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RESEARCH FOR DEVELOPMENT:

The CIAT Cassava Program

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PREFACE

Thirty years ago the Green Revolution gave the world a respite from the specter of mass famine. In the wake of the Green Revolution, CIAT and other international agricultural research institutes were born. Attention was turned to some of the lesser known but important staple food crops for the first time. The aim was to realize their full potential providing food and income in marginal agricultural lands. Among these crops was cassava, the fourth most important source of calories for humans in the tropics.

1994 is the 25th anniversary of cassava research activities at CIAT. This coincides with CIAT's Third External Program and Management Review and an Intercenter Review of Root and Tuber Research across the CG system. Anyone new to CIAT or new to cassava would have to sift through literally thousands of documents to get a clear picture of how cassava research has evolved and what has been achieved over the past 25 years. For these reasons, we felt that it was an appropriate time to reconstruct a record of the Program's evolution and achievements.

After a brief introduction to cassava and its socioeconomic importance, Section 1 describes the origins and development of cassava research at CIAT. Section 2 examines the support and opportunities that CIAT provides to its partners for improving their effectiveness. Section 3 presents the advances made in increasing the body of knowledge about cassava forming the basis for applied research on the crop. Sections 4 to 7 summarize the achievements in what are now recognized as the Program's core research areas: genetic resources, gene pool development, integrated crop management and product, process and market development. Section 8 analyzes the Program's unique experience in promoting a demand-led systems perspective to Cassava R and D. This has led to a model for integrated production, processing and marketing projects. Section 9 examines the socioeconomic, political and institutional environment within which cassava R and D will be done in the future and the implications and challenges that these pose for CIAT's Cassava Program. Finally, Section 10 reviews in bullet form the major achievements of the Program over the past 25 years.

The Cassava Program is indebted to Clair Hershey for tackling the writing of this document with such enthusiasm and dedication. As a breeder with the Cassava Program for 12 years, Clair participated in many of the major phases of the Program's evolution. The results of his work are just beginning to be seen in farmers' fields.

Together with members of the present Program, the decision was taken to use the first person in describing the Program's activities and achievements. We have done this for ease of reading. The term "We, the Cassava Program" is used to embrace not only the past and present Program scientists but all those with whom we collaborate both at CIAT and in our partner institutions. Our recognition and acknowledgement goes out to all, in developing and developed countries, that have supported, encouraged and enriched our work with their knowledge and expertise. We hope you will feel that our achievements are yours as well.

Rupert Best
Cali, Colombia

INTRODUCTION

Poverty is the driving force of the cycle of malnutrition, overpopulation, political instability, and pressure on natural resources afflicting much of the third world. The International Agriculture Research Center (IARC) system has contributed significantly to breaking this cycle, mainly through improving food security. The Cassava Program of the International Center for Tropical Agriculture (CIAT) contributes to human welfare through research and institutional strengthening. We accomplish this by generating knowledge, research methods and tools, and technology components. These lead to improving levels and stability of cassava production, and to diversifying cassava markets. We work with partner institutions in developing and developed countries, following a commodity *system* philosophy in which research on genetic improvement, crop management, processing, marketing and crop use are closely integrated.

CIAT was an IARC pioneer in linking crop research with broader development objectives. From a strong base in production-related research and training, we sought to provide food security for the rural poor of the tropics. The Program then added research on process, and product and market development. We joined these components in an inter-institutional model linking the rural poor to expansive markets—a means of generating income for producers and stabilizing food prices for both rural and urban consumers.

This report highlights Cassava Program achievements in its 25-year history. To put these achievements in perspective, we give background on the cassava crop and its products; describe the underlying philosophy and some milestones in the evolution of the Cassava Program; illustrate how research and institutional strengthening come together to enable development focused on the poor; and present an agenda for the future. We believe the achievements of the Cassava Program and the context in which they emerged are a story of interest and value to other research and development institutions, agricultural administrators, scientists, to donors, and as an historical record.

Cassava: A Versatile Staple

It is tropical Africa's most important food staple, Thailand's second agricultural export earner after maize, Brazil's mainstay for its millions of poor.... the list goes on. Yet, cassava is barely known to people outside the tropics. This anonymity has plagued the cassava research world for decades. A change is taking place. As attention turns to sustainable development, targeting the poor and linking crop production research with income generation, some of cassava's unique attributes highlight its potential to effect positive change.

Cassava originated and evolved in the Americas. Along with its wild relatives it was probably one of the earliest New World crops. Of the *Manihot* genus, only cassava is cultivated. Brazil and northwestern South America contain the most landrace varieties—an invaluable resource for crop genetic improvement.

Ten developing market economies with highest calorie intake from cassava, as percent of total intake:

Zaire	54	Central African Rep.	23
Congo	42	Benin	23
Mozambique	42	Togo	22
Angola	30	Nigeria	20
Ghana	24	Tanzania	18

SOURCE: CIAT, 1993b.

Today, over three-quarters of the world's cassava is grown outside its ancestral home. The Portuguese introduced the crop to West Africa in the late 16th century and it spread rapidly throughout the lowland tropics. Production is spread over many countries. Zaire and Nigeria are the largest producers. Introduction to Asia is less well documented, but several records show it was grown there by the 18th century. Thailand and Indonesia together produce almost three-quarters of Asia's cassava.

About two-thirds of world production is destined for a variety of human food uses. Most of the remainder is used in industry or animal feed. Of 16 countries that consume over 100 kg of cassava per capita annually, 15 are in sub-Saharan Africa. The other is Paraguay (Annex I).

Fresh roots are commonly boiled and eaten directly. But because the post-harvest storage period is short—usually just a few days—many types of processing have evolved to produce a more storable product. All cassava varieties contain cyanogenic glucosides. These are broken down by autolytic enzymes when tissues are injured, to release CN^-, a toxin to many warm-blooded animals. Varieties with low levels may be eaten fresh without risk. Varieties with high levels must be processed to eliminate most of the toxic components before consumption.

Cassava internal use and export (as percent of production).

Use	Africa	Asia	Latin America
Internal use			
Food	82.7	35.8	40.9
Animal feed	1.5	8.9	36.9
Waste	15.3	4.7	13.6
Other	0.2	3.1	0.2
Export	0.2	47.6	0.2

SOURCE: CIAT, 1993b.

The crop has an extraordinary capacity to produce in less favorable environments. In tropical dry areas, food security often depends on cassava's drought tolerance.

About half of Brazil's Northeast receives less than 750 mm of rain per year, yet needs to sustain a population density of over 20 people per square kilometer. Cassava flour (*farinha*) is the principal calorie source for many. The acid, low-fertility soils in much of the humid tropics require high inputs and careful management for most crops to thrive. Here cassava will often do well with little or no fertilizer, and no pesticides. Moreover, productivity under favorable conditions is among the highest of any crop. Experimentally, yields of 75-90 t/ha/yr (25-30 t/ha dry matter) are obtained. Most national averages are 8-12 t/ha.

Many factors keep cassava's productivity well below its potential; cultivation in marginal soil and climate conditions, poor agronomic practices, pests and diseases, and unrealized genetic potential. Also higher yields do not necessarily translate into higher farmer income. Where markets for cassava products are constrained or inelastic, low prices may dissuade adoption of technology. Research on cassava provides many opportunities for positive impact on resource-poor farmers and consumers, but the focus cannot be on the production side alone.

Some common processed cassava food products.

Product	Characteristics	Principal regions
Gaplek	Dried chunks, ground to a meal	Indonesia
Kakonte	Dried chunks, ground to a meal after storage	Ghana
Farinha d'agua	Fermented in water, grated, dried, toasted	Amazon region
Farinha grossa	Grated, dried, toasted	Brazil
Gari	Grated, fermented in bags, dried, toasted/fried	West Africa
Fufu	Grated, fermented under water, dried, toasted/fried	West Africa
Chickwangue	Soaked in water, macerated, wrapped in leaves, boiled or eaten directly	Zaire
Casabe	Grated, dried, kneaded to flat cake, baked	Caribbean
Beer, biscuits, cakes	Various	All regions

Adapted from Cock, 1985, and Balagopalan et al., 1988.

1. A GLOBAL RESEARCH PROGRAM EVOLVES

Program Origins

Despite cassava's prominence in tropical agriculture, neither public nor private enterprise invested significantly in research for many years. Cock (1985) illustrated the *orphan* status of cassava with a comparison of research expenditure on various crops. Investment in cassava was one tenth that of sorghum, maize or potatoes, on the basis of per unit of crop value. Before the 1970s, scientists generally believed that it was a rustic crop with few production problems. Vegetative propagation made it a poor candidate for seed company interests. Cassava's tropical adaptation confined it to the world's poorer countries, whose research institutions had few resources. Yet there were exceptions. Brazil, Indonesia and Madagascar, for example, had successful research programs by the mid-1900s.

A turning point came in the late 1960s with establishment of root crop programs at two of the International Centers—CIAT, and the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria. Initially CIAT had the option of working on other root crops, but in order to focus a critical mass of resources on the most important one, we limited research to cassava. Although more cassava is produced in both Asia and Africa than in Latin America, there were compelling reasons to establish a world center of expertise here. Crop genetic improvement and plant protection were to be two of the main thrusts of the Program. The rich diversity of *Manihot* genetic resources, biological constraints, and biological control agents in the evolutionary home of the crop were essential assets for global responsibilities.

Dr. Eduardo Alvarez Luna, Associate Director, launched cassava research at CIAT when he gained financial support for a major international germplasm collection in 1969-1970. The resulting 2,800 accessions were the foundation of CIAT's breeding program, and later of a global responsibility for comprehensive germplasm management.

The Leading Support of IDRC

The Canadian International Development Research Centre (IDRC), and particularly Barry Nestel and Howard Steppler, saw the potential role of the newly developing system of International Centers for this key tropical crop. They gave strong early support for cassava research at CIAT, especially in animal nutrition, propagation and post-harvest management. In 1971 a series of contracts between CIAT, CIDA and IDRC gave IDRC responsibility for managing a $2.5 million, 5-year grant to CIAT's cassava/swine program, and additional support for basic research in Canadian universities (Nestel and Cock, 1976).

Summary of 1972 CIAT/IDRC Workshop to review the position of cassava research and promote international cooperation among institutions and individuals.

This brought together many of the world's small contingent of cassava experts. The discussions became the core of the research agenda for CIAT's emerging Cassava Program. The extensive treatment of post-harvest management and marketing issues illustrated some of the unique features of cassava that would guide the development of a research program distinct from most in the IARC system. Yet the absence of discussion on entomology seems surprising given current perspectives. The group believed cassava would retain its role as a staple food for a long time to come; that it would be mainly a calorie source, with small importance as a protein provider; and that production for industrial purposes and for export would be based on large-scale mechanized farms. Participants defined a number of issues and areas for CIAT to note in its research planning:

Breeding
* Establish CIAT as a germplasm center
* Develop uniform evaluation schemes
* Emphasize a practical approach to developing more productive types

Physiology
* Explore the role of N both in protein content and cyanogen production
* Study biosynthesis of cyanogens
* Describe the process of starch accumulation in roots, including genetic variability
* Investigate the physiology of flowering
* Study physiological changes in roots during storage

Tissue Culture
* Develop meristem culture techniques for production of virus-free stocks

Agronomy
* Understand plant development as the basis for defining appropriate cultural practices
* Conduct experiments with farmers, in their fields
* Monitor new herbicides, and pay special attention to residual effects of chemicals

Soils
* Stress research on acid soils
* Define nutrient demands, including trace elements
* Define appropriate minimum tillage methods

Plant Pathology
* Characterize viruses in both Africa and Latin America
* Identify and assess pathogens in each country
* Take measures to avoid movement of diseased materials
* Emphasize host plant resistance as a control measure

Utilization
* Develop technology to lower processing costs as a step toward increased use of cassava for feed and export
* Explore the possibility of developing cassava-based foods with enrichment of protein content

Agricultural Engineering
* Develop models to overcome constraints in land preparation, planting, harvesting, and processing
* Develop storage technologies to provide a buffer for processing plants

Economics
* Carry out macro-economic studies
* Characterize the economics of processing
* Define root characteristics required for different markets

Documentation
* Establish a cassava documentation center
* Rapidly publish and disseminate research results in various media
* Make the international bibliography of cassava research widely available

SOURCE: CIAT, 1972, p. 21-27.

At this stage, CIAT had not clearly defined a research program for cassava, beyond germplasm conservation and use as an energy source in swine diets. The IDRC sponsored a seminal workshop in 1972 to discuss the status of cassava research and assist CIAT in defining objectives (CIAT, 1972). The workshop also established an advisory committee that continued to meet through 1975.

The impressive success achieved by sister institutions in increasing yield potential of rice and wheat was a strong influence on early goals. But we also recognized that cassava was unique and research could not be modelled directly after the cereals. The first phase of research in the 1970s aimed at filling some of the major gaps in our knowledge about cassava at the time—to develop a base for generating new technology and for training of national program scientists. Research concentrated on breeding, physiology, plant protection (pests, pathogens, weeds), soil science and agronomy. Within a few years we had selected varieties and production technology with very high yield under scientist-managed conditions, and demonstrated the potential of substituting cassava for grains in animal feeds. The production technology had moved from the experiment station to a network of regional trials in Colombia. Economic surveys and on-farm trials helped define production costs and constraints.

The Interdisciplinary Team Approach

In 1973, CIAT reorganized its research on a commodity basis and established a cassava program with an interdisciplinary team of scientists. James Cock, a physiologist by training, became the first team leader. CIAT could now work more effectively toward the IDRC workshop recommendations.

The commodity-centered interdisciplinary team was a striking departure from previous discipline-based departments, the typical organization of universities. Since knowledge of this crop was scarce, we could only hope to have an impact by a broad-based, comprehensive research approach aimed at solving basic problems of cassava producers and consumers. There was no larger, global network of institutions that would complement one another in research, and provide the critical mass of information for technology development. The Program elaborated its goal at the time: *to develop and disseminate information regarding systems of cassava production requiring relatively low input levels, adapted to a wide range of ecological conditions, and suitable for use on both large and small farms* (Nestel and Cock, 1976).

Key Role of Post-harvest Work Identified

Post-harvest research had to be part of a research agenda because of cassava's high perishability and multiple end-uses. In 1973 this was not well-accepted within the IARC mandate, and we had to support post-harvest work with special project funding for several years.

In 1977 CIAT had its first quinquennial review by the Technical Advisory Committee (TAC) of the center system. The panel concluded that the Program "*has convincingly shown that cassava can compete with any tropical crop in the world in terms of calories produced per hectare per unit of time*;" and that CIAT should expand activities in post-harvest areas. After 3 years of planning and proposals, the Program added a Utilization Section in 1980. The section concentrated on process and product development, with special emphasis on new or improved products from cassava, and the complex, poorly understood area of root quality.

Managing the Diversity of Cassava Environments

Cereal breeders had successfully developed high yielding varieties adapted across many countries. Some interpreted this to mean these varieties were very broadly adapted across ecosystems. In fact, most of the environmental parameters were kept relatively uniform by high inputs of fertilizer, water and pesticides. The same strategy will not work for cassava. Farmers use minimal inputs, and varieties need to be genetically adapted to the stresses of a specific region. As the importance of different biological and physical constraints became clearer in the late 1970s, a long debate ensued within the Program on the appropriate strategy for research. From these discussions came our definition of *edaphoclimatic zones* as a basis for efficiently developing varieties and other production practices adapted to specific regional needs. National programs benefitted from more relevant CIAT technology, and many adopted a similar decentralized strategy for their own research programs.

A Model for Crop-based Development Emerges

Experiences began to show that potential for increased production was sometimes not enough incentive for adoption of new technology. This was especially apparent in the Latin American context. Markets are generally limited to one or two products. Increased production can quickly saturate markets and, with no alternatives, price at the farm gate declines. Also, with a rapidly urbanizing population, cassava was no longer principally a staple of the *rural* poor. But the high perishability of fresh roots was a barrier to delivering an affordable product to the cities.

Economics research, especially a 1980 set of studies in Colombia, showed that production, processing and marketing all needed to be coordinated in order to benefit producers and consumers. This integration would not occur spontaneously because of a general lack of producer organizations and because of the vested interests of those profiting from established marketing channels. Our strategy to *move cassava* could only succeed by becoming involved with a development project. Successful pilot projects in Colombia led to expansion and commercialization, then the adoption of a similar approach in several other Latin American countries.

The integrated production, processing and marketing projects currently define the Cassava Program to the outside world probably more than any other initiative. The projects have fundamentally altered our approach to research, our interaction with partners, and most importantly, the relevance of technology to benefitting target client groups.

A Global Mandate and Decentralized Staffing

CIAT was organized with a Latin American focus. This grew into a recognition within the center and the IARC system as a whole, of potential for broader contributions. Asia rapidly developed its research capacity during the 1970s, with considerable training input from CIAT. There was already a growing demand for new production technology as a history of investment in small-scale processing units showed. We established an office in Bangkok in late 1982 to work more effectively with Asian programs.

We complement IITA's regional responsibility in Africa with germplasm and information exchange. Cassava production in Africa grew at a rate of 2.8% annually over the last decade—three times the rate in Latin America and twice that of Asia. The IARC system recognized the need to shift more emphasis to this region. We placed a liaison scientist at IITA in 1989, and gave further priority to headquarters research on Africa-related problems, such as biological and genetic control of mite and mealybug, drought tolerance, and adaptation of the Latin American experience in integrated projects.

The Demand Studies

The early 1980s was a momentous period for the Program. With a substantially improved knowledge base, promising technology components, and a decade of institution-building, we saw impact beginning to reach farm level. Unfortunately, this coincided with a period of global recession, and a corresponding downturn in funding to the IARC system. In 1982 the Cassava Program was forced to close down Agronomy/International Collaboration and Utilization sections.

The second TAC quinquennial review came in the midst of this. While having very positive commentary on the Program's research, the panel questioned the potential growth in demand for cassava in Latin America, and recommended that new Program initiatives be put on hold until a series of studies were completed on cassava markets.

The comprehensive, 3-year studies that we commissioned made optimistic demand projections, based principally on cassava's competitiveness in balanced feed rations, and fresh cassava for urban markets. Simultaneously, we completed ongoing studies of the cassava situation in Asia.

Summary of projections of demand for cassava in Asia and Latin America, presented to TAC mid-1987

- The observed decline in fresh consumption in Latin America is primarily due to the urbanization process. High marketing costs of cassava have increased prices relative to grain staples in urban areas, resulting in lower consumption in urban Latin America. Fresh cassava has a positive income elasticity and consumption can be expected to grow moderately. New preservation technology is likely to reduce marketing costs and accelerate growth.
- Where human consumption of processed cassava has declined, this has largely been the result of government subsidies of competing cereals. These trends are already being reversed as subsidies are removed, and demand for cassava in processed form can be expected to grow. These products will continue to serve as an important source of inexpensive calories to the very poor.
- Starch, much of which is used in the production of various foods, is expected to provide a growing demand for cassava, especially in Asia.
- A major potential for growth in demand for cassava is as a component of animal feed, chiefly for domestic use in Latin America and for both domestic use and export in Asia.
- The growing market for cassava in Asia has already reached the point where production cannot keep up with demand.
- Cassava is an important tool for equitable development. Its characteristics are such that the benefits of new technology can be targeted to the very people who have normally been left out of the development process—the poorer segments of the population.

SOURCE: CIAT, 1992a.

The crisis led to a stronger and more effective program, but at a cost in lost time. The experience of finding support outside the standard IARC donor channels was to be useful on a continuing basis, especially with the tight budgets of the early to mid-1990s.

Broadening Institutional Participation

Partnerships with both developing and developed country institutions have always been a fundamental part of our modus operandi. The character of these partnerships has constantly evolved. At the outset, we felt that CIAT needed to *do it all*—have expertise in almost every area of cassava research. Partners were seen mainly as *recipients* of our technology and expertise. Now, cassava has moved from an *orphan crop* to one attracting considerable international attention. Research horizons expanded, new challenges arose and partner institutions gained new capacity to manage research and development programs. An example of our early shifts in recognition of a changing research environment was to emphasize segregating populations over finished varieties for the stronger national breeding programs. This allowed them greater flexibility in selecting for specific local needs. Each research section experienced similar changes in their interaction with partners. Training evolved from general production courses at headquarters to network-managed, in-country courses, and a range of other options.

CIAT and IITA are still widely viewed as centers of broad-based expertise and technology generation, but have only a small fraction of the total resources required to cover every need in cassava research and development. We maintain broad research expertise at CIAT, but also rely more on assisting partner institutions, working together to achieve common or complementary goals.

A Framework for Advanced Research

In the mid-1980s, it seemed that significant investment in biotechnology research would bypass some of the major tropical crops. The few cassava-related projects in advanced labs were not coordinated with one another nor with the interests of producing countries. CIAT clearly could not invest in multi-million dollar facilities and support scientists to fill this gap. Douglas Laing, Deputy Director at CIAT, envisioned a network of advanced labs and applied research-oriented institutions that would give cassava biotechnology status, coordination, and direction. The Cassava Biotechnology Network (CBN) was born in a founding meeting at CIAT in 1988. The network now has a full-time coordinator posted at CIAT, publishes a newsletter, sponsors scientific meetings, keeps members in contact with one another, and generally facilitates biotechnology being applied to resolve the real constraints of cassava producers and consumers.

CIAT's Biotechnology Research Unit and Cassava Program scientists collaborate on several key projects, with emphasis on research combining needs for well-endowed lab facilities, ability to grow plants in the field, and a broad germplasm base. We also act as a channel of communication between developed country advanced labs, which may have little appreciation of cassava in the real world; and developing country applied research programs, with considerable practical expertise in cassava.

Impact Accelerates

By the early 1990s IARC donors were justifiably becoming anxious to see more concrete data on the adoption and impact of new technology from the centers. So far, we had been reluctant to channel resources into these types of studies, and detract from investment in the generation of new technology. Further, benefits from multi-institutional efforts are very difficult to credit to individual entities. We have been more concerned about assuring that technology is reaching those who need it most. But impact assessment is more than a justification to donors—it provides crucial feedback for the Program's strategic planning. Producer and consumer benefits can now clearly be seen in disease and pest control strategies, high yielding new varieties, improved agronomic practices, income-generating integrated projects, and others.

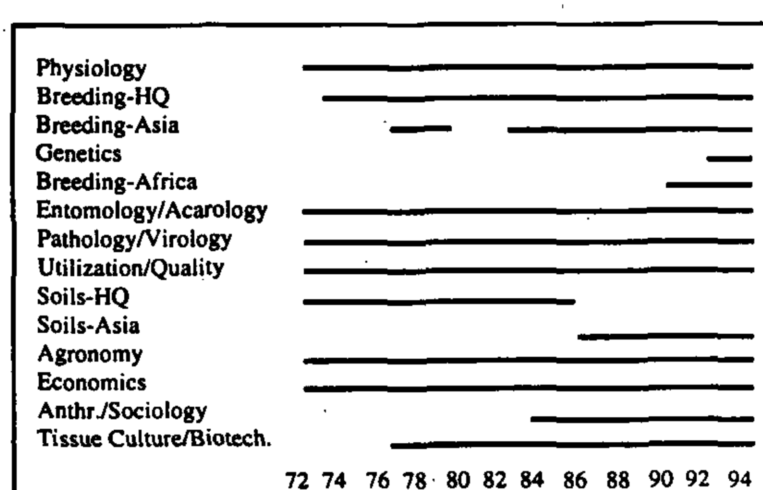
Program Goal and *Modus Operandi*

The Cassava Program embraces a **people oriented** value system; sets goals based on **comparative advantage** and **complementarity**; strives for **scientific excellence** within the context of an **interdisciplinary team approach** to research; and pursues efficiency and effectiveness through **partnerships**. The 1994 Program goal is: *to increase incomes and agricultural sustainability in less favored rural areas by improving the level, stability and quality of cassava production and by diversifying end uses of the crop.*

The contributions of many local, national and regional entities working independently or in coordination toward many of the same goals as CIAT are complementary. The role of CIAT, then, is to fit into this milieu of organizations in an optimally productive manner. As an apolitical international organization we have advantages: in facility to move information, biological control agents and genetic material across national borders; in methodology development with broad applicability; in developing technology components of a strategic nature; in managing an international germplasm collection; in training; and as a catalyst initiating and furthering interactions among institutions.

Our credibility with partner institutions, and our effectiveness in these various roles, rely heavily on the quality and relevance of our science. Internationally recruited scientists, excellent support staff, commodity specialization, interdisciplinary approach, continuity, and adequacy of research support contribute to our goal of scientific excellence.

The **team concept** has been an invaluable part of generating relevant technology, and establishing and maintaining productive partnerships. The team has long-term continuity, where individual scientists, or the projects in which they are involved, may come and go. The interdisciplinary team is the functional unit of decision-making and action; it defines our fundamental style of planning and operation. The strength of this approach is not only scientific, but includes the cohesion developing from day-to-day interaction of a small group of scientists with a common set of goals. The cassava team has undergone various changes in disciplinary composition with time, through most years combining



Disciplinary and regional representation in the CIAT Cassava Program over time (core and special funding), with involvement of an internationally recruited senior scientist as leader of a section.

expertise in socio-economics, physiology, genetics/breeding, entomology, plant pathology, agronomy, soil science, and quality/utilization (Annex II).

By definition, the work of an interdisciplinary team is not easily compartmentalized. The numerous linkages and interactions among research activities mean that any categories used either for organizing research or describing results are somewhat artificial. The Program currently defines five broad project areas as a basis for an operational structure. Several or all disciplines may work within a given area. This interdisciplinary framework is also convenient for presenting achievements in this report. Since much of the *basic knowledge* about the crop, its environments, or the people it benefits cuts across project areas, we provide a summary of these achievements in a separate section.

***Project areas* define organization of Cassava Program activities**

- **Institutional support**
- **Management of genetic resources**
- **Gene pool development**
- **Integrated crop and soil management**
- **Process, product and market development**

2. INSTITUTIONAL SUPPORT: PARTNERSHIPS FOR EFFECTIVE RESEARCH

> ***Increase the effectiveness of national, regional and global cassava research and development systems***

Strong institutions and motivated individuals are basic to successful research and development. We have a significant role in providing opportunities for our partners to improve their effectiveness and a responsibility to learn from their expertise and experience. Information exchange, training, convening meetings for professional interchange (workshops, scientific meetings, symposia, seminars), and assisting network formation and operation are means of doing so.

Information Services

One of CIAT's most appreciated services is that provided by the Cassava Information Service. It has offered numerous services, including pages of contents, abstracting, information retrieval, valuative products, training, photocopy service, promotional products and strategic acquisitions. This service is evolving in the context of changing information technology and user needs, and currently holds about 13,000 documents in its collection.

> **In this *information age* it is difficult to envision managing a research program without easy access to relevant scientific literature. But cassava scientists faced this for many years. Research was sparse compared to that for most crops of comparable importance and publications often were not in readily available international journals. The late Dr. Fernando Monge, CIAT's first head of documentation, homed in on this information gap and clearly saw the type of services CIAT could most usefully provide, both internally and to outside scientists. The effort began with a focus on compiling the *gray* literature from national research centers and libraries in Latin America—experiment station reports, nationally circulated journals and annual reports. These were catalogued, abstracted and archived in CIAT's first commodity-specific documentation center. The service continues to be highly used and appreciated by cassava workers. As commercial abstracting services have become more thorough and more widely distributed, CIAT now concentrates on capturing information typically passed over by them. Technology has vastly improved management of and access to the cassava database, but contributions to research progress were already well established in the vision of Dr. Monge.**

The Cassava Newsletter, published since 1977, keeps cassava professionals and those in industry in touch with one another and current on a broad range of topics. Since 1991, we have published the newsletter jointly with IITA giving a truly global perspective.

Scientific publications in an array of formats are the main method of disseminating research results and other information. About 1,300 Program publications are registered by CIAT's documentation services. Since our audience is diverse (from farmers to scientists to policy-makers) our publications are also diverse. They are found in refereed journals, books, working papers, annual reports, extension pamphlets, training and promotional videos, and others.

Networks

Networks serve to link our partners in planning, execution, and evaluation of research. They vary widely in structure and function. Most are devoted to one or a few related disciplines, some to specific regional interests, and others to broader development objectives.

In an ideal world, these networks would originate spontaneously from the self interest of participants. This rarely happens. Funds needed for network formation and operation are scarce, and most programs do not have the international connections or experience to obtain them. CIAT is wellsuited to the role of convening potential network partners to discuss mutual interests, and facilitating network establishment. With time these networks should become self-sustaining, but we can expect that many will see some degree of continuing CIAT leadership as appropriate.

In 1987, we helped establish **Cassava Breeding Networks** in both Asia and Latin America. In periodic meetings they discuss regional research priorities, collaborative projects to obtain funding and optimize use of resources, and keep current on research progress. The Asia network later incorporated agronomy, and the Latin America Network became linked with the *Manihot* Genetic Resources Network. The **Integrated Projects Network** was formed in 1990, as some countries began to gain experience in establishing and managing projects, and others wished to benefit from that expertise. The **Southern Cone Network**, established in 1992, addresses some of the specific needs of the subtropics. The **Cassava Biotechnology Network** grew out of a founding meeting at CIAT in 1988, and became fully operational with an appointed coordinator in 1992. A group of germplasm specialists and breeders met at CIAT in 1992, and founded the ***Manihot* Genetic Resources Network**. CIAT serves as secretariat. The network raises national program participation in global aspects of germplasm management from an *ad hoc* to a more formalized and participatory mode.

Training

One of our earliest priorities was to help form a critical mass of well-trained cassava scientists in partner institutions. When CIAT was set up there was no national program in Latin America, and only a few in Asia and Africa. But there were some effective state and university programs. We persisted with policy-makers in advocating establishment of national research programs in the early years, and it paid off. Already by the mid-1970s, there were a few moderately well-staffed, interdisciplinary national cassava programs in Latin America (Brazil, Mexico, Colombia and Cuba) and Asia (Thailand, Malaysia, Indonesia, and India). All have had their ups and downs over the years, but we believe that CIAT's presence and support has had a fundamental influence in keeping several of these programs afloat in difficult years, and optimally effective in better times. But overall agricultural research at the national level did not fare well in Latin America or Africa in the 1980s, as many governments struggled to overcome heavy international debt. Tight national research budgets in the 1990s have kept many of our partners poorly funded. This has meant that the stability of trained scientists in national programs is below optimum, and that those who remain often work under very difficult conditions.

Human resources for cassava research and development

Professionals trained in CIAT-sponsored courses. 1972-1994.

Specialty	Latin America & Caribbean	Asia	Africa	North America & Europe
General production/ research & project management	239	94	1	2
Physiology	12	4	1	7
Breeding/genetics/ germplasm management	35	23	2	3
Entomology	58	4	-	14
Phytopathology	45	7	3	6
Agronomy/soils/ seed systems	110	15	2	9
Socio-economics	12	2	-	11
Utilization/quality	70	5	2	8
Tissue culture/ biotechnology	46	1	2	-

For nearly 20 years we offered general and specialized courses at CIAT headquarters. Then most national programs began internal training. We changed our emphasis to assisting in these in-country courses, and the training of trainers, so multiplier effects could be achieved. Our headquarters training is now mainly specialized, specifically tailored to an individual scientist's needs. Training evolved from a classical teacher-student relationship to one based far more on equal partner interchange. The networks have replaced a centralized training structure. In this way, a core of scientists from national programs and universities collaborate regionally in training.

The Move to Decentralize

There are several constraints on our ability to serve Asian and African partner institutions from a Latin American base. Our collaboration with Asia became fully effective with the opening of a **regional office** in Bangkok, staffed by Kazuo Kawano (breeder/regional coordinator) and Reinhardt Howeler (soil scientist). A few stronger programs (India, Thailand, Indonesia, Philippines), or small but mature programs (Malaysia) were already in the region. We were able to provide training and technical support to others, and see them grow from embryonic to well-rounded and effective in a few short years (China, Vietnam).

Our contributions in Africa are largely dependent upon the quantity and quality of interactions with IITA in Nigeria. Since 1977 we have had very fruitful collaboration in the area of biological control of the cassava mealybug and cassava green mite. But the posting of Marcio Porto as a liaison scientist at IITA headquarters in 1989 truly enabled us to begin widening our support of African cassava research and development.

Technical Assistance

We provide technical assistance by visits to partner institutions and projects. This is both a prominent way of spreading technology and information and a feedback to our own research and development design. On-site familiarity with institutions and regions they cover is indispensable to our effectiveness. It is often only after sustained contact with a region that we see the whole picture well enough to contribute to solving problems. Our ability to travel extensively, and compare problems and solutions in different situations, plays an important role in our effectiveness as advisors. Because we work closely as an interdisciplinary team, we often have sufficient familiarity with others' specialties to provide broader recommendations and guidance. Our experience shows that CIAT often becomes a role model for national programs to organize themselves and define research priorities.

An Effective Professional Environment

There are few professional, public, private, or major first world national interests that will keep cassava scientists stimulated and current, independent of International Center activity. CIAT's role is indispensable, it is part of a system. It provides a crucial link in communications and in peer critique that cannot simply be devolved to individual national programs. For many cassava scientists, these opportunities are among the few for international travel and one-on-one interchange with scientists having similar interests and problems. We have sponsored or co-sponsored 48 international, professional meetings, and published many of the proceedings (Annex III). These are an invaluable addition to the global knowledge base on cassava, and a much-used resource.

3. KNOWLEDGE BASE: FOUNDATION FOR RESEARCH

The body of knowledge about cassava was extremely sparse when we began our work. Without such background, applied research is often inefficient or ineffective, as one continually *back-tracks* to fill information gaps.

There is no easy distinction between what can be defined as expanding the knowledge base, and technology generation—the two are intimately interrelated. This basic knowledge is applied across the various project areas that define our research structure.

Target Populations and Environments

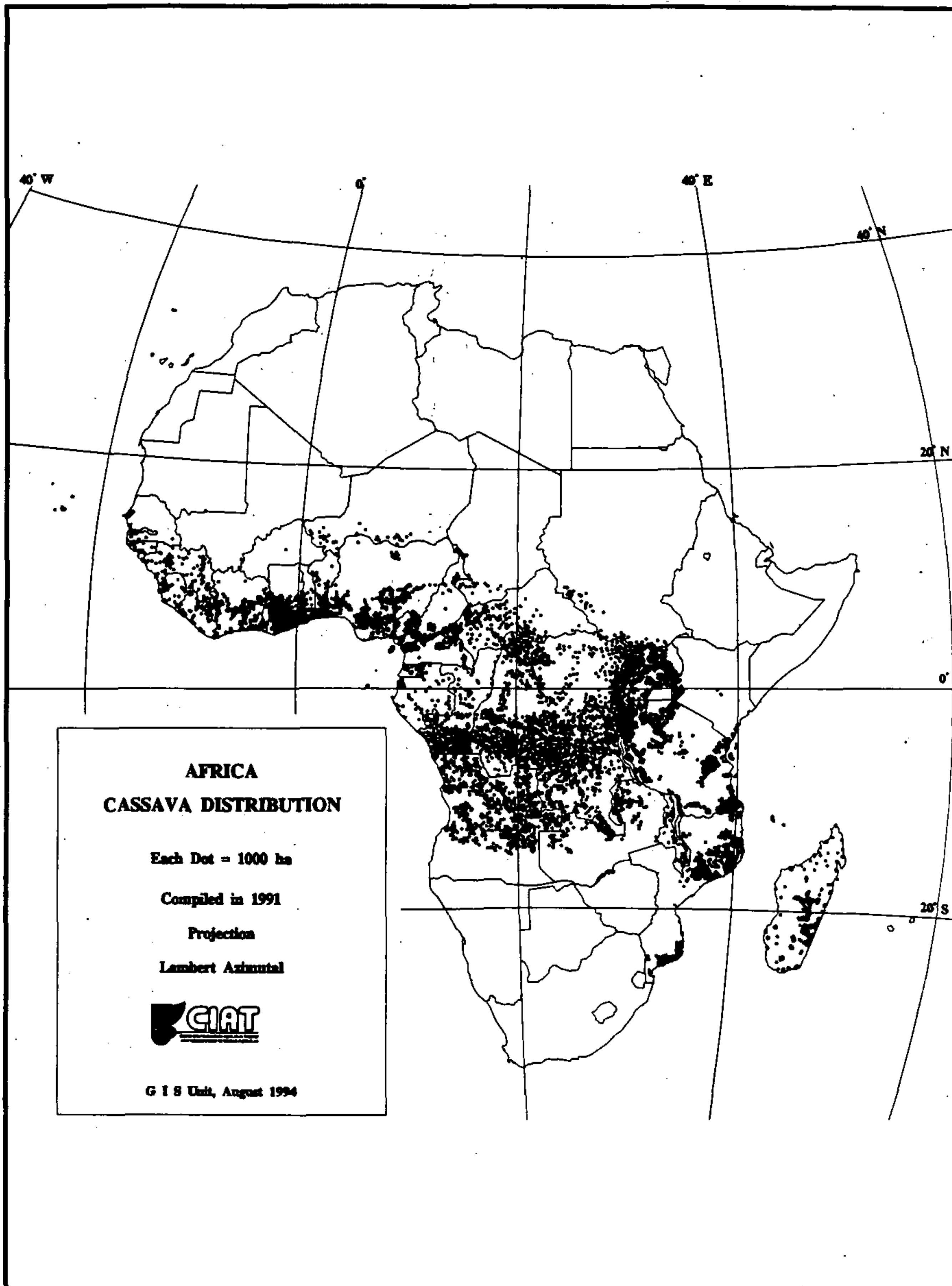
A good description and understanding of the target environment (climate, soils, biological environment, social and economic factors) is one of the first steps in planning a research program. We gained considerable empirical knowledge about our target environments over the years. But the advances in information gathering, consolidation, and analysis, have recently made qualitative contributions. In the early 1980s the Agroecological Studies Unit assisted by mapping cassava production and classifying environments according to soil and climatic parameters (Carter, 1986a & b). Mapping was done first for Latin America and later extended to Africa as part of the Collaborative Study on Cassava in Africa (COSCA) (Carter et al., 1992). The CIAT GIS unit has recently mapped production in Asia. (See maps & Table 1.)

Cassava's special role as a crop which can most benefit the poor, and the diversity of product possibilities, mean that socio-economic input is critical to defining what a research program does. What is the appropriate balance, in a given country, for emphasis on food security versus income generation? How should regions be prioritized for receiving our research attention? How can research best be designed to target specific sectors of society? What has been the economic and social impact of our research and that of our partners?

From the Program's start, baseline economic studies, first undertaken in Colombia, gave us the foundation for defining objectives (Pinstrup-Andersen, 1972; Pinstrup-Andersen and Diaz, 1975). These baseline studies are a continuing need, as countries recognize the importance of establishing well-grounded policies for cassava research and development. As technology components began to emerge from the program, especially new varieties and cultural practices, economics research moved into on-farm trials to look at the new technology's suitability.

During the late 1970s and early 1980s, socio-economic studies opened the way to a basic redefinition of our research roles—to analyze and balance our intervention in the continuum of cassava production, processing and marketing. CIAT's economists and social scientists have devoted considerable time and energy to developing and refining methodologies for establishment, operation and evaluation of integrated projects (Lynam, 1978; Pachico et al., 1983).


LATIN AMERICA
CASSAVA
DISTRIBUTION
Each Dot = 1000 ha
Compiled in 1991
Polyconic Projection
CIAT
G I S Unit, August 1994
30° N
0°
30° S
120° W
90° W
60° W
30° W


40° W
0°
40° E
40° N
20° N
0°
20° S
AFRICA
CASSAVA DISTRIBUTION
Each Dot = 1000 ha
Compiled in 1991
Projection
Lambert Azimutal
CIAT
G I S Unit, August 1994

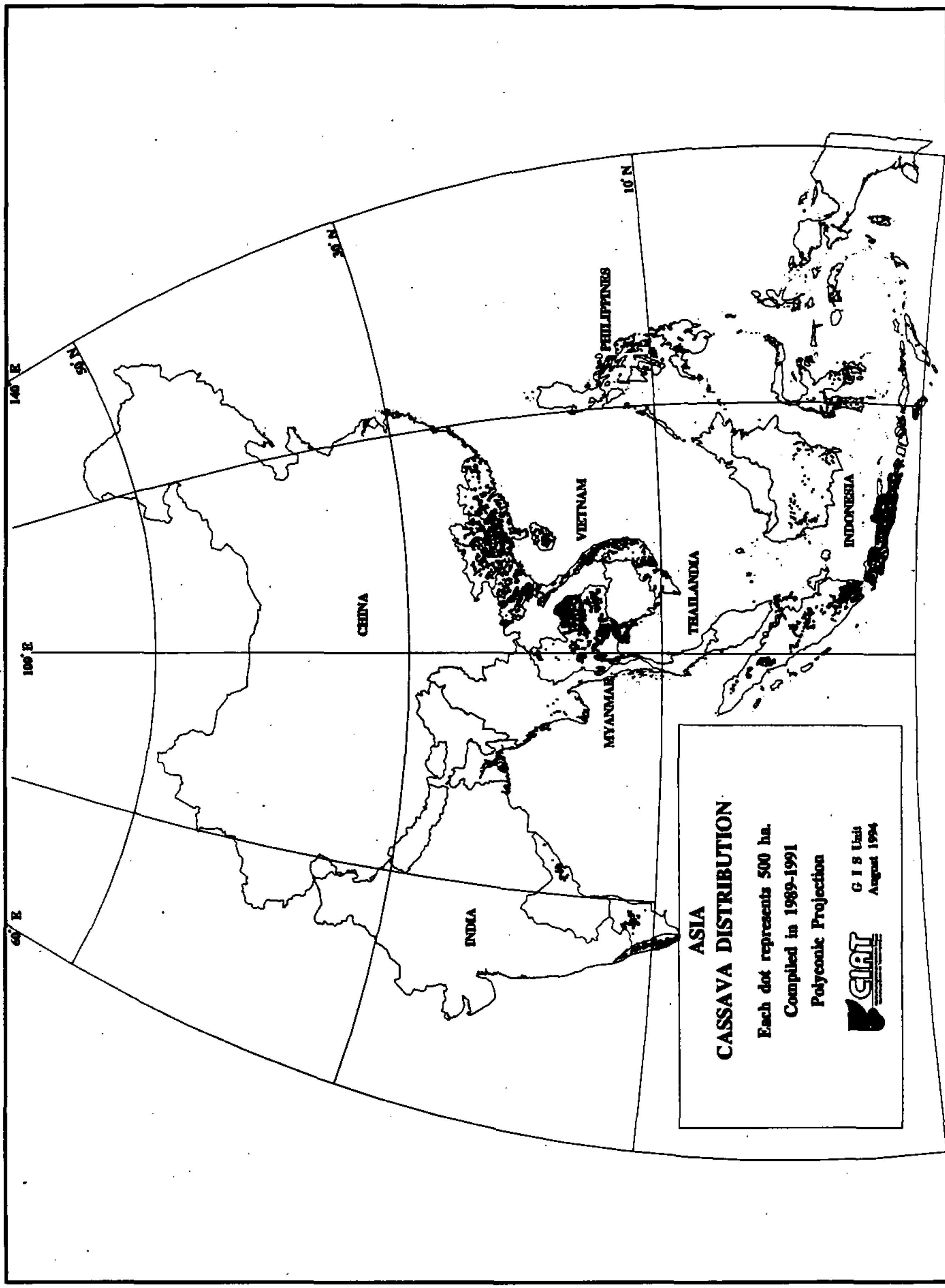

ASIA
CASSAVA DISTRIBUTION
Each dot represents 500 ha.
Compiled in 1989-1991
Polyconic Projection
G I S Unit
August 1994
CIAT
CHINA
INDIA
MYANMAR
THAILANDIA
VIETNAM
PHILIPPINES
INDONESIA
60° E
100° E
140° E
10° N
30° N
50° N

Table 1. Global cassava area by continent and agro-ecosystem.

Climate zone	Latin America		Asia		Africa		World	
	%	000 ha	%	000 ha	%	000 ha	%	000 ha
Lowland humid tropics	15	417	18	690	34	3033	27	4112
Lowland sub-humid tropics	33	918	41	1604	38	3390	38	5850
Lowland semi-arid tropics	8	222	26	1029	8	714	13	1950
Highland tropics	15	417	0	0	10	892	8	1281
Sub-tropics	29	807	15	598	10	892	14	2242
Total	100	2781	100	3921	100	8922	100	15624

SOURCES: Carter, 1986a and 1986b; Carter et al., 1992; Howeler, 1989; 1991 Internal Cassava Program Trip Reports.

A study of cassava's potential in Vietnam

The recent collaborative Vietnam-CIAT study of cassava's potential for that country typifies socioeconomic contributions to broadening the knowledge base about the crop and people who benefit from it (Henry et al 1993). In 1989 the Ministry of Agriculture created the Vietnamese Root and Tuber Research Program as the first step toward reorganizing root and tuber research. The government approached CIAT for help with a cassava sector needs assessment, and in 1990 we jointly began a series of production, processing and marketing analyses, following ISNAR guidelines. We carried out surveys at farm level and on technical and socioeconomic aspects of different cassava products and major marketing channels. A survey on constraints showed that farmers are mainly concerned about soil fertility (partly a result of production shifts to more marginal zones). Data showed that cassava production and processing technologies aimed at the small-scale rural level would have a strong positive effect on overall economic development. The study showed the need to further emphasize utilization/processing research relative to production-oriented research. But soil fertility and erosion control are of prime concern at the farm level, and need further input. Henry et al. (1993) summed up the importance of this strategic planning exercise: "The various outputs . . . will help provide a solid base from which cassava research in Vietnam can generate efficient and effective activities to improve the welfare of the resource-limited cassava producers and processors, while preserving the natural resource base."

Producer and consumer benefits from CIAT's collaboration in technology development and institutional strengthening were growing rapidly by the 1990s. Donors justifiably expected some quantification of impact which is also crucial to the Program's strategic planning. Thus, economists have begun to further emphasize impact studies (Henry, 1991). A significant part of this effort involves helping national programs develop internal capacity for monitoring technology adoption and impact. Although classical methods can be applied, impact studies with cassava can be very demanding of time and resources. Production and processing is on a small scale, so many people need to be contacted. Aggregate statistics are difficult to obtain, or of questionable veracity because production does not enter centralized markets. For these reasons, much of the impact assessment has been within the realm of integrated projects. Generally, good baseline studies exist, and reliable information can be obtained on technology adoption and its effects on client groups.

Focus on Plant Behavior

The Program aims to understand the plant's growth and development, response to various stresses to which it is commonly subjected, and from this understanding, to propose and test hypotheses about genetic or management approaches that could improve productivity (Table 2). Physiologists explored the inner workings of the cassava plant with energy and optimism, that quickly paid off in new understanding of this unusually promising crop.

The ideal cassava plant—a model proves to be broadly applicable

Combining field experiments and simulation modelling, physiologists proposed traits of a cassava plant for maximum productivity under non-limiting conditions (Cock et al., 1979):

- **Leaf size** of 500-600 cm^2
- **Leaf life** of 15-20 weeks
- **Leaf area index** of 2.5-3.5
- **Branching** at about 30 weeks
- **Harvest index** of about 60%

This model soon came under attack as of little practical value—cassava rarely enjoys growing conditions anywhere near optimum. But physiologists had already moved on to the next stage—defining the modifications to the model needed for various kinds of stress. They concluded that the model is broadly applicable across many types of stress, but that a different genotype would often be needed to express the appropriate traits in different environments.

Plant Type

By the time of the Cassava Program's establishment there had been some impressive successes in improvement of other crops through changing plant type. Understanding the ramifications of plant type on cassava growth and yield seemed a promising starting point. From this work, we learned the details of the ideal plant type under favorable conditions, including canopy characteristics, dry matter partitioning, and maximum yield potential (Cock, 1976 and Cock et al., 1979).

Table 2. Mechanisms for cassava tolerance or adaptation in difficult environments.

Type of stress	Mechanisms of tolerance/adaptation	CIAT input[a]
Physical		
Drought	• Rapid stomatal closure under low relative humidity	***
	• Reduced top growth, from lower leaf formation rate and smaller leaf size	***
	• Ability for rapid post-stress recovery of leaf formation rate	***
	• Early root bulking	**
	• Leaves remain photosynthetically active under stress	***
	• Long leaf life to maintain post-stress photosynthetic capacity	***
	• Ability to extract water from deep soil layers (>2m)	**
	• Absence of a critical growth period when the plant is especially sensitive (e.g., as for plants where seed is commercial product)	**
Low temperatures	• Genetic tolerance (unknown mechanisms)	**
Nutrient deficiencies	• Efficient internal nutrient use	**
	• Mycorrhizal associations	***
	• Internal recycling of nitrogen	*
Nutrient or Al/ salt toxicities	• Genetic differences in tolerance observed; mechanisms unknown	*
Long photoperiod	• Lower sensitivity of some genotypes, to maintain high harvest index; unknown mechanisms	**
Excess water	• Genetic differences noted; unknown mechanisms	*
Wind	• Short plant stature	—
	• Well-anchored root system	—
Biological		
Pests and diseases	• Genetic resistance; presumed to be due to various mechanisms	***
	• Foliar pests: damage to commercial product (roots) buffered by spacial distance	**
	• Physiological redundancy: leaf area index in excess of optimum	***

a. — zero or minimal; * low; ** intermediate; *** high.

Temperature and Photoperiod Adaptation

Cassava is adapted to mean daily temperatures ranging from 15 to 32°C. In trials at a range of altitudes, specific genotypes were adapted to a limited temperature range, thus establishing the justification for separating breeding objectives into lowland and highland populations (Irikura et al., 1979).

Photoperiod is a major environmental determinant of yield in many crops. Cassava is moderately sensitive to long days, increasing top growth and decreasing root yield in response. Genetic differences in sensitivity exist, and show the need to select under a photoperiod characteristic of the target production area.

Drought Tolerance

Drought is a defining condition for cassava production. Most cassava undergoes either extended or periodic water deficits. Areas with less than 400 mm rainfall during the growing season, such as Northeast Brazil, Northeast Thailand, and northern Nigeria obtain yields of 3-5 t/h dry roots. We have made extensive use of both natural and controlled drought conditions to unravel the mysteries of the plant's astonishing drought tolerance, and to assure that results are relevant to the real world conditions that farmers face.

Cassava has a number of mechanisms to conserve water, mainly by stress avoidance (Conner and Cock, 1981; Conner et al., 1981; Conner and Palta, 1981; El-Sharkawy and Cock, 1984; 1987b; El-Sharkawy et al., 1984b; El-Sharkawy, 1993). The starchy roots themselves probably evolved as a means of storing energy reserves for periods of stress. A deep fibrous root system allows water extraction at two or more meters below the surface. Leaf formation rate and leaf size quickly reduce under stress. But leaves of stressed plants remain photosynthetically active during these periods of the day when water use efficiency is greatest. Harvest index tends to increase under drought, with a greater reduction in total biomass than in economic yield (roots). Stomata are highly sensitive to relative humidity—they close and reduce water loss to nearly zero under low humidity. When drought stress ends, cassava can recover quickly with new growth. Leaf retention and rooting capacity under water stress are simple criteria which integrate several components of drought tolerance, and are of practical value in breeding.

Cassava's drought tolerance depends on:

- Deep fibrous root system
- Stomata highly sensitive to low relative humidity
- Starchy roots acting as energy reservoir for regrowth when rains return
- Leaf area reduction to conserve water
- Photosynthetically active leaves under drought stress

Nutrient Stress

Most cassava is grown under at least moderate nutrient stress. Distinct varieties are adapted in pH ranges from 3.5 to 8.5. At low fertility, plants restrict leaf growth but maintain high nutrient content in leaves (Cock and Howeler, 1978). Crop growth rate per unit of leaf area index is similar at both low and high fertility levels. Modelling showed that a plant reducing leaf area index but maintaining photosynthetic rate of individual leaves will have greater primary production potential under nutrient stress. Prolonged water deficits improve nutrient use efficiency, although total uptake is reduced. Thus, there may actually be a beneficial effect of water stress on conserving soil fertility through better nutrient use efficiency (CIAT, 1993a).

Photosynthesis

Cassava's photosynthetic rate is nearly as high as C_4 species like maize, sorghum and sugarcane, and there is a wide range of genetic variation both within cassava germplasm, and across *Manihot* species (El-Sharkawy et al., 1984a; El-Sharkawy and Cock, 1987a). Leaves can recycle large amounts of respiratory CO_2 in light, an ability which should allow gain in root yield during drought, with stomata closed.

We have repeatedly found a positive association between photosynthetic rate of individual attached leaves in field-grown plants, and crop productivity in both favorable and unfavorable environments (El-Sharkawy et al., 1990). New technology and techniques for quick and precise measures of photosynthesis mean that these differences can more readily be exploited in breeding and in the design of crop management systems. We are using molecular techniques to understand more about photosynthesis in cassava. Results so far support our working hypothesis that the top of the leaf works more like a C_4 plant and the bottom like a C_3 plant, probably with some kind of CO_2 recycling (El-Sharkawy et al., 1984a; El-Sharkawy and Cock, 1987a).

Plant Health

Both genetic and management approaches to reducing pest[1] losses rely on basic knowledge that was lacking when CIAT began its work. Up to the early 1970s, there was little appreciation for the range and potential severity of biological constraints in cassava; the literature often claimed that the crop was essentially free from serious pests and diseases. The 1969 CIAT Report observed, "... in 1966, *The Review of Applied Mycology* published two references to cassava diseases, 17 to carnation diseases and 234 references to research on tobacco diseases."

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1. For convenience, we use the term *pest* to include both arthropod pests (mainly insects and mites) and pathogens.

CIAT entomologists and plant pathologists initiated research to improve our understanding of which problems were important; which were future threats given appropriate conditions; and of approaches to effective, low-cost, and environmentally sound protection of the crop from losses in yield and quality.

CIAT has a strong comparative advantage for doing basic work in plant protection. Worldwide there are only a handful of pathologists and entomologists specialized in cassava. Most of them have principal responsibilities in applied research. As an international entity, our ability to see situations first-hand across countries and continents on a regular basis is a key to placing problems into a broad perspective, and to defining appropriate strategic research.

The Germplasm Collection at Risk

The first need for plant protection input arose in 1970 when CIAT's newly established germplasm collection began showing signs of cassava bacterial blight (CBB). This was a potentially devastating development. Difficulty in maintenance and propagation, and quarantine implications for distribution of germplasm would negate many of the potential benefits of this collection. Fortunately, we were able to eradicate CBB through careful selection of clean planting material and an indexing system based on rooted sprouts. CBB was eradicated. In spite of CBB presence in nearby plantations, we have been able to keep the germplasm collection at CIAT headquarters CBB-free ever since.

Defining the Targets

Like cassava, most of the pests and pathogens which affect the crop, and their biological control agents, co-evolved and diversified in the American tropics. Pests and pathogens were gradually introduced to Africa and Asia, probably mostly with planting material, but many are still limited to the Americas. Natural enemies often suppress pests in their native habitat, but these enemies may be absent when a pest arrives in a new location, allowing serious outbreaks and crop losses. Cultural practices, especially chemical applications and extensive monoculture, can also upset the balance between pests and naturally occurring control agents (Lozano and Nolt, 1989). Some 32 pathogen, 20 insect, and 6 mite species affect cassava; many were first described by CIAT as cassava pests (Bellotti and Schoonhoven, 1978; Lozano, 1979). Fortunately, relatively few of these have any economic significance. We estimate that, globally, 19% gains in cassava yield could be achieved by eliminating losses from diseases and 13% from pests. The principal constraints, in order of yield loss which they cause are: (highest) African cassava mosaic virus, cassava green mite, cassava bacterial blight, mealybug, root rots (around 15 pathogenic species), and anthracnose. Other species may be priorities for research due to future threats of broader dissemination (burrowing bug); as disease vectors (whitefly), for quarantine considerations (frog skin disease and other viruses); as problems of regional importance (superelongation disease); or as sporadic and localized problems which can be severe when they occur (hornworm).

Using soil and climatic data, superimposed on cassava's distribution, we have produced maps of the current and potential distribution of major pests and diseases in the neotropics. We have collected, conserved, classified and developed a database on a complex of cassava pests and their natural enemies. Methodologies developed at CIAT for rearing/culturing major pests and natural enemies are the basis of many control strategies.

Pests take their toll

In a 1993 exercise to help prioritize research, the Cassava Program estimated yield losses from a broad range of constraints on a global basis. While summary data do not do justice to the complexity of this analysis, they provide a general overview of relative importance of these problems.

Expected percent yield gain from complete alleviation of principal pest and disease constraints.

Pest or disease		Africa	Asia	Latin America
Diseases		19.6	4.0	14.7
	African cassava mosaic virus	10.2	0.2	0.0
	Cassava bacterial blight	5.9	1.1	3.9
	Root rots	1.0	0.3	4.0
	Anthracnose	1.4	0.3	2.3
	Leaf/stem pathogens	1.1	2.1	2.4
Pests		12.5	3.0	8.9
	Green spider mite	8.0	1.9	2.8
	Mealybug	2.7	0.0	0.6
	Mammals	1.1	0.1	0.3
	Hornworm	0.0	0.0	1.5
	Termites	0.5	0.1	0.0

Challenges of the Viruses

The viruses present special challenges as they can be very difficult to isolate and identify. Rapid development of molecular techniques over the past few years has made a major contribution. We have determined the distribution and magnitude of the problem caused by cassava frog skin disease, cassava vein mosaic virus and cassava common mosaic virus. The last was fully sequenced for the first time at CIAT, and in fact is the first plant virus to be sequenced in Latin America (CIAT, 1993a). We are also in the process of sequencing the cassava vein mosaic virus.

Frog skin disease, which for many years eluded full characterization, is now confirmed as caused by a virus. Since it is a highly labile virus, purification is very difficult, but we have made progress. The virus is localized in the cytoplasm, and is not transmitted through true seed. This finding is reassuring for our germplasm exchange with Africa and Asia.

We developed and described a range of diagnostic techniques increasing the probability of germplasm being virus-free for international distribution and aiding the design of disease control strategies. Elite clones and the core collection are indexed to give the highest probability of freedom from viruses. These clones are available for distribution to any country (except in Africa, where vegetative introductions are not yet permitted).

Pathogen Variability

We studied genetic variability of bacterial and fungal pathogens, the possibility of differential reaction to host genotype, and its implications for control strategies. There are apparently only weak interactions (e.g., superelongation disease (Zeigler et al., 1983)). The resistance genes we are using seem to be broadly effective across pathogen biotypes, and there is no evidence of pathogens evolving to overcome resistance (Kawano et al., 1983; Umemura and Kawano, 1983).

The causal agent of superelongation disease, as well as its sexual phase, was described at CIAT. This unique fungus produces Gibberellic Acid (GA_4), causing exaggerated stem elongation, a mechanism for generating additional juvenile, susceptible tissue.

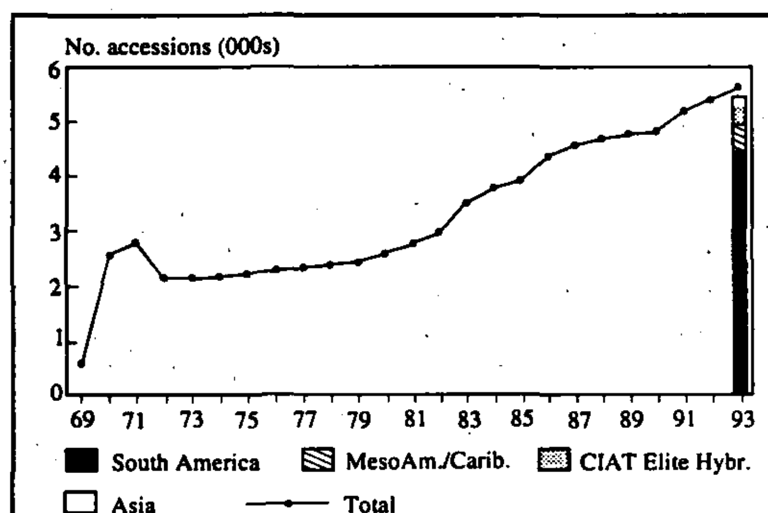
4. GENETIC RESOURCES FOR SUSTAINED VARIETY IMPROVEMENT

Preserving Genetic Diversity

Enhance the use of Manihot *genetic resources for cassava crop improvement at CIAT and at partner institutions*

We established the base of the present international collection with expeditions in northwestern South America and Meso-America in 1969-70. Though little was known about cassava genetic diversity at that time, the areas chosen proved to be extremely rich in traits for breeding, and in representing a broad spectrum of total species diversity. Most of cassava's genetic diversity is found in the Americas, its evolutionary home. But the unique selection pressures in Africa and Asia have continued to produce new gene combinations, and possibly even genes that should be part of a world collection. IBPGR's (now IPGRI) interest in cassava in the early 1980s, and it's co-sponsorship of two workshops on cassava genetic resources laid the groundwork for several years of active collecting in Latin America, along with a standardized methodology for germplasm characterization (Gulick et al., 1983).

The collection has grown steadily to now include over 5,300 accessions, with good Latin American representation, moderate Asian representation, and a small African sampling (to date, IITA hybrids only). In 1984 CIAT signed an agreement with IBPGR to take long-term responsibility for cassava germplasm conservation within the CG system. This role was reinforced by members of the *Manihot* Genetic Resources Network at its 1992 founding meeting.



Number of accessions and regional representation in CIAT cassava germplasm collection.

The Wild Species

We gave relatively little emphasis to the wild *Manihot* species (some 100 are identified) until a significant part of the extensive diversity had been exploited within the cultivated *M. esculenta*. While there is no evidence that we have approached a plateau in breeding within cultivated cassava, wild species do represent a *critical* part of the *Manihot* gene pool. We cannot truly fulfil our global role in germplasm management without some attention to them.

There are now 31 species in the collection. We are studying them with regard to seed and vegetative propagation, crossability, and characterization for biochemical and agronomic traits. Unlike related species of many crops, the initial challenges in using wild *Manihot* are related more to conservation and propagation than to interspecific crossability, *per se*.

Conservation Alternatives

Our first responsibility in germplasm management is to have a secure system of conservation. Initially the only option was field-grown plants exposed to potential threats from pests, diseases, adverse weather, and soil problems. CIAT established an in vitro lab in 1977 to improve the sanitary status and security of the collection. At the time, only some rudimentary work had been done on in vitro methods for cassava. The lab dedicated several years to fine-tuning methods for secure and cost-efficient conservation. In vitro conservation is now routine, and also feasible for many of the wild species (Roca et al., 1989).

> **Of genes, genotypes and their conservation**
>
> Cassava varieties are generally made up of genetically uniform, heterozygous plants. Conserving the specific gene combinations of a landrace needs vegetative propagation. Any individual plant can completely represent a variety for conservation by vegetative means (e.g., field or in vitro). When a plant's seeds are collected, the resulting progeny will not be uniform but will segregate for many characters. Specific gene combinations cannot be retained, but we can conserve genes if an adequate seed population is collected. Most cassava germplasm collections are based on vegetative propagation. It is most straightforward from a *gene management* standpoint, and breeders usually prefer to work with parental materials of well-known traits.

Although the cassava collection is not large by the standards of some seed-propagated species, its management is cost- and labor-intensive. Cryopreservation offers the promise of stable, cost-effective, and secure long-term storage. Research has focussed for several years on improving the rate of recovery to acceptable levels. We have made steady progress, and processing the collection for cryopreservation will soon begin at the pilot level (CIAT, 1993a). Several studies have demonstrated that cassava has remarkable genetic stability through various tissue culture procedures, including meristem culture, cryopreservation and somatic embryogenesis.

A Core Collection to Prioritize Research

In 1991 we defined a *core collection*—a sub-sample of 630 accessions selected to represent the genetic diversity of the entire species genepool (Hershey et al., 1994). Virtually every activity involving the cassava genebank is now prioritized based on the core collection. It defines the first set of clones for **duplication** in other institutions (planned in the near future for Brazil and Thailand, and in the medium term for Africa), for **characterization**, for in vitro **pathogen testing**, for **cryopreservation**, and for **distribution** to the Cassava Biotechnology Network's genetic diversity studies.

Within just a few years of its definition, we have probably made more use of this core collection than that of any other crop. This is partly because breeders and germplasm specialists are jointly responsible for overall germplasm management, and partly because we still broadly and actively use the collection in genetic improvement.

The core collection serves multiple roles

A large germplasm collection is an invaluable resource for crop improvement. But it entails a massive commitment to safe conservation and thorough evaluation. The 1980s saw an increasing awareness of the long-term value of genetic resources, and of risks to their preservation in rapidly changing natural or agricultural systems. Many programs established or expanded ex situ collections, but breeders were often unable to keep pace in evaluating and using accessions. The core collection concept grew out of these concerns. It is a strategy for prioritizing some of the key management components of germplasm, by defining a sample that closely represents total genetic diversity of a genus or species.

We became one of the early adopters of this strategy. The payoff was immediate. There were several traits we knew to be important, but evaluation of the entire collection was a daunting prospect. We evaluated the core for amylose/amylopectin ratio, cyanogens by a modified quantitative method, photosynthetic rate, post-harvest deterioration, and several pest and disease resistances. We now better understand the range of variation for these traits, and have promising sources for further exploration. The core collection also has priority for in vitro disease indexing and cryopreservation.

Germplasm Needs to be Well-Characterized

To be a useful breeding resource, germplasm has to be characterized for those traits which can be potentially useful to producers and consumers. Unfortunately, the value of detailed passport data (a description of an accession's origins) was not broadly recognized when most of the collection was established. Only with later collections do we have extensive passport data. Many collections introduced from national programs are completely lacking in information about origins. This limits our ability to do certain types of genetic diversity studies, but is not a severe limitation for making use of the germplasm in gene pool development.

Percent of germplasm collection with:

• basic passport data	40
• complete passport data	17
• agronomic evaluation	98
• isozyme characterization	90
• morphological characterization	90

We considered agronomically significant characters like plant type, yield components, quality, and pest and disease resistance almost exclusively for the first germplasm evaluations in 1973 and 1974 (Kawano et al., 1978b). This focus continued through most of the 1980s, with emphasis on evaluation over a broad range of environmental conditions. There is an extensive database on these evaluations' results. We are continuing biochemical and physical characterization for varietal *fingerprinting* and duplicate identification; and studies on genetic diversity, phylogeny and evolution.

The cassava genebank is an international resource held in trust by CIAT. It is freely available on request. We have sent accessions, or their progeny in seed form, to numerous Asian and Latin American countries, and to IITA in Nigeria. We have distributed a broad range of genetic diversity in the form of single and multiple crosses among selected accessions (Table 3).

Genetic resources management is the basis for manipulating genes to obtain improved varieties, via the process of **gene pool development.**

Table 3. Summary of international cassava germplasm shipments from CIAT, 1972-1993.

Region	Number of crosses	Number of seeds[a]	Number of clones[b]
South America	1762	125,292	1806
Meso-America & Caribbean	1201	65,313	717
North America & Europe	373	73,313	1058
Africa	2947	353,086	0
Asia & S. Pacific	5912	360,055	630
Australia	52	1,405	48
Middle East	0	0	12
Total	12,247	978,464	4271

a. Each individual seed is genetically distinct.

b. Clones may be repeated for different countries within and across regions.

5. GENE POOL DEVELOPMENT

> *Develop and deliver to national programs improved cassava gene pools for the major cassava-growing agroecosystems*

Crop genetic improvement requires serious investment in personnel and research infrastructure. Cassava does not attract private investment by seed companies because of vegetative propagation, minimal trade in planting material, and the small-scale nature of most producers. Few public institutions are able to give a level of priority to cassava which it merits. CIAT aims to focus on *strategic* research in genetic improvement—methodologies broadly relevant to national programs, and germplasm tailored to breeding systems of any level of sophistication.

We define a *gene pool* as a set of genotypes selected for adaptation in one of the major agroecological zones for cassava production. We use the term *adaptation* broadly to include yield, resistance to biotic and abiotic constraints, and adaptation to soil and climatic conditions. The components of a gene pool may or may not be interrelated.

Defining Basic Principles

Even before starting agronomic characterization of the germplasm collection, breeders were thinking ahead to the likely need for using recombination among accessions as a way of improving existing landraces. The early crosses, a kind of *trial run* of breeding methodology, were based on preliminary observations and intuition. Even so, many of these first-identified accessions became outstanding contributors to superior new hybrids over many years.

Although rudimentary cassava breeding had a long history in a few institutions, documentation of even the basics, such as flowering biology and pollination methods, was limited. Our early research on these topics, quickly enabled us to define efficient methods for crossing and seed management (Kawano et al., 1978a). Vegetative propagation simplifies cassava breeding. A superior plant, identified at any stage of evaluation, can be genetically fixed by cloning.

There were few guidelines for assessing the potential value of germplasm accessions as parents in the early years. Criteria for parental selection became a principal contribution of work in physiology, plant pathology, entomology, plant nutrition, and root quality. Extensive studies under a range of conditions of intra- and intergenotypic competition, led to defining several critical selection criteria related to yield potential and yield stability: early vigor, pest and disease resistance, branching habit, leaf life, leaf area index, number of roots and harvest index. Harvest index proved to be a key criterion for yield selection in segregating populations. It is often more reliable than yield itself as a predictor of yield potential at the level of large

Strategies for durable resistance to pests and pathogens

In the post-World War II era, pesticides seemed an easy, economical option for tempering the ravages of insects and diseases. Their adoption in Europe and North America was rapid and widespread. Tropical countries soon followed suit as chemical manufacturers made inroads into these large potential markets. Plant breeders often took this *opportunity* to further concentrate on yield potential. Breeding nurseries were kept well protected on the principal that more rapid genetic gains can be made when few characters are considered.

Concerns about the human health and environmental effects of extensive pesticide use are now widely held. But there is less awareness of the genetic consequences of the many years of selection in pesticide-protected nurseries.

CIAT cassava breeders followed a different strategy from the outset. Cassava's long growing season means that the crop may be exposed to various biological problems that occur, especially as weather patterns change over a growing season. We were also well-aware that very few cassava farmers are inclined to apply pesticides, even where it might be shown to be economically viable on an experimental level.

Our strategy, then, was based on use of natural enemies and of genetically controlled resistance. For both parts of this strategy, we chose selection environments with especially high and uniform pest pressures. The most severe of these selection sites is Carimagua, an experiment station of the Colombian national research agency, ICA. The site has highly acid infertile soils, and a complex of wet-season diseases and dry-season pests. The first extensive germplasm evaluations here in 1977 and 1978 were revealing. Of over 2,000 accessions evaluated, only 5 genetically distinct clones showed good combined resistance to bacterial blight, superelongation disease, and anthracnose. These and several of the intermediate-resistant accessions, were the basis for a long process of incorporating a broad base of resistance into advanced gene pools. We used the same strategy for other types of physical and biological stress.

By *adopting this strategy* at the outset of our genetic improvement work, we avoided the classical dilemma of breeders who find that their advanced materials have lost resistance genes due to genetic drift. Returning to germplasm accessions to retrieve these genes is then a lengthy process, and one in which it is highly tempting to concentrate on a narrow range of just one or a few genes that seem to have a major effect. This narrowing of the genetic base of resistance can have consequences that are all too well-known—the eventual ability of a pest or pathogen to overcome the resistance. We complement our core strategy with basic studies on host-pest interactions, genetics, artificial rearing and infestation, and others.

We cannot be certain that the resistance we have developed will be forever stable, but there are as yet no indications of resistance breakdown after some 20 years of continual evaluation in high pressure environments.

plots (Kawano, 1990). We developed and adapted techniques for rapid screening for dry matter content, cyanogenic potential, and post-harvest deterioration. These techniques are now widely used by national programs.

Our early emphasis on host plant resistance profoundly influenced the composition of breeding populations. There is probably no other major crop where the broad-based and stable resistance of landrace varieties has been so effectively retained in advanced breeding materials (Hershey and Jennings, 1992). This contrasts with the conventional approach taken for most crops whose initial intensive genetic improvement coincided with an era when chemical control of pests and diseases predominated. In programs where resistance *was* sought, single-gene resistance was often the choice. The final result in cassava advanced gene pools is that many resistance genes, to many pests, have been retained, and their frequency intensified over the years.

An Eco-Regional Basis for Breeding Objectives

By the late 1970s, the potential for genetic improvement was becoming clearer. We had developed many hybrids which were consistently outyielding local checks. We identified resistance to cassava bacterial blight, superelongation disease, root rots, *Cercospora* sp., anthracnose, *Phoma* concentric ring leaf spot, thrips, mites, whiteflies, mealybugs, and lacebugs. Some resistances were incorporated at high levels in advanced clones.

During this period, it became apparent that continued progress toward our goals in genetic improvement could best be accomplished by further decentralization of selection—designing gene pools around eco-regional objectives (soil and climate constraints, pests and diseases). This would allow some narrowing of objectives within each particular gene pool, as compared to incorporating all resistances, adaptation traits, and quality parameters into single, broadly adapted varieties.

These *edapho-climatic zone* descriptions became internalized as a fundamental way in which we thought about and planned research, not only in gene pool development, but also other areas of research. Over time the concept was adopted by several national and international programs.

Headquarter's Breeding Culminates in *Elite Clones*

Breeding lines that are repeatedly outstanding performers in our advanced yield trials become *elite* selections. This designation means that the clone becomes part of the permanent germplasm collection, is virus-indexed and prepared for in vitro conservation, and usually enters hybridization nurseries. There are now over 200 elite clones, fully described for many traits, and available for transfer to national breeding programs or other research institutions.

Measures of Genetic Progress

Ultimately, we must measure success in breeding by farmers' adoption of new varieties. But we also need indications at earlier stages as a means of assessing breeding strategy and making timely adjustments. Most characters of interest for improvement are controlled by several to many genes. Their expression follows a continuum from low to high, as opposed to strictly *presence* or absence. A further complication for measuring genetic progress is that many characters have only low to

A strategy for cassava's varied environments

One can find vigorous, healthy cassava in a very diverse array of environments: dry or wet; cool or hot; short or long daylength, acid or alkaline soils. It is not obvious that cassava varieties evolved for specific adaptation to each of these conditions, until varieties are moved among ecosystems. Our experience with a broad genetic base yielded some empirical observations, which we gradually turned into scientifically supported principles for cassava adaptation. Early physiology studies showed a clear distinction in adaptation of varieties above or below 22 °C. Experimentally demonstrated genetic differences in photoperiod sensitivity helped explain tropical/subtropical adaptation. High variability for tolerance to soil acidity or nutrient stress, and for drought tolerance, each further clarified cassava's patterns of adaptation. Pests and diseases occurred in characteristic complexes according to environmental adaptation.

The accumulating evidence culminated in what came to be called *the ecosystem debate of 1978-81*. The fundamental outcome was to define major *edaphoclimatic zones* (ECZs) having combinations of physical and biological traits typical of major cassava-growing areas. The Agro-ecological Services Unit helped quantify the characteristics of these zones and refine their definition, to map them, and to describe production and utilization practices.

The breeding section then developed *gene pools* for each ECZ. The underlying concept is that we can achieve more rapid genetic progress by narrowing the number of factors to consider in selection. Several other breeding programs later modelled their strategies after this CIAT approach. It is a model which will continue to require analysis and refinement, but which has served its purpose well for over a decade.

Eco-regional basis of gene pool definition:

- Lowland humid tropics
- Lowland sub-humid tropics
- Lowland semi-arid tropics
- Mid-altitude and highland tropics
- Subtropics

intermediate heritability, i.e., their expression can vary markedly according to growing conditions. This situation is by no means unique to cassava, and standard statistical procedures are available for measuring genetic versus environmental influences on expression of variability.

With early breeding work concentrated on yield potential, this was logically the focus of first measures of progress. Colombia's regional trials, conducted mostly by CIAT in the first decade, showed that new varieties typically yielded 100% more than local varieties, with good management but no fertilizer or pest control (Toro, 1979).

As we began to place more emphasis on breeding for stress conditions, we focused more on measures of progress in pest resistance, acid soil adaptation and drought tolerance. We stressed a holistic approach to measuring yield progress under conditions where typical combinations of stress occurred. For example, analysis of data from the high stress conditions of Colombia's eastern plains over 10 years of breeding showed yield gains of about one t/ha/year, mainly from improved disease resistance and acid soil adaptation (Hershey et al., 1985).

Iglesias and Hershey (1992) analyzed genetic progress in CIAT gene pools during the 1980s for various traits and from several ecosystems. Overall, best progress could be documented for yield, resistance to superelongation disease, dry matter content, and the composite character of *foliage evaluation*. In Asia, the focus of breeding has been mainly on yield potential and root dry matter, and progress in these characters as a result of introgression of CIAT germplasm is well-documented. Compared with yield level of local breeding populations when we began our collaboration, yields increased by 57% in Thailand, 45% in Sumatra, Indonesia; 63% in East Java, 25% in Hainan, China; and 87% in South Vietnam (CIAT, 1993a).

A Global Force in Genetic Improvement

Our commitment to fulfilling a global mandate for cassava genetic improvement evolved over time. Scientists from Asia were among the early participants in the cassava production courses at CIAT, and these continuing contacts proved extremely productive over the years. Breeders took seeds back to their programs and these formed the basis of several successful new varieties in Asia. With special funding from IDRC we placed a liaison scientist in the Philippines from 1977 to 1980, setting the stage for a longer term presence when we opened the Asian regional office in 1983.

Tailoring germplasm to our partners' needs

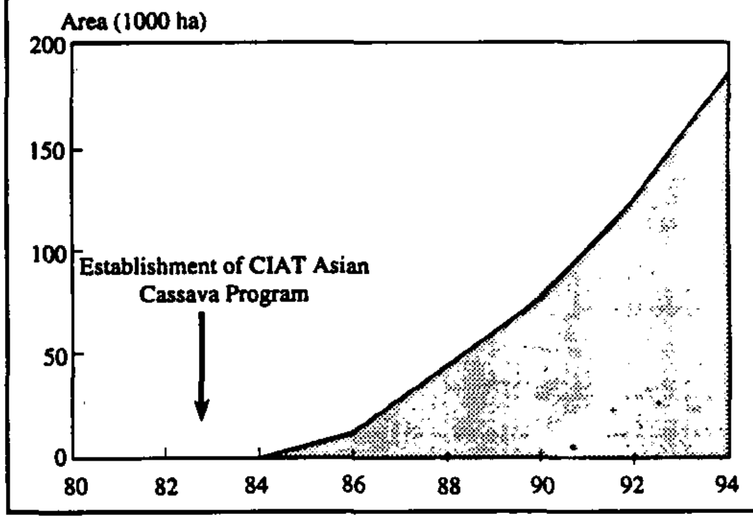
Cassava can be propagated either by stem cuttings (*vegetative*—each progeny is identical to the parent plant), or by seed (*sexual*—each progeny is genetically distinct from each other, and from the parents). This allows considerable flexibility in terms of the *type* of germplasm we provide breeding programs. Those with fewer resources may make best use of advanced lines in vegetative form (stem pieces or in vitro culture). These lines will have an extensive background of information on adaptation, yield potential, resistance and quality. A disadvantage is that it may be difficult to identify lines having the precise combination of traits for any specific region's needs.

At the other end of the spectrum, programs with more advanced breeding skills and resources can introduce segregating populations. Thousands of seeds are easily introduced, giving a wider range of possibility of identifying plants that possess the specific traits' combination that a region needs.

Asian countries were in an ideal position to benefit from closer linkages to CIAT's gene pool development activities. Thailand, a strong program in the region, has been very supportive as a base for regional coordination, even including international sharing of valuable germplasm developed with their own resources. Our concentration on production technology has a good chance of success because of generally well-developed, diversified markets. The major ones are for processed cassava, where quality requirements are generally less stringent than for the fresh market.

Most countries have a narrow genetic base, which formerly limited potential for genetic advance. There is no doubt that in the past 20 years we have introduced a far greater range of cassava genetic diversity into Asia than was introduced in all previous history. The longer term benefits of this broader diversity should be profound.

Given the favorable conditions for new variety generation and adoption, the spread of new CIAT-related varieties is beginning to have impact. By the end of 1993, farmers planted new varieties on approximately 160,000 ha in Thailand (mainly *Rayong 3)* and Indonesia (mainly *Adira 4*). Benefits are clearly in the early stages, and should accelerate rapidly at least for several years. Further improvement of yield and adaptation, and a sustained commitment to supporting national programs, are necessary to attain this challenging target.



Adoption of CIAT-related cassava varieties in Asia.

SOURCE: CIAT, 1993a.

Strengthened Ties to Africa

Within the CG system, IITA has regional responsibility for cassava in Africa. Our collaboration with Africa is almost exclusively in coordination with IITA. Up to 1990, our main germplasm input into Africa was in the form of occasional seed introductions, and periodic interchange of visits. Though neither frequent nor systematic, these introductions had substantial impact on IITA's breeding program, through a significant introgression of Latin American germplasm over the years.

GENETIC DIVERSITY SENT TO AFRICA

Percent of CIAT elite clones used as parents for adaptation to:

Lowland subhumid and semiarid tropics	64
Lowland humid tropics	55
Middle altitude and highland tropics	46

Most Latin American germplasm is susceptible to African cassava mosaic virus. Direct introductions often suffer severe infection and have no chance of demonstrating potential for other traits. In the late 1980s we introduced 19 IITA elite, mosaic-resistant hybrids to CIAT through a rigorous virus-testing protocol at the Scottish Crop Research Institute. We used these extensively to create *bridge hybrids*—materials that combine moderate mosaic resistance with new diversity from Latin America. These hybrids are the principal means of introducing new genes into African germplasm for those areas where mosaic is limiting.

Since 1990, the CIAT liaison scientist has worked within IITA's Tropical Root Improvement Program to assure optimum interchange between CIAT and IITA programs. To date, this interchange has centered on establishing an efficient flow of germplasm, and assuring that traits of value are incorporated into locally adapted germplasm. This has been specially important for semi-arid and highland zones, where the African germplasm base is very narrow. Our combined experience in the physiology of drought adaptation and breeding for semi-arid conditions is contributing greatly to the potential future expansion of cassava in Africa.

With over 250,000 seeds introduced to IITA just since 1990, there is now a substantially expanded genetic base available in Africa which will provide breeders with new opportunities long into the future.

National Programs Assume International Roles

The Brazilian national cassava program at CNPMF in Bahia state has expertise and long experience in breeding, manages a broad native germplasm base, and works in key environments where selection can have global significance. To capitalize on these resources we collaborated with several Brazilian programs and IITA establishing a project in 1990, to develop semi-arid and sub-tropical adapted cassava germplasm. Benefits are aimed at areas of the world with similar environments, especially in Brazil and Africa.

Using screening nurseries in extremely harsh environments in the Northeast, breeders identified varieties combining drought tolerance, high yield at an early harvest, good starch content, and intermediate cyanogen levels. Efficiency and effectiveness are reinforced by the presence of other projects with strong CIAT involvement—integrated pest management; and production, processing and marketing projects. All work to complement each other. We expect a continuing trend toward national programs taking on international responsibilities within a network-defined prioritization of goals and strategies.

Farmers Fine-Tune Variety Development

Typically the International Centers consider their role in variety development ends at the point of turning over basic or improved germplasm to national programs. These then continue to adapt it locally, and move selected material through on-farm testing, release, multiplication, distribution to farmers, and follow-up analysis. The under-

Farmer evaluation of experimental lines

Plant breeders have formal training in discriminating desirable from undesirable plant traits, and gain practical experience over years. Even with these skills, it is not uncommon for breeders to select varieties that are eventually rejected by growers. This is less frequent for industrial or intensively managed crops where high inputs are used to create relatively uniform growing conditions—or where a single market absorbs production. Cassava is subject to many variations in soil fertility, pest and disease pressures and market requirements. Unless farmers and consumers actively participate with breeders to select new varieties, experience shows that chances of failure are high.

From the mid-1980s we developed and tested techniques for efficient farmer feedback—*participatory research*. The basis of the methodology is a series of open-ended farmer interviews, by trained scientists, to elicit reactions on all aspects of a potential variety's acceptance. Within just a few years of implementing the methodology in Colombia, the national program, ICA, released two new varieties based largely on convincing evidence of farmer acceptance—ICA-Costeña and ICA-Negrita.

Several national programs are now adapting the methods to their own needs. The experiences will also be invaluable in designing systems for farmer evaluation of other technologies such as pest management packages or erosion control practices.

funding of nearly all national cassava programs means that there are often inadequate resources for any of these steps in the interface between technology generation and impact. One of our main concerns was to assure that our selection criteria were fully on target with farmers' and consumers' needs.

From 1986, we began to develop simple, effective methods to evaluate new varieties not only on-farm but with close farmer participation. The methodology covers institutional involvement, trial design and management, farmer and consumer interview procedures, and data analysis and interpretation (Hernandez, 1993). Initially, we intended this to be strictly a feedback mechanism for breeders, and we strongly recommended against using the procedures as a means of promoting new varieties to farmers. But in the final analysis, national programs are adapting the methods for both functions.

Breaking Barriers to Technology Dissemination

Formalized seed multiplication, certification, and distribution systems are nearly non-existent in cassava (Cuba is a notable exception). Our hypothesis has been that new methods can build upon and improve the typical on-farm seed production, and farmer-to-farmer distribution that prevail in most of the world. In some situations, there are also opportunities for private seed enterprise. Again with the Colombian case as a model, we worked with local institutions and private entrepreneurs to develop and test various seed systems. The principal components of generalized relevance are; criteria for production of basic and certified seed, methodology for establishment and management of designated plots within farms for seed production, criteria for phytosanitary evaluation, and seed management (selection, treatment for pests and pathogens, and adequate storage). These simple procedures, not relying on sophisticated national seed systems, can contribute to substantial yield gains (Garay and Lopez, 1992).

New Varieties Move to the Marketplace

Release of varieties developed with CIAT input

Landrace and national program clones pre-selected at CIAT	
• Latin America:	12
• Asia:	5
CIAT hybrids introduced to national programs	
• Latin America:	6
• Asia:	2
Selected from CIAT seed introductions:	
• Latin America:	3
• Asia:	8
Selected from local x CIAT crosses:	
• Latin America:	-
• Asia:	5
Selected from local crosses:	
• Latin America:	Many
• Asia:	Many

The lead time between planning a cross and realizing significant on-farm adoption is normally 10-12 years for crops where multiple generations per year can be managed, and a good research/extension system is in place. Not surprisingly this interval is even longer for cassava which has a long growing cycle, under-funded extension systems, and economically marginal farmers. Though this process has been poorly documented, we are now gaining some good information from Asia showing that even in the stronger national programs, 15-20 years are needed. There are some obvious implications in the importance of careful long-range planning and stable funding if benefits are to be achieved.

New Tools

Tools and methodologies for genetic improvement of crops are evolving rapidly. We are increasingly using more precise methods for genome analysis and gene transfer. The stage is set for practical use of molecular markers, knowledge of mechanisms of resistance and individual components of complex traits, to complement empirical selection.

Since 1988, the Cassava Biotechnology Network has expedited the development and application of advanced techniques to cassava genetic improvement. This brought better communication and coordination among existing research thrusts and has stimulated considerable new cassava research in advanced labs. Currently, major research areas are cyanide potential, starch, tissue culture and propagation methods, mapping, molecular characterization for fingerprinting and genome analysis, transformation and regeneration, and pest and disease resistance. As an institution placed at the interface between advanced research labs and farm-level applications, we have a role in facilitating communication among diverse entities working toward common development goals.

Advanced research on cassava

CIAT participates in a number of projects for the application of advanced biological techniques to cassava improvement (Suppl. to CBN Newsletter, April 1994):

I. Biotechnological tools: for genetic improvement of cassava

- Molecular and cytological characterization of Manihot species genomes
- Framework molecular map of cassava
- Biochemical pathways, useful gene promoters, characterized and/or cloned
- Improvement of cassava plant regeneration and genetic transformation
- Regulation of reproductive biology
- Diagnostic and phytosanitary methods for safe cassava germplasm transfer
- Cryopreservation for long-term conservation of cassava genetic resources
- Tissue culture for cassava germplasm conservation and micropropagation

II. Biotechnology applications: for realizing cassava opportunities

- Starch quality and quantity for diverse end uses of cassava
- Genetics, biochemistry, fermentation or other biotechnologies
  1. New product development
  2. Products with desired nutritional value, taste and texture
- Cassava performance in stress environments
- Integrated pest management for cassava
- Resistance to important viral diseases of cassava
- Modified cyanogen biochemistry for optimal cassava production and use
- Enhanced fermentation for cyanogen reduction in cassava processing
- Enhanced fermentation systems for waste management in cassava processing
- Enhanced post-harvest keeping quality of cassava

6. INTEGRATED CROP AND SOIL MANAGEMENT

> *Develop with national programs appropriate integrated crop, pest and soil management technologies for sustainable cassava production*

Management technology and genetic improvement have contributed roughly equally to past successes in improving productivity for many crops. But *immediate* yield gains and direct crop inputs are not the only parameters for measuring technology benefits. Impact on the natural resource base and human health concerns must enter the analysis of technology costs and benefits. For example, pesticides may give immediate net income benefits, but disrupt balances between biocontrol agents and pests.

Crop management in cassava is particularly relevant because of its slow early growth, long growth cycle and vegetative propagation. Weeds are often serious up to 3 or 4 months after planting, when the canopy closes. Pests and diseases can attack over extended periods, and repeated application of control measures can be prohibitively expensive. Vegetative propagation allows dissemination of more pests and pathogens from one cycle to the next than is typical for seed propagation.

There are reasons for optimism about cassava's role in environmentally sound cropping systems, but there are also areas of special concern. Most cassava improvement programs aim to exploit the plant's inherent rusticity—its ability to efficiently use low rainfall and low soil nutrient levels. Plant protection research is based largely on host plant resistance, and biological and cultural control practices. With current priorities there seems little risk that cassava will become a crop dependent on toxic protectant chemicals.

One area of concern is the common practice of planting cassava on erosion-prone and degraded soils. In fact, this has led to a popular misunderstanding that cassava, as a crop, is especially prone to *cause* soil erosion and excessive nutrient degradation. The misconception arises from cassava's ability to thrive on soils which have already been degraded by cultivation of other crops. This of course does not exempt us from concern about soil degradation in cassava cropping systems, but rather provides a basis for planning more effective strategies that may involve a range of genetic, management and policy options.

Cultural Practices: Adapting to New Realities

Our earliest work in crop management covered some basic, simple cultural practices; land preparation, planting material management (selection, treatment, storage), planting density, planting position, fertilizer and lime application, weed control, and harvesting tools. New recommendations could expect relatively easy impact. Many of these are reviewed by Toro and Atlee (1985). The distinction between *strategic* and *adaptive* research, and CIAT's comparative advantages in these areas, were less well defined in the early years. For example, we first considered research on planting position (horizontal, vertical, inclined) to be *strategic*, and we made fairly strong recommendations to national programs about this practice. With more data, from both CIAT and national programs, it became evident that the most appropriate planting position varied according to soil, water and temperature conditions. Before we could train and rely on national programs to take on adaptive research, we first had to fill many of these basic information gaps.

> **Cuba promotes the *Colombian System* for high-yields**
>
> Cuba took an early lead in adapting improved cultural practice components to local conditions. State-managed farms produced cassava under a uniform set of high inputs based on practices used for sugarcane. After several cassava scientists received training at CIAT, and we assessed their situation through visits and consultations, the national program assembled a new set of recommendations on cassava. They named these the *Colombian System*, in recognition of CIAT's contributions.
>
> *Instead* of planting stakes on the bottom of ridges, they began planting on top to reduce root rot problems. Fertilizer rates were reduced, and tailored to local soil conditions. Irrigation was discontinued, except for very dry periods. Farm managers designated plots to receive special care for production of planting material. According to Cuban scientists, the system not only doubled yields, but reduced production costs.

Through the 1980s we worked on cropping systems, including maize and grain legumes, the crops most often associated with cassava, and on the principles governing their productivity. This research led to an understanding of how planting times, arrangements, competition and varietal traits influenced productivity. We investigated land use efficiency ratios and analyzed the economics of the systems. Some programs directly adopted and recommended CIAT-developed practices. More often they were used as we intended—a starting point for testing and adapting technologies for programs' specific conditions.

With much of the basic information on cultural practices now reasonably well studied and documented, we are more clearly defining our role as being cropping systems analysis and methodology development, rather than technology component development. But many national programs still lack facilities for good adaptive research, and we will need to continue evaluating our role in cultural practices research.

Quality Planting Material, a Key to High Yields

Planting material for commercial production is derived from stem pieces. Many elements impinge on the quality and quantity of those stems, and hence of planting material: nutrient status, water content, pest and pathogen infestation/infection, maturity, size. All in turn can be influenced by variety, growing environment, treatment, and conditions of storage. We estimate that these multiple constraints cause about 10% reduction in yield on a global basis. Though losses are high, they often result from factors not easily seen, and usually their importance is unappreciated by farmers.

Over many years of research, we showed that there can be a huge benefit from the simple and inexpensive practices of stake selection, chemical treatment, and proper storage (Leihner, 1986; Lozano, 1993). But there is a large interaction of management with environment, so recommendations have had to be fitted to specific conditions.

Improved Propagation Systems

The normal multiplication rate of cassava by stem cuttings is on the order of 10-15:1—very low when compared with most seed-propagated crops. This is not a limitation in normal cropping systems, but there are many situations where higher multiplication rates are desirable—establishment of multi-location trials, introduction of a new variety to a region, post-cleaning multiplication of an established variety. In the early 1970s we developed a rapid propagation system based on rooted shoots from stem cuttings, a method that has been widely adopted (Roca et al., 1980; Wholey and Cock, 1979). We later developed several variations on a method involving rooting of buds attached to a single leaf. This has potential for a much higher multiplication rate than the rooted-shoot method.

Currently, rapid-propagation research centers on in vitro methods. These include adding hormones to culture media to induce multiple shoot development, and somatic embryogenesis from leaf mesophyll tissue. Both methods have been used only at the laboratory level, but could eventually be developed as a stage in multiplication for field use (Roca and Nolt, 1989).

Maintaining Soil Fertility

The Program studies nutrient deficiency stress for cost-effective ways of long-term improvement, and as potential for breeding for nutrient use efficiency. In the early years, the CIAT mandate area was limited to the American lowland tropics, and the acid soil savannas received highest priority. So we targeted mainly the constraints found in the acid, highly infertile soils of the *Llanos Orientales* (eastern savanna) of Colombia (Howeler and Cadavid, 1990).

Our first steps were to define nutrient requirements of cassava (both in nutrient solution and in field trials), and diagnostic criteria to determine fertilizer recommendations based either on soil or plant tissue analysis. From the early work in the Llanos, soil and plant nutrition research expanded to include all the cassava ecosystems in which the Program works.

Mycorrhizae: basis of cassava's phosphorus efficiency

If one grows cassava in sterilized soil of normal nutrient levels, pathetically weak plants emerge. Evaluation of rooted cuttings in nutrient solution showed a P requirement several times higher than expected from field results (Asher et al., 1980). These observations quickly led plant nutritionists in the late 1970s to the discovery that cassava is strongly dependent upon mycorrhizal associations—root-specific symbiotic fungi—for phosphorus absorption.

A range of questions immediately arose about the potential to improve upon naturally existing associations—by augmenting populations of existing colonies, by selecting more efficient strains, or by improving the conditions for mycorrhizal activity.

We established a collection which grew to 800 strains from 25 species, including 6 newly described species. This became the basis for evaluating fungal genetic diversity for adaptation, infectivity and efficiency.

Unless soil P levels are very high, which is quite rare where cassava is grown, plants will produce virtually nothing in the absence of mycorrhizae. On the other hand, nearly all soils have native mycorrhizal populations. Usually these populations are efficient, and little or no advantage was realized by inoculation. Where local strains are inefficient, inoculation can be effective to increase yields (Howeler and Sieverding, 1983). Viable technologies for inoculum production, storage, distribution and application are constraints yet to be overcome.

Mycorrhizae are of such basic importance to cassava growth that it is tempting to believe some additional striking contribution to cassava productivity lies ahead.

CIAT is not in the business of making fertilizer recommendations for specific situations. But our large database, from responses in numerous situations in Latin America and Asia, is a considerable contribution to the national programs' abilities to do so.

Fertilizer commonly gives levels of yield response that suggest its use should be profitable, but in fact it is applied on a very small percentage of total area. A farmer's decision involves more than simple cost/benefit considerations. Lack of availability in remote areas, lack of credit, concern about changes in root quality, risk avoidance, and other reasons account for this. Impact studies on Colombia's north coast show that credit availability through the farmer cooperatives, plus market expansion and stabilization, can sometimes provide the incentives for purchase of inputs, including fertilizer (Henry, 1991).

There are alternatives to chemical fertilizers as means of soil fertility maintenance. But some of the traditional methods, such as fallowing, are a diminishing option, given increased pressure on land resources. Experimental results with rotation schemes and green or organic manures are encouraging but, where available, chemical fertilizers tend to be much more effective in increasing yield. Extensive on-farm trials and farmer participation in technology design/validation are still needed in the area of soil fertility maintenance.

Production Systems to Conserve Soil

Soil loss and cassava yields (t/ha); mean of four locations in Thailand.			
Spacing/ ridging	NPK	Soil loss	Cassava yield
Normal/ flat	Without	61	21
Normal/ flat	With	36	26
Normal/ ridges	Without	15	24
Narrow/ flat	Without	42	25
Narrow/ ridges	With	22	28

SOURCE: CIAT, 1993a.

Without enforced government measures to the contrary, farmers will continue to grow crops on erodible soils. Few farmers choose their crops based on soil erosion considerations, but they are open to modifying how they manage their crops when they understand the potential and the consequences of erosion.

Our research is centered in the Andean zone of Latin America, and in several Asian countries that have identified this as a priority concern. We employ a three-phase approach of: quantification of losses and elucidation of contributing factors; experimental-level testing of management options to reduce erosion, including economic viability and probability of adoption; and farmer participation in testing and feedback to technology design (Table 4).

Erosion control research used simple run-off plots with channels for collecting soil and water, on different slopes and soil types. We established these jointly with national programs in Colombia, China, Thailand, Malaysia, Vietnam, Indonesia and the Philippines, on slopes normally of 10-15%. Soil losses on bare soil are typically 100-200 t/ha/yr. This is a maximum potential loss, rarely realized, since some type of vegetative cover (crops, weeds or bush fallow) is normally present during much of the year. With typical cassava-growing practices (usually planting on flat, tilled soil), losses vary widely, but are usually below 50 t/ha/year (CIAT, 1993a).

Experimentally reducing erosion loss to 5-10 t/ha/yr, or even lower, is possible in most sites. Although research findings are often situation-specific, the basic principles are becoming clearer. Minimum to zero tillage or contour ridging during soil preparation, use of cover crops, and live contour barrier strips are effective control measures (Table 5). Planting varieties with vigorous early growth, and applying fertilizer to achieve early canopy cover, are often very effective as well.

Table 4. Conserving the soil resource in cassava-based cropping systems.

Options	Level of CIAT research[a]
I. TECHNOLOGICAL	
A. Erosion Control	
1. Improved canopy closing	
a. Fertilization	***
b. Closer plant spacing	**
c. Intercropping	**
d. Cover crops	**
e. Vigorous varieties	**
f. Weed management	*
2. Improved soil cover	
a. Organic mulch	**
b. Inorganic mulch	—
3. Land preparation	
a. Contour ridging	***
b. Minimum tillage	**
4. Barriers	
a. Live barriers	***
b. Terraces	—
B. Fertility Maintenance and Improvement	
1. Erosion control	***
2. Fertilization	***
3. Green manure	**
4. Fallow	*
5. Cover crops	**
6. Nutrient use-efficient varieties	**
II. SOCIAL, ECONOMIC AND POLITICAL	
A. Farmer awareness (demonstration plots, other educational fora)	**
B. Economic incentives	—
C. Policy/legal incentives	—

a. — zero or minimal; * low; ** intermediate; *** high.

Table 5. Erosion effects of different crop and soil management options in Quilichao (QCH, 10% slope) and Mondomo (MND, 15% slope), Cauca, Colombia.

System	Soil loss (t/ha/yr)		Cassava yield (t/ha)		Forage yield (t/ha)	
	QCH	MND	QCH	MND	QCH	MND
Bare fallow[a]	152.5	183.2	-	-	-	-
Cassava with contour ridges[a]	3.0	2.0	29.6	14.5	-	-
Traditional (ploughed, flat)[a]	7.8	16.4	29.2	15.8	-	-
Cassava with Vetiver barrier[b]	1.3	2.6	26.9	12.8	-	-
Cassava with Pennisetum barrier[b]	3.8	0.7	20.0	9.6	5.0	3.1

a. 5-years' data.
b. 8 m apart.

SOURCE: CIAT, 1992b.

The more difficult challenge is to achieve erosion control with practices whose economic advantages will motivate farmer adoption. The most effective practices often do not increase cassava yields or reduce production costs, and therefore have limited scope for success if voluntary adoption is expected. Practices that seem promising include the use of fertilizers where available, closer plant spacing, live barriers, intercropping, minimum tillage, subsoiling and contour plowing.

In Colombia (Cauca), intercropped legumes and barriers with highly productive forage grasses reduced cassava yields by 20-40%, but this was compensated by forage dry matter production of 3-5 t/ha for legumes and 5-9 t/ha for forage grasses. *Chamaecrista rotundifolia* seems a very promising legume for erosion control on acid, poor soils, providing good soil cover and minimum competition with cassava. Some forage legumes and grasses control erosion and have industrial markets. These include *Partiña* grass for brooms, and *Citronella* (lemon grass) for essential oils (CIAT, 1993a).

There are likely to be increasing examples of local or national legislation to require adoption of erosion control practices in critical areas, but we cannot rely on this having widespread impact in the foreseeable future. Farmer-motivated adoption needs to be a research goal. Farmers need to be educated on the long-term consequences of erosion, and shown an erosion control technology with immediate economic advantages. To move quickly toward this goal, we are starting a series of on-farm and farmer-participation trials in Asia and Latin America, that will systematically incorporate farmer viewpoints with technology design and evaluation.

Water Management

Cassava is almost never irrigated; where facilities for irrigation exist, higher value crops are usually planted. Water management, then, is generally limited to cultural practices to *conserve* soil water, or sometimes to *protect* a crop from excess water. In poorly drained soils, losses from root rots and from other effects of water-logging can be relieved by planting on top of ridges. This simple technology has been widely adopted in the Caicedonia region of Colombia, in Cuba, and in the *varzeas* (flood plains) of Brazil.

Mulches of various types are an effective water conservation practice. Colombia's north coast, has sandy soils, high temperatures, low and seasonally distributed rainfall, and low relative humidity. Here yields increased an average of 35% with surface mulches of chopped weeds and crop residues applied over a 4-year period (CIAT, 1993a). In addition, root cyanogen levels were reduced. Advantages were probably the combined result of various effects, including improved soil fertility, better water retention, and lower soil temperature.

Biological Control

In nature, beneficial microorganisms probably play a larger role in pathogen suppression than is generally appreciated. As a management tool in agriculture, they have barely been touched. Some unexpected results from in vitro-processed cassava plants first led us to suspect that there was some extraneous factor causing variability in field performance. Sometimes, in vitro-derived plants were more vigorous and yielded more than their stem cutting-derived counterparts of the same genotype. This was easily explained as the result of eliminating pathogens, and could be confirmed by pathogen indexing. But sometimes, in vitro-derived plants performed less well. To state simply what was a complex process of analysis and discovery, we found several species of beneficial bacteria (fluorescent pseudomonad species) that could inhibit growth of many pathogens. They are effective against the organisms causing bacterial blight, superelongation disease, and root rots. They are even effective in suppressing microbial-induced post-harvest deterioration of stored roots (Lozano, 1987).

These pseudomonads are part of a cassava plant's natural fauna, and are passed from one vegetative cycle to the next on the surface of stem cuttings. But with in vitro procedures designed to eliminate pathogens (small meristem tips), beneficial bacteria were also eliminated. The detrimental effects of eliminating these bacteria can apparently last for a few growing cycles, until populations rebuild on the plant. Use of these bacteria has so far been limited to the experimental phase, but we are in the process of conducting semi-commercial trials focusing on root rot control and post-harvest storage.

A multi-faceted attack on an intransigent disease complex

Changes in cultural practices to improve productivity can have unexpected negative side effects. Sometimes these effects may not show up for several years. Root rots in cassava can be devastating because they directly affect the main commercial product of the plant. The problem has been aggravated parallel with intensification of cassava production systems. In traditional systems of low density planting, intercropping, fallow, and crop rotation, root rot pathogens are suppressed. Resistant varieties also seem to have played a role. These control systems are being reduced or eliminated as pressure on land increases, and farmers move from subsistence to market-oriented production.

CIAT's pathologists knew at the outset that this was a specially challenging area of research--many pathogen species are involved, and most have a generalized pathogenic activity. That is, they do not have the type of specific pathogen-host tissue interaction that is usually associated with successful resistance breeding. Further, as the problem is hidden underground until harvest, evaluation or treatment is complicated.

The best hope seemed to be to try an array of approaches—biological control, cultural practices, genetic resistance and chemical control. All are found to have a potential role. We found surprising levels of resistance in materials of Amazonian origin, and several varieties were released by Brazilian state programs (Lozano and Fukuda, 1993). Some naturally-occurring bacteria from the rhizosphere are antagonistic to root rot pathogens, and we developed techniques for inoculant production and application, now at the semi-commercial stage. Chemical treatment of planting material is a cost-effective way to reduce pressures from some of the pathogens, especially *Diplodia* and *Fusarium* sp. Planting on ridges and specific crop rotation schemes are a solution in other situations.

The technology now exists to begin reversing the trend toward increasing root rot problems brought about by pressures to intensify land use.

Trichoderma harzianum is a myco-parasite, from the cassava rhizosphere. Some strains inhibit growth of *Fusarium*, *Diplodia* and *Phytophthora* root rot pathogens. We are developing biofungicides based on this fungus.

Since 1990 we have isolated and tested over 200 strains of cassava endophytes, fungi found systemically throughout vascular tissues, but not invading cells. Most had detrimental effects on cassava growth, but 3 strains, of different species, had positive effects on early plant growth (CIAT, 1993a).

In comparison with pathogens, biological control of mite and insect pests has a broad research and application background across many crops. We have given the most attention to biocontrol of mealybug (*Phenacoccus* sp.), hornworm (*Erynnis ello*), and green mite (*Mononychellus tanajoa*). A multi-institutional network supports each area.

Several biocontrol agents can effectively control the **hornworm** at the field level—*Trichogramma* egg parasites (wasps); *Bacillus thuringensis* (bacteria which produce a lepidopteran-specific toxin); and hornworm baculovirus. Baculovirus is very promising from the standpoint of ease of use and adoption potential. The virus is prepared by grinding infected late-instar larvae in a blender. The homogenate may be

applied directly, or frozen and stored. The technique is us‹
Brazil. It is being adapted for other regions where farmers
electricity for preparation or refrigerators for storage (Bell

The cassava **green mite** is widespread in Africa and decline of mealybug losses in Africa, this mite is the princı cassava. We participate in a multi-institutional project exp (predators on other mites), testing their effectiveness for b to Africa for further testing. *N. idaeus* is well-established, ı effectiveness has yet to be evaluated (Yaninek et al., 1993 attention is on exploring areas climatically similar to targe maximize probability of predator adaptation (Braun et al.,

Cultural Practices

Inappropriate cultural practices can aggravate pest and disease problems. Conversely, appropriate practices can be effective means of control. Systems that increase the density of foliage (high plant populations, vigorous varieties) can create more favorable environments for foliar diseases. Time of planting can be used to effectively avoid peak periods of pressure from some pests and diseases. Influences of intercropping are specific to the prevailing problems. For example, maize is a highly preferred host of the burrowing bug, and intercropping can create severe problems for cassava when this pest is present. Yet bacterial blight can be reduced by the non-host barrier (maize), which interferes with pathogen dissemination. We could give many other examples.

Eventually we should be able to model the interactions between many permutations of cropping systems and the pests that affect them. So far we have established broad principles with which hypotheses can be formed, and

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specific systems are then evaluated by national programs. Convincing farmers of the need to adjust cultural practices to achieve pest control is most successful when probability of yield losses is high. As well as understanding the physical and biological components and their interactions, we need to analyze and understand economic implications and farmer acceptability. A newly initiated project involving CIAT, IITA and several Brazilian institutions proposes to develop just such an holistic approach to include farmers in the design and application of integrated pest management practices.

Chemical Control

We give generally low priority to *chemical* control of pests and diseases, on the principles of human and environmental safety, and economic impracticality for resource-poor farmers. The exception to this is chemical treatment of stakes, a practice which uses minimal amounts of chemicals. It is a type of *insurance*, which may have little effect in some years but can have huge payoff where damaging pests and pathogens are present. We have developed recommendations for chemical stake treatment tailored to predominant problems in a region.

7. PRODUCT, PROCESS AND MARKET DEVELOPMENT

> *Contribute to the strengthening of links between farmers and markets through collaborative research on cassava end use diversification*

Few crops provide the opportunity of as diverse a range of products as does cassava. As internal and international trade dynamics undergo rapid change, there is a continuing challenge to anticipate our role in the various market sectors for best benefits to target populations. With many players on the scene, our role needs to be well-focused to optimize our comparative advantages both in germplasm and as an international entity able to facilitate coordination and integration among institutions.

Unravelling the Complexity of Root Quality

Cassava's great versatility gives rise to some challenges. Dozens of products are obtained from primary processes, and hundreds from higher order processing of flour and starch. Because the crop is grown with few inputs, it is subject to wide variations in soil fertility and water availability, and sometimes pests and diseases. We know that all these factors impinge on root quality. Each layer that we peel from the root quality mystery seems to reveal an ever-more-complex picture. Our initial concern with starch and cyanogen contents remains valid. But each of these is being broken into numerous components and variations of processor/consumer preferences. Quality depends on complex genetic and environmental interactions, and is specific to processing techniques and end use.

Our attention to root quality is motivated by: recognition of fairly precise and varied processor and consumer demands for quality; increasing sophistication of the marketplace in discriminating quality factors; and possible implications of cyanogens for human health, pest resistance, and environmental adaptation.

About 85% of root dry matter is starch. Both quantity and quality can vary widely due to genetic and environmental influences. For most purposes, a high starch content is desirable, but quality requirements vary according to the market. Eating quality, drying time and conversion efficiency are closely linked to starch content. The adoption of Rayong 3 in Thailand was mainly due to improved starch content as compared to the widely grown Rayong 1.

Since starting breeding activities, we have made cyanogen and starch evaluations a routine part of germplasm evaluation and gene pool development. Either high or low cyanogen may be required in specific products and markets, so our main thrust has been to *monitor* levels rather than change them. Cyanogens only rarely pose health risks to humans, mainly in situations that combine acute undernourishment with inadequate processing of high cyanogen potential roots. Yet the risks are sufficient to warrant our research attention. We began to increase selection pressure for cyanogens by creating specific low-cyanogen gene pools, and to study the effectiveness of various processing methods on cyanogen elimination.

We introduced some modifications in analytical methods. Semi-quantitative methods are rapid enough to use effectively in screening thousands of samples every year from preliminary through advanced stages of breeding. At advanced selection stages we apply the more precise quantitative analyses.

A turning point in root quality research—the Media Luna experience

The Cassava Program had high expectations when the first new varietal selections passed through a long series of breeding and regional trials, and were placed on-farm in one of our principal *field laboratories*. Media Luna, a small community on Colombia's north coast, depends heavily on cassava as a food and cash crop. Several years of regional trials had shown some of our selections from the germplasm collection and new hybrids were easily yielding 100% above local varieties.

In 1979 we took these selections to farmers, for an in-depth cost/benefit analysis of the new technology. This first formal reaction from producers was not what we had hoped. The principal market at that time was for fresh consumption, and quality standards were very high. In particular, high starch content was an absolute prerequisite to market acceptance. The new varieties did not come close to meeting local standards and were never adopted.

The experience was a disappointing one for the Program, and prompted an intense reexamination of the root quality question, as well as the need for farmer participation in variety evaluation at earlier stages.

Producers, processors and consumers have long associated root bitterness, usually accompanied by high cyanogens, with many adaptation, yield, resistance and quality traits. Nearly all these relationships have proved elusive under scientific scrutiny. But we know that we refute centuries of traditional farmer knowledge at our own peril. Recently, for the first time, we were able to demonstrate a significant correlation between root cyanogen content and several starch functionality measures: viscosity at a range of temperatures, ease of cooking, gel instability and gelification index. Percent amylose and gelatinization temperature were unrelated to cyanogen level (CIAT, 1992b).

Quality is most complex for the fresh market. With specially-trained panels of Colombian consumers, we found that many components can be discerned: **visual**—color, starch, glassiness, moisture, freshness; **olfactory**—cassava aroma, deterioration smell; **taste**—sweet, bitter, or cassava taste; **texture**—fibrousness, hardness, consistency, dryness; **aftertaste**—bitter aftertaste.

The next challenges were: to understand the physical and biochemical basis of these individual components, in order to develop rapid and precise quantitative evaluation criteria; to determine effects of a range of environmental factors; and to assess genetic variation and potential for modification through breeding.

Multivariate analysis helped determine that *cassava taste* and *hard texture* of the fresh root were most related to *like/dislike* of the same samples after cooking (CIAT, 1992b). While environmental variations strongly influenced eating quality, starch physical properties were not significantly affected. This is good news for starch markets, but does not help explain why eating quality is so variable. We are now turning our attention to structural components of cells and to cell wall adhesion. Much remains to be done, and evaluation in breeding programs is still largely accomplished by the slow process of cooking and tasting.

The core collection now serves as a basis for assessing genetic diversity for many quality-related traits (Table 6). We have defined a subsample of 33 accessions from the core for some of the more time-consuming or costly evaluations. Initially we are subjecting this small group to a range of analyses of starch physical and biochemical properties.

Extended Shelf Life for Fresh Roots

During the course of evolution, farmers probably attached little importance to selecting varieties for post-harvest root storability. Flexibility in harvest period, and development of various processes converting vulnerable roots to easily stored products, reduced the need for storing roots. Urbanization with the concomitant increased distance between production and markets, and trends toward processing centralization, now call for more attention to this problem. We are taking a three-pronged approach: development of storage techniques; research on the biology and biochemistry of deterioration; and genetic modification to prolong shelf life.

Our early research showed that deterioration consists of two processes—physiological and microbial. This determination was fundamental in the search for solutions. Storage under high humidity (field clamps, boxes, plastic bags) could substantially delay physiological deterioration, and treatment with fungicides could slow microbial deterioration. The most practical outcome of several technologies is treatment with Thiabendazole (a fungal growth inhibitor used in many food products), followed by storage in plastic bags (Wheatley et al., 1990). We carried this technology through pilot phase testing in several sites. Currently, commercialization is managed in the private sector and functioning on a small scale in Colombia (Soccorro, Barranquilla), and in Paraguay. The methodology is being researched in Ghana for adaptation to African conditions.

Early germplasm screening showed substantial differences in rate of deterioration (24 hrs to over 2 weeks). But we were discouraged from pursuing this route by consistent findings of a correlation between high starch and rapid deterioration, and by the greater potential that post-harvest management seemed to offer. In the early 1990s, we returned to a genetic approach, with the potential to combine conventional breeding with genetic engineering. This work is still in preliminary stages, but may finally lead to surmounting this age-old barrier to wider commercialization of cassava.

Cassava Products as Animal Feed

CIAT's first research thrust in cassava use was in the area of animal feeding trials, as part of the Swine Production Systems Program. This early work showed that fresh cassava is a satisfactory energy source for growing or finishing swine, when combined with supplemental protein. We further studied dry cassava for use in pig and poultry rations; and silage for pig feeding.

In 1990, Julian Buitrago, a former CIAT animal nutritionist, wrote a comprehensive review of current knowledge on cassava in animal feeding. The private sector is now the principal force in basic and adaptive research in animal nutrition studies, complemented by continuing university and national program research.

For several years, the University of Guelph sponsored CIAT research on single cell protein derived from cassava-based culturing of *Aspergillus* and *Rhizopus* sp. (Gregory, 1977). The technology was promising at a small scale experimental level but was discontinued because of human health concerns about the fungal inoculants, and disappointing projections on the economics of commercialization.

Cassava chipping and drying are not CIAT inventions—they have probably been practiced to some degree for millennia. Thailand has taken this process to its height of commercialization, with most of the country's production destined for chipping and sun-drying. At CIAT we introduced refinements in chipping machine design; defined optimum procedures for sun-drying on concrete patios; developed tray-drying techniques for high quality chips; designed and built model systems for artificial drying in bins with forced air; established procedures for comprehensive analysis of these systems; documented all these components; and trained numerous scientists, technicians and farmers in drying-related activities.

Starch and Flour: Artisanal to Industrial

Starch is a highly commercial product. Our input into this sector of the cassava market is aimed mainly at root quality research, improving processing by small-scale industries, investigating new uses and facilitating communication among the diverse groups working on starch. In 1994 we co-sponsored an international meeting on cassava flour and starch. Over 130 participants from 29 countries attended, indicating very broad interest and expertise in this area.

Starch markets are rapidly becoming specialized. To be competitive, cassava starch must be fully characterized for its potential to fit diverse market needs. Further, there can be big economic advantages to producing market-specific modified starches through genetic modification or industrial conversion. Starch quality evaluation is a well-developed science, but it has not been extensively applied to cassava. Our research is concentrated on the influences of genetic and environmental variations on starch quality, and the microbiology of fermentation. We have applied a range of standard analytical methods; microscopic technique, x-ray analysis, amylose content analysis, differential scanning calorimetry, viscoamylograms, and solubility and swelling power studies.

The amylose/amylopectin ratio is one of the most important factors for industrial specialization. Genetic variation ranges substantially from 15-29% but can very likely be increased even further (CIAT, 1992b). Work is underway to clone the starch branching enzyme and engineer gene constructs with different promotor regions for root-specific expression (CIAT, 1993a). Further progress depends on developing routine regeneration of genetically transformed cassava plants. There may also be potential to extend the range through conventional breeding.

Fermented, or *sour starch*, is a specialty commodity produced primarily in Colombia and Brazil for use in baked goods. We introduced improvements in the efficiency of small-scale starch extraction processes, and in product quality. We collected and conserved more than 75 isolates of amylolytic bacteria, and studied their genetic diversity. Efficient strains have been selected for sour starch fermentation and their industrial potential will be analyzed.

Flour, in many different forms, is traditionally one of the main products of processed cassava. It is specially important in Brazil and Africa. Our research has been principally in the area of wheat flour substitution for food industry uses. Subsidized wheat imports caused many countries, traditionally large cassava flour consumers, to acquire a taste for wheat flour products. Through the 1980s, to stem the tide of rising trade imbalances, many countries reduced import subsidies, and wheat flour became less competitive with local products. This opened opportunities both for a return to traditional dried cassava products such as *farinha de mandioca*, and for partial substitution of cassava in wheat flour-based products.

We worked with millers and bakers in Colombia to assess substitution potential. On the basis of promising results, we collaborated in a multi-institutional pilot project for flour production. We established optimum procedures for washing, chipping, drying, milling and classifying flour for use in bakery products, processed meats and other industrial uses. This project is currently in the expansion phase, seeking to improve market penetration, consolidate agroindustry, and establish foundations for future plant replication. Flour processing technology is now being used in Ecuador and Peru as a result of the Colombia-based research.

8. AN EXPERIMENT IN CROP-BASED DEVELOPMENT

Policymakers have typically prime targeted agricultural commodities to achieve social and political goals. In the last few decades Latin America has gone from being a mainly rural to an urban society. Many countries adopted policies of subsidizing production or importations of grains to provide cheap food to the cities. For cassava, this meant stagnating markets for traditional products by the late 1970s. Where fresh cassava was important, transportation from distant rural production zones meant high marketing losses, and thus higher consumer prices. There were few alternatives to traditional markets, and these were saturated (*constrained)* or declining (*inelastic)* markets (Table 7).

Asian countries are mainly characterized by *diversified* or *elastic* markets. Here we emphasize sustaining or improving the cost and price competitiveness of cassava with respect to alternative sources of carbohydrates, by reducing production costs and improving root quality.

Africa can generally be classified as having constrained markets, but demand elasticities tend to be greater than in Latin America. Research attention both to new markets and to cost-reducing technology can be effective.

Table 7. Cassava-growing areas defined by agro-ecosystem and market diversification (%).

Climate zone	Latin America		Asia		Africa	
	Constrained market	Diversified market	Constrained market	Diversified market	Constrained market	Diversified market
Lowland humid tropics	100	0	48	52	100	0
Lowland subhumid tropics	90	10	30	70	100	0
Lowland semi-arid tropics	100	0	10	90	100	0
Highland tropics	90	10	—	—	100	0
Sub-tropics	75	25	37	63	100	0
Total (%)	88	12	30	70	100	0

SOURCE: Henry and Best, 1993.
— = do not exist.

The poor can be linked to growth markets

There is much debate among development experts on the challenges of incorporating the poor into economic growth. Socio-economic analyses, some creative thinking, and a bit of blind faith convinced us in the early 1980s that people on the margin could be linked to growth markets for cassava products.

The inherent, labor-intensive nature of cassava husbandry makes it generally a small farmer crop. Technology benefits to cassava growers are nearly always benefits to the poor. But these growers needed to have new markets for their product to realize any benefits from increased production.

As a first step to apply the model we identified the main potential market for cassava in Colombia to be the animal feed concentrate industry. This *potential* market demand, *strong* as it was, could not spontaneously lead to the coordinated development of infrastructure, farmer organizations, training and institutional support needed for processed cassava to reach feed mills. Only an institutional network with long-range commitments could assure that the various elements were put in place at the right time.

Luckily, at the same time these ideas were evolving at CIAT, Colombia's Program for Integrated Rural Development (DRI) sought our collaboration to solve problems related to inelasticity of demand and the instability of cassava prices, in several departments of the North Coast. We jointly agreed on starting a pilot project to produce dried cassava chips. The feed concentrate industry was growing rapidly, and anxious to explore alternative energy sources in least-cost rations. Purchase agreements assured a market for dried cassava, so this market became a focus of the project.

The *phased approach* was going to be crucial. Because so many new elements had to be coordinated—technological, institutional, organizational, economic—a small scale beginning was needed to solve problems and provide a basis for an expansion phase.

The story is a long and fascinating one, whose details cannot be told here. Essentially, economic benefits estimated at $21.9 million were distributed to small cassava producers and producer/processor organizations up to 1992 (CIAT, 1993; Gottret and Henry, 1992). These farmers, in addition to better incomes, have new tools and the self confidence to continue exploring how to translate their expertise in cassava production to a better livelihood.

Against this economic and social backdrop in Latin America, cassava research to increase production alone will not be effective. With constant or declining demand, increased production will quickly translate to a drop in market price, and production will no longer be profitable. This concern and its implications for CIAT research on cassava, led us to undertake an extensive series of demand studies from 1985 to 1987, in Brazil, Colombia, the Dominican Republic, Ecuador, Jamaica, Mexico, Panama, Paraguay, Peru and Venezuela. These studies yielded convincing evidence for potential growth in demand both for human and animal consumption.

But new demand would not necessarily evolve spontaneously, nor favor the poorer sectors of society that CIAT aims to help. There needed to be coordinated development of new processes and products to tie into growing markets, and cost-reducing production technology keeping cassava-based products competitive with other alternatives. We initially saw three expansive markets as having high potential;

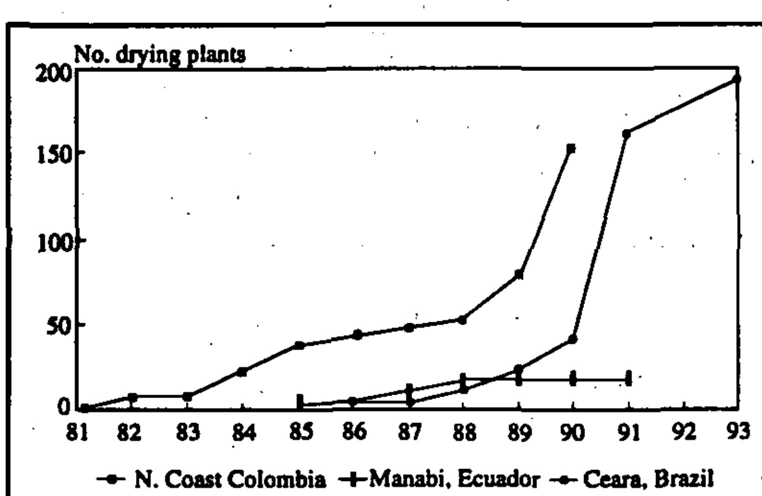
balanced animal feed rations, flour as substitute for imported or subsidized grains, and fresh cassava for urban markets (parallel with an improved fresh root storage technology).

Government policy changes in South America in the 1980s resulted in reduced subsidies to products that compete with cassava, so improving the competitive edge of the crop. In Meso-America, cassava has potential to compete in animal feed markets, but lack of institutional support for the crop is a constraint. Cassava has a significant role in Cuba, Haiti and the Dominican Republic, but not elsewhere in the Caribbean.

The Integrated Projects Model

Out of this socio-economic background we developed a model for **integrated production, processing and marketing projects**, increasing income of small farmers, and generating social and economic development in tropical regions.

There had already been several negative experiences with large commercial cassava projects in Latin America, in both the private and public sectors. Large production projects failed to link to markets in some cases and in others large processing plants could not get sufficient supply of roots. A *phased approach* was clearly indicated for these new integrated projects. The **pilot project** phase is small-scale and highly experimental. Hypotheses are tested and modified to apply to the **expansion** phase. Strong institutional support is still usually required. In the final phase —**commercialization**—markets, processing and production are well-integrated and should be moving toward sustainable operations with little outside institutional support.



Expansion of number of drying plants in Colombia, Ecuador, and Brazil.

Following this strategy, we began the first pilot project on the north coast. This includes a 300-m^2 drying patio, training of technicians and farmers in processing and production technology, and formation of a team for directing the project. With a similar philosophy, we started a project for marketing conserved fresh cassava in the urban market of Bucaramanga, Colombia, and a wheat flour substitution project in Cordoba Dept.

We have been an active catalyst in the development of projects in Colombia, Panama, Mexico, Ecuador, Paraguay and Brazil; and in the exploratory phases of methodology implementation in Asia and Africa (Table 8). Many projects are based on drying for the animal feed concentrate industry, but also include flour, starch, fresh roots and leaves.

Not all projects have gone beyond the pilot phase, an illustration of the importance of small-scale start-up as a way of exploring market and production potential. In Mexico, the traditional structure of agricultural policy did not favor strong farmer involvement in the projects. Import subsidies made it difficult for cassava to compete in animal feed markets. The project in Peru involved preservation of fresh roots from production areas in the jungle, and marketing them in Lima. The long transportation distance and competition from coca-growing were strong negatives for the cassava project. On balance, the methodology has been highly successful, and is most advanced in Colombia, Ecuador and Brazil, where number of drying plants and farmer organizations continue to expand (Ospina et al., 1994).

Farmer Cooperatives: Basis of Successful Projects

The high perishability of cassava roots means high risks in the steps between producer and consumer, which in turn creates high marketing costs. If producers themselves take on the processing and associated risks, they can realize additional profits. Thus producer cooperatives became the principal organizational structure for the integrated projects. We did not know what to expect from the first pilot project in Colombia. In spite of the total lack of experience and tradition in cassava processing activities, farmers quickly adopted and assimilated the technology. Ospina et al. (1994) noted three guiding principles observed from the experience of working with farmer groups:

- Technology transfer is more rapid, efficient and effective when end users are directly involved and responsible.

- Farmers' organizations are effective intermediary agents between farmers and institutions, and can be used as an efficient channel for project services, credit, training and dissemination of information.

- Farmer organizations should be designed to function without creating dependencies upon supporting institutions.

Table 8. Integrated cassava projects in Latin America.

Countries	Products and markets						
	Dry chips	Cassava flour		Starch		Fresh roots	Cassava leaves
	Animal feeding	Human uses	Industrial uses	Human uses	Industrial uses	Human uses	Animal feeding
Colombia	Commercial	Pilot		Pilot	Pilot	Commercial	
Ecuador	Commercial	Commercial	Commercial	Commercial	Commercial		
Brazil	Commercial					Pilot	Pilot
Paraguay	Pilot			Pilot		Pilot	
Panama	Commercial						
Bolivia	Pilot						
Argentina				Pilot			
Mexico	Abandoned						
Peru		Pilot				Abandoned	

SOURCE: Ospina et al., 1994.

Despite the many advantages of farmer organizations in integrated project design and operation, they are generally very weak in business management and administration. Second-order farmer organizations have at least partially overcome these constraints in the Ecuador and Colombia projects. These organizations can support their members with a wide range of services and represent their interests in dialogue with government policy-makers or industry representatives. Successful formation of second-order groups seems essential to sustainability and autonomy of the integrated projects.

A Measure of Benefits

Processing cassava in farmers' organizations can provide significant economic benefits to participants—men and women, young and old, farmers and landless poor. In the Colombia north coast drying projects, producers gained the largest share of benefits, but processors and consumers also benefitted (Table 9). Only marketing agents suffered a small loss, from a more efficient marketing system where farmer organizations acted as their own agents.

Benefits are not only economic, but also *organizational and institutional*. The integrated project model can link research and extension to achieve direct adoption of technology in a fairly short time. Farmer and processor organizations can also carry out their own research. In Ecuador for example, the farmer/processor organizations' demands for new services motivated the reorienting and strengthening of the national research program. The release of Portoviejo 650 (Colombian variety introduced by CIAT) gave them a sense of accomplishment. A strong national program can be an outgrowth of integrated projects more than a precondition to their success.

Table 9. Economic benefits (million $US) from the Integrated Cassava Project in Colombia's N. Coast, 1984-91.

Group of society	Benefits from cassava utilz./mkt. technologies	%	Benefits from cassava production technologies	%	Total benefits from Integrated Project	%
Consumers of fresh cassava	233	3.4	1,806	12.1	2,039	9.3
Users of dried cassava	4,334	62.4	0	0	4,334	19.8
Cassava market agents	-78	-1.1	- 584	-3.9	-662	-3.0
Processors of dried cassava	1,150	16.6	0	0	1,150	5.3
Cassava producers	1,307	18.8	13,706	91.8	15,013	68.6
Total net benefits to society	6,946	100	14,928	100	21,874	100

SOURCE: Gottret and Henry, 1992.

Lessons of the integrated projects

Each project in which we have participated is unique. There is no universal formula that will assure success. But with a decade of experience in a number of countries, we can draw some broad conclusions as to why projects succeed or fail (Ospina et al., 1994):

- Long-term viability depends on projects' flexibility to enter a range of markets, especially those with a high margin of profitability.
- Crop production technology which is cost-reducing and resource-conserving is critical to maintain market competitiveness.
- There is rarely if ever a single institution able to manage all aspects of an integrated project. There is a need to identify an effective coordinating institution, clearly designate functions of participating institutions, and develop coordinating mechanisms at the project, regional and national levels.
- There is a need to develop skills of first level farmer organizations in business management and administration; and to support second level organizations to provide a range of services to members, and represent members in dialogue with government policy-makers.
- Training is needed in cassava processing, plant management, basic accounting, production technology, marketing, monitoring and evaluation.
- The integrated project strategy would have been impossible without the foundation in basic knowledge and technology component generation from the Program's first years of research.
- Networking is needed to forge links between regions and countries, and to resolve problems common across regions and projects.
- Monitoring and evaluation are essential for defining potential products, markets, research priorities, sites, and beneficiaries. The models need to be internalized and coordinated by second order farmer organizations, and to be dynamic and flexible over time.
- Integrated projects are closely related to and affected by policy decisions and support, including import and subsidy policies, production credit and technical assistance. The ability to monitor these policies is crucial to appropriate project design.

9. RESEARCH FOR DEVELOPMENT: THE WAY AHEAD

Agricultural research and development institutions are being challenged to address a wider range of concerns than ever before. The *Green Revolution* centered on increasing food security for producers and consumers. The interests supporting the IARC system and many other institutions now expect science to simultaneously address broader issues of resource conservation, poverty, and equity (distribution of benefits to lower income strata, inclusion of women as beneficiaries, and others). Commodity-based research can address all these issues, but not equally effectively. The challenge is to effectively continue with a strategy of *complementarity* and *comparative advantage* across a much broader institutional environment.

The ongoing assessment of constraints to and opportunities for improving the production and use of cassava and the evolution in our partners' expertise and capability shapes our agenda. Best and Henry (1994) projected economic and demographic trends in Latin America, Asia and Africa that will influence cassava's future contribution to economic development.

Latin America

Urbanization exceeded 70% by the early 1990s. The impact of this process is still reverberating through political and social systems. City dwellers seeking cheap food supplies pressure governments for direct subsidies and easing of import restrictions. Though primary commodity producers have little political influence, they want price supports and restrictions on imports that drive down the value of local products. The continued need for government austerity and global pressures for liberalization of trade policies will prevail. Transport subsidies, support prices and input price controls for the major grains will gradually decline. This will indirectly favor cassava's ability to enter alternative markets. A growing animal feed market will lead the demand for alternatives to imported grains. Cassava starch can compete strongly with imported starches when production and processing efficiencies are improved, and stable quality is assured. The key challenge here may be to manage the crop and its processing to achieve that stability requirement.

Brazil, with nearly 80% of Latin American cassava, dominates trends in the region. In the North and Northeast, cassava will continue to have a key role in food security, especially during the cyclic droughts that devastate the Northeast. The growing animal feed markets will absorb production surpluses in favorable growing years. The South will further develop industrial starch production, and research to develop specialized products and markets for modified starches.

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Asia

The continuing predominant position of rice in Asian diets is virtually assured. Cassava's role will continue to grow in importance due to further market diversification. Growth in export-led demand for production increases slowed in the 1980s, but is still strong due to new markets in modified starches and starch-derived products in Asia, Eastern Europe and the former USSR. The Thai position as leader of cassava exports will not be challenged for some time, but Indonesia, China and Vietnam will increasingly vie for external markets in chips/pellets and starch. Asia will lead in value-added processing for specialized starches and diverse food products, bringing new sources of income to the industrial sector and a demand for higher production.

Population growth, urbanization, and overall economic growth in the region will fuel cassava's growth in internal food, feed and industrial markets. Pressure to reduce government subsidies in agriculture will favor cassava because it depends relatively less on purchased inputs. Along with efficiency gains from new production technology, this will motivate partial substitution of cassava for rice, maize and wheat in processed food products and in animal feed.

Africa

Cassava is already the most important food staple in many sub-Saharan countries. Food deficits will continue to plague tropical Africa, and therefore be a primary development target. Urbanization, though less than in Asia or Latin America, is rapidly increasing. Reduced food costs and income generation will have roles equally important to higher total food production. With a low yield base (7.7 t/ha fresh roots), the potential for gains in productivity is high. Introduced germplasm, pest and disease management, and better agronomy can all have high impact, if government policies are favorable.

Peoples of the semi-arid regions face life at the margins all too often, exacerbated by population pressures and deteriorating land resources. Drought-tolerant cassava and water-conserving cultural practices are promising options that are just beginning to get broad research attention. In Africa more than in other regions, the nutritional and human health factors associated with high levels of cassava in the diet will continue to command attention.

Resources: Funding and Collaborating Institutions

Funding for cassava research and development will move from almost exclusively public funding to a blend of private commercial and public funding. This is already taking place in situations where value-added processing creates lucrative industries with potential to invest in future crop/product development. Starch processors in Thailand were largely responsible for promoting distribution of the new high-starch Rayong 3 variety. Farmers' associations in Ecuador sponsored both agronomy and processing research among members.

Process and product development rather than production research will attract private investment. Most public investment is already aimed at the production side and the payoff in creating value-added processes is generally quicker and more attractive to private enterprise. Closely monitoring trends in funding, CIAT will act both to influence donors to bring total resources to adequate levels, and to keep a balance among R&D areas.

Overall, public agricultural research institutions are unlikely to see substantial, if any, growth in the coming years. Non-governmental organizations have proliferated as foundations, church groups and other special-interest groups try to fill gaps left by receding government programs, and sometimes to achieve philosophical objectives.

Africa, especially, is inundated with a myriad of international aid groups, usually not well inter-coordinated. CIAT is well-recognized as a leader for work in cassava research and development, and as a facilitator of effective inter-institutional collaboration. We will continue to refine and promote this role. It is a role fraught with risk and frustration—at odds with our traditional expertise in research, but one with high payoff potential that no other institution is better prepared to assume.

Our traditional partners in research will need support in obtaining additional funding. We have already had many successful examples of this form of collaboration.

CIAT's Role

CIAT holds a unique position in the field of cassava R&D—that of an international entity with a long and globally oriented experience in cassava. This will continue to be the foundation that shapes our future role within the five *broad project* areas described throughout this report.

Institutional Strengthening

Learning and assuming an increasing role as a facilitator of institutional collaboration has occupied much of our time and resources in the past decade. Just as many of our earlier roles in research and training have been assumed by partners, our current institution-building and networking roles will evolve and devolve. The International Centers perform a delicate balancing act between leading, and encouraging leadership of partners. Research management will become broader, by including partners more fully in all phases of research planning and execution.

The national cassava research programs will continue to be key partners though many have suffered disappointing stagnation or decline in personnel and research resources. But a strong core of trained scientists does exist in many institutions. An important change in the past decade has been the entry of many new institutions, especially non-governmental and private, on the cassava research and development scene. This is our basis for expecting overall institutional strength to continue improving. These organizations have a diverse array of philosophies and objectives, and CIAT can be effective in easing communication and cooperation among them.

The several cassava-related networks have stimulated wide and fruitful communication among partners in R&D programs, but much remains to be done in getting programs to share resources and seek similar interests more efficiently. The Program will link more frequently and effectively with other commodity efforts where similar research approaches or development objectives apply. For example, many of our partners already work across various root and tuber crops.

Our role of facilitating communication will be particularly relevant between advanced research labs with little connection to the reality of cassava production or use, and practical, applied cassava programs. CIAT must continue to provide this bridge, supporting efforts to improve the assessment of constraints and opportunities which are the basis for priority setting.

Genetic Resources Management

Biodiversity is a basic asset of humankind. Continuing advances in crop productivity depend on wise management of this resource. The recently established *Manihot* Genetic Resources Network will be at the center of our activities. Network members recognized CIAT as having a pivotal role as curator of the world's largest germplasm collection. This implies that we must be proactive in fulfilling research's obligations on genetic diversity, collection, safe conservation, evaluation, information management, exchange, and use. Many institutions will be involved in these activities, but the international germplasm community clearly expects CIAT to play a lead role. Even while we broaden the participation of national organizations in the various genetic resources activities, the network will not expect us to devolve a fundamental responsibility for managing a centralized global germplasm collection. Many other activities will be shared by network members—strengthening programs for all phases of management of national collections and linking these to global efforts and standards.

Our understanding of *Manihot* genetic diversity will expand rapidly with the application of molecular tools. A cassava molecular map will be completed in the near future, and will be the basis for launching a wide range of genetic diversity studies.

Gene Pool Development

Over the next few decades, the national research programs will continue to be our principal partners in gene pool development. Private sector involvement will then slowly increase, especially as products of biotechnology create potentially profitable markets. Initially, biotechnology applications will be in the public sector, and principally in the domain of our traditional partners. A challenge for the near future, for CIAT and national programs, is to define the appropriate balance between resources for biotechnology and those for conventional genetic improvement. The formation and success of the Cassava Biotechnology Network has to some degree eased the pressures for CIAT to make this difficult decision. We can keep a good level of input into conventional genetic improvement and at the same time benefit from many institutions working on biotechnology solutions to problems relevant to our own objectives. National programs are possibly finding the decision more difficult. Administrators find allure and status in having biotechnology programs, but this often drains resources from existing productive programs.

The bottom line for CIAT's research planning is that our partners expect us to retain considerable capability in gene pool development. Our emphasis will be on broadly applicable methodologies, and genetic improvement of key characters defined as high priority within the breeding networks. The creation of new and useful genetic combinations depends on a sound knowledge of the plant's response to its biological and physical environment, identification of useful genes, and effective methodologies to combine them into new varieties.

We will look for ways to bring the gene pool development process as close as possible to clients' needs and conditions. We will seek and create more opportunities for stronger national programs to assume broader responsibilities—to take advantage of special expertise or agroecologies in particular programs. This will mean a gradual reduction in Colombia-based selection, and an increase in national programs' participation in strategic breeding to meet global objectives. We will further emphasize characters that add value to the crop, as opposed to strictly yield - specialty starches, high beta-carotene, or high post-harvest storability for example.

Crop and Soil Management

The massive shift toward environmental quality issues in agricultural research policy in the past decade will evolve toward greater concern about how to make these practices more relevant and acceptable to farmers and consumers. The Cassava Program has already started research on methodologies for farmer participation in the areas of pest management and soil erosion control/fertility maintenance.

We will continue to emphasize research that exploits cassava's ability to produce well under difficult conditions. But as the success of cassava development projects expands, farmers will have increased capability and interest in applying yield increasing/stabilizing inputs. Fertilizer and weed control will be most in demand. Much of the research background for this technology is already established. National programs, not CIAT, will carry out the necessary adaptive research.

Pest problems evolve and shift continuously. Even in the most advanced and sophisticated crop production systems, pests can surprise and outwit science. Our growing body of basic knowledge on pests and pathogens will allow better predictive modelling of potential problems as agronomic practices or weather patterns shift. With this information we can take preemptive action to design management strategies before pests reach economic threshold levels.

If other crops are any indication, biotechnology for cassava will have some of its first applications in pest management. Currently there are no such technologies at the field-testing level, and farm-level impact will be well into the future. But these technologies can move relatively quickly, and within 15 or 20 years, impact should be broadly felt.

Process, Product and Market Development

There is already a large diversity of products derived from cassava. The continuing expansion of products will drive much of the growth in demand for cassava raw material. Further growth will come from the food needs of growing populations that depend on cassava as a basic calorie source.

The private sector has shown imagination and innovation in developing and marketing new food products. There is reason to believe that private industry will play an expanding role in cassava. Sometimes industry may move on its own initiative, but often it requires some prior basic research to motivate interest and justify investments. Simply a matter of awareness of new possibilities may be enough to motivate the private sector. We have a role in both these areas—background research in process, product and market development, and facilitating communication among relevant public and private sectors.

Simple shifts in the market can profoundly affect directions of technology development, and we need to keep abreast of these trends. Thai starch factories for example, have been paying farmers on the basis of root starch content for over 10 years, but this is not yet the case in most countries. This type of market shift can create immediate demand for new technology.

CIAT's position as curator of a world germplasm collection gives us a unique comparative advantage in research on genetic diversity for quality traits. We will work with universities and national research programs in both developing and developed countries to coordinate the necessary basic research on quality. Capability for many analyses—simple or sophisticated—exists within industry. We can form partnerships with those entities that are motivated by potential new economic enterprises to jointly characterize the germplasm for many quality traits.

Cassava's competitiveness in industry depends as much on national economic and trade policy as on technology. We will work extensively with national governments upon request to provide input on policy alternatives that affect cassava production and use. This is a natural extension of ongoing work with national programs on design of baseline economic studies and research alternatives.

Cassava's continuing critical role in food security can also benefit from our input into process, product and market development. Here, our principal contribution can be in fresh root storage and processing technology. Fresh root storage can most benefit urban populations by lowering food costs. Processing improvements are needed to reduce risks of cyanide poisoning in some of the famine-prone areas of Africa, to ease some of the onerous processing labor mainly affecting women, and to reduce waste.

Finally, we will be involved with other appropriate institutions in sociological research on organizational aspects of process, product and market development, especially farmer and processor cooperatives. We have seen these cooperatives to be highly effective vehicles for development in virtually all the integrated cassava projects.

Who Benefits?

Our principal clients are the poor who depend on cassava for food and income. This will not change. Our ability to represent their interests with appropriate technology is honed by a long history of interaction, communication and compassion. Research and development strategies can be designed to preferentially benefit the poor, and cassava is a good vehicle for this to occur. Past evidence shows integrated projects are specially effective at generating income for the poor. But the role of cassava in food security will continue to be critical. New cassava production technology offers hope for some of tropical agriculture's most at-risk regions.

In 20 years, benefits of CIAT-related cassava technology will be broadly felt on three continents (see Henry, 1994 for a detailed analysis of costs/benefits of cassava R&D to the year 2028).

Among research benefits, those from effective genetic resources management and genetic improvement are easiest to associate with CIAT activities—concrete, physically identifiable technology components. At the scientific level, we will have achieved a globally inclusive, securely preserved and genetically well-characterized germplasm collection. Genetically improved varieties will cover 35% of area in Asia, and 20% in Latin America and Africa[2] thanks to a breeding history going back to the mid-1970s, and early results from the greatly expanded work in biotechnology of the early 1990s. Net benefits to technology adopters will average US$70/ha/yr from improved yield potential and quality (excluding pest/disease resistance, treated separately below), or about US$115m for Asia, $162m for Africa, and $41m for Latin America, in 1994 US dollars.[3]

Advances in crop, soil, and pest/disease management bring higher productivity at low cost to the environment, and generate a higher standard of living for farmers and consumers through income or lower food costs. Lower losses from pests can easily be converted to monetary benefits, while soil erosion and soil fertility maintenance are less tangible. New crop and soil management technology benefits will be at a level similar to those of genetic improvement, but with higher overall adoption costs for the producer. We estimate net annual benefits in 20 years to be about 20% below those of germplasm, or, in 1994 US dollars, $92m for Asia, $130m for Africa, and $33m for Latin America. Cassava pests are relatively less important in Asia, and few benefits will accrue from new technology in 20 years. Gains will be highest for Africa, where research is concentrated on three main problems; mealybug, green mite and cassava mosaic virus. Advances in biological control and in resistance breeding will save

2. Benefits from combined efforts of IITA and CIAT for African conditions, but principally attributable to IITA.

3. Assumes area increases of 30% in Africa, 20% in Asia and 10% in Latin America over 1993 levels.

farmers about $406m annually. Benefits in Latin America, where a much more complex biological environment occurs, will be about $56m.

Process, product and market development give cassava producers alternatives that sustain prices at more stable levels in the face of production fluctuations, provide incentives to adopt new production technology, and benefit consumers with diversity of products in the market at lower prices. Benefits will be most notable in Latin America and in Africa, where markets are currently constrained. Asia is already characterized by mainly diversified markets. Over time, producers and consumers benefit approximately equally. By 2014, annual net benefits from CIAT's contributions should be approximately $US 203m in Africa, $112m in Latin America, and $33m in Asia.

Institutional strengthening gives individuals the potential to maximize their contributions as scientists or in other capacities. The monetary benefits from these efforts are distributed across all the technology components.

10. SUMMARY OF ACHIEVEMENTS: 1969-1994

The Cassava Program describes its work, and often elaborates on future plans, in an Annual Report. The 1969 report had four pages, and those of recent years typically have 300 to 400—some 5,000 pages over the Program's history. These reports, and over 1,300 publications of Program staff, detail the achievements in cassava research and development, in which CIAT has had a role. These achievements can be summarized in a few broad areas:

Institutional Strengthening

- National cassava research programs formed in several Latin American countries with CIAT encouragement
- CIAT broadly used as a role model in national program research planning and execution
- Giving status to the broad area of cassava R&D
- 855 professionals trained in cassava R&D
- Cassava Information Service assembles, catalogues and distributes information resources for professional enrichment
- Program offices in Asia and Africa enable region-specific problem and opportunity analysis and feedback for headquarters
- Networks formed to enable efficiencies in communication, and research planning and execution
- Over 50 professional meetings sponsored for furthering cassava's contributions to human welfare

Management of Genetic Resources

- A world germplasm collection assembled, representing approximately 80% of total species diversity of *Manihot esculenta*
- A wild species collection initiated

- Field and in vitro conservation systems established and effectively used for a high level of confidence in long-term integrity

- Morphological and biochemical characterization of the collection for improved understanding and management

- Evaluation of a broad range of economically significant characters

- Germplasm exchange with most cassava-producing countries of Latin America and Asia, and introduction to Africa through IITA.

Gene Pool Development

- Basic breeding methodology elaborated, used, and disseminated to partner institutions

- Identification of key characters for selecting for high and stable yield, especially harvest index, leaf life, leaf area index, and plant architecture

- Definition of constraints and opportunities for genetic improvement on an agroecosystem basis

- Improved gene pools developed for five broad agroecological systems, and for end uses requiring high or low root cyanogens

- Broad based and durable resistance to major insects, mites and pathogens identified and incorporated into gene pools

- Characterization of genetic control of many traits

- Design and validation of a precise methodology for obtaining farmer input

- Characterization of mechanisms for drought tolerance and their potential use in genetic improvement

- Description of C_3-C_4 intermediate characteristics of cassava photosynthesis

Crop and Soil Management

- Characterization of cassava's nutrient needs, practical analytical methods for their determination

- Integrated crop/soil management strategies for long-term fertility maintenance

- Methodology for erosion control experimentation and principles of soil conservation in cassava-based systems

- Components of crop management for optimizing economic returns, in low- to moderate input systems

- Principles and components of managing pests and diseases in systems generally free of pesticide inputs

Process, Product and Market Development

- Basic principles of nutrition of swine and poultry with cassava-based diets

- Characterization of post-harvest physiology of cassava roots

- Improvements and local adaptations of technologies for cassava chipping, drying, starch extraction and flour production

- Baseline economic studies of cassava production, processing and marketing in several countries

- Demand studies for cassava in Asia and Latin America, and a key role in conducting collaborative studies on cassava in Africa (COSCA) with IITA

Integrated Project Design and Implementation

- Elaboration of a research and institutional framework to maximize benefits of cassava technology through simultaneous consideration of constraints on and opportunities in production, processing and marketing

- Design and field testing of a staged model for implementing integrated projects: pilot, semi-commercial, and expansion phases

- Promotion of farmer/processor organizations as the primary structure for project implementation and innovation.

- Drying/processing plants were established in projects in Panama, Colombia, Ecuador and Brazil. In Colombia, economic benefits are estimated at $22 million over the period 1984-1991.

POVERTY, NUTRITION AND QUALITY OF LIFE: REFLECTIONS

As diverse and complex as our varied technological and organizational interventions have become, the basic goals and principles with which we began and developed as a team remain unchanged: to contribute to an improved quality of life for rural and urban poor. This *quality of life*, we recognize, is dependent on more than adequate nutrition or increased income, though these often need to be the first steps. Statistics are an important way to look at progress; what we can measure as economic benefits to society is a satisfying reward for our work. What is probably even more satisfying on a personal level is to see and experience first-hand many of the concrete benefits realized by individuals, communities, and organizations: a member of a women's starch cooperative in Ecuador can now provide for her children's education; a farmer's group in Colombia has been able to gain a sense of independence from large landowners by purchasing their own tractor; a family in Vietnam added a room to their house with extra income from selling cassava; a research team in Brazil gains new pride, status and motivation because of exciting new research projects they have helped develop and implement.

Poverty and acute food shortage will not soon disappear as part of the human condition. Solutions will come only through the massive and collaborative efforts of committed people and organizations. Agricultural science has a key role in this process. We see the achievements of the global community on cassava research and development as an encouraging success story—a reason for optimism—y and we are proud to be a part of it.

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Annex I. World cassava production and per hectare yields.

Region/country	Production (MT, 1000)			Per cap. consumption (kg/yr)	Yield (t/ha)
	1969/71	1979/81	1992	1990	1992
Africa	38,560	48,776	70,435	96,2	7.6
Nigeria	9,473	10,833	20,000	191.9	11.1
Zaire	10,232	12,942	18,300	390.9	7.6
Tanzania	3,373	5,547	7,111	207.3	10.4
Mozambique	2,516	3,100	3,239	251.1	3.3
Uganda	1,926	2,122	3,780	154.6	8.8
Ghana	1,533	1,894	4,000	160.4	7.4
Madagascar	1,227	1,641	2,320	121.0	6.6
Angola	1,597	1,850	1,885	189.6	3.6
Côte d'Ivoire	546	1,067	1,350	98.7	4.5
Cameroon	637	1,273	1,230	76.0	13.4
Benin	537	631	932	179.8	8.0
Congo	461	631	790	332.9	7.9
Kenya	510	588	770	26.2	8.1
Burundi	430	412	597	107.8	11.3
Rwanda	333	578	400	73.7	8.0
Central Afr. Rep.	767	920	606	169.5	3.0
Togo	500	404	480	167.9	7.4
Guinea	482	480	660	66.5	8.0
Chad	136	205	330	52.3	4.6
Liberia	264	300	300	131.9	6.5
Zambia	159	183	270	29.2	3.6
Gabon	133	242	260	116.7	5.7
Niger	182	191	218	22.3	7.6
Malawi	90	292	129	16.4	2.0
Sierra Leone	75	94	91	29.3	4.2
Zimbabwe	46	55	110	8.8	3.9
Asia/Oceania	22,923	44,680	51,256	6.9	13.5
Thailand	3,208	15,128	21,130	3.9	14.7
Indonesia	10,695	13,592	16,318	50.5	12.2
India	4,993	5,921	5,200	6.3	21.1
China	1,938	3,390	3,310	1.5	14.6
Viet Nam	948	3,300	3,000	31.3	10.8
Philippines	441	2,226	1,320	26	8.3
Malaysia	246	347	430	25.4	10.5
Sri Lanka	376	520	302	17.7	8.8
Laos	15	66	67	12.6	13.4
Papua New Guinea	n.a.	n.a.	113	21.6	10.7
Fiji	n.a.	n.a.	40	46.9	18.2

(Continued)

Annex I. Continued.

Region/country	Production (MT, 1000)			Per cap. consumption (kg/yr)	Yield (t/ha)
	1969/71	1979/81	1992	1990	1992
Latin America/Caribbean	**34,441**	**29,790**	**30,342**	**18.4**	**11.5**
Brazil	29,922	24,315	22,652	64.7	12.0
Paraguay	1,442	1,977	3,300	168.7	15.0
Colombia	1,380	2,070	1,836	37.8	10.0
Bolivia	223	204	515	34.6	10.5
Peru	477	481	406	16.0	10.4
Venezuela	317	322	382	6.7	9.1
Haiti	205	252	240	32.2	3.5
Cuba	217	280	290	17.9	4.1
Argentina	296	202	150	2.2	10.0
Dominican Rep.	173	98	210	13.6	6.8
Ecuador	382	216	90	9.5	4.7
Nicaragua	17	26	71	9.3	11.4
Costa Rica	8	17	60	0.4	12.0
Panama	32	36	37	11.2	6.6

SOURCES: Trends in CIAT commodities 1993. Henry, G. (ed.). CIAT working document no. 128, Cali, Colombia. 221 p.
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Annex II. Cassava program staff list—1973-1994.

Section	Name	Title/position[a]	Years
Office of Leader	Cock, James H.	Ph.D./Program Leader	1972-1989
	Best, Rupert	Ph.D./Program Leader	1990 →
	Chaux M., Miguel Angel	Administrative Assistant	1981 →
Africa Regional Office	Porto, Marcio Carvalho M.	Ph.D./Senior Staff	1989-1994
	Okogbenin, Emmanuel	M.S./Research Associate	1990 →
	Osuwa, I.O.	B.S./Research Assistant	1990 →
	Edet, Michael	B.S./Research Assistant	1990-1994
Asia Regional Office	Kawano, Kazuo	Ph.D./Senior Staff, Coord.	1982 →
	Howeler, Reinhardt	Ph.D./Senior Staff, Soils	1986-1984
Asia Liaison	Obordo, Romeo R.	Ph.D./Senior Staff (SEARCA, Philippines)	1977-1980
Agronomy/ Cultural Practices	Moreno, Raúl	Ph.D./Senior Staff	1984-1993
	Leihner, Dietrich	D.Agr./Senior Staff	1977-1984
	Toro, Julio César	Ph.D./Senior Staff	1973-1983
	Castro, Abelardo	Ph.D./Senior Staff	1976-1980
	Doll, Jerry	Ph.D./Weed Control	1973-1975
	Hegewald/Bodo	Ph.D./PDF Intercropping	1979-1980
	Thung, Michael	Ph.D./PDF Multiple Cropping	1976-1977
	Sánchez, Jaime	M.S./Research Associate	1989-1992
	Acuña, Luis Guillermo	Ing. Agr./Research Assistant	1974
	Sterling, Roso Elias	Ing. Agr./Research Assistant	1974
	Calderón, Humberto	Ing. Agr./Research Assistant	1974-1977
	Celis, Ernesto	Ing. Agr./Research Assistant	1974-1982

a. Only most recent position is listed.

(Continued)

Annex II. Continued.

Section	Name	Title/position[a]	Years
	Holguín, Julio Eduardo	Ing. Agr./Research Assistant	1976-1983
	Puente, José Antonio	Ing. Agr./Research Assistant	1983-1984
	Acosta, Nancy	Ing. Agr./Research Assistant	1978
	Martelo, José Manuel	Ing. Agr./Research Assistant	1989-1993
	Muñoz, Fernando	Ing. Agr./Research Assistant	1989-1991
Socio-Economics	Pinstrup-Andersen, Per	Ph.D./Agric. Economist	1970-1975
	Lynam, John	Ph.D./Senior Staff	1977-1988
	Henry, Guy	Ph.D./Senior Staff	1989 →
	Romanoff, Steve	Ph.D./Sr. Res. Fellow, Anthropologist	1984-1989
	Pérez Crespo, Carlos A.	Ph.D./Sr. Res. Fellow, Mexico	1986-1989
	Poats, Susan	Ph.D./Sr. Res. Fellow, Sociologist	1990-1994
	Pachico, Douglas	Ph.D./PDF Economist	1980
	Ibañez Meir, Carlos Alberto	Ph.D./PDF Economist-Brazil	1985-1987
	Saez, Roberto	Ph.D./PDF Economist-Mexico	1985-1987
	Sanint, Luis	Ph.D./PDF Economist	1985-1987
	Janssen, Willem	Ph.D./Visiting Scientist	1984
	Díaz, Rafael Orlando	M.S./Research Associate	1974-1991
	Strobosch, Peter Jan	M.S./Visiting Res. Assoc.	1978-1979
	Gottret, Verónica	M.S./Research Associate	1992 →
	Varón, Uldarico	Ing. Agr./Research Assistant	1974-1978
	Correa, Carolina	Economist/Research Assistant	1979-1992
	Cárdenas, Darío	Ing. Agr./Research Assistant	1976
	Izquierdo, Diego	Economist/Research Assistant	1979-1993
	Mosquera, Liliana	Economist/Research Assistant	1993-1994

(Continued)

Annex II. Continued.

Section	Name	Title/position[a]	Years
Entomology	Bellotti, Anthony	Ph.D./Senior Staff	1974 →
	Schoonhoven, Aart van	Ph.D./Entomologist	1972-1975
	Braun, Ann	Ph.D./Senior Staff	1987-1993
	Lapointe, Steven	Ph.D./Sr. Res. Fellow, IPM	1993 →
	Reyes, Jesús A.	M.S./Visiting Scientist	1978-1979
	Vargas, Octavio	M.S./Research Associate	1977-1991
	Mesa, Nora Cristina	M.S./Research Associate	1989-1992
	Arias, Bernardo	M.S./Research Associate	1976 →
	Hernández, Martha Rojas de	Ph.D./Visiting Scientist	1983
	Sullivan, Daniel	Ph.D./Visiting Scientist	1988
	Byrne, David	M.S./Visiting Res. Assoc.	1977-1979
	Lohr, Bernhard	M.S./Visiting Res. Assoc.	1978-1981
	Salick, Jan Margareth	M.S./Visiting Res. Assoc.	1980-1982
	Riis, Lizbeth	M.S./Jr. Research Fellow	1993 →
	Gaigl, Andrés	M.S./Visiting Res. Assoc.	1989 →
	Peña, Jorge	Ing. Agr./Research Assistant	1974-1977
	Varela, Ana Milena	Biol./Research Assistant	1978-1981
	Castillo, José Aquileo	Biol./Research Assistant	1983 →
	Hernández, Maria del Pilar	Ing. Agr./Research Assistant	1989 →
	Herrera, Carlos Julio	Ing. Agr./Research Assistant	1989 →
	Alvarez, Juan Manuel	Ing. Agr./Research Assistant	1991-1993
	Cuéllar, Maria Helena	Biol./Research Assistant	1993 →
Genetics	Bonierbale, Meridith	Ph.D./Senior Staff	1992 →
	Bedoya, Jairo	Ing. Agr./Research Assistant	1989 →
	Claros, José Luis	Biol./Research Assistant	1993 →

(Continued)

Annex II. Continued.

Section	Name	Title/position[a]	Years
Physiology	El-Sharkawy, Mabrouk	Ph.D./Senior Staff	1980 →
	Cock, James H.	Ph.D./Asst. Physiologist	1971
	Hunt, Leslie A.	Ph.D./Visiting Physiologist	1974
	Irikura, Yokio	Ph.D./Visiting Scientist	1975-1977
	Conner, David	Ph.D./Visiting Scientist	1979-1980
	Sawada, Sinichi	Ph.D./Visiting Scientist	1982
	López, Yamel	Ph.D./Visiting Scientist	1988
	Cadavid, Luis Fernando	M.S./Research Associate	1989 →
	Veltcamp, Hendrick Jan	M.S./Visiting Res. Assoc.	1978-1981
	Pellet, Didier	M.S./Jr. Research Fellow	1989-1992
	Gutiérrez, Oscar	Ing. Agr./Research Assistant	1974-1975
	Sandoval, Guillermo	Ing. Agr./Research Assistant	1974-1976
	Parra, Germán Enrique	Ing. Agr./Research Assistant	1976-1983
	Azis, Zainol Abd	M.S./Visiting Res. Assoc.	1981
	Mejía, Sara	Ing. Agr./Research Assistant	1977-1984 1990-1994
	Kadoch, Lucy	Biol./Research Assistant	1980-1982
	Hernández, Ana del Pilar	Biol./Research Assistant	1982-1989
	Acosta, Alvaro	Ing. Agr./Research Assistant	1989 →
Phytopathology	Lozano, José Carlos	Ph.D./Senior Staff	1972 →
	Booth, Robert H.	Ph.D./Visiting Scientist	1972-1974
	Umemura, Yoshiki	Ph.D./Visiting Scientist	1977-1979
	Jayasinge, Upali	Ph.D./PDF Virologist	1981-1983
	Nolt, Barry	Ph.D./PDF, Sr. Res. Fellow, Virology	1985-1988
	Castaño, Jairo	M.S./Research Associate	1975-1978
	Elango, Fritz	M.S./Visiting Res. Assoc.	1977-1979

(Continued)

Annex II. Continued.

Section	Name	Title/position[a]	Years
	Teri, James	M.S./Visiting Res. Assoc.	1977
	Laberry, Rafael	M.S./Research Associate	1977-1994
	Pineda, Benjamín	M.S./Research Associate	1979-1989
	Wheatley, Christopher	M.S./Visiting Res. Assoc.	1979-1980
	Zeigler, Robert	M.S./Visiting Res. Assoc.	1980-1981
	Velasco, Ana Cecilia	Tec. Med./Research Assistant	1977-1989
	Zarate, Rubén Darío	Ing. Agr./Research Assistant	1974-1975
	Hernández, José María	Ing. Agr./Research Assistant	1989-1991
	Bejarano, Carlos A.	Ing. Agr./Research Assistant	1990-1993
Plant Breeding	Kawano, Kazuo	Ph.D./Senior Staff	1973-1981
	Hershey, Clair	Ph.D./Senior Staff	1978-1991
	Iglesias, Carlos	Ph.D./Senior Staff	1989 →
	Carey, Edward	Ph.D./PDF Plant Breeder	1985-1988
	Amaya, Alvaro	M.S./Research Associate	1974-1976 1979-1982
	Hernández, Luis Alfredo	M.S./Research Associate	1989 →
	Millán, Pedro	Ing. Agr./Research Assistant	1979-1982
	Jaramillo, Gustavo	Ing. Agr./Research Assistant	1974 →
	Calle C., Fernando	Ing. Agr./Research Assistant	1977 →
	Ocampo, César Humberto	Biol./Research Assistant	1989
	Morante, Nelson	Ing. Agr./Research Assistant	1992 →
	Lenis, Jorge Iván	Ing. Agr./Research Assistant	1989 →
	López, Javier	Ing. Agr./Research Assistant	1978-1994
Soils and Plant Nutrition	Howeler, Reinhardt	Ph.D./Senior Staff	1971-1985
	Sieverding, Ewald	Ph.D./PDF, Sr. Res. Fellow, Mycorrhiza	1980-1986
	Mueller-Saemaan, Karl	Ph.D./PDF Soil Erosion	1991 →

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Annex II. Continued.

Section	Name	Title/position[a]	Years
	Reining, Ludger	M.S./Jr. Research Fellow	1987-1989
	Fleske, Wolfgang	M.S./Jr. Research Fellow	1990-1994
	Ruppenthal, Martin	M.S./Jr. Research Fellow	1990-1992
	Cadavid, Luis Fernando	Ing. Agr./Research Assistant	1974-1977
	Buckhardt, Eitel Adolfo	Biol./Research Assistant	1977-1986
	Salazar, Edgar	Ing. Agr./Research Assistant	1977-1984
	Medina, Carlos	Ing. Agr./Research Assistant	1978
	Hernández, Julián	Ing. Agr./Research Assistant	1980-1982
	Ballesteros, Darío	Ing. Agr./Research Assistant	1982-1986
	Floerchinger, Felicitas	M.S./Jr. Research Fellow	1990 →
	Castillo, Jesús Antonio	Ing. Agr./Research Assistant	1991 →
Utilization	Wheatley, Christopher	Ph.D./Sr. Res. Fellow, Quality	1982-1993
	Best, Rupert	Ph.D./Visiting Scientist	1976-1977 1982-1989
	Gómez, Guillermo	Ph.D./Senior Staff	1980-1983
	Chuzel, Gerard	Ph.D./Visiting Scientist	1988-1993
	Dufour, Dominique	Ph.D./Visiting Scientist	1992 →
	Jones, Deborah	Ph.D./Sr. Res. Fellow	1993 →
	O'Brien, Gerry	Ph.D./PDF Quality	1993 →
	Santos, Jorge	M.S./Research Associate	1980-1982
	Ospina, Bernardo	M.S./Senior Research Fellow	1983 →
	Ostertag, Carlos	M.S./Research Associate	1989 →
	Bravet, Catherine	M.S./Visiting Scientist	1993-1994
	Echeverry, Luis Fernando	Químico/Research Assistant	1974
	Valdivieso, Mauricio	Zootec./Research Assistant	1980-1983
	Alonso, Lisímaco	Ing. Agr./Research Assistant	1983-1994
	Orrego, Jorge Iván	Ing. Agr./Research Assistant	1983-1994
	Figueroa, Francisco	Ing. Agr./Research Assistant	1989-1992

(Continued)

Annex II. Continued.

Section	Name	Title/position[a]	Years
	Sarria, Helberth	Ing. Agr./Research Assistant	1989-1991
	Viera, Miguel Angel	Ing. Agr./Research Assistant	1989-1993
	Arrieta, José Rafael	Ing. Agr./Research Assistant	1990-1991
	Sánchez de Salcedo, Teresa	Laboratorista/Research Asst.	1990 →
	Sánchez, Carlos Alberto	Ing. Agr./Research Assistant	1990-1992
Associated Staff			
Cassava Biotechnology Network	Thro, Ann Marie	Ph.D./Senior Staff	1992 →
	Belt, John	M.S./Jr. Research Fellow	1993-1994
Training	Domínguez, Carlos	M.S./Research Associate	1977-1984
	Reyes, Jesús	M.S./Research Associate	1981-1993

Annex III. Meetings sponsored or co-sponsored by CIAT Cassava Program, 1976-1994, and resulting proceedings.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Workshop on the international exchange and testing of cassava germ plasm	04-06 Feb. 1975 Colombia	?	?	IDRC. 1975. The international exchange and testing of cassava germ plasm. Nestel, B. and MacIntyre, R. (eds.). IDRC-049e, Ottawa. 74 p.
IV Symposium of the International Society for Tropical Root Crops	01-07 Aug. 1976 Colombia	173	44	IDRC. 1977. Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops. Cock, J.; MacIntyre, R.; and Graham, M. (eds.). IDRC-080e, Ottawa. 277 p.
Cassava plant protection workshop	07-11 Nov. 1977 Colombia	42	11	CIAT 1977. Proceedings Cassava Protection Workshop. Brekelbaum, T.; Bellotti, A.; and Lozano, C. Series CE-14, Cali, Colombia. 244 p.
Workshop on *intercropping* with cassava	27 Nov.-1 Dec. 1978 India	27	12	Inter cropping with cassava: proceedings on an International workshop held at *Trivandrum*, India. Weber, E.; Nestel, B.; and Cambell, M. (eds.). IDRC-142e. 142 p.
Workshop on Cassava Cultural Practices	18-21 March 1980	42	10	IDRC 1980. Cassava Cultivation Practices. Proceedings of a workshop held in Salvador, Bahia, Brazil. Weber, E.J.; Toro, J.C.; and Graham, M. (eds.). IDRC-151e. 152 p.
Simposio sobre alcohol carburante	18-22 May 1980 Colombia	124	6	CIAT 1980. Memorias 1 Simposio Colombiano sobre alcohol carburante. Brekelbaum, T.; Toro, J.C.; and Izquierdo, V. (eds.). Cali, Colombia. 216 p.
Reunión de trabajo sobre intercambio de germoplasma de yuca y papa	26-28 Jan. 1982 Colombia	31	12	CIAT. 1982. Primer taller latinoamericano sobre intercambio de germoplasma de papa y yuca: memorias. Roca, W.M.; Hershey, C.H.; and Malamud, O.S. (eds.). CIAT series 03SC-6(82), Cali, Colombia. 295 p.

a. Excluding countries represented by CIAT participants.

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Annex III. Continued.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Reunión de trabajo sobre evaluación de germoplasma de yuca en América Latina	10-14 May 1982 Colombia	9	8	CIAT. 1983. Evaluación de variedades promisorias de yuca en América Latina y el Caribe. Toro, J.C. (ed.). CIAT series 03SC(1)83, Cali, Colombia. 185 p.
Reunión internacional de trabajo sobre propagación de raíces y tubérculos	13-16 Sept. 1983 Colombia	23	14	CIAT. 1986. Global workshop on root and tuber crops propagation. Cock, J.H. (ed.). Cali, Colombia. 235 p.
Reunión de trabajo sobre proyectos integrados para producción, procesamiento y utilización de yuca	20-24 March 1984 Colombia	37	7	No publication.
Workshop on the future potential of cassava in Asia and the research development needs	05-08 June 1984 Thailand	49	11	CIAT; ESCAP CGPRT Centre. 1986. Cassava in Asia, its potential and research development needs. Lynam, J.K. (ed.). Cali, Colombia. 442 p.
Cassava breeding workshop	04-07 March 1985 Philippines	21	11	CIAT. 1987. Cassava breeding: a multidisciplinary review. Hershey, C.H. (ed.). Cali, Colombia. 312 p.
Primera reunión semestral de evaluación. Procesamiento de yuca en Colombia	08-09 April 1985 Colombia	20	1	
Caribbean root and tuber workshop	09-10 July 1985 Guadeloupe	39	24	Regional Workshop on Root Crops Production & Research in the Caribbean. Guadeloupe 1985 Proceedings. CIAT, Cali, Colombia. 236 p.
II Semestral de evaluación del proyecto CIAT/IITA/UNIVALLE-CIID sobre producción y uso de harina de yuca para consumo humano	10-11 Sept. 1985 Colombia	23	1	
Reunión de trabajo sobre proyectos para producción, procesamiento y comercialización de la yuca	31 March-05 April 1985 Colombia	39	8	No publication.

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Annex III. Continued.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Taller interinstitucional sobre estrategias de capacitación para el proyecto de yuca seca de la Costa Atlántica	14-18 July 1986 Colombia	39	3	
Reunión de trabajo sobre intercambio de germoplasma, cuarentena y mejoramiento de yuca y batata, CIAT-CIP	08-12 June 1987 Colombia	48	16	CIAT. 1991. Mejoramiento genético de la yuca en America latina. Hershey, C.H. (ed.). CIAT Publ. no. 82. Cali, Colombia. 426 p.
Regional workshop on cassava breeding and agronomy in Asia	26-28 Oct. 1987 Thailand	19	8	CIAT. 1988. Cassava breeding and agronomy research in Asia. Howeler, R.H. and Kawano, K. (eds.). Bangkok, Thailand. 350 p.
Congreso latino-americano sobre metodologías aplicadas a proyectos integrados de yuca	26-28 Oct. 1987 Mexico	49	7	ISBN 958-9183-00-X. Pérez Crespo, C.A. (ed.). CIAT, Cali, Colombia. 119 p.
Reunión de trabajo para establecer vínculos de comunicación entre proyectos de yuca	07-08 April 1988 Colombia	30	8	
Workshop for the advanced cassava research network	06-09 Sept. 1988 Colombia	55	14	Working Document no. 52. Report on the founding workshop for the advanced cassava research network. Held at CIAT 1988. CIAT 1989, Cali, Colombia. 61 p.
Taller de trabajo para mejorar la capacidad de diagnóstico de sistemas de producción de raíces y tubérculos	12-17 Sept. 1988 Colombia	26	11	Memorias taller de trabajo para mejorar la capacidad de diagnóstico de sistemas de producción de raíces y tubérculos. Cartagena, Colombia. 1988. cist/ap. Moreno, R.A. (ed.). 1989 Documento de trabajo no. 56. CIAT/CIP/IITA, Cali, Colombia. 198 p.
VIII Symposium of the International Society for Tropical Root Crops.	30 Oct-5 Nov.	190	39	Thailand 1990. Proceedings 8th Symposium of the International Society for Tropical Root Crops. Bangkok, Thailand. Howeler, R.H. (ed.). 724 p.

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Annex III. Continued.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Taller para discutir experimentación de campo con investigadores en yuca del ICA	27-31 March 1989 Colombia	37	1	No publication.
Reunión sobre el plan estratégico del programa de yuca	27-31 March 1989 Colombia	16	2	Cassava Program Strategic Plan June 1989. Workshop Document no. 54, CIAT, Cali, Colombia. 22 p.
Reunión de trabajo con secretarías de agricultura y funcionarios de entidades de investigación y desarrollo del nordeste del Brazil	29 April-12 May 1989 Brazil	18	2	No publication.
Reunión sobre el plan estratégico del programa de yuca	10-12 May 1989 Colombia	18	4	Cassava Program Strategic Plan June 1989. Workshop document no. 54, CIAT, Cali, Colombia. 22 p.
Primer seminario latinoamericano sobre producción y uso del almidón de yuca	03-06 July 1989 Brazil	26	6	
Second meeting of the advisory committee to the UNDP GLO/87/001 project "Human resources development for generation and transfer of root and tuber crops technology"	22-26 Jan. 1990 Colombia	13	5	
Technical guidelines for the safe movement of cassava germplasm	08-10 May 1990 Colombia	10	6	FAO/IBPGR Technical guidelines for the safe movement of cassava germplasm. Frison, E.A. and Feliu, E. (eds.) in collaboration with CIAT, 1991. 48 p.
II Reunión panamericana de fitomejoradores de yuca PNUD-CNPMF-CIAT	21-25 May 1990 Brazil	25	11	CIAT. 1992. Memorias de la segunda reunión panamericana de fitomejoradores de yuca. Iglesias, C. and Fukuda, W.M.G. (eds.). CIAT Working Document no. 112, Cali, Colombia. 184 p.

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Annex III. Continued.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Workshop on integrated pest management CIP-CIAT	15-22 Oct. 1990 India	20	8	
Reunión regional de cooperación en yuca en el subtrópico de América Latina	16-17 Oct. 1990 Paraguay	24	2	
III Asian regional workshop on cassava research	22-28 Oct. 1990 Indonesia	47	12	Cassava breeding, agronomy & utilization research in Asia. Proceedings of III Asian regional workshop on cassava research. Howeler, R.H. (ed.). CIAT, Cali, Colombia. 438p.
Taller colaborativo CIP-CIAT-IITA sobre procesamiento, comercialización y utilización de raíces y tubérculos en América Latina	08-12 April 1991 Guatemala	27	9	Desarrollo de Productos de Raíces y Tubérculos Vol II-América Latina. Memorias del taller sobre procesamiento, comercialización y utilización de raíces y tubérculos en América Latina. Scott, G.; Herrera, J.E.; Espinola, N.; Daza, M.; Fonseca, C.; Fano, H.; and Benavides, M. (eds.). 1992. 375 p.
Workshop on root & tuber processing, marketing & utilization in Asia.	22 April-1 May 1991 Philippines	38	15	Proceedings of the International workshop held at Visayas State College of Agriculture. VISCA. Sponsored by CIIP, CIAT & IITA. Scott, Wiersema, G.S. and Ferguson, P.I. (eds.). 1992. 384 p.
Taller para mejorar la capacidad de diagnóstico de sistemas de producción de raices y tubérculos tropicales CIAT-CIP	20-24 May 1991 Brazil	25	9	
Avances sobre almidón de yuca	17-21 June 1991 Colombia	68	8	
Segundo taller sobre proyectos integrados de yuca FUNDAGRO-CIAT	22-26 July 1991 Ecuador	42	8	No publication.

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Annex III. Continued.

Event	Dates and venue	Participants/ countries represented[a]		Proceedings/Reports
Seminario "De la investigación a los campos de agricultores: el caso de nuevas variedades de yuca"	03-05 Sept. 1991 Colombia	37	2	CIAT. 1991. Participación de los productores en la selección de variedades de yuca. Hernández R., L.A. (ed.). Cali, Colombia. 112 p.
International workshop on root & tuber crop processing, marketing & utilization for tropical agriculture. CIP, IITA & CIAT sponsored.	26 Oct.-2 Nov. 1991 Nigeria	?	?	Production development for root & tuber crops Vol III - Africa. Proceedings of the Workshop held in Ibadan, Nigeria. Scott, G., Ferguson, P.I. and Herrera, J.E. (eds.). 1992. 506 p.
International workshop on cassava genetic resources	19-23 Aug. 1992 Colombia	36	15	IPGRI in Press.
First international scientific meeting of the Cassava Biotechnology Network (CBN)	25-28 Aug. 1992 Colombia	112	28	CIAT. 1993. Proceedings of the first international scientific meeting of the Cassava Biotechnology Network. Roca, W.M. and Thro, A.M. (eds). CIAT Working Document no. 123, Cali, Colombia. 496 p.
III Taller de proyectos integrados de yuca	28 Sept.-02 Oct. 1992 Brazil	71	8	No publication.
Primera reunion anual "Proyecto de producción y comercialización de harina de yuca en Colombia. Fase 3. Expansion Comercial	03-04 March 1993 Colombia	34	1	
Tercera reunión panamericana de fitomejoradores de yuca CIAT-INIVIT	04-08 Oct. 1993 Cuba	17	8	CIAT. 1994. Interfase entre los programas de mejoramiento, los campos de los agricultores y los mercados de la yuca en latinoamérica. Iglesias, C. (ed.). CIAT Working Document no. 138. Cali, Colombia. 279 p.
International meeting on cassava flour and starch CIRAD-CIAT	11-15 Jan. 1994 Colombia	134	29	International meeting on cassava flour and starch CIRAD-CIAT ABSTRACTS Jan 11-15, 1994, CIAT, Cali, Colombia. 144 p.