 1990 the plywood factory began buying cassava flour at a rate of 6 t/mo; in August, their demand doubled to 12 t/mo; and they anticipate doubling production and thus their demand for cassava flour in 1991. UAPPY, which has also explored other buyers in the wood industry, just received a new order for 7.5 t from another plywood factory, which intends to substitute 50% of its wheat flour filler.

UAPPY also continued to explore the market for selling starch to the cardboard box industry. After several tests, one company began buying at a rate of 25 t/mo in July; the following month, it was doubled. The type of starch demanded by the industry, which is referred to as common starch ("corriente"), requires less labor to produce than higher quality starch and can be dried directly on a cement patio. As this demand is far greater than UAPPY's current capacity for starch production, they are buying starch from selected private producers. Although UAPPY plans to increase starch production capacity during the coming year, management is considering how these small starch producers might be organized into an association and join UAPPY.

UAPPY has started producing cassava flour for human consumption on a somewhat smaller scale. The flour is produced at the Demonstration Center using an artificial dryer, as well as at one of the associations which dries all the chips on trays raised above the ground. The flour (3 t/mo) is sold to a noodle factory in Ambato. Although the market is small, UAPPY intends to maintain it while it explores other potential buyers in the food industry.

With these new markets, UAPPY has moved into a commercial phase of production. Rather than being 95% dependent on the shrimp feed industry, 40% of the production this year is going to the new markets. New products are being produced requiring different processing technology (e.g., sifting the cassava meal); and some associations are beginning to look at specialized production (e.g., flour for human consumption). Both efforts will require a different research focus.

Despite the growth in the commercial sector, cassava production was poor in the Manabí region this year. Rainfall was lower than normal during the rainy season, which was also shorter. Some private starch producers never stopped production; they simply continued making starch through the scant rainy season and drying when it was sunny. Some made a product called "bagazo y todo," where the cassava is grated and dried without removing the starch. Middlemen, taking advantage of the market for shrimp feed opened up by the UAPPY, buy this product for sale to the feed factories.

The low rainfall had another important impact. Unless farmers irrigated their crop, much of it was too poor to harvest this year. This created a shortage of fresh roots for both UAPPY associations as well as private starch producers. In addition, the short rainy season allowed for processing to begin much sooner than normal, before the local harvest would begin even in a good rainfall year. To meet the demand, UAPPY and the APPYs themselves traveled to the humid zone (4-5 h to the east of Manabí) and made contracts with cassava growers to buy their production. Located in a zone with year-round rainfall, these producers, normally supply much of the large urban fresh market demand; however, production has increased and prices have fallen, making it attractive for both producers and processors to bring the cassava to Manabí for processing.

The roots from this region are usually larger and of better starch quality than those produced locally. APPY processors have noted that the conversion rate is better than local cassava during a normal year and that the roots are much easier to peel by hand. Large quantities of cassava were brought in during the June-September period until the better local areas began to be harvested. It is likely that the comparison for this year between fresh supply from UAPPY members vs nonmembers will be on the order of 25 to 75%.

The move to purchase cassava outside the region is indicative of the overall maturation of the UAPPY and its members as a whole. The experience of the past year has taught them that they must be quick and flexible to take advantage of the entire period of sun-drying. The farmers are discontent with the quality of their own production and are making quite vocal their demands for better, early-maturing (7-9 mo) varieties that are more drought tolerant and maintain a consistent DM content despite fluctuations in rainfall over the growing season. These demands were presented by farmer representatives at the interinstitutional committee meeting in October to develop the next work plan for FUNDAGRO support. Changes in the plans by INIAP agronomists for on-farm trials reflect these demands.

UAPPY maturity is also demonstrated in the management and administration of the commercialization and the distribution of credit to the APPYs. As a result of last year's experience, UAPPY did not invest all its profits in construction; instead, funds went into strategic activities to support the development of new markets. Although supporting institutions are collaborating in the search for new funds, UAPPY pursued the remaining PL-480 funds that had been promised the previous year. This sum (S./20,000,000) was now worth less than half its value in dollars the previous year; however, it was still a sizable amount for operating expenses. PL-480 administrators decided to make this a donation to UAPPY, with the restriction that it be used as a revolving fund with near-commercial rates of interest so as not to lose its remaining value. Once again, there were multiple changes in the bureaucracy, and the money again arrived quite late in the season (early Nov.). This time, however, UAPPY used reserve funds and its own credit at the bank to tide over the demands for operating capital from the associations. A broader range of products and markets also kept UAPPY funds circulating until the PL-480 funds arrived. Nonetheless, UAPPY has stepped up its efforts to locate other funding sources; and even some of the associations are beginning to consider seeking independent grants for their specific construction needs. As such funds are captured, UAPPY will push ahead with plans to bring all the APPYs up to full processing capacity with adequate drying space and ultimately with the infrastructure to process either flour or starch in order to have greater flexibility in responding to market demands or variations in price.

After a fairly long hiatus in the building of new associations, several new groups are entering UAPPY. One group of women worked with a Peace Corps volunteer to secure a donation of US$5000 for constructing their processing plant. UAPPY assisted them in developing the proposal and is now focusing promoter activities on assisting and training the new members in operating and managing their processing activities and association. UAPPY assisted a second group of women, organized last year, in securing funds to purchase a plot of land; and with a small operating fund from UAPPY, they will process using borrowed equipment in order to earn funds for construction next year. A third group of women has recently initiated discussions with UAPPY to consider starch making as an economic activity for their community organization. In Esmeraldas, two women's groups recently received external funding from the UK and will begin processing shortly.

The growing involvement of women in both UAPPYs is quite interesting and appears to demonstrate some practical lessons regarding women's participation in agricultural development projects in the coastal region of the country. Women and men are considered as individuals rather than household representatives in the UAPPY associations. A limit of 3 related persons in any APPY is generally the rule; however, both men and women from the same household can be members of the same APPY or members from one household can belong to different APPYs as is the case in both of the older all-women APPYs. This makes calculating the benefits on a per-member or per-household basis more complicated, but it serves to encourage female participation in the organization. Women are also part of mixed associations; and in several, they hold the senior elected offices. Women participate fully in the UAPPY general assembly, hold office on the directorate, and hold the administrative positions of secretary, office manager and accountant. Although the women have not been active as promotors, they have been involved in farmer-to-farmer technology transfer, hosting new women members and teaching them how to process starch.

While it appears that women in mixed associations have earned more than those in all-female APPYs, this is due more to the limited production areas of the two older womens' groups rather than to their production ability. This issue will be tested as the new Las Piedras women's group starts to work in its plant, which was designed to be the same in size as the best of the all men's groups. The prevalent gender-based division of processing activities in the UAPPY (men produce flour and women do starch) has likely contributed to the presence of women in the organization. The validity of the division will be tested as more groups begin to process starch. However, the experience of the one all-male group processing starch shows that the men may build the structure, but they hire women as the processors. This increases the job opportunities for women in the community, which has probably been the most important gender impact of the project. External observers of the UAPPY have noted in several reports that the income generated by the women in UAPPY has served to enhance their socioeconomic status as well as their economic independence, which in turn appears to be affecting their social status with respect to men. This observation requires further careful analysis, however.

While UAPPY operates on a July-to-June calendar, research operates on an annual calendar funding and planning basis. Research results for this year are mixed. Three years of agronomic testing show that the var. M Col 22-15, introduced from CIAT because it is widely used in drier areas of Venezuela and Colombia, is appropriate to the region; and it will be released next year as INIAP Porto Uno. Plans for wider scale multiplication of planting material are under way and will involve considerable UAPPY participation in managing five multiplication plots with association members. A collaborative project among UAPPY, INIAP and thesis students will be in charge of this effort.

The socioeconomic farm-level production systems survey was finally completed in August, and analysis is under way in collaboration with CIAT. Collection of the processing plant monitoring information from 1989-90 was also completed. A major initiative in this area for next year will be the merging of the various data bases on cassava production and socioeconomics and the comparative analysis and interpretation of results. The methods for conducting the monitoring of production and processing activities will be modified to allow for a more focused data collection procedure, greater involvement of APPY members in the data collection, and a more agile analysis system to permit more immediate use of the information by UAPPY.

Unfortunately, a large part of the research planned by INIAP was not implemented. Less than half the research budget was spent, and a large part of the training funds (> US$30,000 allocated by FUNDAGRO) were not touched. UAPPY, on the other hand, normally uses all of its FUNDAGRO budget for its planned activities in institutional support, development and training of farmer members. Consequently, FUNDAGRO has changed its procedure for allocating research funds. Explicit attention will be paid to INIAP's actual capacity for implementing the planned activities; and budget allocations will be made only for those where sufficient human resources are available. All training funds will be placed in a central fund for access by all project participants rather than being explicitly allocated to INIAP's research program. Finally, a separate research fund will be created to meet project demands that INIAP is unable to meet. These funds will focus on postharvest issues, quality control, environmental impact, marketing, and new product research. Collaborative research projects between private and public sector research entities will be encouraged. The intent is to bring a larger community of R&D institutions together in support of the Cassava Program's needs.

Research activities undertaken by the CIAT technical advisor for the Cassava Program are only just getting under way. In addition to synthesizing the project's history and development, considerable time has been allocated to assisting in the reorientation of the research program and to facilitating greater interinstitutional participation in the project planning process. Equal time has been spent in providing direct assistance to the farmer groups in Manabí and Esmeraldas in identifying R&D needs and directions, as well as arbitrating a reorganization of the Esmeraldas project. Greater FUNDAGRO support for this group will decrease this role and allow for some more focused research activities to get under way in support of the farmer groups.

The major focus of CIAT-supported research activities this year has been on cassava starch. In direct support of UAPPY's need to open new markets, a diagnostic survey of the traditional and potential starch industry was initiated in July. First an inventory of all industrial users in the country was made using secondary sources at bank and ministerial levels. This information was used to select industries from the wood, textile, box, food processing and glue sectors for informal interviews. This information was analyzed by the economist hired to conduct the study in collaboration with CIAT and FUNDAGRO specialists. The report, which has stimulated further exploration of additional markets, will be the basis for designing a more formal study of the potential starch market next year.

An important finding of the starch users survey was that virtually none of the potential users outside of the box and shrimp feed factories had had any previous experience with cassava starch and had very little information about its potential. To address this knowledge gap, the Cassava Program is planning to hold an industrial users seminar in order to provide information on how to use cassava starch and experiences in using the starch at industrial levels in other countries. The FUNDAGRO-supported seminar will receive collaboration from CIAT and other national programs.

The second part of the starch diagnostic study focuses on the local marketing system of the well-known middlemen in the region. Because of difficulty in using formal or even informal research methods and the lack of researchers to obtain this information, a group of UAPPY members with long-term involvement in the traditional starch productio areas are collecting this information on their own via their personal relationships in the communities. This information will be assembled in December, and a strategy designed for further research in this area.

The final and lengthier part of the diagnosis consists of a survey of all starch processors in the region. The survey instrument, which was adapted from one designed by CIAT for Colombia, is applied in interviews (30-60 min) of all the private, largely family-based processors in three zones covering nearly all of the known starch-production areas in the country. The survey team consists of two university students and one farmer member from an association in the major starch-producing zone. To date 154 have been interviewed, and an estimated 100 remain in part of one zone and all of the third. The survey will be completed in December.

Preliminary findings indicate that two processing systems are in operation: one is semimechanized with the grating done by machine; the other, entirely by hand. There is a total absence of machinery for peeling, washing or straining starch. Products include three types of starch ("corriente," "chillón industrial" and "consumo humano") and two by-products ("cachaza," the proteins, fats and phenols with the starch, known as "mancha" in Colombia; and "bagazo," the fibrous mash left after straining). As variations have been observed in product quality at different processing sites, a study of quality of production will be initiated at the end of November in collaboration with a specialist from Colombia. There is also some product adulteration among processors; but this practice is more widespread among middlemen. As a result UAPPY is faced with a major constraint in opening up new markets among the box factories because they have had bad experiences in the past with the quality of starch supplied by the local middlemen. All these products have markets, but the by-products tend to be stored for sale during the rainy season when starch is scarce. Prices fluctuate greatly over the processing season and very few formal credit systems are used. A small group of middlemen in each locality control the commercialization of the products, advancing credit or buying on credit with different producers.

8.3 Colombia

8.3.1 DRI/ICA Atlantic Coast

An ongoing agreement (since 1981) between CIAT and the Integrated Rural Development Fund (DRI) of the Colombian government has provided the institutional framework within which the Cassava Program can conduct research at a pilot level in Colombia. Initially, research concentrated on the technology for producing dried cassava for the animal feed market; but since 1988 CIAT has had no role in this now successful small-scale rural agroindustry. Upon request, CIAT does provide some support to the National Association of Cassava Producers and Processors (ANPPY) in the form of technical advice and assistance in project formulation.

Research activities within the DRI/CIAT framework in 1990 were fresh cassava storage, cassava flour for human consumption, and cassava production (especially the pre-production plots destined to supply the pilot plant for high-quality cassava flour). For details of these areas of research, see the Utilization and Agronomy sections. This institutional arrangement is valuable in providing (a) a means for the Program to generate technologies in close contact with farmers, processors and consumers; and (b) a highly efficient interface between research, extension and development--something that has been amply demonstrated in previous years.

In January 1990 another meeting of the GRUYA (Group of Cassava and Associated Crops' Research) was held on the Atlantic Coast of Colombia. This group, which has been meeting for five years, consists of people from ICA, the Caja Agraria (Agrarian Bank), the universities of Sucre and Córdoba, and the Agricultural Secretariats of Bolivar and Córdoba in addition to CIAT. GRUYA planned all experiments to be planted in the Atlantic Coast states of Sucre, Córdoba, Bolívar and Atlántico during 1990. In Atlántico the emphasis was on associations with sorghum and early-maturing maize. In Córdoba, experiments with yuca, maize and yam associations were planted; while in Bolívar and Sucre the yuca/maize association was of most interest. Experiments were conducted either in farmers' fields or at the ICA experiment station in Carmen de Bolívar.

In July a group of GRUYA members received training at CIAT in experimental techniques and statistical design. Results of their field experiments were used for the statistical exercises. Many of the experiments planted by the GRUYA involved the new cassava varieties due for release by ICA in 1991, and planting material of these varieties is being multiplied. Moreover, all field experiments that resulted in the acceptance of these varieties had been carried out by this group.

Over and above the traditional research activities in farmers' fields, GRUYA maintains 10 pre-production plots distributed throughout the region which, together with those carried out in collaboration with CIAT, total 30 plots in which the most advanced cassava production technology components are tested as a package. Finally, GRUYA published another volume of research results, covering 1988-89.

8.3.2 National Rehabilitation Program (PNR)

In 1989 a joint project was initiated between CIAT and the PNR of the Popular Integration Secretariat attached to the Office of the President. The PNR is a government program designed to bring development to those areas of the country ignored by the public sector (hence suffering from public order and rural poverty problems). The small-scale cassava processing coops were viewed as one of few viable alternatives available to the small farmers in these areas.

Under the auspices of the agreement, the Cassava Program is working in a multi-institutional environment in three regions of the country (Sucre, Córdoba and Cesar on the Atlantic Coast; Meta; North and South Santander) where cassava is a traditional crop but lacks alternative markets. During 1990 drying plants were built in Sucre, Córdoba, Santander and Meta, and another is under construction in Cesar. In Meta, where there is high precipitation during the harvest season, a mixed natural-artificial drying plant was built.

In order to test promising CIAT clones in the region, trials have been established in collaboration with ICA in Cesar, North and South Santander, and a program for the multiplication of two recently released varieties is under way in Meta (PNR/ICA/CIAT Seed Unit). This two-year project will end in mid-1991, when responsibility for those activities currently undertaken by CIAT will be assumed by Colombian national institutions.

8.4.1 Paraguay

The agricultural research and extension team that works with cassava in Paraguay was trained at CIAT and has gradually increased in capacity to the point where it now receives greater in-country support for its activities. A study of fresh cassava commercialization in the country was published this year. Team members have participated in international meetings and courses, and two members will obtain masters degrees in 1991.

Four years of field research have resulted in the characterization of at least seven local varieties of good yield and eating quality. In addition, improved production technology now exists, and appropriate crop management recommendations can be made. Current field research is focusing on soil management and conservation and on germplasm improvement.

Research on cassava utilization is becoming increasingly important. Diagnostic studies have been completed, with the termination of surveys on starch processing industries and markets during 1990. The cassava storage technology developed at CIAT is now being used at a pilot commercial level in Asunción, with excellent results. The first cassava drying plant is under construction in collaboration with a farmers' coop. Equipment improvements for small-scale starch extraction will be tested, based on solving the problems identified in the surveys. Animal feed trials using fresh, ensiled and dried cassava are also planned.

8.4.2 Panama

CIAT reduced its activities over the last two years in light of the financial problems of local institutions. Despite these difficulties, farmers participating in the Integrated Cassava Project have continued drying cassava for sale to private industry. The agricultural policy of the new government appears favorable for small farmers in cassava-producing areas, and renewed government interest in cassava is anticipated.

The Ministry of Agriculture recently named a coordinator of a National Cassava Program, who works closely with the national agricultural research institute, IDIAP, in all cassava-related activites. The national research team recently compiled a document summarizing the experiences of the Integrated Cassava Project since its inception. This document will be useful in planning future activities.

The private sector has responded efficiently to the opportunity for using cassava in animal feed rations (especially for chickens), and at least one business has planted considerable areas of cassava close to Panama City in order to cut transport costs.

8.4.3 Bolivia

Contact was resumed with Bolivia after an interim of 8 years. Two development projects (UN and USAID funding) working on coca substitution in the Chapare region contacted CIAT with respect to developing cassava processing for the local animal feed industry. In addition, the University of Santa Cruz is carrying out cassava production research and is also interested in processing.

Although the difficulties caused by working toward substitution of coca by other crops are enormous, they are not insurmountable. Cassava is one of the most attractive alternative options if small-scale processing can be introduced for small farmers. One advantage is that most farmers already have drying patios. Nevertheless, the economics of cassava processing are not clear: the price offered to farmers for the fresh root must be attractive to compete with coca, but the cost of the dried cassava must be low enough to compete as a carbohydrate source with local maize. As prices of coca and maize fluctuate in a relatively free market, economic feasibility is not easy to estimate.

The UN project in Chapare has funded a pilot plant for producing dried cassava, based on the Colombian model with some innovations. Project personnel were trained at CIAT in processing and cassava integrated projects. CIAT will monitor the operation of the pilot plant during 1991 and collaborate in feasibility studies for project expansion. An in-country course on cassava, organized by IBTA-Chapare, is planned for June 1991.

9. REGIONAL NETWORKS AND TRAINING

9.1 II Latin American Cassava Breeders' Workshop (Cruz das Almas, Brazil, 21-25 May 1990)

As a result of a meeting held at CIAT in 1988, a Pan-American Cassava Network was created with representatives from eight countries. The network's original objectives were to promote the integration of and communication among Cassava Programs in the hemisphere through meetings, training, publications and other network activities. A set of priority areas was established in order to organize workshops (marketing, transfer of technology, breeding, etc.). This breeders' workshop was the second to be organized at the Pan-American level and the first within the framework of a cassava network.

The objectives of the meeting were to:

-- Interchange information about cassava breeding activities, the status of the crop, and its main limitations

-- Discuss breeding related aspects that were mentioned as relevant in a previously conducted "Delphi" survey

-- Analyze and propose specific breeding activities to be conducted within the network.

Discussion was organized around the country presentations, and roundtables were organized on specific topics. The most important points arising from these discussions were:

9.1.1 Characterization of the main environments for cassava

Some ten years ago CIAT proposed a classification based on edaphic, climatic and biological factors, intended to provide a broad framework for the different cassava regions to be classified. The discussion raised the issues of how well the different growing regions in Latin America fit into that classification and the importance of considering other aspects of the crop such as product utilization for future subdivisions of the present classification.

Determining the homology among cassava-growing areas of the continent will facilitate the movement of elite germplasm among regions. Classification into different agroecosystems (ECZs) reduces the variability within a particular ECZ, but does not eliminate it. There is still variation in soil type, incidence of pathogens, differences in pathotypes, utilization aspects, etc., representing what is referred to as microenvironments or intra-ECZ variation.

The working group concluded that environmental variation at the regional (micro) level could be studied using regional trials with the main varieties for the area. The network will develop a project for uniformity trials, including the most common varieties for the principal predefined ECZs (I, II, III and IV). Participants from the different countries are to provide detailed information about their main cassava regions. This activity will generate a continuous flow of improved genetic material (basically centralized at CIAT) and information among countries.

9.1.2 Germplasm movement

Germplasm movement among countries has to be accomplished with minimum guarantees of being pathogen- and pest-free. It was generally agreed that in-vitro transfer represents the safest means for germplasm movement within the continent. Indexed stakes were also regarded as a safe procedure by most countries (except for Brazil), and the one that permits the availability of enough planting material for yield trials in the shortest time.

Germplasm movement as sexual seeds raised some doubts about phytosanitary safety as the list of seed-transmitted pathogens is constantly growing. Close observation of introduced progenies at the experiment station level will help prevent introducing diseases to areas that are presently free of them. Some participants regarded the risk of disease transference by seeds to be minimal as they considered the continent already colonized by the main diseases.

9.1.3 Multiplication of promising genotypes

Few countries have institutionalized or commercial stake-multiplication enterprises, and there was a general consensus that this can restrict the rapid spread of improved genotypes and the expression of the potential of local varieties through quality seed production. As this area requires further attention, it was recommended that it be a topic for further discussion on a regional level.

9.1.4 Agronomic evaluation of breeding material

One of the most important desicions taken at the meeting was to establish a basic list of characteristics to be reported when germplasm is interchanged or when advanced yield trial results are reported. A list of passport data, qualitative descriptors and agronomic traits will accompany each clone that is distributed. When data from yield trials are reported, information about the experiment site, crop management and mean RY plus an indication of experimental variation for agronomic traits for each clone (RY, % DM, HCN, starch, HI, branching height and quality) must be submitted. Mantequeira (CMC 40, M Col 1468) will be included as a common check for advanced yield trials on the continent.

9.1.5 Communication within the Cassava Breeder's Network

Reactivation of the Cassava Network Bulletin was recommended. It was also decided to include in it two annual reports from the participating programs, describing the main activities conducted and results. Given its comparative advantage, CIAT will centralize the information and disseminate it.

The next meeting of the Breeders' Network was proposed for 1992, to be hosted by Cuba (first priority) or Mexico (second).

9.2 III Asian Cassava Research Workshop (Malang, Indonesia, 22-27 Oct. 1990)

One of the functions of CIAT's Regional Cassava Program is to promote collaborative research among national programs by forming networks through which information exchange and utilization of technical expertise can be enhanced. One of the mechanisms for achieving this goal has been the organization of periodic (every 3 yr) regional research workshops.

The first workshop, co-sponsored by the ESCAP-CGPRT Centre, Bogor was held in Bangkok in 1984, the primary emphasis of which was on cassava in Asia, its potential and research development needs. The second workshop was held in 1987 in Rayong, Thailand in cooperation with the RFCRC, Dept. of Agriculture. Each national program reported on its major research accomplishments in varietal improvement and cultural management, and priority research areas were discussed.

In this year's workshop, the main emphasis was on cassava processing and utilization, with seven countries presenting papers on the markets, products and processes for cassava, together with a description of the research being undertaken and future areas of priority. Progress made in varietal improvement and agronomic research during the past three years was also discussed.

Regional-level achievements in varietal improvement and agronomic research have been reported herein (sections 1.4 and 5.5) and in previous annual reports. With respect to modifications in regional research priorities that will have a bearing on future CIAT collaborative activities, it is interesting to note that quality factors are now an important criterion for selecting improved genetic materials. There was also a felt need for further economic analysis of the data being generated on soil fertility and erosion control measures, coupled with on-farm testing of those technologies that appear both technically and economically viable.

The presentations on cassava processing and utilization highlighted the diverse end uses in Asia (Table 9.1), particularly the import role of starch production. In terms of common research priorities, two major areas were apparent. Indonesia, India, the Philippines and Vietnam are interested in small-scale rural processing, especially for producing dry cassava products or intermediate products for further processing. On the other hand, Thailand, China, Malaysia, India and, to a lesser extent, Indonesia, are focusing on industrial-scale production of derived or modified products principally from starch. In both areas the link between the physicochemical properties of the raw material and the quality of the end product was recognized.

The workshop was the first opportunity for integrating breeders, agronomists and processing specialists at the regional level. It was proposed that this integration be strengthened at the next workshop through country presentations that cover the three areas, rather than treating the disciplines separately. Finally, a recommendation was made that communication among countries be improved, and the Asian Institute of Technology, Bangkok agreed to act as a clearinghouse for collecting and disseminating information, possibly through a regional newsletter, if funds could be found.

Table 9.1 Current cassava-based products and their relative importance in Asian countries.

Country	Dry Cassava (AF)[1]	Cassava Flour (HC)	Fresh Cassava (HC)	Starch (IU)	Starch-Derived Products (IU)
Philippines	X[2]	X	XX	**XX**	X
Thailand	**XXX**	X	-	**XX**	X
Vietnam	-	X	X	XX	X
India	X	X	XXX	XXX	X
Indonesia	**XX**	**XX**	XX	XXX	X
China	-	-	-	XXX	XX
Malaysia	X	-	X	XXX	X

[1] AF = animal feed, HC = human consumption, IU = industrial use.

[2] X = relative importance; those in bold denote products for export

9.3 Meeting on Cassava Cooperation in the Latin American Subtropics (Asunción, Paraguay, 15-16 Oct.)

Since its inception in 1972, the Cassava Program has been unable to cover the research needs and potential opportunities of the subtropical cassava-growing regions adequately. On a world basis the importance of this ECZ in terms of cassava production may not be that significant; however, 22% of the total area planted to cassava in Tropical America is located in the subtropics, making it the single most important cassava ecosystem on that continent. Other important subtropical cassava-growing regions are found in southern China and North Vietnam. Although CIAT has provided training and research support for national programs in southern Brazil, Paraguay and more recently northern Argentina, little systematic attempt has been made to promote horizontal cooperation among these countries or to define the principal research areas that might be dealt with on a regional basis.

The objectives of this meeting were therefore threefold:

-- Analyze the convenience of improving communication among professionals working on cassava in the countries.

-- Identify technical areas of specific interest to the institutions in each country and about which it would be useful to interchange more information.

-- Prepare an agenda on future activities among the institutions that will satisfy their common information needs.

Interestingly, while supporting enthusiastically the idea of improving subregional communication among the countries, participants also recognized that there is deficient communication among institutions within the same country. Steps will be taken to improve this situation. With respect to mechanisms for improving communication among countries, it was recommended that:

-- A country coordinator be designated who would meet periodically with counterparts in the other countries

-- An information network be formed with the interchange of annual reports in the first instance

-- A study be carried out on the feasibility of creating a regional cassava society

-- A regional cassava workers directory be prepared

The technical areas in which it was felt there was insufficient expertise within the subregion were soil microbiology, soil conservation, root rots, postharvest physiology and genetic tolerance of low temp. To support these research needs, it was proposed that agreements be sought with both national and international institutions.

Four areas of expertise that could present opportunities for horizontal cooperation were identified: breeding, production, postharvest aspects and socioeconomics. The resulting information will be used to formulate a project to obtain funding for these regional activities. The project will be formulated jointly at a meeting of country coordinators, together with a representative from CIAT in mid-1991.

9.4 HQ-based training

The training activities of the Cassava Program, carried out in collaboration with the Training and Communications Support Program, have been progressively changing their focus and content. In common with other commodity programs, there is now a reduced need for the intensive type of multidisciplinary course usually targeted at young research workers and extension leaders with little or no previous experience with the crop in question. In the case of researchers, a period of in-service training in their particular discipline is now seen as the most effective way of preparing them for carrying out their jobs. On the other hand, extension/development personnel and on-farm researchers, many of whom have several years' experience with cassava, often require greater skills in problem and opportunity identification so as to respond to the changing needs of their client farmers. Problem areas may arise from production, processing or marketing limitations. The Program's experience in executing integrated cassava development projects in collaboration with national cassava research and development organizations in Colombia, Ecuador, Paraguay and Brazil has provided the basis for structuring a course that meets the needs of on-farm researchers and development personnel more directly. The first course was held this year (see 9.4.1).

To complement both in-service specialization and training in integrated projects, a two-week introductory course on cassava production and utilization was offered, mainly for those country professionals who had not previously attended a CIAT cassava course.

9.4.1 Introductory course on cassava production and utilization (CIAT), 3-14 Sept. 1990)

This two-week course gave the 16 participants (8 Latin American countries) a general overview of cassava production and utilization research within the context of the development of the crop, after which they either continued on for a period of disciplinary specialization or took the integrated cassava projects course. For this reason, it was structured in a modular form, following the sequence of events in the cassava production, processing, marketing, utilization cycle. This was a departure from previous courses which have been presented more on a disciplinary rather than on an interdisciplinary basis. The course consisted of seven modules: Introduction, Cultural Practices, Planting Material, Plant/Environment Interactions, Biological Environment, Socioeconomics, Processing and Utilization. While this organization does not allow certain subjects to be dealt with in the accustomed depth (e.g., soils and fertilization), it was quite adequate for highlighting the type of disciplinary interaction needed to approach the resolution of farmers' problems. This is of particular importance as many national cassava programs cannot afford to have specialists in every discipline. The modular organization was appreciated by the participants, and a similar form of organization has been adopted for a national course in at least one country.

9.4.2 Integrated Projects Course (CIAT, 17 Sept.-4 Oct., 1990)

The Cassava Program recognizes that a high priority must be given to developing in-country expertise in the conceptualization, design, execution and evaluation of integrated cassava production, processing and marketing projects. This will require the training of personnel from national research, extension and development programs/projects in technical aspects of cassava research, as well as in the subjects of project management, farmer and institutional organization, and farmer-, market- and consumer-oriented research methods, etc.

A first attempt at organizing a course on integrated cassava projects was made during 1990, with the participation of personnel from cassava projects in Colombia, Ecuador, Brazil, Paraguay, Bolivia, Panama and Argentina. The course consisted of country project presentations, conceptual/methodological information based on the CIAT experience, the analysis of case studies, a field visit to projects in Colombia and the development of future action plans by all participants. A manual on integrated projects will be produced as a result of the information collected.

The course was highly successful in motivating participants to use an integrated, multi-institutional approach to cassava research and development. This clearly demonstrates the importance of areas such as farmer organization, relevant technology selection and scale of operation to project success. An informal information exchange network was established, and a second meeting tentatively arranged for 1991 in Ecuador.

10. PROGRAM PUBLICATIONS

Bellotti, A.C.; Arias, B.; Reyes, J.A. 1990. Biological control of the cassava hornworm, Erinnyis ello (Lepidoptera: sphingidae) with emphasis on the hornworm virus. In Howeler, H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crop. pp.354-363.

Bellotti, A.C.; Braun, A.R.; Yaninek, J.S.; Newenschwander, P.; Herren, H. 1990. Cassava agroecosystems and the evolution of pest complexes. Paper presented at the International Congress of Plant Protection, 11, Manila, Philippines. (in press).

Bellotti, A.C.; Cardona, C.; Lapointe, S.L. 1990. Trends in pesticide use in Colombia and Brazil. Journal of Agricultural Entomology 7(3):191-201.

Best, R.; Menéndez, L. 1990. Cassava utilization in animal feed. Supplement 1989. Cali, Colombia, Centro Internacional de Agricultura Tropical. 147p.

Best, R.; Menéndez, L. 1990. El uso de la yuca en la alimentación animal. Suplemento 1989. Cali, Colombia, Centro Internacional de Agricultura Tropical. 155p. ISBN 958-9183-20-4.

Best, R. 1990. The role of the International Agricultural Research Centers in generating and transferring root and tuber crop post-harvest technology: CIAT's experience. In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, International Society for Tropical Root Crops. Department of Agriculture of Thailand. pp.76-91.

Best, R.; Wheatley, C.C.; Chuzel, G. 1990. Cassava process and product development at CIAT. Paper presented at Asian Cassava Research Workshop, 3, Malang, Indonesia, Brawijaya University, Oct. 1990. 17p.

Bottema T., J.W.; Henry, G. 1990. History, current status and potential of cassava use in Asia. Trabajo presentado al Asian Cassava Research Workshop, 3, Malang, Indonesia, Brawijaya University, Oct. 1990. 17p.

Buitrago A., J.A. 1990. La yuca en la alimentación animal. Cali, Colombia. Centro Internacional de Agricultura Tropical. 450p.

Carter, S.E. 1990. A survey method to characterise spatial variation for rural development projects. Agricultural Systems 34:237-257.

Carter, S.E.; Jones, P.G. 1990. A model of cassava distribution in Africa. Trends in CIAT commodities. Economics Document 1.15 (Nov):39-59.

Carter, S.E.; Jones, P.G. 1990. A model of cassava distribution in Africa. Economic Geography (in press).

Castaño, J.; Correa, C.; Echeverry, A.; Franco, M.A.; Monsalve, A. ; Rivas, L. 1990. Trends highlights FAO data: cassava. Trends in CIAT commodities. Economics Document 1.15 (Nov):195-203.

Chavez, R. 1990. Especies silvestres de Manihot: un recurso valioso. Yuca Boletin Informativo 14(1):2-5.

Chuzel, G. 1990. Diagnóstico tecnológico de las plantas de producción de almidón agrio de yuca. Trabajo presentado al Seminario Latinoamericano y del Caribe de Ciencia y Tecnología de Alimentos, San José, Costa Rica, Abr. 1990. Alimentos para la paz. 20p.

Cock, J.H.; Lynam, J.K.; Wheatley, C.C.; Correa, C.; Izquierdo, D. 1990. Benefits to cassava consumers and producers: new market options in Colombia. Food Policy 15(3):255-257.

Cock, J.H.; Lynam, J.K. 1990. Research for development. In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture, International Society for Tropical Root Crops. pp.109-119.

De Llamas, P.A.; Moreno, R.A.; Izquierdo, D.A. 1990. Comercialización de la mandioca en Paraguay. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo no. 71. 87p.

El-Sharkawy, M.A.; Cock, J.H.; Lynam, J.K.; Hernandez, A. del P. 1990. Relationship between biomass, root yield and single leaf photosynthesis in field grown cassava. Field Crops Research 25:183-201.

El-Sharkawy, M.A.; Cock, J.H. 1990. Photosynthesis of cassava (Manihot esculenta). Experimental Agriculture 26(3):325-340.

El-Sharkawy, M.A. 1990. Effect of humidity and wind on leaf conductance of field grown cassava. Revista Brasileira de Fisiologia Vegetal 2(2):17-22.

Empresa Brasileira de Pesquisa Agropecuaria. 1990. Cultivares de mandioca recomendadas para Varzea do Estado do Amazonas. Cali, Colombia. Centro Internacional de Agricultura Tropical. Plegable. 2p.

Estrada, R.D.; Seré, C.; Ferguson, J.E.; Best, R. 1990. Vínculos entre la investigación en fincas, la extensión y desarrollo agropecuário. Estudio de caso: El establecimiento de la industria de yuca seca en la Costa Atlántica de Colombia. Trabajo presentado a la Reunión del Comité Asesor de la RIEPT, Lima, Perú, Ago. 1990. 11p.

Gold, C.S.; Altieri, M.A.; Bellotti, A.C. 1990. Direct and residual effects of short duration intercrops on the cassava whiteflies Aleurotrachelus socialis and Trialeurodes variabilis (Homoptera: Aleyrodidae) in Colombia. Agriculture, Ecosystems and Environment 32(1-2):57-67.

Gold, C.S.; Altieri, M.A.; Bellotti, A.C. 1990. Effects of intercropping and varietal mixtures on the cassava hornworm, Erinnyis ello L. (Lepidoptera: Sphingidae), and the stemborer, Chilomima clarkei (Amsel) (Lepidoptera: Pyralidae), in Colombia. Tropical Pest Management 36(4):362-367.

Gold, C.S.; Altieri, M.A.; Bellotti, A.C. 1990. Response of the cassava whitefly, trialeurodes variabilis (Quaintance), (Homoptera: Alyerodidae) to host plant size: Implications for cropping system management. Acta Ecológica 11(1):35-41.

Hernández, J.; Lozano, J.C. 1990. Efecto de la cepa c-5a pseudomonas fluorescens en la producción de yuca (Manihot esculenta Crantz). Trabajo presentado al Congreso de ASCOLFI, Ibagué, Colombia, Jun. 1990. (in press)

Hernández, J.; Lozano, J.C. 1990. Evaluación sobre resistencia a Phytophtora spp. en yuca. Trabajo presentado al Congreso de ASCOLFI, Ibagué, Colombia, Jun. 1990. (in press)

Henry, G.; Janssen, W. 1990. Snap Beans in the Developing World: Potential Benefits of Research. In Trends in CIAT Commodities 1990. Working Document No. 74, Nov. 1990. (Economics Document No. 1.15). CIAT. Cali, Colombia. pp. 89-115.

Hershey, C. 1990. Nuevo impulso al mejoramiento de yuca en América Latina. Yuca Boletin Informativo 14(1):8-9.

Howeler, R.H., ed. 1990. Symposium of the International Society for Tropical Root Crops, Bangkok, Thailand, Nov. 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crop. 724p.

Howeler, R.H.; Cadavid, L.F. 1990. Short and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Research 26:6-80.

Howeler, R.H. 1990. Long-term effect of cassava cultivation on soil productivity. In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, Nov. 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crops. pp.269-270.

Howeler, R.H. 1990. Phosphorus requirements and management of tropical root and tuber crops. In Symposium on Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania, Manila, Philippines, 1989. Proceedings. Manila, Philippines, International Rice Research Institute. pp.427-444.

Improving cassava quality for new products and markets. 1990. CIAT International 9(2):6-8.

Izquierdo, D.; Wheatley, C.W.; Henry, G. 1990. Metodología para ampliar la demanda tradicional de yuca Cali, Colombia. Centro Internacional de Agricultura Tropical. Trabajo presentado al Taller Latinoamericano sobre Métodos para Estudiar la Comercialización agrícola, Lima, Peru, 1990. 27p.

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

Janssen, W.G.; Lynam, J.K. 1990. Integrated ex ante and ex post impact assessment in the generation of agricultural technology: cassava in the Atlantic Coast of Colombia. In Echeverria, R.G., ed. Methods for diagnosing research system constraints and assessing the impact of agricultural research. 2. Assessing the impact of agricultural research. The Hague, Netherlands, International Service for National Agricultural Research. pp.215-250.

Janssen, W.;Sanint, L.;Rivas, L.;Henry, G. 1990 CIAT'S Commodity Portfolio Reexamined: Indicators of Present and Future Importance. In Trends in CIAT Commodities 1990. Working Document No. 74, Nov. 1990. (Economics Document No. 1.15). CIAT. Cali, Colombia. pp. 1-38.

Jantawat, S.; Vichukit, V.; Putthacharden, S.; Howeler, R.H. 1990. Cassava cultivation practices for erosion control in Thailand. (Abstract). In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crop. pp.242-243.

Kawano, K. 1990. Harvest index and evolution of major food crop cultivars in the tropics. Euphytica 46:195-202.

Kawano, K.; Sarakarn, S.; Limsila, A.; Tongglum, A.; Supaharn, D. 1990. Cassava cultivar evolution viewed through harvest index and biomass production. Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crops. pp. 202-210.

Laberry, R.; Lozano, J.C. 1990. Efecto del origen del material de siembra y el sistema de cultivo en la severidad e incidencia del añublo bacterial, el añublo fungoso y el superalargamiento de la yuca. ASCOLFI Informa 16(5):39-42.

Lopez, J. 1990. Almacenamiento del material de siembra de yuca en la Costa Atlántica. In Yuca y cultivos asociados. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo No.02. pp.35-50.

Lopez, J. 1990. Producción comercial de semilla de yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical. Unidad de Semillas. 33p.

Lopez, C. 1990. Evaluación sobre la resistencia a Phytophthora spp. en yuca. Proceedings XI Congreso ASCOLFI (Ibagué, Junio 6-8, 1990) (in press).

Lozano, J.C.; Laberry, R 1990. Problemas patológicos que afectan la calidad sanitaria del material de siembra (estacas) de la yuca en Colombia. Trabajo presentado al Congreso de ASCOLFI, Ibagué, Colombia, Jun. 1990. (in press)

Lozano, J.C.; Zeigler, R. 1990. Methods to screen for resistance against foliar bacterial pathogens. In methods in Phytobacteriology. Edited by Z. Clement, K. Rudolf. D.C. Sands. Akademiai Kiadó, Budapest 1990. Chapter II.8. p.334-338.

Marin, M.L.; Mafla, G.; Roca, W.M.; Withers, L.A. 1990. Cryopreservation of cassava zygotic embryos and whole seeds in liquid nitrogen. Cryo-Letters 11:257-264.

Menendez F., L.; Lopez S., J. 1990. Cassava in Asia: East and Southeast Asia. Cali, Colombia. Centro Internacional de Agricultura Tropical. National Bibliographies. 486p.

Menendez F., L.; Lopez S., J. 1990. Cassava in Asia: South Asia. Cali, Colombia. Centro Internacional de Agricultura Tropical. National bibliographies. 305p.

Mesa, N.C.; Braun, A.R.; Bellotti, A.C. 1990. Comparison of Mononychellus progresivus and Tetranychus urticae as prey for five species of phytoseiid mites. Experimental and Applied Acarology 9:159-168.

Moraes, G.J. de; Braun, A.R.; Yaninek, J.S.; Alencar, J.A. 1990. Distribution and abundance of phytoseiid predators of the cassava green mites in Brazil. Paper presented at the International Congress of Acarology, 8, Ceske Budejovice, Czechoslovakia. (in press)

Moreno B., A. 1990. Resultados preliminares de ensayos realizados en el CIAT con la asociación maíz-ñame-yuca. In Yuca y cultivos asociados. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo No. 02. pp.51-59.

Moreno B., A. 1990. Uso del analisis bivariado para presentar, analizar e interpretar datos provenientes de cultivos asociados.. In Yuca y cultivos asociados. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo No. 02. pp.127-137.

Moreno, R.A.; Moreno B., A.; Muñoz, F. 1990. Cassava-yam intercrop in the North Coast of Colombia (Abstract). In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crops. p.311.

Moreno, R.A.; Tobón, H., eds. 1990. Yuca y cultivos asociados. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo No. 02. 183p.

Muñoz, F.; Lopez, J.; Moreno, R.A. 1990. Protección química del material de siembra de la yuca: Validación de tecnología de la Costa Atlántica de Colombia. In Yuca y cultivos asociados. Cali, Colombia, Centro Internacional de Agricultura Tropical. Documento de Trabajo No.02. pp.109-116.

Orozco, J.; Duque, M.C.; Mesa, N.C. 1990. Efecto de la temperatura sobre la tabla de vida de Oligonychus yothersi en Coffea arabica. Cenicafé 41(1):5-18.

Porto, M.C.M. 1990. Growth of cassava intercropped with maize and cowpea. In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture, International Society for Tropical Root Crops. pp.300-310.

Roca, W.M. 1990. Cassava production and utilization problems and their biotechnological solutions. In Sasson, A.; Costarini, V., eds. International Symposium on Plant Biotechnologies for Developing Countries, Luxembourg, 1989. Proceedings. Wageningen, The Netherlands, Technical Centre for Agricultural and Rural Co-operation. Food and Agriculture Organization of the United Nations. pp.215-219.

Rodriguez, H.; Nubia, S.; Hershey, C. 1990. Dos nuevas variedades de yuca de alta producción para los Llanos Orientales. Bogotá, Colombia, Instituto Colombiano Agropecuario. Plegable Divulgativo No. 220. 6p.

Thingstrup, I.; Laberry, R.; Lozano, J.C. 1990. Efecto de algunos hongos micorrizógenos en la ocurrencia de pudriciones radicales. Trabajo presentado al Congreso de ASCOLFI, 11, Ibagué, Colombia, Jun. 1990. (in press)

Urias l., M.A.; Reyes, Q.J.A. 1990. Fluctuación poblacional y ciclo biológico de Erinnyis ello (L), gusano de cuerno de la yuca (Manihot esculenta Crantz) Rivista di Agricoltura Subtropicale e Tropicale 84(2):265-271.

Velasco, A.C.; Nolt, B.L.; Pineda, B. 1990. Comparacion de tres métodos de la técnica inmunoenzimática ELISA para el diagnóstico del virus del mosaico común de la yuca. Fitopatología Colombiana 14(1):3-9.

Wheatley, C.C.; Best, R.; Chuzel, G. 1990. A product development approach to cassava utilization. Paper presented at National Symposium on Recent Advances in Production and Utilization of Tropical Tuber Crops, Nov. 1990. Indian Society for Root Crops. 20p.

Wheatley, C.C. 1990. Cassava quality research at CIAT. Paper presented at Asian Cassava Research Workshop, 3, Malang, Indonesia, Oct. 1990. 20p.

Wheatley, C.C.; Izquierdo, D.A.; Lynam, J.K. 1990. Increasing fresh cassava consumption in urban Latin America: the introduction of storage technology. In Howeler, R.H., ed. Symposium of the International Society for Tropical Root Crops, 8, Bangkok, Thailand, 1988. Tropical root and tuber crops changing role in a modern world: proceedings. Bangkok, Thailand, Department of Agriculture. International Society for Tropical Root Crops. pp.364-373.

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