CASSAVA PROGRAM

Achievements, constraints and impact

1989 - 1994

Document prepared for the Fourth External Programme and Management Review of the Centro Internacional de Agricultura Tropical

Centro Internacional de Agricultura Tropical

September, 1994

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30 March, 1995

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EXECUTIVE SUMMARY

Cassava cultivation and processing provide household food security, income and employment for over 500 million people in Africa, Asia and the Americas. The crop is tolerant of low soil fertility and drought, and recovers from the damage caused by most pests and diseases. The roots can be stored for long periods in the ground and have multiple end uses. These attributes have contributed to the crop's important role in alleviating hunger and in providing opportunities for economic development in less favored rural areas.

The goal of CIAT's Cassava Program is to enhance the crop's contribution to the wellbeing of cassava farmers, processors and consumers. Its specific purpose is to generate knowledge, research methods and technology components whose deployment will lead to a sustainable improvement in the level, stability and quality of cassava production and to a diversification in the end uses of the crop. The relevance of the Program's work depends on the establishment of strong links with partner institutions in both developed and developing countries.

The Program has adopted an interdisciplinary, commodity system philosophy which seeks to integrate research on germplasm improvement with research on crop management and process, product and market development. The products of this research and the most recent advances include:

- Conserved and characterized *Manihot* genetic resources. CIAT holds the largest, most comprehensively characterized *Manihot* germplasm collection, freely available to researchers around the world. The definition of a core collection, a model for identifying duplicates and the assembling of a molecular linkage map are among recent achievements. Diagnostic methods are now available for the detection of all viruses of quarantine significance. Cryopreservation of cassava shoot tips will become an alternative method for germplasm conservation within the next 5 years.

- Improved cassava gene pools, with adaptation to the principle biotic and abiotic constraints and appropriate quality characteristics. A total of 17 varieties, derived directly from CIAT's gene pools or having CIAT's materials as one of the parents, have been released since 1989. A model has been developed for the participatory evaluation of cassava varieties with farmers and successfully implemented in Colombia and Brazil. Marker-assisted selection and the opportunity for genetic manipulation of cassava will provide additional tools for solving a number of breeding challenges, among them the modification of certain root quality characteristics, resistance to stress with mechanisms for protecting fragile environments and the development of true seed propagated cassava.

- Crop management practices for economically and environmentally sustainable cassava production. Natural enemies for biological control of mites, mealybugs, burrowing bugs and the cassava hornworm have been identified and studied. Ten species of predatory mites have been introduced into Africa via IITA. Recommendations for the integrated control of root rot pathogens, cassava bacterial blight, superelongation and the witches' broom disease have been implemented in Brazil and Colombia. Technologies for maintaining soil fertility and arresting soil loss have been developed in Asia and for hillside and subhumid agroecologies in Colombia. The development of farmer participatory methods for selecting and adapting appropriate technological solutions to biotic and abiotic stresses will receive emphasis over the next five years.

- Cassava agroindustrial processes that strengthen links between small-scale farmers and markets. Processes for the primary transformation of cassava into dry chips, flour and starch have been developed and adopted commercially in Latin America. Technology for the conservation of fresh cassava for human consumption has been pilot tested both in Latin America and Africa. Collaborative interinstitutional projects in the future will focus on the extension to Africa of an integrated approach to process, product and market development and the identification of opportunities for the development of second generation products.

In addition to research in the above areas, the Program seeks to enhance the effectiveness of cassava research and development at national, regional and global levels through the provision of needs assessment methodologies for priority setting, information services and training. A global Cassava Biotechnology Network has been established and regional research networks have been consolidated.

Cassava Research at the Centro Internacional de Agricultura Tropical

~~**CASSAVA PROGRAM**~~
~~**Achievements, constraints and impact**~~
~~**1989-1994**~~

1. INTRODUCTION

Total world cassava production has risen from 132 million t in 1984 to 154 million t in 1993, a growth rate of 1.8% per annum. Growth in production has been fastest in Subsaharan Africa (3.3%) followed by Asia (1.0%), while production in Latin America has stabilized (0.0%) after experiencing negative growth during the previous decade. On all continents, cassava area is increasing at a faster rate than cassava yields. This trend is attributed to the movement of cassava production from relatively fertile environments, where it is being replaced by higher value crops, to regions with poorer soils and/or lower rainfall.

Cassava has maintained its critical importance as a household food security crop in Subsaharan Africa where it is also increasingly a major source of cash income. Product and market diversification has continued rapidly in S.E. Asia and is starting to occur in several Latin American countries. Production and transformation of the crop remains concentrated in the hands of small-scale farmers and processors.

The environment within which cassava research and development (R and D) takes place has evolved over the past ten years. There is now a much greater governmental and donor awareness of the contribution that cassava, and roots and tubers in general, can make in meeting development goals, especially those associated with marginal rural areas, such as food security and income and employment generation. However, since 1989, economic policies of developing countries have changed significantly. ~~with~~ an almost universal trend towards trade liberalization and the concern for environmental conservation has grown. Both these factors have important implications ~~with respect to~~ the research and development agenda for cassava. The strengthening of market links and improved cost and quality competitiveness of cassava products will be of paramount importance. However, gains in productivity will need to be environmentally sustainable.

In parallel with these socioeconomic and political changes, there has been a progressive consolidation of the institutional environment, with closer links between international, regional and national institutions involved in cassava R and D. ~~Cassava has often been termed an "orphan crop" in terms of research investment. There is still considerable need for basic knowledge generating research on the crop. The creation of the Cassava Biotechnology Network (CBN) has been instrumental in promoting relevant advanced research and enhancing communication between institutions involved in this work. Of particular importance has been the evolving relationship between CIAT's Cassava Program and the Brazilian and Thai national cassava programs which are now sharing with CIAT international responsibilities for certain areas of cassava R and D. The last five years have also seen a major renewal of CIAT's collaboration with IITA.~~

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At the applied research level, national cassava programs face budgetary difficulties similar to those faced by all government financed agricultural research institutions. However, progress has been made in understanding better the institutional constraints to the development of technologies that, through client (farmer, processor, consumer) involvement in the R and D process, have a greater probability of adoption. In Latin America, an institutional model known as "Integrated Cassava Research and Development Projects" (ICRDP) has been successfully tested in a number of countries. These projects have proven to provide effective links between research and development institutions, including farmer organizations, and the integration of production, processing and marketing components.

Over the past five years, the mission of CIAT's Cassava Program has not altered substantially. The Program's continuing concern is to enhance cassava's contribution to the wellbeing of cassava farmers, processors and consumers. Its specific role is to generate knowledge, research methods and technology components whose subsequent deployment by our national partners will lead to a sustainable improvement in the level, stability and quality of cassava production and to a diversification in the end uses of the crop.

The considerable financial restrictions imposed on the CG system since 1990 has required a constant process of examining priorities and an appraisal of CIAT's advantage in undertaking certain types of research compared with either advanced laboratories or national cassava research programs. There has been a reallocation of core resources to strengthen the Program's competence in the area of genetic resources. This resource reallocation, together with the budgetary reduction experienced in 1992 and 1994, have had repercussions on our capacity (a) to link with our national program partners in collaborative research on the validation and adaptation of technology components and their subsequent integration into cropping systems at the farm level in Latin America and (b) to provide leadership in integrating product, process and market research. The acquisition of special project funds and the development of collaborative links with other international institutions has only partially offset these gaps.

The internal reorganization of the Program around "Project Areas" has been an important step towards reaffirming the Program's interdisciplinary commodity system philosophy in which research on germplasm improvement must be integrated with research on crop management and process, product and market development. Resource allocation across Project Areas reflects the fact that CIAT's most important asset is the world *Manihot* germplasm collection which bestows on the Program a comparative advantage in characterizing and using genetic diversity to enhance cassava production and utilization. A competency and an ability, albeit reduced, to link with other R and D institutions in collaborative projects has been maintained in crop management and in process, product and market development research, both vital aspects if CIAT is to fulfil its global cassava mandate and provide intellectual leadership to our partners while act as a real bridge between advanced labs and national cassava R and D systems.

This document presents an historical assessment of the activities and outputs of the Program over the period 1989-1994 and a summary of the strategy that will be pursued by the Program in the following five-year period.

2. HISTORICAL ASSESSMENT AND FUTURE STRATEGY

(1) Manihot genetic diversity

Historical Assessment

The project area *Manihot* Genetic Diversity has developed relatively recently to houses the Cassava Program's activities in optimizing opportunities and strategies for the conservation and use of genetic diversity. Activities in collection, conservation and evaluation are multidisciplinary efforts; concepts of ecological adaptation/geographic distribution (GIS mapping) and tools of biotechnology (cryopreservation and molecular markers) have been incorporated into the research strategy.

The World cassava collection has increased its holding from 4344 to 5491 accessions during the past five years, largely through national or international collecting missions, or germplasm exchange, with Brazil, Argentina, Paraguay, Cuba, China and Thailand. Collaborative collecting efforts have proven to be very efficient in terms of describing germplasm (as preliminary data taken at site helps to minimize duplication), and establishment of the accessions both in the country of origin and in the world collection. Morphological and isozyme characterization of the base collection has been completed, but will continue to be required for new acquisitions. The cassava collection is maintained at CIAT both in a field collection, and *in vitro*. Approximately 300 accessions of wild *Manihot* species, and a progeny of 150 individuals selected for molecular mapping are also held *in vitro* and analysed in the field.

The definition of a core collection for cassava, accomplished since 1991, took advantage of extensive characterization data collected on accessions of the world collection. The definition of the core was based on the parameters of geographic origin (passport data), diversity of morphological characters, diversity of δβ esterase banding patterns, and *a priori* considerations in favor of particular genotypes. The consideration of geographic origin accounted for the importance of the accessions' origin as a center of diversity for the crop, and representation of diverse ecosystems. The core collection of 630 accessions is a manageable size which is actively used to assess genetic diversity in cassava for characters which require specific, expensive evaluations and may be difficult to apply to the base collection.

A model for the identification of duplicates in the collection has been developed and implemented in the past five years. The procedure consists of three steps in which the data base of morphological and isozyme characteristics is first consulted to identify accessions with identical descriptors. Next, putative duplicates are observed side by side in the same year, and compared morphologically. Accessions still appearing as duplicates are then subject to molecular fingerprinting using an *M13* DNA probe. To date, 35 groups of putative duplicates at the morphological and isozyme level have been evaluated with *M13*. Enhanced resolution provided by DNA fingerprinting showed 17% of the groups to contain unique individuals, while the remaining 83% were confirmed as duplicates. Accessions which are identical at this resolution are reported to the source country and eliminated from the field collection at CIAT, but at present they are still being maintained *in vitro*.

Research on the methodology of cryopreservation of cassava shoot tips has continued toward the application of this conservation method to a broad range of genotypes. Adjustments to pre-culture conditions, and freezing and thawing profiles have extended the range of genotypes that can successfully be recovered from cryopreservation.

A large number of ~~genetic~~ markers have been generated through the development at CIAT ~~of cassava DNA libraries. These markers are currently being assembled into a linkage~~ map, ~~which~~ will help to define the genome structure of cassava and to monitor and 'tag' traits of agronomic interest. Collaborative research with US Universities has been established to strengthen mapping efforts and ensure that appropriate analytical methods are applied to understanding the phylogeny of *Manihot* species.

International workshops/conferences have helped to set research and support priorities in *Manihot* genetic resources. A conference held in Rome in 1991, under the auspices of the FAO, determined that post harvest deterioration is a significant constraint to cassava utilization, and that sufficient knowledge of the biological processes involved in the phenomenon are at hand to justify research toward extending the storage life of cassava. An international workshop held at CIAT in 1992 to address needs in the area of cassava genetic resources, recommended the establishment of a *Manihot* Genetic Resources Network. Working groups developed recommendations for 1) the development of a global conservation strategy for cassava genetic resources, 2) the development of a global data base, and 3) the utilization of genetic resources for germplasm enhancement. ~~Participants represented national programs, IPGRI, IITA and CIAT~~. An international workshop was held at IITA in 1994 to clarify aspects surrounding the issue of the safety of cassava as a cyanogenic food crop. As results of these conferences, a comprehensive proposal has been developed for collaborative research on post harvest deterioration, and responsibilities have been assigned for researching and resolving constraints and issues, such as safety standards, surrounding cassava cyanogenesis. Training in the area of germplasm maintenance has contributed to ~~NAR~~ ability to conserve and utilize cassava genetic resources. The formation and subsequent operation of the Cassava Biotechnology Network (CBN) have also stimulated communication and research in the area of *Manihot* genetic diversity.

While the workshop held for the formation of the *Manihot* Genetic Resources Network helped to prioritize needs of various institutions concerned with germplasm and genetic diversity, staffing at CIAT in the area of genetic resources has not been adequate to meet our commitment as network Secretariat. The recent appointment of a Cassava Curator will strengthen our networking capacity. The lack of a Head of the GRU during CIAT's adjustment to global expectations following the Convention on Biodiversity has further handicapped our positioning with respect to the evolution of our role in the area of genetic diversity.

Germplasm screening under field and controlled conditions has identified outstanding sources of desirable traits such as resistance to white fly, mites, root rots and bacterial blight, and high photosynthetic capacity and water use efficiency, which have been made available to improved gene pools. A search for resistance to cassava frogskin disease is also underway. Screening of the wild species collection for resistance to pests and diseases and for root quality characteristics has been intensified in the past two years, indicating potential new sources of desirable traits. Approximately 2,500 *in vitro* plantlets, representing several hundred genotypes from the cassava and wild species collections have been shipped to programs outside of CIAT in the past five years, requested either for their specific adaptation or for particular desirable traits.

The presence of virus and "virus-like" diseases of cassava has greatly hindered the introduction and distribution of promising cassava germplasm in Latin America, Asia and Africa. ~~The "frogskin" and "Caribbean mosaic" diseases of cassava in Colombia and cassava vein mosaic virus, which is widespread throughout the semi-arid region of Brazil, are the diseases considered to be of quarantine significance~~. The distribution and causal pathogens have been identified and diagnostic methods are now available. These methods are used at CIAT but have yet to be adapted for use by national programs; exchange of *in vitro* germplasm among continents is still a bottleneck due to lack of quarantine facilities. (of diseases of quarantine importance)

Future ~~Research Strategy~~ Directions

In the past, conservation and evaluation efforts have concentrated on cassava, with limited attention being paid to *ex-situ* or in-situ conservation and characterization of the crop's wild relatives. A broader conservation strategy is now envisioned, considering thoroughly both the genetic diversity of the primary gene pool, and valuable genes and gene complexes in other *Manihot* species as targets of conservation. Molecular markers are being incorporated into the germplasm evaluation process to obtain objective measures of genetic diversity. Through molecular mapping, we hope to develop markers for genes of interest which can be used to simplify the selection process. As mapping may reveal the genetic basis of quantitative traits, it is also likely that breeding methods may be refined according to the resulting knowledge. We may apply this strategy to the introgression of genes from wild species. Another facility of biotechnological research is the modification of the expression of existing genes in cultivated germplasm, or the introduction of foreign or synthetic genes. For this approach, basic understanding of specific biochemical processes critical to cassava development are essential.

Future research will stress improved understanding of the distribution and structure of genetic diversity among cassava's genetic resources, toward the development of sound conservation and use strategies. An important component will be improved global communication around germplasm issues among curators and disciplinary scientists, geographers and biotechnologists to accomplish this large task efficiently. ~~In collaboration with IITA and the Genetic Resources Network, more attention will be given to the conservation of African germplasm and assessment of the genetic base of cassava in Africa.~~

The culmination of several years of germplasm screening by the Cassava Program and our partners have identified specific useful genetic variability in important quality characteristics and for adaptation to biotic and abiotic constraints. Biochemical and molecular techniques and specially constructed genetic stocks will be used to generate knowledge on the mechanistic and/or genetic control of essential traits for practical use in cassava improvement. Resistance to white flies, African cassava mosaic virus, cyanogenesis, and photosynthetic efficiency under conditions of drought or temperature stress are among traits in the best position to utilize these approaches. Collaborative research ~~will be undertaken~~ with ORSTOM, France, toward studying the genetic diversity of the bacterial blight pathogen, *Xanthomonas campestris* pv. ~~*Manihotis*~~ in the center of diversity of cassava. This will relate to the effective development and deployment of resistant germplasm.

Integration across programs at CIAT is promising in the areas of genetic diversity and molecular biology, where concepts and research technologies are not commodity specific, and may in fact cross-feed each other. Integration across Centers may also be beneficial, particularly in devising strategies for germplasm conservation. Relatives of various crop plants may share eco-geographical sites of origin, rendering them conducive to coordinated, collaborative study, and crops with similar mating strategies (such as vegetatively propagated roots and tubers) may share biological principles relevant to conservation strategies.

~~During the next five years~~ the cassava collection will be expanded to fill gaps in current eco-geographic representation, and it will be safely conserved in two additional institutes and under cryopreservation. Better *ex-situ* representation of cassava's wild relatives will be sought, with accompanying knowledge of their ecological provenances and particular adaptive features. Changes in genetic diversity at the field level will be documented, and *in situ* conservation considered. The molecular map of cassava is the first to be constructed at a CG Center, its use will be a short term milestone for CIAT.

(2) ~~Gene pool development~~

~~Historical Assessment~~

The ~~Program's~~ selection scheme has been based on the subdivision of ~~the~~ cassava growing environments into different agro-ecological zones: Sub-humid tropics, acid soil savannas, humid tropics, mid-altitude tropics, highland tropics, sub-tropics and semi-arid tropics. Gene-pools for each of these ecozones are enhanced by the recombination of selected parental material after the evaluation in representative environments where the principal traits of interest are consistently expressed at levels appropriate for selection. Recognizing that wide variation for edaphoclimatic conditions and end product uses exist within each zone, the enhanced genetic variability is taken by national programs and selected and adapted to local needs.

During the last five-year period, gene pool development activities for different agro-ecological zones has resulted in considerable gains when comparing selected genotypes with the best local and/or released cassava varieties. The percentage gain in terms of dry matter production per hectare was: 45% for sub-humid lowland tropics, 40% for acid soil savannas, 70% for mid-altitude tropics, 90% for highland tropics, 12% for the sub-tropics and 46% for the semi-arid tropics. Considering the relative importance of the different ecosystems and that the heritability of the trait is estimated at 40% on average, the selected material could potentially increase the productivity of cassava across ecosystems by 19%.

These gains have been achieved by evaluating 3,000 germplasm accessions and 150,000 hybrid clones for all the ecosystems. From these evaluations, 112 elite clones have been selected and used as parents to generate segregating progenies from which to initiate a new selection cycle. The elite materials have also been placed *in vitro* for their transfer to homologous ecosystems in Latin America and Asia. A total of 600,000 recombinant seeds were introduced to different cassava producing countries on the three continents. This infusion of germplasm represents an increase in the existing genetic base beyond the genetic diversity already existing in Africa and Asia.

A total of 17 varieties, derived directly from CIAT's gene pools or having CIAT's materials as one of the parents, have been released in Asia and Latin America since 1989. These new varieties are covering an area close to 200,000 hectares in Asia and 60,000 in Latin America. The impact from these new varieties is probably at the beginning of the exponential phase. Slow multiplication rate and the almost total absence, particularly in Latin America, of well organized cassava multiplication systems hinders the rapid diffusion of improved varieties. It is expected that measurable impact will be significant during the coming 5-year period.

A total of 251,744 recombinant seeds have been introduced to IITA for evaluation and selection in different agro-ecosystems, expanding significantly the genetic base for cassava breeding for the semiarid tropics, highland tropics, humid tropics and the sub-tropics of Africa. The joint evaluation by IITA and CIAT of this germplasm has resulted in the selection of 33 clones with good adaptation to African semiarid conditions.

One of the major constraints to adaptative breeding and cassava varietal diffusion is the lack of appropriate mechanisms for understanding farmer, processor and consumer perceptions regarding the acceptability of new cultivars. During the last 5 years, major emphasis has been placed on the development of a model for the evaluation of cassava varieties with the participation of farmers. Important feed-back from farmers has been gained in Colombia and Brazil using this methodology. It also resulted in improved opportunities for varietal diffusion. This work is now concentrating on training national program researchers in the use of the model and its adaptation to differing conditions.

Reduced personnel and operational resources have limited the study and implementation of alternative breeding methodologies that could boost the genetic progress and the efficiency of cassava breeding programs throughout the world, and at the same time complement the efforts being made on the development and application of new tools.

During this period, the support for implementing different methodologies for planting material multiplication at national program level was discontinued when CIAT's Seed Unit was phased out in 1992. Although the Program itself took the responsibility to continue that support, that activity was cancelled in 1994 as a result of budgetary restrictions.

Greater emphasis is now being placed on ~~given to~~ gene pool development for semi-arid and sub-tropical agro-ecosystems through a ~~special~~ project being implemented together with the Brazilian national program. ~~and funded by IFAD, Rome~~. For the semi-arid tropics, drought and mite resistance materials have been evaluated. Additional criteria have been incorporated into the selection scheme following basic studies conducted on the physiological basis of drought tolerance and nutrient use efficiency. Breeding activities for the humid tropics, sub-humid (including savannas) and highlands (including mid-altitude) have been maintained. For all ecosystems, greater attention is now placed on the enhancement of starch content and the selection ~~reduction~~ of low cyanogenic potential materials.

Over the past 5 years, ~~During the last 5-year period,~~ the Latin American and Asian breeders' networks have been consolidated as the most important mechanism for germplasm and information exchange with national program counterparts (Kawano, 1995). Network activities have been important for the strengthening of the relatively weaker Latin American national programs. In Asia, China and Vietnam, two countries with which we had little prior experience of cooperation, have received priority attention.

Future Direction ~~Research Strategy~~

The process of developing broad based gene pools from which national programs will select varieties for release to farmers is a long term endeavor. A breeding cycle at CIAT takes 8 years, and once the recombinant seeds or elite materials are introduced to national programs, it can take up to 10 years to select and release a cassava variety to cover an area of 1000 ha. Although major shifts in the ongoing process are not anticipated for the next five years, there will be refinements to further stratify and target the gene pools to the particular needs of the intermediate and end users of that germplasm. The available genetic diversity, the representative sites where the germplasm is evaluated and selected, and the recombination process will ensure that a 25% increase over the most elite germplasm available today, could be realized under farmer's conditions by the end of the next 5-year period. ~~In order to improve the efficiency of gene pool development, a cycle of inbreeding will be implemented in between two cycles of recombination. This method ensures an extensive elimination of deleterious recessive alleles, normally carried in heterozygous condition.~~

Marker-assisted selection of parents and segregating progenies will be implemented particularly for those traits that require expensive, destructive and time-consuming screening methodologies, and for those needing particular conditions for their expressions (i.e. selection of resistant germplasm to ACMV carried out at CIAT without the need to introduce the virus to Latin America).

The improvement of micronutrient and vitamin content (particularly vitamin A) and the extension of storage life for cassava roots are research lines recently initiated and could bring global benefits for the people who grow and consume cassava (Iglesias et al., 1996).

Conventional approaches to cassava improvement have not yet been exhausted in bringing the crop to its potential in terms of adaptation, productivity and tapping existing and future markets. However, there are challenges that go beyond ~~what the~~ have not conventional approaches are able to handle, and if successfully achieved, ~~would~~ will have global significance in terms of how the crop is grown, processed and consumed. These challenges will require a major investment and dedication from a network of collaborators. During the next 5-year period it is expected that a reliable protocol for cassava transformation will be available. This will be an important component of an integrated approach to solving some of those breeding challenges. The following appear to be the most important challenges where biotechnology can make its greatest contribution: a) acyanogenic cassava and its biological and utilization consequences; b) qualitative improvement in the potential for post-harvest storage; c) modification of starch characteristics for specialized markets; d) coupling an increase in tolerance to stress with mechanisms for protecting fragile environments; and e) overcoming several of the constraints associated with vegetative propagation, through the development of a seed-propagated cassava crop, preferably through apomixis.

Integrating crop management components for sustainable cassava production systems

(3) ~~Integrated crop management~~

Major achievements

<u>~~Historical~~ Assessment</u>

Small-scale farmers grow most of the world's cassava crop over a broad range of tropical environments, often on fragile or poor soils, under rainfed conditions, and in areas where resources are limited. The Cassava Program, since its inception, has addressed this situation by ~~continual~~ undertaking strategic and applied research in crop management, including pest and disease management. Crop management technologies and recommendations are ~~continually being~~ designed for the major agroecological zones, previously described in this document. Research has shown that each ecological zone often requires a unique package of management practices to obtain optimal yield. Crop management technologies generated include the production, selection and treatment of planting material; proper land preparation; the adequate use of fertilizers; the use of mixed cropping, rotations, and cover crops; biological control of pests and diseases; the use of ecosystem adapted varieties, with resistance to major biotic and abiotic stresses; and soil conservation and fertility maintenance practices.

Extensive and continued research over two decades have identified and characterized the most important biotic constraints associated with cassava in the major ecosystems where the crop is grown. A constraint assessment exercise carried out by the Cassava Program in 1993, based on field and research data, indicate that average yields could be increased by 25% globally through the effective control of arthropod pests and diseases.

Arthropods are primarily pests of cassava in seasonally dry or semi-arid agroecosystems. Major pests include mites, mealybugs, whiteflies, lacebugs, the cassava hornworm and burrowing bugs. ~~During the last five years,~~ Natural enemies for biological control of mites, mealybugs, burrowing bugs, and the cassava hornworm have been identified and many have been extensively studied in the laboratory and field. The mealybug parasite *Aenasius vexans* was found in Venezuela and has been released in Colombia where it has become established and has decreased mealybug populations in the ~~Llanos~~ Eastern plains. Three key parasite species are being introduced into N.E. Brazil for mealybug control. The collaborative effort between CIAT and IITA for mealybug control continues and a new predator from Colombia was released recently into cassava fields in Africa.

Extensive surveys for natural enemies of the cassava green mite in 12 countries have been conducted. Methodologies for culture, packing and shipping have been developed; ecological and biological characterization of predatory mites, coleopteran predators, and the fungal pathogen, *Neozygites* sp. is being advanced. Ten species of predatory mites have been introduced into Africa via IITA, and three species from Brazil have become established.

Effective biological control of the cassava hornworm, a migratory lepidopteran, is based on a hornworm-specific baculovirus, which can be formulated into a spray by very simple technology. The timing, application frequency, optimal concentration, effects of prolonged storage, and field duration of the virus spray have been determined. Successful field application of the virus has been achieved in S. Brazil, Colombia and Venezuela, where in one large plantation pesticide costs were reduced by US$50,000 per year. In Southern Brazil it is estimated that virus application reduces pesticide use by 60%.

HCN production is a known defense mechanism to arthropod pests in many plant species. Its role in cassava is being defined. High cyanogen potential in cassava roots is shown to be detrimental to the development of the burrowing bug (Cyrtomenus bergi), causing considerable mortality.

The integrated control of several diseases including root rot pathogens, cassava bacterial blight, superelongation disease, and the mycoplasm or witches' broom disease have received priority. Root rots constitute a major source of yield loss in cassava, and their incidence is increasing in Latin America. Root rots are caused mainly by species of *Phytophthora, Pythium* and *Fusarium*. Integrated control of these pathogens include planting on ridges, intercropping cassava with corn or sorghum, use of pathogen-free planting material, elimination of affected plant debris after harvesting, and the use of genetic control. The use of biocontrol of root rot diseases using *Trichoderma* as a biofungicide is also promising. A set of technical recommendations consisting of the use of host plant resistance and several cultural practices has increased yield by as much as 300% in the Pivijay area of Colombia, and as high as 80% in the Varzea region of the Amazon, Brazil.

Several cultural practices have proven to be effective in the control of the cassava bacterial blight disease in tropical environments. Intercropping and crop rotation together with the use of pathogen-free planting material provide the highest reduction in incidence and severity of this disease. The implementation of these integrated control practices in Brazil and Colombia has provided control of this disease as well as in the severity and incidence of the superelongation and the mycoplasm witches' broom diseases. Corrective application of potassium to K-deficient soils has also been found to reduce superelongation disease and increase cassava yields.

The confirmation of the existence of beneficial endophytes or microorganisms able to grow inside cassava tissues without inducing visible necrosis opens the possibility of increasing biomass production by direct application of these endophytes to plantations or by inducing indirect plant protection against detrimental parasites. The treatment of planting material with these beneficial microorganisms, reestablishes yield stability of meristem culture-derived plants and controls root rot diseases.

(Empresa Brasileira de Pesquisa Agropecuaria)

A CIAT/EMBRAPA four year integrated pest management pilot project, ~~financed by UNDP~~ is in progress in N.E. Brazil. The project focuses on farmer-participatory selection, integration, testing and adaptation of cassava pest and disease management practices at the farm level. This project includes the incorporation of entomology, acarology, pathology, virology, soil conservation and management, and weed control technology components, as well as the use of improved germplasm. This project is also linked to IITA and four west African countries primarily through the introduction into Africa of cassava green mite natural enemies. Cassava green mite predators and mealybug parasites are presently being introduced into Brazil from Colombia, and released in cassava fields.

In the area of crop-soil management, the Program has increased its attention to soil fertility maintenance and erosion control through research in representative ecosystems in both Latin America and Asia. In Colombia, the long-term response of cassava to fertilizer application indicated that reasonable and sustainable yields could be obtained on infertile soil with moderate levels of K fertilizer, and to a certain extent P fertilizer. No response to N was observed, provided that soil organic matter was high. In sandy soils with low organic matter, sustainable cassava production requires application of NPK fertilizer.

These results are being corroborated in Asia, where soils are low in organic matter and nutrients. In short-term NPK trials in several Asian countries, cassava has shown a marked response to N application but little response to either K or P. Green manures, particularly of legumes, and application of surface mulch of crop residues, were beneficial in improving soil fertility and hence crop productivity. In addition to these cultural practices, screening cassava germplasm for adaptation to acid and infertile soils (i.e. low in P and K) have revealed the potential for identifying and selecting genotypes with good level of acid soil tolerance and greater nutrient use efficiency. These genotypes are incorporated as parental materials in the development of improved germplasm.

Research on soil conservation practices for hillside or upland cassava-based cropping systems has continued both in Colombia and several Asian countries. This work focuses on the identification and evaluation of appropriate technologies which include forage legume green manure crops, grain legume intercrops, mulch of weeds and crop residues and the planting of live barriers. Results on both continents have shown that soil erosion in cassava-based cropping systems can be greatly minimized by cultivating cassava in contour ridges, with grass barriers, or by *in situ* production of mulch by inter-planting cassava with green manure species. Agronomic practices that result in rapid canopy closure, such as the use of appropriate genotypes, application of fertilizer in poor soils and closer spacing, also reduce soil loss.

These research efforts on soil conservation are currently continuing in Colombia. ~~with the financial support of BMZ, Germany~~. On-farm evaluation of soil conservation practices are being conducted on three different locations on hilly lands in the Cauca Department in collaboration with farmers' communities, NGO's, national agencies and CIAT's Hillsides Program. In Asia, a five-year soil conservation and management research project in collaboration with several Asian national programs was initiated in 1994. ~~with the financial support of the Sasakawa Foundation of Japan~~. The project focuses on the development of a farmer participatory methodology for the selection, testing and adaptation of management practices that are most appropriate under the local physical and socio-economic conditions.

Future ~~research strategy~~ [directions]

Strategic research on pest and disease management will continue to focus on low-input environmentally-sound technologies that will avoid the use of pesticides.

Arthropod pest management will concentrate on the selection of cassava varieties resistant to major pests (mites, whiteflies and lacebugs) and the identification and evaluation of natural enemies of key pests (mites, mealybugs, hornworm and burrowing bugs). Biological control of the cassava green mite in N.E. Brazil and Africa will involve foreign exploration based on analysis of prior geographic surveys. Candidate natural enemies will be evaluated in the laboratory for suitability for foreign establishment. Field experiments will be used to improve methods of establishment and conservation of mite predators. More emphasis will be given to the burrowing bug *Cyrtomenus bergi* and the role of ~~HCN~~ [cyanogens] as a defense mechanism in cassava.

Research on the integrated control of cassava bacterial blight and root rots will continue with particular emphasis on determining the feasibility of employing biological control at the field level. The actual role and possible deployment of beneficial endophytes will also be investigated in further depth. Following the characterization of cassava vein mosaic virus and the determination of the epidemiology of this disease, integrated pest management solutions will be developed.

Research in crop-soil management in cassava-based production systems will focus on the seasonally dry and semiarid ecosystems where cassava production is expanding due to continued food shortage in many marginal environments in South America, Africa and Asia. The Program is currently active in seeking additional funds to support these research activities. ~~Work for Latin American hillside ecosystems will continue within the on-going interprogram project~~.

The two major ~~special~~ projects that are under execution in Brazil (IPM) and Asia (integrated crop-soil management), which both seek to develop farmer participatory methods for designing options and adapting appropriate technological solutions to biotic and abiotic constraints, ~~will both run for the greater part of the next planning period. The information generated and results of these projects will be instrumental in providing feed back which~~ will help determine future research directions. ~~As the Hillsides and Tropical Lowlands Programs reach greater definition with respect to opportunities for integrated crop management in cassava-based systems in their pilot study areas, it is expected that collaboration with these two Programs will increase through the formulation of additional interprogram projects.~~

(4) Cassava markets

Historical Assessment

~~Early in the history of CIAT's Cassava Program it was recognized that~~ research on process, product and market development is key to maximising the crop's true potential as a source of additional income for small- to medium-scale farmers. This is especially true in situations where the role of cassava is changing from being a rural staple to a multipurpose carbohydrate source. CIAT has concentrated its research effort on the development of technologies for the small-scale primary processing of cassava into (a) dry chips for the animal feed market, (b) cassava flour for the food industry, (c) cassava starch and (d) the conservation of fresh cassava for human consumption.

~~At the beginning of the period under review,~~ research on dried cassava for animal feed was phased out. The commercial expansion of dry cassava chip production, introduced by CIAT in collaboration with the Integrated Rural Development Fund on Colombia's Atlantic Coast in the early 80s, had reached a self-reliant and autonomous growth phase. The Program has continued to provide technical support to national programs that have research on cassava drying for animal feed, notably Ecuador, Brazil, Paraguay and Bolivia.

In 1992, research on the conservation of fresh cassava was terminated. Pilot scale testing in the city of Barranquilla, Colombia, demonstrated the technical and economic feasibility of the storage technology developed by CIAT and NRI. Problems of urban distribution and farmer organization prevented large scale adoption of the storage technology although market intermediaries have adopted certain aspects of the handling and packaging recommendations. The technology is being used commercially by one cooperative in Colombia, has been successfully pilot-tested in Paraguay and is now under validation in Ghana.

The project to develop high quality flour for human consumption has passed from the pilot phase to semicommercial operation of the processing plant established by COOPROALGA, a farmers' cooperative on the Atlantic Coast of Colombia. Market studies, including industrial trials of the flour, have demonstrated that cassava flour can find market niches in both food and non-food applications where it has either price or quality advantages over flours and starches from conventional sources (e.g. wheat and maize). The cassava flour processing technology is being employed in Ecuador by the Union of Cassava Farmers in Manabi province and five plants are being installed in different sites in Peru.

A joint research program with CIRAD-SAR, Montpellier, on cassava starch started in 1989 focusing primarily on sour or fermented starch. Evaluation of existing traditional small-scale production units in Colombia identified areas for process improvement to reduce losses and improve product quality. Following on-site evaluation of process improvements, these have been transferred successfully by national institutions to processors in Colombia, Ecuador, Paraguay and Honduras. The "self raising" characteristic of sour starch has been found to be unique in terms of conferring expansion properties to bakery products. This cassava starch characteristic could open up important niche markets in dietary and gluten-free products.

Based on 10 years experience of postharvest research, the Program has defined a four stage methodology for cassava product, process and market development, comprising identification of opportunities, lab and prototype research, pilot scale testing and expansion to commercial scale operation. In collaboration with CIP and IITA, this methodology has been developed in the form of a manual for use by root and tuber postharvest research practitioners. The draft manual was reviewed by national program partners in workshops held in Latin America, Asia and Africa, to incorporate their experiences, and ~~will be~~ published. ~~shortly~~.

~~The Program initiated plans at the end of the 80s to increase its postharvest activities in S. and S.E. Asia. Given the relatively greater emphasis and investment in the development of postharvest technologies for root and tuber crops in this continent, the focus of CIAT's interventions was to improve the communication among workers in the postharvest area and enhance the transfer of technologies and experiences between countries.~~ Cassava utilization was a principal theme of the 3rd Asian Regional Cassava Research Workshop held in 1990, which was followed in 1991 by a workshop on Product Development for Root and Tuber Crops held in collaboration with CIP. ~~Since then, resource restrictions have limited our activities to evaluating the impact of the development of the cassava flour industry in Indonesia.~~ In 1994, a joint project with CIP ~~has been~~ initiated in N. Vietnam to identify and develop with national institutions opportunities for improved processing of cassava and sweet potato in four distinct regions where these crops are important sources of food and cash income.

A three-year multinstitutional project, financed by the E.U., is now in execution, whose objective is to develop new products and markets for cassava in Latin America. CIRAD-SAR is the lead institution. CIAT, NRI, ORSTOM, the University of Valle, Colombia, the State University of Sao Paulo, Brazil, the University of Buenos Aires, Argentina and the National Polytechnic School, Ecuador, are participants. The project has five research areas: raw material/product quality relations, waste treatment, bioconversion of starch and flour, new product development and market studies. CIAT is involved in research on raw material/product quality relations and is the coordinating institution for the market studies.

Future Research Strategy

(Consultative Group for International Agricultural Research)

The Cassava Program's incursion into the area of postharvest processing and marketing at the beginning of the 80s was virtually unique within the CG system at that time. The adoption of a demand led or market driven philosophy to process and product research and the successful hands-on experience obtained through collaborative projects with national institutions in Latin America is now internationally recognized and the approach has been adopted by other research and development institutions involved in rural agroindustrial development, among them CIP and IITA. However, with the exception of conserved fresh cassava for human consumption, the products of primary cassava transformation have a relatively low value especially when sold into existing markets. The long term economic sustainability of small- to medium-scale rural agro-processing will therefore increasingly depend on both product and market diversification. The question therefore arises as to the extent to which CIAT should actively encompass the development of second generation products from cassava.

CIAT will seek to strengthen its

The strategy that has been adopted and that will be pursued in the next five years will rely on the strengthening of links with food science and technology research institutions in both developed and developing countries that have the infrastructure and human resources to undertake collaborative cassava product development research. The Cassava Program's core competence contribution to these projects will lie in three areas:

(a) the identification, economic evaluation and development with national programs of market opportunities;
(b) research on the relationship between raw material quality characteristics and the physico-chemical and functional properties of cassava products; and
(c) support at the national level to the integration of process and product research with market demand and consumer research.

Plans are already laid to support IITA in the development of a regional postharvest program for East and Southern Africa and it is hoped to build on the experience of the joint project with CIP in Vietnam, extending collaboration to other countries such as the Philippines, Indonesia and India in the future.

In early 1994, representatives of CIAT, IITA, CIP, NRI, ORSTOM and CIRAD-SAR agreed to initiate a dialogue with the objective of achieving a greater degree of communication and complementarity in their respective root and tuber postharvest R and D programs. Bilateral and even trilateral projects among these institutions are already in execution and others are in the pipeline. However, in the past there has been no attempt to identify, as a group, common areas of interest and gaps in our knowledge which could lead to a more coherent and effective deployment of the collective resources of the individual institutions. The first meeting of this group will be held in Salvador, Bahia in November, 1994.

Within CIAT, the Cassava Program's experience in market opportunity identification and assessment of processing options will be an input to a wider cross program proposal involving the Hillsides and Tropical Lowlands Programs. The purpose is to identify in the pilot study areas agroprocessing activities that will create additional income generating activities, thus providing farmers with an incentive to invest in resource conserving technologies.

(5) Institutional development

Historical Assessment

The Cassava Program is part of a global cassava R and D system made up of a wide range of institutions. The effectiveness of our work relies upon the building of strong relations with our partners in the system. This is a two-way process. We need to draw on their knowledge and expertise to help formulate our strategies and, conversely, we have the opportunity to support them in making best use of the products of our research. Traditionally, CIAT has been instrumental in providing information services and training, acting as a convener for professional interchange and a catalyser of collaborative initiatives, and assisting in network formation and operation.

Needs assessment and priority setting has been a major area of concern, both within the Program and among our partners. We were involved in the design and implementation of the first phase of the Collaborative Study of Cassava in Africa (COSCA) and, in Asia, the Vietnamese and Chinese national programs have been supported in the organization and analysis of cassava sector studies. These studies provide information for the formulation of national cassava research plans and feed into a global needs assessment and priority setting exercise that the Cassava Program is undertaking within the framework of the Cassava Biotechnology Network (see below).

The Program has directly participated in the formulation and execution of Integrated Cassava Research and Development Projects (ICRDP) in Manabi, Ecuador, and Ceara, Brazil. Interchange of information and experiences on the ICRDP methodology has been achieved in three regional meetings (1990, 1991, 1992) with participants from seven Latin American countries. The projects have proved to be an important inter-institutional mechanism for achieving closer links between research and development activities, an integration of production, processing and marketing components and a targeting of benefits towards cassava farmers and processors. Adoption and impact studies conducted to analyse both on-farm and region effects of the Colombian ICRDP have shown very favorable rates of return over a 10-year period. ~~Staff reductions in the areas of Agronomy and Utilization have limited the Program's ability to extend the ICRDP methodology more widely~~.

A major investment was made in setting up a Southern Cone Cassava Development Network involving S. Brazil, N. Argentina and Paraguay. A "training of trainers" project successfully completed the formation of a group of 22 trainers from this network and the production of six learning units on principal cassava production and utilization topics. The elimination of the Latin American agronomy position in 1992 has restricted CIAT's ability to provide support to this initiative and to catalyse similar networks on the Andean and Central American and Caribbean regions.

Networking activities in Asia have been consolidated with the establishment of a regional Advisory Committee made up of country representatives. This consultative and regional planning mechanism was instrumental in securing funding for the integrated crop-soil management project. The 3rd and 4th Regional Network workshops were held in 1990 and 1993. Both reviewed progress in breeding and agronomy with utilization research (1990) and technology transfer (1993) being theme areas that received special attention.

The Cassava Biotechnology Network (CBN) became operative in 1992. CBN seeks to integrate biotechnology into inter-disciplinary research of national programs of cassava growing countries. It supports needs assessment research with the objective of prioritizing biotechnology research towards providing solutions to the principal constraints of small farmers and processors, promotes collaborative research and facilitates exchange of information on biotechnology. CBN has held ~~two~~ three scientific meetings, in Cartagena, Colombia (1992), ~~and~~ in Bogor, Indonesia (1994), ~~A third is planned for~~ and in Kampala, Uganda (1996).

The biennial "Cassava Newsletter", published since 1977, keeps cassava workers in touch with each other and informed about a broad range of topics. Since 1991, the newsletter has been produced jointly with IITA. The publication "Abstracts on Cassava" has been discontinued and replaced by a more focused and targeted "Bibliographic Bulletin" that gives priority coverage to gray or non-conventional literature on cassava not widely diffused by commercial data bases.

Centerwide reductions in Institutional Development Support (IDS) since 1992 have led to a significant decline in the number of national program scientists receiving training and a consequent reduction in contact with those that can provide us feedback to orient our work.

Future strategy

The extent to which the Program will be able to maintain or extend the type of activities described in the previous section will depend largely on the success that we together with our partners have in attracting complementary funds for collaborative projects at the regional and global levels. Attention will therefore be given to mobilizing national program support and their demand for the services that CIAT and the Cassava Program can offer so that these activities can be included within both bilateral and multilateral project proposals. Indications are that there will be increasing contact with the private sector, including both small and large processing industries and NGOs who provide technical assistance to the small farm sector.

New initiatives that are at present being discussed include (a) the transfer of the ICRDP methodology to Africa in collaboration with IITA, NRI, CIRAD-SAR and ORSTOM and (b) the formation of a Root and Tuber Crop Network for Central America and the Caribbean in collaboration with CIP, IITA, CATIE and CARDI. CIAT's role as the convening center for ecoregional research in Latin America should greatly facilitate obtaining consensus around national needs in the area of institutional development. In Asia, it is conceivable that, in the medium term, it may be possible to attract resources through a consortium approach similar to the one being developed for rice in Latin America with strong participation of the private sector.

3. CONCLUDING REMARKS

The complexity of the issues that need to be tackled to achieve sustainable agricultural development, especially in the socioeconomically more marginal regions, is substantial. Realizing the true potential of cassava as a vehicle for this development is no less complex. However today, perhaps more than at any time in the past, there is a greater understanding of how this potential can be achieved. CIAT's Cassava Program is confident that it can continue to ~~provide intellectual leadership~~ within a global Cassava R and D system. We know that ~~this leadership~~ role depends on the credibility that we earn through striving for and achieving excellence in our research. Experience has shown us that, in order to meet this goal, we must adhere to two fundamental principles:

(1) Interinstitutional partnerships and links, based on mutual respect and complementarity, are vital for maintaining the relevance of our research.

(2) Interdisciplinarity and an integrated commodity system perspective are critical requirements that ensure a correct prioritization of research issues.

These principles underpin the Program's efforts to ~~fulfil its global responsibilities and~~ to ~~serve~~ the cassava R and D community, especially those who depend on the crop for their livelihood.