A Regional Initiative for Integrated Pest Management in Latin America and the Caribbean:

How CIAT Can Contribute

Prepared by the Pest and Disease
Management Scientific Resource Group

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Executive Summary

Integrated pest management (IPM) is a central part of CIAT's new initiative in resource management research and one of its main contributions to sustainable agricultural development. IPM helps increase crop production, maintain biodiversity in farming systems, prevent ecological damage, and reduce human health risks from chemical pest control.

Since IPM programs must be tailored to specific cropping systems, their development is ultimately a local affair. Even so, an international center can support this work by developing widely applicable component technologies and methods for assessing needs and implementing IPM. In some cases we can perform these tasks across commodities and thus gain significant economies of scale. We can also develop methods for integrating farmer participation into the diagnosis of pest problems and for strengthening training and extension.

CIAT's research capabilities in the pest control disciplines and related areas, such as biotechnology and the social sciences, are essential for promoting IPM. In support of this work, the Center will continue to conduct strategic research and develop component technologies, as it has done for many years. But increasingly, we will also use our position as an international center to serve as a bridge between advanced institutions in the developed countries and researchers in the developing world.

In Latin America and the Caribbean, we will play an even broader role. Cooperating with national and local institutions and using special-project funds, we will work closely with farmers, researchers, and others to implement IPM in specific areas of the region.

As an interdisciplinary activity, IPM does not fit neatly in any single administrative unit at CIAT. Instead, working through cross-program scientific resource groups, we will assess the needs in major agroecologies (using methods that draw on farmer participation) and design projects for implementing IPM. Pilot projects already underway—focusing on cassava in Brazil and on beans in the Andean zone—will serve as models for such projects. Thus, while using "core" funds (provided by the CGIAR system) to conduct strategic research and develop component technologies, we will extend the products of this work under projects supported by special funds and aimed at promoting IPM.

The Need to Promote IPM

Despite growing awareness of the hazards to human health and the environment, pesticide use in Latin America is increasing. By the year 2000, it is expected that the region will be spending US$3.97 billion on pesticides every year (Belloti et al., 1990).

Increasing pesticide use in the region results from important trends in demographics and agricultural development. The human population is growing and societies are urbanizing at a rapid rate. This, together with more aggressive exportation of agricultural commodities, puts growing pressure on farmers to increase the quantity and quality of output. Under these circumstances, farmers are extremely averse to risk, and there is a marked shift away from traditional small-scale farming toward more extensive enterprises characterized by mechanization, monoculture, and intensive use of agrochemicals.

In some instances integrated pest management (IPM) has significantly reduced pesticide use, and such cases can serve as models for the region. But to offset the powerful trends that account for increasing pesticide use, national research and development institutions, international centers, and donor agencies will have to place major emphasis on alternative management methods. To develop and implement IPM will require a significant and sustained commitment from all these actors.

Modern chemical pest control is a rare example of a technology developed in the industrialized world that can be readily transferred to developing countries in the tropics. More sophisticated techniques, in contrast, which involve economic thresholds, biological and cultural control, etc., must be developed for specific cropping systems. Even though the underlying concepts apply across continents and ecosystems, we must still devise unique component technologies for each agroecological niche. The medium- to long-term payoff to IPM is high. But it does require a significant initial investment in research, which may account for part of the difficulty in implementing IPM.

To promote wider application of this approach in Latin America, we need to stress its benefits for agricultural production, environmental protection, and human health. Another factor that should encourage IPM is increased integration of the region's agriculture with international markets, which enforce strict limits on pesticide residues in produce.

This paper describes the main features of IPM and discusses the role CIAT can play in promoting the adoption of this approach in Latin America as a principal component of sustainable agriculture.

What Is IPM?

Although we tend to see IPM as a new approach to controlling pests, farmers throughout history have used many of its components. There are numerous early examples in which these have controlled single pests in monocropping systems.

In our own time, IPM emerged as an alternative to applying chemicals on a calendar basis for pest control. With IPM the use of chemicals is carefully timed on the basis of "action thresholds"; these are population levels that result in significant damage to the crop and therefore warrant chemical control. Over the years we have developed increasingly sophisticated tools, such as crop and pest modeling, for developing IPM strategies.

Today, IPM is more than just an approach for reducing pesticide use. In CIAT's work, for example, it is a critical part of what we refer to as "integrated crop management." We also consider IPM a central element of our new initiative in resource management research and one of our main contributions to sustainable agricultural development. With reference to US agriculture, Edens (1985) notes that "IPM has been adopted as the basic foundation of the entire sustainable agriculture movement."

IPM encompasses a number of practices, including the use of pest-resistant germplasm, cultural practices, crop sanitation, and biological and chemical controls. All these methods have been used to reduce losses caused by pests, including arthropods, plant pathogens, and weeds.

Dent (1991) describes IPM as "essentially an holistic approach to pest control that seeks to optimize the use of a combination of methods to manage a whole spectrum of pests, e.g. weeds, pathogens and insects within a particular 'cropping system'." This definition, like many we could have cited, recognizes that IPM calls for an interdisciplinary approach to research, development, and implementation. This definition also implies that control methods must be derived from a large knowledge base. An important matter it does not address, however, is the need for farmers to participate from an early stage in the design and implementation of IPM programs.

IPM consists of two main steps: first, the development of control methods and, second, their integration into production systems. The result should be a nearly optimum combination of control components that maximize returns to the grower while minimizing the use and cost of environmentally damaging chemicals or practices.

A fundamental goal of IPM is to stabilize the production system, based on a thorough understanding of biological and human variables. A system in which pests are controlled by a single method is inherently unstable. In contrast, one involving several measures (chemical, biological, cultural, and genetic) can better respond to the evolving complex of arthropod pests and diseases and to changes in crop management. This system is therefore more stable and sustainable. It is not static, however, since IPM interacts dynamically with an evolving agroecology.

By limiting pest attack, effective IPM programs allow crops to realize their genetic potential more fully. By reducing the use of toxic agrochemicals and encouraging the adoption of ecologically sound agronomic practices, such programs can also contribute to human health, to the conservation of biodiversity, and in other ways to preservation of the natural resource base.

The Phases of IPM

For the purposes of designing and executing IPM projects, we divide the work into four phases, as shown in Figure 1 and described below.

1. *Problem and opportunity identification*—In this phase entomologists, phytopathologists, weed scientists, etc., work with social scientists to diagnose pest problems in a target area. The input of technical specialists is essential for designing the survey and interpreting the results. An important contribution of social scientists is to apply methods for gauging the needs and perceptions of farmers. The output is a detailed proposal for an IPM project.

2. *Research*—This phase generates component technologies, such as host plant resistance (HPR), biological and cultural control measures, and crop sanitation practices, for integration into the production system.

3. *Pilot project*—In this phase the project sets up a model system to evaluate component technologies and determine whether these can be successfully integrated into farmers' production systems. This evaluation must take into account technical, social, and economic considerations. The outcome is a study of the feasibility of implementing IPM over a wider area.

4. *Implementation*—The project promotes widespread adoption of IPM through training and extension in the target area. At this stage it is critical that an effective system be established for supplying IPM inputs, such as improved varieties, information

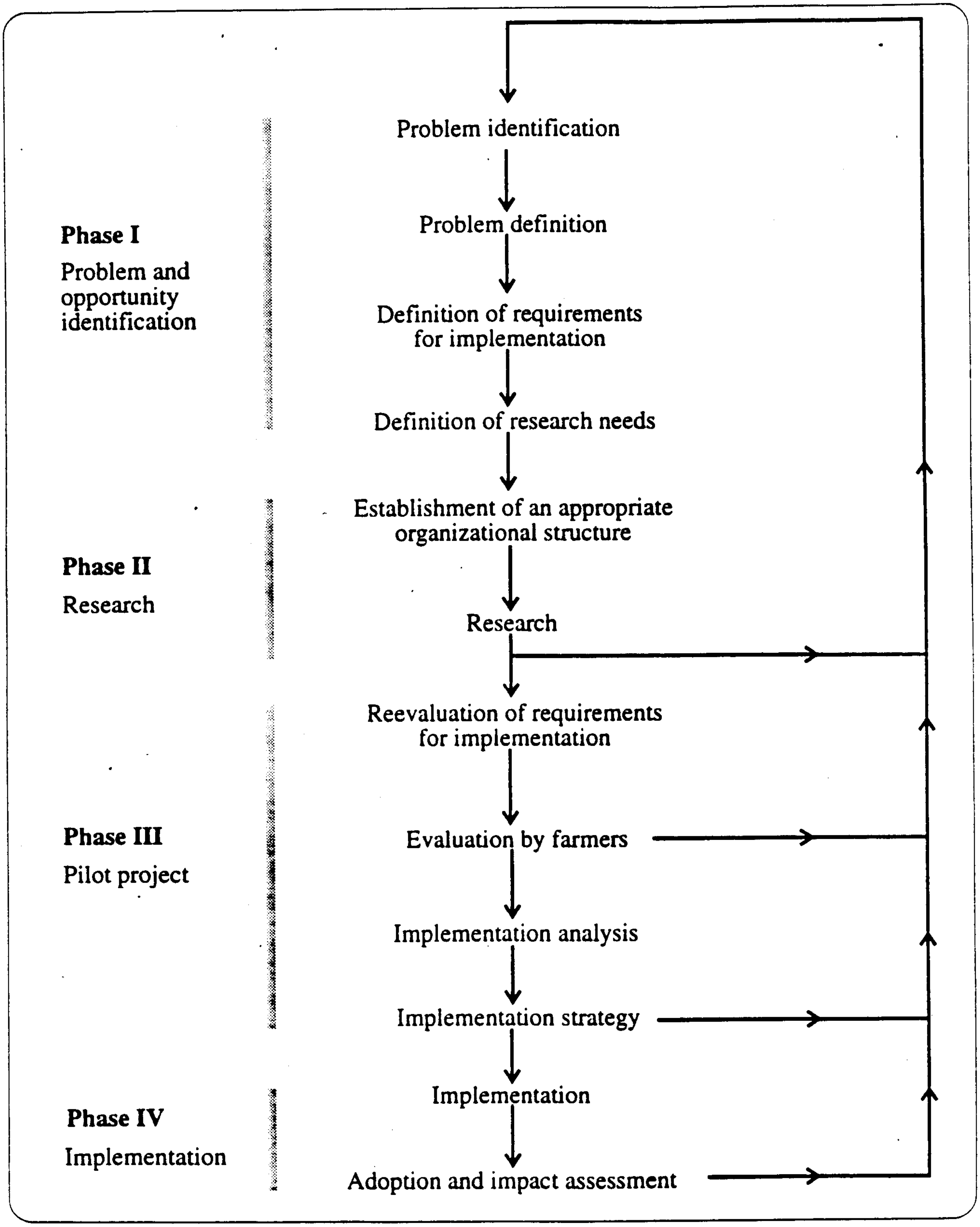

Figure 1.

Four phases in the development of an IPM program. Modified from Dent (1991).

systems, and natural enemies. This is also the time to resolve any institutional or policy issues (e.g., pesticide subsidies) that may affect adoption of IPM.

In the course of an IPM project, it is important to obtain feedback from farmers for validating the original definition of pest problems, guiding research, and shaping the implementation strategy. The four phases are not necessarily sequential. Phases II, III, and IV in particular may overlap.

Key Features of IPM

IPM, as outlined above, shows a number of key features, which we describe in more detail below:

1. *Specific to cropping systems*—IPM is specific neither to commodities nor to agroecologies but rather to cropping systems. Control programs that focus on a single crop and ignore associated species (e.g., beans with maize, rice with pastures, and cassava with cover crops) will miss important elements affecting pest dynamics. Similarly, IPM cannot be implemented uniformly across an entire agroecology, because each environment may encompass numerous cropping systems, each of which presents a unique pest situation. Thus, cashew growers in the savannas face different pest constraints from those of rice producers or graziers in the same agroecology.

2. *Integration of components*—To accumulate knowledge about individual pests and develop methods of controlling them does not constitute IPM in the strict sense. Using natural enemies to control a particular species, for example, or developing a resistant variety or guidelines for rational pesticide use does not, by itself, amount to IPM. These are merely *components* of IPM, which refers to the whole process of developing components (including agronomic practices, biological control in its many forms, host plant resistance, and chemical controls) and integrating them in cropping systems.

3. *A broad knowledge base*—IPM is impossible without detailed information on pest organism biology, ecology, epidemiology, population dynamics, etc. If cropping systems that depend on high levels of external inputs are to be replaced by sustainable systems that use the natural resource endowment more efficiently, farmers must increasingly exchange agrochemical inputs for knowledge and for more sophisticated components, such as biological controls (Figure 2). To bring about this transformation will require a significant investment in research. Moreover, policy makers, donors, and research administrators will have to recognize the importance of

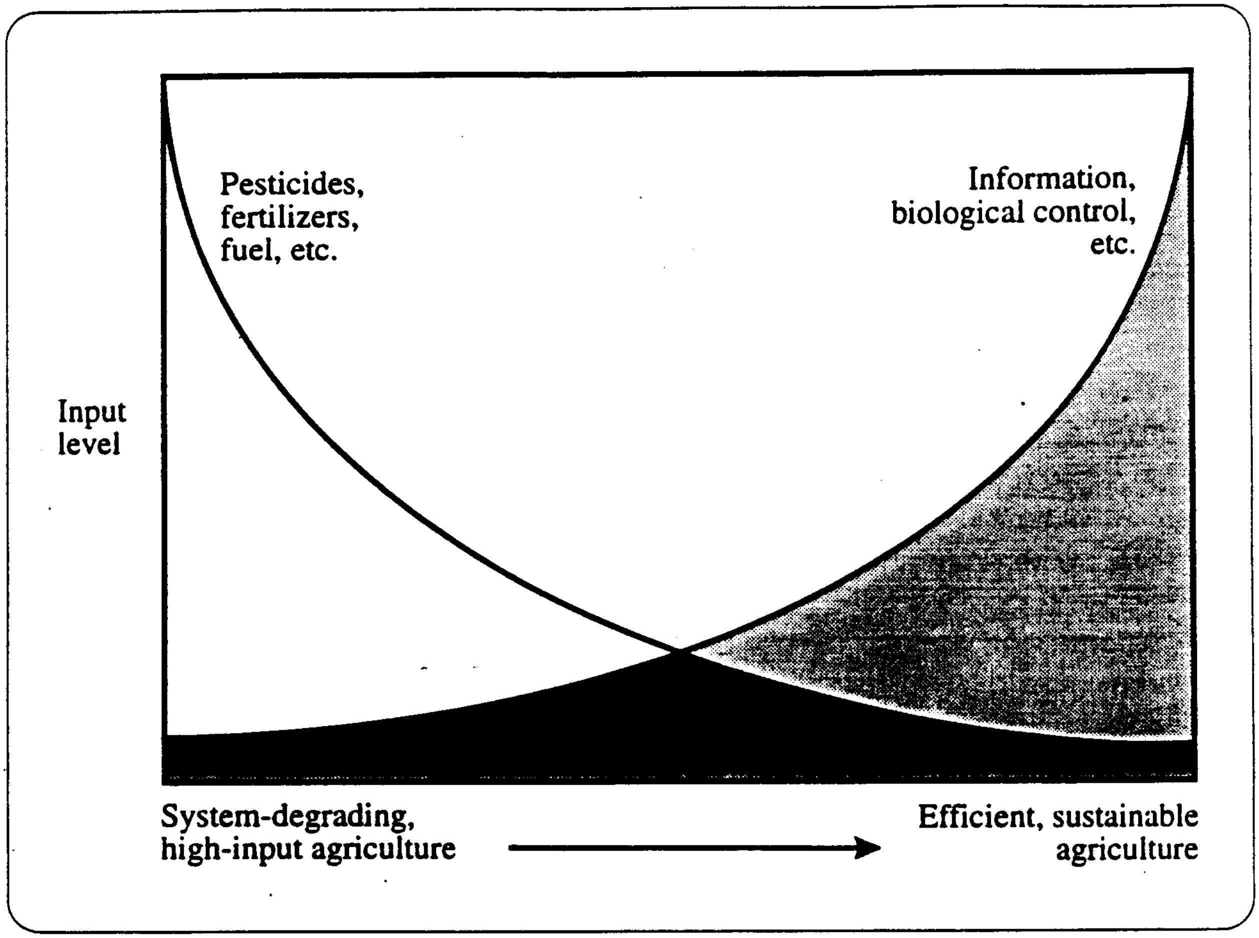

Figure 2.

As high-input cropping systems that degrade natural resources give way to sustainable systems based on IPM, farmers rely less on agrochemicals and more on other control methods and on expert systems for decision making (Stinner and House, 1988).

IPM for maintaining adequate rates of growth in agricultural production and for protecting the environment.

4. *Farmer participation*—Pest management methods can be technically feasible but unacceptable to farmers. For that reason communication between scientists and farmers is essential for successful implementation of IPM. In fact, one of its goals should be to establish permanent channels of communication, by which farmers can help determine research agendas (through a bottom-up approach) and provide feedback on the performance of technologies under realistic conditions.

5. *Flexibility*—The ideal combination of pest control and agronomic practices for a given group of farmers cannot be a static prescription or recipe. Such an approach ignores a fundamental property of biological systems, which is their ability to evolve in a dynamic environment. IPM practitioners must constantly monitor changes in these systems and be flexible in responding. The breakdown of a particular IPM component, for example, need not be seen as a failure but rather as the expected response of a complex biological system to selection pressures imposed on it by crop production. The best remedy is an IPM system employing the best combination of practices available, based on a thorough understanding of the production system, including both its biological and socioeconomic aspects. The exact combination of control techniques will vary by region, depending on socioeconomic factors, the availability of inputs, and the complex of pests present. Adapting IPM systems to particular regions requires continuous participation of farmers and extension personnel.

6. *Interdisciplinary cooperation*—Farmers are unlikely to adopt pest control measures that are difficult to handle and incompatible with other production practices. For that reason IPM researchers must communicate not only with farmers but with researchers working on other problems with the same crop or cropping system. In addition, they need to evaluate methods to control insects, pathogens, and weeds for their interactions with each other and for their ease of adoption by farmers. The ideal arrangement is for interdisciplinary teams, with specialists in the biological and social sciences, to focus on a common crop or cropping system.

7. *Interinstitutional cooperation*—To implement IPM effectively is beyond the capabilities of any single research or development organization working in isolation. To varying degrees national, state, and farmer organizations as well as NGOs must be directly involved to ensure that farmers in the target area receive enough institutional support and to ensure on-going promotion of the improved practices once a successful program has been developed and its feasibility demonstrated.

CIAT'S Role in IPM

Through its crop improvement work and it new initiative in resource management research, CIAT is addressing key aspects of sustainable agricultural development, one of which is IPM. If the Center is to play a major role in promoting this approach in Latin America and the Caribbean, we will need to extend our pest management research beyond its traditional concerns.

As an international center, we can contribute in many ways: by acquiring and documenting essential biological and socioeconomic information, by developing pest management components, and by devising widely relevant methods (e.g., for organizing farmer participation and assessing needs and opportunities) that facilitate the implementation of IPM.

Clearly, CIAT can do a great deal to promote IPM in Latin America and the Caribbean. The reason we should do this is that IPM will probably not be adopted widely without strong support at the regional level. Currently, there are only two regional actors in IPM, and they work exclusively in Central America. For the rest of the region, CIAT could take the initiative in designing IPM projects and attracting special-project funds.

As indicated in the appendix to this document, CIAT's commodity researchers are already engaged in a number of pest management activities. Here we outline ways in which the Center could contribute in each phase of IPM.

Phase I: Problem and Opportunity Identification

Methods for assessing needs in target areas—Sociologists, economists, and anthropologists should participate, together with pest management specialists, in assessing the needs of target areas. This is essential for accurately characterizing current practices, farmers' perceptions, etc.; for identifying key players in the region; and for ensuring that farmers participate and generate feedback. These activities are necessarily site-specific. CIAT can support them by providing training in methods for organizing farmer participation, in economic assessment of alternative practices, and in the IPM approach.

A bridge between developed and developing countries—Many institutions in the USA and other industrialized countries are interested in promoting IPM in developing countries. CIAT could help build links between those institutions and IPM researchers in the region. In this and subsequent phases of IPM, there is a clear opportunity for the Center to put experts from developed countries in contact with scientists who can benefit from their expertise.

Phase II: Research

Pest biology—Any IPM program will be severely handicapped unless it can conduct research on the basic biology, ecology, and epidemiology of pests and has access to tools from biotechnology. The information generated by entomologists, plant pathologists, and weed scientists working on specific commodities is essential for developing IPM components. CIAT already has these "tactical" research capabilities, along with a sizable knowledge base.

Host plant resistance—CIAT is a well-known source of finished lines and germplasm pools, from which adapted varieties can be selected. Appropriate germplasm resistant to pathogens and arthropod pests often provides effective control of major pests at no cost to farmers. Even if HPR is not effective against all major pests, improved varieties still provide a solid foundation on which IPM strategies can be built.

Biological control—CIAT can contribute importantly in various areas of this work:

- *Classical biological control.* This is the introduction of exotic natural enemies to control an imported pest. CIAT is one of the few institutions in the region that has a strong capacity for insect scouting, collecting, and rearing and can arrange for their shipment and release. A well-known example of this activity is the collection of cassava mite predators in South America and their introduction in Africa.

- *Augmentative biological control.* CIAT could take the lead in developing methods for using entomopathogens as biopesticides. Although at present we have only limited expertise in this area, we could gain access to more through mutually beneficial partnerships with other institutions. The Center could also make periodic releases of parasitoids or predators and conduct research on microorganisms, such as mycoviruses, fluorescent *Pseudomonas*, etc., that are antagonistic to fungal and bacterial pathogens.

- *Natural biological control.* This can be enhanced by reducing the use of broad-spectrum pesticides, which eliminate naturally occurring predators, parasites, etc. The most common alternative is to apply pesticides strictly according to action thresholds, based on a thorough knowledge of the biology of pests and their natural enemies (see rational pesticide use, below).

Biotechnology—In support of IPM, CIAT can apply the tools of biotechnology to characterize genetic diversity of pathogens, insect biotypes, and pest species; diagnose viruses; use monoclonal antibodies; and increase the efficiency of genetic enhancement, etc.

Rational pesticide use—Basing pesticide use on action thresholds is an effective means of minimizing pesticide expenditures, reducing environmental contamination and human health problems, and encouraging natural biological control. Farmers and pest control technicians are not likely to adopt this technique, however, unless they are closely involved in the research and design phases. To promote rational pesticide use requires extensive farmer participation. CIAT has developed methods for organizing farmer participation in other areas of research and will consider adapting them for IPM as well.

Agronomic practices—To integrate cultural practices for controlling weeds, pathogens, and pests with other agronomic practices requires interdisciplinary research. In key areas of the American humid tropics (such as forest margins), this research should focus on the development of agronomic practices for pathogen management, especially where HPR is not available. For example, cassava root rot can be controlled by a combination of resistant varieties, planting at the appropriate date, and chemical treatment of planting material. In rice production in the region's savannas, it has been shown that excessive nitrogen tends to increase the severity of blast disease.

Phase III: Pilot Project

Farmer participation—CIAT can train national extension and research personnel (particularly social scientists) to employ methods for organizing farmer participation in the adaptation and validation of IPM systems. Although current methods were developed primarily for varietal selection, we could modify them for the purposes of IPM.

Implementation strategies—The only way to gain expertise in implementing IPM is through repeated participation in IPM pilot projects. By taking part in a cassava IPM project in Brazil, for example, CIAT staff are learning a great deal about the institutional, technical, and socioeconomic factors affecting the integration and adoption of IPM components. We would like to be involved in additional projects of this type, covering different agroecologies and crop combinations.

Phase IV: Implementation

Monitoring, adoption and impact—Although CIAT should be an active member of IPM pilot projects in carefully selected target areas, it can play only a limited role in more widespread implementation of IPM. The most it can do at this stage is monitor continued use and modification of IPM methods in selected agroecologies. We should take a particular interest in the effect of government policies on adoption of IPM and in its impact both on crop production and natural resources.

In defining a useful role for itself as a regional promoter of IPM, CIAT will need to obtain feedback from programs implementing this approach. As we gain additional experience, we will be even better positioned to provide training (both at our headquarters in Colombia and in other countries where we work) in all aspects of the work, including research techniques, farmer participation, assessment of adoption and impact, and appropriate methods for implementing IPM in the region.

The Future of IPM at CIAT

Over the next decade, CIAT expects to contribute significantly to sustainable agricultural development in Latin America. If IPM is to be a major part of our effort, we will need to go well beyond the development of component technologies in our traditional areas of expertise (such as germplasm improvement). The Center must take an integrated approach, involving assessment of pest problems and the development and implementation of IPM systems. In doing so we should establish an overall framework for promoting IPM throughout the region and support this work through research in key areas.

To accomplish all this, CIAT will need to develop credibility as a regional actor in IPM. The only way we can develop a strong capacity to facilitate IPM projects is for our core-funded and special-project staff to participate directly in such projects. The point of departure will be our work on the Center's "mandate" crops (beans, cassava, rice, and tropical forages) in selected agoecologies. Where appropriate we will ensure that IPM is fully integrated with the Center's research on resource management.

Listed below are major agroecologies in which CIAT has worked, along with a description of the current status of our pest management research (also see Table 1):

1. ***Andean hillsides***—Problem definition (phase I) is underway. Component technologies have been developed for beans, cassava, and tropical forages but have not been implemented.

2. *Savannas*—Phase I is underway. Technologies (the result of phase II activities) are being developed for rice and are already available for forages and beans.

Table 1. Current status of IPM activities at CIAT. The dot indicates that the phase has been completed or is underway and that information and component technologies are available.

		Phase			
Agroecology	Crop	I	II	III	IV
Hillsides	Beans	●	●	●	
	Cassava	●	●		
	Forages	●	●		
Savannas	Forages	●	●		
	Rice	●	●	●	
Forest margins	Cassava	●	●	●	
	Rice	●	●		
	Beans	●	●		
	Forages	●	●		
Seasonally dry areas	Cassava	●	●	●	
	Beans	●	●		
Irrigated lowlands	Rice	●	●	●	●

3. *Forest margins*—Phase I is underway, and technologies are available for beans, cassava, rice, and tropical forages. Integrated strategies for management of cassava root rots have been implemented (phase III).

4. *Seasonally dry areas*— Phase I is underway for cassava and will be completed by 1994. Technologies have been generated, and we are awaiting feedback on them from phases I and III. Phases III and IV will be initiated in 1994 with funds from the United Nations Development Programme (UNDP). This work may include beans as well.

5. *Irrigated lowlands (rice)*—Some tasks of phases I, II, and have been completed. There is a need for implementation and farmer participation.

Organizing IPM at CIAT

To promote the adoption of IPM components developed by the four commodity programs at CIAT will require close collaboration between the Center's Germplasm Development and Resource Management Research Divisions. The latter can play a particularly important role in implementing IPM technology and in gathering feedback to direct future pest management research.

Table 2 indicates the expected outputs and personnel requirements of an IPM initiative at CIAT. Applied outputs will be developed in particular countries in areas representing selected agroecologies. Strategic outputs—the result of synthesizing experience with IPM across many sites—will be more widely applicable across agroecologies and commodities.

With its current complement of disciplinary expertise (in the Germplasm Development and Resource Management Research Divisions), CIAT can embark on an IPM initiative that includes its current mandate crops and agroecologies. However, any erosion of our expertise in either division, as a result of financial constraints, will limit the Center's ability to take a more active role in promoting IPM in Latin America and the Caribbean.

The Center should have little difficulty attracting specialists in areas (such as epidemiology, insect pathology, acarology, and pathogen biocontrol) where we need new expertise to complement that of our current crop protection researchers. Once appropriate projects have been designed for particular agroecologies, we will seek special funds to acquire additional IPM specialists and cover project operations, perhaps including the costs of personnel hired locally.

Table 2. Expected outputs and resource requirements of an IPM initiative at CIAT.

Phase	Applied output	Strategic output	Personnel requirements	Origin of funding for personnel
Phase I Problem Definition	Pest complexes identified Existing components identified Indicators quantified: -yield losses -pesticide use -production costs -residue levels	Participatory methods for problem diagnosis Identification of appropriate cropping systems for IPM	Production economist Sociologist Agronomist Crop protection specialists Biometrician National counterparts	RMRD RMRD RMRD GDD DSU National programs NGOs
Phase II Research	Resistant or tolerant varieties Biocontrol practices and agents Crop management options Recommendations for rational pesticide use Ecology of plant diseases and pests Pathogen variation	Resistance mechanisms Identification of key natural control agents Trained national program personnel Identification of epidemiological factors Host pathogen interaction	Acarologist Entomologist Plant Pathologist Virologist Insect pathologist Epidemiologist Pathogen biocontrol specialist National counterparts	GDD GDD VRU CABI Special project Universities National programs NGOs

Phase	Applied output	Strategic output	Personnel requirements	Origin of funding for personnel
Phase III Pilot Project	Economically viable IPM systems Training materials for extensionists and growers Trained research and extension personnel	Participatory methods for integrating components and validating systems Methods for institutional integration Information systems	IPM specialist National counterparts Support from RMRD and GDD staff	Special project National National program and special project RMRD and GDD
Phase IV Implementation	IPM systems adopted over a wide area Local IPM policies in place	Methods for monitoring establishment of IPM Methods for measuring adoption and impact Conceptual and operational framework Policy recommendations for IPM implementation	IPM specialist National counterparts Support from RMRD and GDD staff	Special project National program and special project RMRD and GDD

GDD = Germplasm Development Division
RMRD = Resource Management Research Division
NGOs = Nongovernmental organizations

IPM projects will be designed by our scientific resource groups, a new mechanism at CIAT aimed at encouraging cross-program collaboration. In exploring opportunities and developing special-project proposals, these groups will work closely with national programs. Resource groups will include only those specialists that are necessary to define projects for particular target areas during phase I. In most cases this will require an economist, entomologist, sociologist, plant pathologist, weed scientist, and agronomist. The functions of the resource groups will be to:

1. Initiate phase I.
2. Formulate projects and seek special-project funding.
3. Represent CIAT in international (including regional) discussions of IPM issues.
4. Ensure that projects are coherent and fulfill their objectives.

Initially, we will develop IPM projects by agroecology, emphasizing the predominant cropping systems that include CIAT mandate commodities. As we strengthen our capabilities in IPM project management, however, we will consider including other crops and cropping systems through partnerships with other international or national research institutions.

As CIAT becomes more deeply involved in IPM through special projects, we may need to create a position for an IPM coordinator at Center headquarters. Until then, this responsibility could be rotated among staff members in one or more of the working groups. The coordinator will be responsible for stimulating communication and sharing experience in implementating IPM among projects and for ensuring that we meet goals in the development of strategic outputs. He or she will also be responsible for interaction with other international institutions.

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Appendix
Current Pest Management Research at CIAT and Its Potential Contribution to IPM

Beans

Entomology—Germplasm with resistance to bean pod weevil, Mexican bean weevil, and leafhoppers has been developed. Leafhopper-resistant materials could be integrated with cultural practices and action thresholds to control this pest. But we have so far made no attempt to develop IPM systems for these species. Resistant germplasm is not available for other important pests, such as whiteflies, leafminers, and pod borers. But these are the focus of an IPM project underway in Colombia, Peru, and Ecuador with funding from the International Development Research Centre (IDRC). Project staff are testing an IPM strategy with small-scale growers of snap and dry beans, which combines action thresholds, destruction of crop residues, sticky traps to control adults, and uniform planting dates. Farmers are participating actively in the research, and adoption of new practices is being measured.

Plant pathology—With a view to broadening the genetic base of beans, we are identifying new sources of host resistance genes and elucidating mechanisms of resistance to fungal and bacterial diseases. We are also investigating pathogen diversity and evolution. Germplasm has been identified that has resistance to the most important diseases, such as anthracnose, common bacterial blight, angular leaf spot, fusarium wilt, and root rots. In developing resistant materials, breeders are using gene deployment strategies and disease-resistance mechanisms based on pathogen diversity and evolution studies. Our objective is to generate varieties with durable resistance by maximizing genetic diversity in the bean germplasm.

Our work on cultural control measures emphasizes the use of practices such as minimum tillage to manage web blight. There is potential for managing foliar pathogens with plant extracts and induced resistance.

In the following cases, integrated control of bean diseases could have significant impact: 1) management of foliar pathogens in areas where certain bean types (dry and snap) command high price and fungicide use is excessive (epidemiological studies could indicate ways to reduce fungicide applications and production costs); 2) cultural practices and HPR for managing web blight in the forest margins of Brazil and Peru; 3) cultural practices and HPR to manage fusarium wilt and root rots in Brazil, the Andean hillsides, and Africa; and 4) cultural practices to manage root knot nematode in coastal Peru and southern Brazil.

In work on viral diseases, the dominant I gene and several recessive genes have been deployed in CIAT germplasm to make it resistant to bean common mosaic virus. Varieties with tolerance to bean gold mosaic virus have been identified and deployed. Where tolerance is not sufficient, cultural practices (such as the use of fallows to lower whitefly populations) are needed for effective control. There is potential for combining HPR, vector management, and cultural practices to control bean golden mosaic virus (BGMV) in the Brazilian savannas.

We have developed a project proposal for integrated control of BGMV, using epidemiological parameters to design a disease forecasting model that could be applied at the farm level. The project will involve epidemiologists, entomologists, plant breeders, meteorologists, and virologists. It will feature close collaboration with national institutions and will require the use of advanced meteorological techniques available at CIAT. The project will focus on the irrigated lowland agroecology, extending from central Brazil to northern Mexico and including the Caribbean region.

Cassava

Entomology—Component technologies have been developed as part of an IPM package for controlling arthropod pest complexes. Resistance to thrips, mites, and whiteflies has been incorporated into finished varieties. Now, we need to identify new sources of resistance to mites, whiteflies, and lace bugs and to evaluate and quantify the resistance mechanisms. Agents for biological control of mites, mealybugs, hornworms, and burrowing bugs have been identified and are being evaluated and deployed. Additional work is required before we can identify and use entomopathogens. We also need to conduct further studies on the release and establishment of predators and parasites. CIAT is involved in a UNDP-funded IPM project in the seasonally dry agroecology of northeast Brazil, where insect and mite complexes cause considerable yield reductions. The project will implement various components technologies, including HPR and biological and cultural control of mites, mealybugs, whiteflies, lacebugs, and hornworms. Methods of encouraging farmer participation will be integrated into the research and extension work.

Plant pathology—For the most important diseases of cassava, we have determined the edaphoclimatic factors that favor outbreaks. Component technologies are available for control of root rots, cassava bacterial blight (CBB), witches' broom mycoplasma, superelongation, and phoma leaf spots. We have also identified sources of resistance to the causal agents of those diseases, plus cercospora leaf spot, and clones resistant to witches' broom mycoplasma have been released to growers. Progeny with high levels of resistance to root rot complexes, CBB, witches' broom, phoma leaf spot, and superelongation are in the advanced stages of evaluation. Antagonistic strains of a fluorescent pseudomonad and *Trichoderma* spp. have been identified, and cultural and storage systems have been developed for commercializing and making them available to farmers. We have also developed systems for selecting high-quality planting material as well as chemical treatments to eradicate some seedborn pathogens and protect cuttings from soilborne pathogens. Sanitation practices include selection of cassava stakes from plants without symptoms of cassava frogskin (FSD) and bacterial blight. Domesticated cassava and its wild relatives are being tested for resistance to FSD. Use of clean stake materials is being tested to determine if it is effective in controlling cassava vein mosaic virus. The above-mentioned project in northeastern Brazil involves genetic, biological, and cultural control of several pathogens and virus diseases.

Rice

Entomology—CIAT has made a major effort to develop germplasm resistant to the hoja blanca virus and its planthopper vector (*Tagosodes orizicolus*). We continue identifying and characterizing resistance sources. Progeny are routlinely screened for resistance in the glasshouse. We have also accumulated information on the biology and life cycles of several rice pests and developed methods for determining action thresholds. In some areas we began integrating these thresholds into production systems in collaboration with national programs and commodity federations. But this work has been cut back as a result of budgetary constraints. There is potential for using entomopathogens to reduce pesticide use and encourage natural biological control, but CIAT currently lacks expertise in this area. We have started to collect and identify fungal and bacterial pathogens and to establish a collection of biological control agents. Although there is considerable interest in IPM for rice in Latin America and the Caribbean, CIAT cannot currently satisfy the demand.

Plant pathology—Our main strategy for controlling rice blast and hoja blanca has been to develop resistant germplasm. Currently, we are using biotechnology tools to characterize the pathogens. This is improving the efficiency of our strategy for breeding more durable resistance. Its stability depends largely on the diversity of the pathogen population to which a resistant variety is exposed. Resistance both to the rice hoja blanca virus and to planthopper vector have been identified. Since sources of resistance to the virus are few, we are characterizing additional ones to be incorporated into germplasm pools. CIAT is also investigating novel methods of genetically engineering resistant genotypes. In addition, our research emphasizes cultural practices and the interactions of water management, fertilization (including silicon fertilizer), seeding rates, and chemical control to limit the pathogens causing blust, leaf scald, sheath blight, and grain discoloration.

To implement the technologies already available will require further testing under farm conditions and good communication with rice growers. If widely adopted, these technologies could reduce fungicide applications to control rice diseases.

Weeds—Before 1989, CIAT addressed weed problems chiefly through training, which dealt with the biology of major weeds and the options for control. That year the Center's rice researchers began developing components for integrated weed management. In this work we defined the critical periods of weed competition in rice and the plant characteristics that can reduce its effects, which should then receive emphasis in breeding.

Red rice, a serious weed problem in Latin America, is particularly difficult and expensive to control. We developed a model to establish economic thresholds, which allow farmers to time control measures according to red rice density. We also studied the biology of several red rice accessions to identify characteristics responsible for its competitiveness as well as the variability among biotypes to identify sources of competitiveness for commercial rice. Since farmers have to deal with mixtures of weeds at various densities and since few economic thresholds have been established for these conditions, we developed a way to predict yield loss from multispecies infestations. These yield-loss functions can be incorporated into expert system models for integrated weed management. By using action thresholds, Colombian rice farmers could reduce herbicide applications by 30%. Current work focuses on the development of competitive rice cultivars. We are also studying the implications of traits that make rice more competitive for rice plant type and productivity.

In much of this work CIAT collaborates with the International Rice Research Institute (IRRI) and West African Rice Development Association (WARDA). The Center is also working with the US Department of Agriculture to develop allopathic rice cultivars. Implementation of IPM during 1990-1991 in Colombia and Venezuela substantially reduced rice farmers' use of pesticides.

Tropical Forages

Entomology—Sources of HPR to cercopids (spittlebugs) have been identified, and methods of resistance screening have been developed for national programs. Through studies on resistance mechanisms, we hope to determine the biochemical basis of resistance and thus find ways to improve selection methods. We have demonstrated that there is potential for controlling cercopids with fungal pathogens. This approach is particularly relevant to intensive production systems of the Andean hillsides and to more fertile conditions at higher altitudes. A small collection of fungi has been established at CIAT. But we can do little more at this point for lack of expertise in insect pathology.

Various technology components for controlling leaf-cutter ants are available, including techniques for estimating population, action thresholds, cultural control measures, and HPR. We have also devised a bioassay to test the ability of resistant forage grasses to inhibit the ant fungal symbiont.

Plant pathology—Our work focuses principally on biological control and HPR. We have developed inoculation methods for major diseases of key forage genera as a step toward identifying resistance sources. A major effort is underway to identify sources of resistance to rhizoctonia foliar blight in the *Brachiaria* collection, to anthracnose in *Stylosanthes*, and to rhizoctonia in *Centrosema*.

Bacteria have been isolated from seeds of *Arachis pintoi* and *Stylosanthes guianensis* and from the phylloplane of *S. guianensis*, which inhibit the growth of fungi causing major diseases of forages, beans, cassava, and rice. Some of these beneficial microorganisms or their antibiotic products may also have antagonistic effects on other bacteria and may be useful for controlling diseases in the field or through seed treatment. It may even be possible to produce transgenic plants resistant to a wide range of pathogens, using genetic engineering methods to transfer the genes encoding these antibiotics.