1987/88 Annual Report

Consultative Group on International Agricultural Research

Established in 1971, the Consultative Group on International Agricultural Research—CGIAR—is an association of countries, international and regional organizations, and private foundations dedicated to supporting a system of agricultural research centers and programs around the world. The purpose of the research effort is to improve the quantity and quality of food production in developing countries. The World Bank, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) are cosponsors of this effort. The World Bank provides the CGIAR's chairman and secretariat. CGIAR is advised by a Technical Advisory Committee (TAC) whose secretariat is provided by the three cosponsors and located at FAO headquarters. CGIAR has 50 members, of which 38 were donors in 1987. Total contributions were about US$243 million.

CGIAR-supported international agricultural research centers

CIAT	Centro Internacional de Agricultura Tropical. Cali, Colombia.
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo. El Batan, Mexico.
CIP	Centro Internacional de la Papa. Lima, Peru.
IBPGR	International Board for Plant Genetic Resources. Rome, Italy.
ICARDA	International Center for Agricultural Research in the Dry Areas. Aleppo, Syria.
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics. Hyderabad, India.
IFPRI	International Food Policy Research Institute. Washington, D.C., United States.
IITA	International Institute of Tropical Agriculture. Ibadan, Nigeria.
ILCA	International Livestock Center for Africa. Addis Ababa, Ethiopia.
ILRAD	International Laboratory for Research on Animal Diseases. Nairobi, Kenya.
IRRI	International Rice Research Institute. Los Banos, Philippines.
ISNAR	International Service for National Agricultural Research. The Hague, Netherlands.
WARDA	West Africa Rice Development Association. Bouake, Cote d'Ivoire.

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CGIAR Secretariat
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Washington, D.C. 20433
United States

Foreword

Financial difficulty has become so much a characteristic of international development institutions that it gives me particular pleasure to be able to cast the fortunes of the CGIAR in a somewhat different light. At least for the present, our finances are sound, a condition that endows the working environment of international centers with stability, and thereby enhances their opportunities for sustained research. Those who want the details of that encouraging situation will find them in the financial chapter of this report. Briefly, contributions from donors rose during the current reporting period, giving the CGIAR system a US$243 million pool of resources. In 1988, we were able for the first time in several years to operate on the basis of assured full funding for all the programs approved by the Group.

Healthy finances cannot be invoked by magic incantations. They do not just happen. They are the product of commitment and hard work. The continued generosity of the Group, sound management, an impressive record of research at the centers, and the enthusiasm of those whose task it is to keep the resources flowing all helped in equal measure to give the CGIAR system its current financial strength. Fortuitously, international exchange rates and policies worked in our favor as well. We cannot guarantee that they will always work to our advantage. We can, however, ensure that our own efforts— whether as donors, scientists, or managers—remain constant. Indeed, we must.

Rural poverty seems almost inescapable in some of the developing regions of the world. Moved by the sights and sounds of deprivation and disaster, it is easy to forget that millions more would have remained at the level of marginal people but for the creative partnership that has grown between national and international agricultural research. Farmers have been drawn into this effort, more recently, as a result of innovative methodologies developed by the research community. Men, women, and children have been fed and farm incomes enhanced. More important, their varied hopes including their hopes in themselves have been kept alive.

Looking back on the past 20 years, all of us who have been connected with that partnership in any way can only recommit ourselves to its continuance over the next 20 years...and beyond. As part of that recommitment, the CGIAR has looked both inwards and outwards, closely examining its own structures and activities and assessing how best they might be reshaped in response to changes and challenges in the world around us. As this report recounts, the size, scope, resources, and priorities of the CGIAR system have all been scrutinized. We have even looked at proposals for changing the liturgy of our sacred rite, International Centers' Week. This process of self-examination will inevitably lead to new research thrusts and renewed emphasis on those priorities that have been at the heart of the CGIAR system from the beginning.

Text boxes

Text figures

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Editor's note:

This report covers financial information in detail for calendar year 1987, the latest available. On other matters, the report deals with events through mid-1988.

1. CGIAR: The year in review

Focus on sustainability

Two interrelated themes—sustainable agriculture and the breadth of CGIAR sponsorship of international agricultural research—were the focus of concern and activity in 1987-88. Both will continue to receive major attention in the foreseeable future.

Sustainability was reemphasized as part of the CGIAR mission when the Group held its mid-year meeting in May 1988 at Berlin, hosted by the Federal Republic of Germany. A report from the Group's Technical Advisory Committee (TAC) and *Our Common Future*, the report of the World Commission on Environment and Development chaired by Gro Harlem Brundtland, Prime Minister of Norway, served as a backdrop to the discussions at Berlin. The broad sweep of the TAC report was approved, and the need to move into specifics in the area of sustainability confirmed.

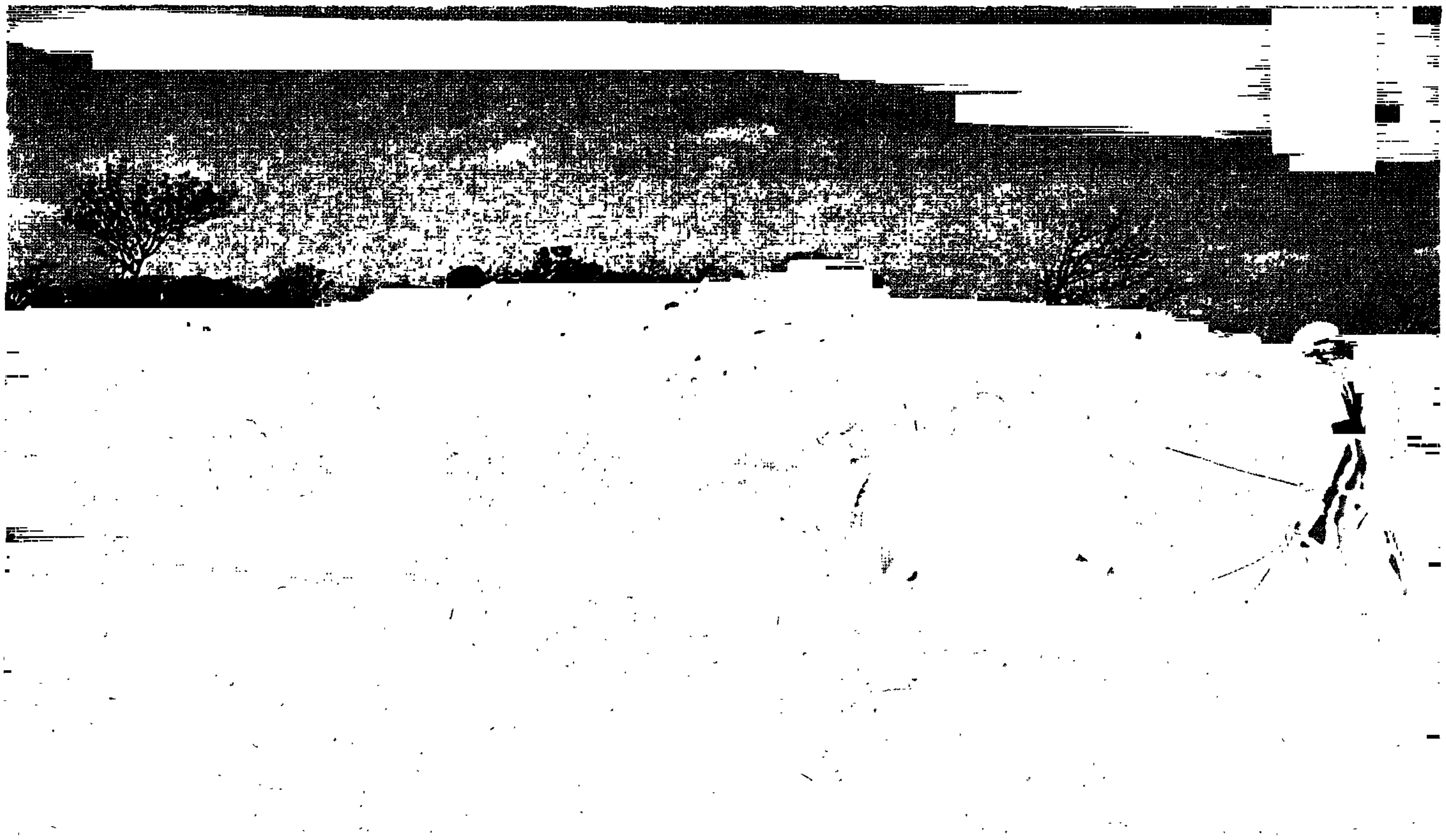
The Group recognized that the overall issue of sustainable development remained controversial. No generally accepted definition of sustainable agricultural systems exists, and there is no generally acknowledged analytical framework one can use to organize the issues involved. The interconnected aspects of sustainable development as a whole far surpass the capabilities of the CGIAR in research alone, and problems of policy and implementation need to be addressed in other fora for the most part.

The CGIAR system has been doing substantial work relevant to sustainability, but the Group saw clearly that more needs to be done. It also found that the range and content of CGIAR research on sustainability, or the implications of approaching all research from a sustainability perspective, as the TAC paper put it, were still to be defined. To help with such a definition, a working group including the scientific leadership of the centers will spell out concretely the changes in research programs required. At the same time, the CGIAR will commission a consortium of non-governmental organizations to summarize the state of knowledge about sustainability of agricultural production in developing countries.

The second major theme involves an investigation of how broad CGIAR responsibilities should become, as reflected in the identity and purpose of centers supported by CGIAR donors. At issue is the relationship of the CGIAR to more than 10 other international agricultural research centers, programs and activities not directly associated with the Group at present.

Future role of non-associated centers

The two themes are closely tied, because a substantial number of the non-associated international research centers focus on resources—such as soil, water, and forests—whose future contribution to food and agricultural production is at the heart of the issue of sus-



In India's semi-arid tropics, traditional farming methods are sustainable at a subsistence level of production.

plants and animals responsive to improved management and the use of manufactured inputs are used. Chemical fertilizers are added to the soil, pesticides are used to protect the improved types from insects and diseases, and more energy is applied to soils through machines or animal-drawn equipment.

None of these changes is necessarily bad; they are compatible with environmental concerns if they are undertaken wisely. The environmental problems caused by agricultural and industrial development that plague the industrialized world are not found in many places in the developing world; where they do exist, it is usually because of poverty or ignorance.

Poverty and ignorance

People who lack the simple necessities of life may not be able to consider the long-term implications of the agricultural practises they use. Their greatest concern is survival: for themselves, their families and their animals. Subsistence farmers then often cannot afford to maintain conservation programs, which in some instances have deprived them of the use of portions of their own lands. Only when poor farmers have increased their incomes will there be any hope of restoring soil and sustaining erosion control.

An example of how increased farm income provides a setting for increased attention to the environment comes from central India where ICRISAT has developed a successful watershed-based technology for double cropping on highly erodible Vertisol soils. Over seven years of tests using this technology at ICRISAT, the increased annual value of crops averaged Rs4,000/ha and farmer profits increased 2.5 times. Because the soils are covered by vegetation during the rains, erosion is greatly reduced. In adopting the new technology, farmers are quick to take up the double cropping, improved seeds and the use of fertilizers. They are slow to take up conservation measures like broadbeds and furrows. Fortunately, the most important erosion control measure is to crop the soil during the rains and the farmer seems willing to do this because of the extra profits involved.

Ignorance, like poverty, can also can have a devastating effect on the environment. In the past 3-4 years in eastern India where ICRISAT's headquarters is located, farmers have found it profitable to grow cotton. Their biggest problem has been insect attack by white fly and the cotton bollworm, *Heliothis armigera*, the tropical world's worst insect pest. They controlled the insects initially with insecticides formulated from synthetic pyrethrum, generally among the safest and most effective of such chemicals.

Unfortunately, through ignorance, the persuasions of unscrupulous insecticide dealers and in the absence of expert advice, the farmers equated increased profits with increased amounts of chemicals and excessive numbers of chemical sprayings. This year a catastrophic situation occurred due to the combination of a poor cropping season and the emergence of new generations of insects almost completely resistant to the synthetic pyrethroids and to all available pesticides. The crop has been virtually wiped out.

Heliothis armigera also attacks pigeonpea, one of the crops on which ICRISAT conducts research. For more than 10 years, ICRISAT scientists have been developing pigeonpeas with natural resistance to the attack of this insect pest. Although cultivars with complete resistance have not been produced, several tolerate *Heliothis* attack quite well and sustain much less loss than susceptible varieties. The new resistant forms of *Heliothis armigera* have been carried on the wind from the cotton-growing areas to ICRISAT's fields. While 40 times more resistant to pyrethroid insecticides than their local brethren, the pyrethroid-resistant insects are no more devastating to the tolerant pigeonpea lines.

Developing resistant varieties is the center's main approach to integrated pest management, but alternatives such as biological control through natural parasites of the pests are also explored. A novel line of investigation is being developed with *Heliothis* through cooperation with the Max Planck Institute for Biochemistry at Munich (Federal Republic of Germany). Chemicals from pigeonpeas and chickpeas that attract egg-laying *Heliothis* females have been extracted and used in field traps at ICRISAT. By developing such approaches, further limitations on crop losses due to insects without the use of pesticides may be possible.

Runoff and erosion due to rainfall in the sandy soils of the West African Sahel are among the obstacles to sustainable production faced by small farmers.

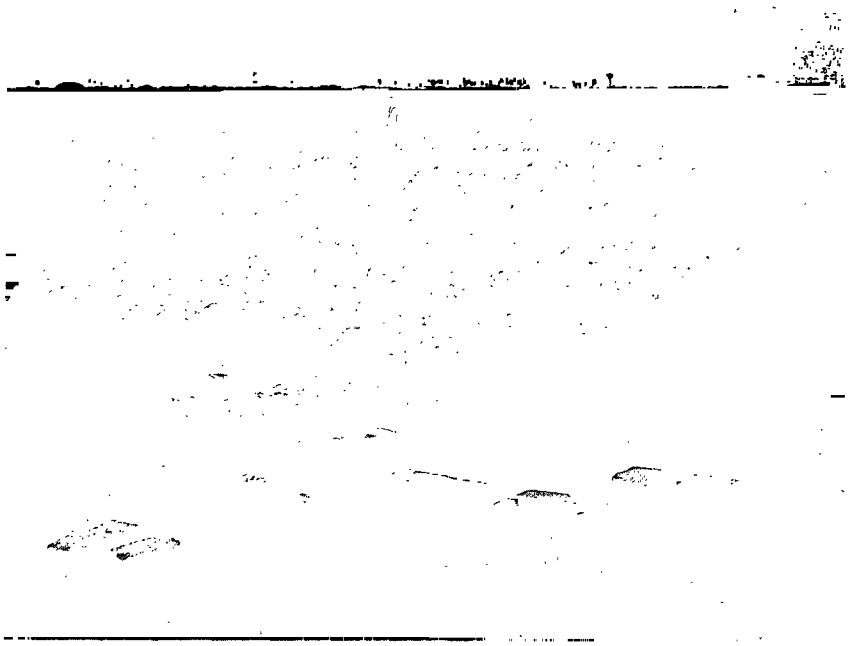
Sustainability and concerns for the environment cover much the same ground. If there is a difference between them, it is perhaps that the term "sustainability" conveys the idea of a balance between human needs and environmental concerns. The CGIAR accepts the proposition that human needs will increase and that the environment must not suffer. To make it so, we must find ways to make agriculture greatly more productive without the excessive use of external inputs and we will need a much better understanding of the long-term implications of change. We do not believe that these subjects can be handled by the CGIAR alone, but it is possible that the centers can have a significant impact through their ability to influence the nature of research in national institutions. We have asked our donors and other components of the CGIAR system to help in focussing attention on sustainability and encouraging governments and relevant institutions to accord it high priority.

High- versus low-input. Much public concern in industrialized countries about sustainability has been generated because of high-input agricultural systems. Without them, it is claimed, it would not be possible to meet the food demands of an increasing world population unless more, and less suitable, lands are brought into cultivation. Without a more intensive agriculture, sustainability is certainly not assured. However, there are many disturbing features about highly intensive agriculture.

The use of high-input agriculture in the developing world is increasing and the CGIAR centers devote time to it. By and large, however, the centers work towards improving agriculture at a lower level of productivity, using far fewer commercial inputs. Research that emphasizes the recycling of nutrients, the incorporation of crop residues, and the use of intercropping systems—including agroforestry—and the combination of cereals and legumes, are contributions to the sustainability of low-input agriculture. So too are the development of crop varieties tolerant to environmental stresses and of animals and crops tolerant or resistant to existing pests and diseases. Farming systems approaches are used to incorporate these components into systems of sustainable agriculture.

In much of West Africa, the soils are extremely deficient in phosphate. It is such an overriding constraint that the improvement of other system components provides little benefit, certainly not enough to allow farmers to contribute significantly to increasing food production. Many West African countries, however, have exploitable deposits of phosphate rock. Moving the phosphate from where it is concentrated to where it is needed would transform the agriculture of West Africa over time. It would reverse the trend towards desertification, make other improved components viable and profitable, and contribute substantially to agricultural development.

Favorable versus less-favorable environments. Many soils are inherently productive. The prairie soils and chestnut soils of temperate regions have long been the breadbaskets of the industrialized world. In the developing world, too, there are favorable regions for intensifying agriculture. The Vertisols and their high potential have already been mentioned. Soils known as rhodustalfs and eutrustox occupy vast areas of the tropics and could be exploited more. The natural and derived savannas, ecological regions with rainfalls generally between 700 mm and 1400 mm, have fewer constraints to development than dryer or wetter regions. Intensified agriculture is more sustainable in these places than in others. Higher population densities than currently exist could often be sustained.



Relatively simple changes in traditional practises, such as contour bunding and grassed waterways, can minimize soil depletion and enhance crop growth. Above, the gated outlet releases water but keeps soil within the field.

The resettlement of people from less- to more-favorable environments has long been government policy and social practise in many developing countries. Even with good development planning, however, and almost invariably without it, the short-term results have often been disastrous, both in human and environmental terms. When national boundaries are involved, resettlement is both socially and politically unacceptable.

Consequently, no matter how difficult the problems may be, it is not possible to envisage a sustainable worldwide strategy which develops only favorable environments at the expense of the less-favorable. CIAT, ICARDA, ICRISAT, IITA and ILCA among the CGIAR centers all have area-related mandates that require them to devote portions of their work to less-favored environments in the humid tropics, dry semi-arid tropics and arid regions. We accept the challenge of serving the needs of people in these more difficult regions.

Helping where it is needed most

The most important way we can help the poorest people is to help them reduce the costs of their staple foods. To do so, we must strive to make agriculture in the developing world more productive and more efficient. The centers are well aware of environmental concerns. They are targeted to the needs of small, resource-poor farmers and they receive much guidance and advice from developing countries, donors and United Nations agencies. There is no evidence to suggest that the products of their research have led directly to environmental deterioration. If anything, the evidence points in the other direction. In many cases, the effects of their research have succeeded in lifting the least advantaged a few rungs up the ladder of profitability and better living. Only farmers with disposable income have the possibility of investing something in the future.

3. TAC and sustainable agricultural production

by Michelle Hibler[1]

Comprehensive approach to complex issues

Sustainable development is a process in which the exploitation of resources, the direction of investment, the orientation of technological development and institutional change are made consistent with present and future needs.

The diagnosis and the prescription, voiced perhaps most eloquently in 1987 in the report of the World Commission on Environment and Development, also known as the Brundtland Commission, are central to the CGIAR's activities and concerns. It is therefore no accident that at Berlin, in May 1988, the CGIAR considered the implications of the Brundtland report and debated a comprehensive document on sustainability in agriculture prepared by TAC, the body of 14 scientists who identify research priorities and advise the Group on a wide range of issues. (See Box 3.1.)

Concern for sustainability of agricultural production is not something new in the CGIAR. As pointed out in Chapter 2, many of the individual research programs at the centers bear directly on elements of the problem. Moreover, concern for the future was an important element in the centers' efforts to increase food production in developing countries and to sustain the environment at higher levels of production.

Those efforts led to the Green Revolution, as a result of which millions who might otherwise have starved, were fed. But millions more, particularly in Asia and Africa, have not shared in the progress of the past 20 years. In some parts of the developing world, agricultural gains are being threatened, as farming pushes its frontiers onto more marginal croplands, and under the onslaught of higher energy prices, shorter fallow cycles, the loss of topsoil, and increased pest resistance to pesticides, among other factors.

Meanwhile, the need for food does not diminish. Population growth continues: some 80-100 million more people must be fed each year. Successful development programs sometimes exacerbate the problem because higher incomes translate into greater demands for food. Growing urbanization also accelerates the increase in demand and the shift from staple grains towards more "convenient" foods and more livestock products, fruits and vegetables. FAO predicts that by the end of the century, if present trends continue, at least 64 countries will be unable to meet the food needs of their people.

As it set to work in June 1982, about the same time that the Brundtland Commission began its efforts, on a periodic, broadly based

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study of matters of strategic importance to the CGIAR, TAC recognized that the food situation in many developing countries remained insecure—in some, precarious.

TAC's review of CGIAR priorities and future strategies, presented to and approved by the Group at the December 1986 meeting in Ottawa (Canada), confirmed the continued viability of the CGIAR's multidimensional approach to addressing world food needs in the future. It also introduced a revised goal statement for the CGIAR that gave prominence, for the first time, to the notion of sustainability. Chairman of TAC's Standing Committee on Strategic Considerations, chancellor emeritus of the state university system of Florida, E. T. York explains that "much of the work of the centers in the CGIAR has historically been concerned with developing techniques that would contribute to sustainable agricultural systems." However, TAC in its 1986 paper stressed the need for even greater emphasis on the subject "because the global community grew more concerned that the remarkable gains in agricultural productivity in some parts of the world could not easily be maintained."

The CGIAR concurred. It also noted that its earlier study on the impact of CGIAR-supported research had recommended that sustainability should, with stability, be a measure of agricultural performance in the humid tropics. Concerned about how the centers should address this issue in light of the broader scope of the CGIAR's goal, the Group requested TAC to elaborate its views on sustainable food production and give further consideration to how its recommendations could be implemented and monitored. The CGIAR asked that, in addressing problems related to sustainability, consideration should be given to the rehabilitation of areas that had lost their productive base. It further stressed the need to consider the relationships between the work of the CGIAR centers and non-associated centers that deal with key interacting environmental factors such as soil, water, and trees.

The sustainability subcommittee

Acting on this request, then TAC Chairman Guy Camus of France, entrusted the task to a multidisciplinary, continuing subcommittee, comprising ecologist Cornelis T. deWit, professor of production ecology and member of the Netherlands Government Council for Science Policy; ecology and forestry specialist Ibrahim Nahal, rector of the University of Aleppo, Syria; Thomas R. Odhiambo, director of ICIPE in Nairobi, Kenya; and York of the United States. Winfried von Urff, an economist of the Federal Republic of Germany, who served as TAC member from 1981 to 1987, also worked closely with the subcommittee in its early deliberations. York, a veteran agricultural administrator, was chosen to head the committee.

Meeting in February 1987, the "sustainability subcommittee"—as the group became known—agreed to respond to its charge by developing a comprehensive paper that would characterize the problems of sustainability in agricultural systems, outline what the CGIAR system was doing to address them, identify additional work that might be needed, and recommend strategies for the CGIAR in order to address these problems and achieve sustainability objectives.

As a first step, Peter Oram, an agronomist at IFPRI, was commissioned to prepare a resource paper on policy issues and research priorities in sustainable agricultural development. His report clearly identified the challenges of finding technological solutions to problems of resource depletion and the subcommittee took to heart his comments on the need "to find solutions to the problems impeding sustainability whether these solutions are technical, institutional, social, or some combination of approaches."

Concurrent with an exhaustive literature search on the subject, international agricultural research centers both in and out of the CGIAR were asked to assess sustainability problems, detail what they were doing to address the problems, and recommend additional activities they might undertake. International organizations such as FAO and the United Nations Environment Programme (UNEP) were also invited to comment.

A new look at sustainability

In the course of the subcommittee's deliberations, it became obvious that there were many different concepts of sustainability. A standard definition suggested that agricultural systems would be sustainable if production or output could be maintained at current levels. But the members found such a static concept totally inadequate. They urged that sustainability should be dynamic, reflecting the changing needs of a steadily increasing global population. Sustainable agriculture should involve the successful management of resources for agriculture to satisfy changing human needs. The concept, according to York, was somewhat original and took into account the complex interactions of physical, biological and socioeconomic factors at the base of all production systems.

The survey of the international agricultural research centers revealed that many of their efforts contributing to short-term increases in food production also had an impact on long-term sustainability. Germplasm improvement as well as genetics and breeding carried out at centers with commodity mandates, for instance, emphasized breeding tolerance to environmental stress. This played a vital role in efforts to achieve sustainable production systems by addressing many of the circumstances that limit the achievement of sustainability. Moreover, much of the centers' work was devoted to maintaining productivity gains already made, a priority identified by TAC and advocated by many development organizations. Programs designated "resource management," "pest control," and "soil management," among others, all touched on sustainability.

Box 3.1. The Technical Advisory Committee (TAC).

Composed of 14 international agricultural and social scientists, TAC was established simultaneously with the CGIAR to define research priorities and select new activities for the CGIAR system.

Nominated by the three cosponsors—FAO, World Bank and UNDP—and appointed by the Group for a renewable two-year term, TAC's members are drawn equally from industrialized and developing countries. TAC's chairman is appointed by the CGIAR. Current chairman, Alexander F McCalla of Canada is TAC's fourth, succeeding Sir John Crawford (Australia), Ralph Cummings (United States), and Guy Camus (France). Advisors with special expertise may be invited to serve individually or on TAC panels to consider particular problems.

Reporting to the CGIAR, TAC advises the Group on the main gaps and priorities in agricultural research related to the problems of developing countries; recommends feasibility studies to explore how best to organize and conduct research on priority problems; examines the results of these and other studies and presents its views and recommendations for action; advises the CGIAR on the effectiveness of existing programs; and encourages the creation of an international network of research institutions and the effective interchange of information among them. At its thrice-yearly meetings, TAC also reviews the CGIAR centers' strategic plans and examines programs of work and budgets before transmittal to the CGIAR.

TAC's administrative arm, an independent secretariat housed by FAO in Rome, is funded by the three cosponsors.

Whether focussed on specific commodities, agroecological regions, germplasm conservation or assistance to national systems or policy research, all centers found sustainability of major importance to their mandates. Non-associated centers similarly worked towards sustainability of agricultural production systems, highlighting the potential contribution and obvious opportunities for collaboration with centers within the CGIAR.

The question, therefore, was not whether the centers were working to make agriculture more sustainable—clearly, they were—but whether they should be doing more, whether their work should be given a different emphasis or direction, and whether major restructuring of their approaches might be necessary or desirable.

Identifying the issues

While sketching the broad problems threatening sustainability and listing the constraints to sustainable agricultural production, the first draft of the subcommittee's report stressed that "the central issue, then, is what priorities should be attached to the range of research activities being carried out by the centers and what strategies should be adopted to most effectively achieve sustainability goals." As deWit puts it: "We're directing ourselves very much to the research. Our business is to give advice from a technical, sensible point of view."

Reporting on progress to TAC at its 43rd meeting in Nairobi in June 1987, the subcommittee identified seven priority issues:

- devising production systems that can meet short-term needs, while maintaining or enhancing the ability to achieve longer-term production objectives;
- directing research to increase agricultural productivity in favorable environments in order to relieve pressure on fragile environments while, simultaneously, emphasizing increased production of agriculture in unfavorable environments to achieve greater equity for the worlds' disadvantaged;
- maximizing the productivity of low-input systems through measures such as the development of disease- and pest-resistant cultivars and improved production systems, and also giving greater research attention to the potential of fertilizers and other inputs when justified and possible;
- developing improved production systems that incorporate sound traditional practises such as intercropping, rotational cropping, and agroforestry;
- increasing research on resource management and conservation problems such as erosion control and water conservation both in commodity-mandated centers and others, while reducing genetic improvement work;
- exploring the potential applications of biotechnology;
- increasing policy research, because many obstacles to sus-

tainability cannot be overcome by purely technical correctives, and providing adequate funds for policy research.

The subcommittee stressed the need for collaboration with research institutions outside the CGIAR such as the International Council for Research in Agroforestry (ICRAF), IIMI and the IFDC. It recommended that efforts to achieve sustainable agricultural production be continuously monitored and that the staff and boards of the centers should assess the impact their technologies may have on sustainability.

A clearer definition

Wide-ranging discussions at the June 1987 meeting and comments submitted by CGIAR center directors and chairs of center boards helped the subcommittee refine the issues, in its second draft report, which was presented to TAC's 44th meeting in October 1987, at Washington, D.C. Members of the Group and several organizations concerned with resource conservation and environmental issues also received copies and provided extensive comments.

At this stage, the subcommittee broadened its definition of sustainability to reflect the possibility that agriculture could be both perpetrator and victim of environmental degradation. The new characterization saw sustainable agriculture as "the successful management of resources for agriculture to satisfy changing human needs, while simultaneously maintaining or enhancing the natural resource base and conserving natural resources."

The subcommittee formulated a key conclusion, later agreed by the Group, when it made clear that it did not view research related to sustainability as a separate or discrete area of activity, but rather as one that must be reflected in the way in which research is planned and conducted; that all CGIAR-supported research needed a "sustainability perspective."

The second version also identified new priority issues. It stressed, for instance, that the central role played by CGIAR centers in research made them effective in encouraging national agricultural research systems. As recently-appointed TAC member Raoul J.A. Dudal, professor of soil sciences at the Catholic University at Leuven (Belgium), explains: "Sustainability is a general concept that hides a tremendous diversity of environments. Action will need to be site-specific." TAC therefore recommended that CGIAR centers give high priority to strengthening the capacity of national agricultural research systems to incorporate a sustainability perspective into their endeavors. And because centers' training programs are a vital mechanism for doing so, the committee stressed the need to incorporate a sustainability perspective into them.

The revised report added that despite the contribution made by centers and national agricultural research systems, the total effort was inadequate for the task. Moreover, the committee considered that both developing country governments and international donor agencies had crucial roles to play in emphasizing the need to consider sustainability when allocating future resources and selecting future thrusts.

Low-cost, high-efficiency agriculture

This second version further clarified the subcommittee's position on one of the more contentious issues, the role of external inputs in increasing and sustaining food production. The draft noted that low-input agricultural systems tend to be stable and use few external inputs, but they produce little more than subsistence needs. They also carry the risk that most nutrients removed in crops are not returned to the soil. Farmers usually manage these systems efficiently, but there is little scope for increased production without increasing their inputs. As deWit puts it: "In general, it is underestimated what a farmer can do and overestimated what the environment can produce. The farmer already does well given his resources, and the environment can yield far less than many persons appreciate."

At the other end of the scale, high-input "industrial" systems of agriculture produce considerably more than subsistence needs and require considerable external inputs and often raise questions about sustainability. While the report did not advocate widescale adoption of these systems, it recognized that traditional systems could produce enough to meet the needs of a growing population only if the areas under cultivation were expanded. Doing so at the expense of fallow periods or by converting rangelands threatens sustainability. Doing so by expanding onto virgin areas less suited for agriculture destroys natural ecosystems. Excessive reliance on external inputs, on the other hand, can also harm the environment and consume scarce, non-renewable resources. One is faced with tradeoffs, not absolutes. In the tradeoff between two non-renewable resources, soil and oil, TAC considered that fossil fuel today was more abundant, and more easily substituted for other factors than soil.

The draft recommended that the centers review the emphasis given to low-input farming in their research programs and increase it where appropriate. But recognizing that high-input technologies are essential to meeting food demands and can contribute to sustainability, the subcommittee also recommended that high-input production systems and related policy issues be included in CGIAR research programs. This dual emphasis is a recognition that the yield of some commodities can be increased using low levels of inputs if the materials are applied efficiently. It also recognizes that small farmers can benefit particularly from judicious use of inputs.

Some observers had questioned the subcommittee's emphasis on the need for increased inputs, its seeming rejection of the "less-is-best" philosophy. For the subcommittee, and for TAC, there is no dichotomy between low- and high-input agriculture, or what members of the subcommittee prefer to call low-cost and high-efficiency agriculture. "We aim, not at low-input agriculture, but at efficient agriculture," says deWit. "Biological systems are faced with a range of limiting factors," explains York, "and it is not reasonable to assume that there can be ever-increasing, ever-larger increases in the productivity of these systems without accommodating these limiting factors, without removing them. It's often necessary to utilize techniques involving external inputs to overcome these limiting factors. At the same time, I think we need to recognize that there are many parts of the developing world that may have difficulty in either having access to these inputs, or affording them. And for these and other reasons, we should attempt in every way possible to maximize the output with resources that are available."

Laying the foundation

Following a recommendation made during the CGIAR meeting in May 1987 in Montpellier, France, TAC arranged for the third version of its report to be reviewed at a three-and-a-half day workshop in Rome, Italy, in January 1988. This meeting brought together the newly-appointed TAC chairman Alexander F McCalla, members of the subcommittee, and 23 other participants from the CGIAR donor community, international agricultural research centers, international organizations and national agricultural research systems, invited in their personal capacity, and representing a wide range of viewpoints about sustainability.

The consultation enabled the subcommittee to sharpen its focus on a number of questions. One of these was the determinants and constraints to sustainability, where the problems of desertification, soil erosion, atmospheric pollution, hazardous chemicals, energy and the unbridled exploitation of forests and rangelands loom large. What aspects of sustainability could be quantified? The question was posed but the answer left for possible future research. Given the sound principles on which many traditional systems are based, the need to improve those systems, or devise intensive production systems based on them, was reinforced.

Approved by TAC at its 45th meeting in Rome in March 1988, the final document presented to the CGIAR in May in Berlin, reflected wide consultation with numerous individuals and institutions, a "long process, but a good one in terms of our ability to involve a lot of people, a lot of the vital elements that should be involved." It also represented, said TAC member Thomas R. Odhiambo "the first attempt to indicate how to implement research, how to begin to deal with the problem of sustainability."

From the outset, the authors clearly differentiated sustainability from productivity. While greater productivity will be required to achieve sustainability goals, they said, it must be achieved in a way that does not jeopardize the ability of agriculture to meet future needs. Productivity goals might, on the other hand, be achieved in the short run through approaches that may not be sustainable.

In addition to the thrusts and priorities already set out in previous versions, the final TAC document introduced the need to assess technologies designed for less-endowed regions and the cost-effectiveness of incorporating new capabilities of biotechnology into research programs. It further stressed the need for commitment on the part of developing countries and urged that all CGIAR members and associated organizations work to promote awareness of sustainability issues among policymakers.

No matter how great the effort, TAC is well aware that many of the circumstances limiting the achievement of sustainability cannot be changed by the CGIAR or through agricultural research alone. National governments and their development services will bear the brunt of the responsibility. And although the CGIAR system can make a significant contribution, its total effort must be kept in perspective. In 1980, total expenditures of the CGIAR represented only 1.6 percent of the global public sector expenditure and only approximately 5 percent of developing country expenditure on agricultural research. Nonetheless, CGIAR centers can have an impact far greater than their relative level of expenditure through their ability to influence research activities in other institutions throughout the world.

"The common challenge," as the TAC report concludes, "is to find ways of removing the impediments to sustainable agricultural production, whether the causes are technical, social, institutional, political or some combination of all four. A significant part of this challenge rests with the international agricultural research centers. Accepting it offers them opportunities for making unprecedented contributions to the global community as they help to find solutions to serious problems that threaten the future welfare of humanity."

4. Biological control of cassava pests in Africa

by Edward Glass[1]

Century-old concept gains a new use

One hundred years ago, the young thriving citrus industry in California was on the verge of collapse because of the ravages of the cottony cushion scale which had been inadvertently introduced into the state about 1868. The insect spread rapidly throughout the orange groves, killing thousands of trees and threatened the existence of the orange industry in the state. It was not until 1888 that the United States government appropriated US$2,000 to send an entomologist to Australia, where the pest had originated, to find its natural enemies. A lady beetle predator, now commonly called vedalia, was found and 140 were shipped to California in 1888. The beetles thrived and rapidly spread throughout the citrus plantings. The impact was incredible—in one year shipments of oranges increased from 700 to 2,000 railroad cars. Since then, vedalia has been introduced and been equally effective in controlling cottony cushion scale in at least 32 countries. Vedalia still controls it in California and elsewhere.

This was not the first attempt by agricultural scientists to use natural enemies of pests as a means of controlling them in an environment where they had been inadvertently introduced. However, the spectacular, quick, inexpensive and permanent success of vedalia was convincing evidence for the potential of this approach to controlling pests. It encouraged many similar efforts in the United States and other parts of the world. It also provided impetus for the development of the theory and technology of biological control.

With the introduction of DDT and several other effective organic insecticides during the 1940s and 1950s, the biological control approach was overshadowed by chemical successes against many insect and mite pests of crops, animals and humans which had not been satisfactorily controlled by other methods. Not until several years later when the problems of built-up resistance, secondary pests, and environmental and health problems surfaced were the limitations of pesticides generally recognized and alternative approaches actively pursued. This recognition led to the evolution of the integrated pest management or integrated pest control concept in crop protection which is generally accepted throughout the world today. The concept is based on an ecological approach employing all applicable tactics such as biological control and farming practises, resistant crop plants and the judicious use of pesticides in integrated systems. Integrated pest control is now widely accepted as the optimal approach to sustainable pest control. (Pest and pesticide refer to all classes of noxious organisms [insects, plant pathogens, weeds, etc.] and all substances used to control them [insecticides, fungicides, herbicides, etc.].)

[1]Glass is professor emeritus of entomology at Cornell University (United States).

In nature, populations of organisms are regulated by such factors as the availability of food, weather and natural enemies. When food is abundant, as in modern agriculture, pest populations which feed on the crops increase rapidly unless controlled by other factors. Natural enemies also multiply as their food supply increases and provide commensurate control. The objectives of biological control efforts are to preserve, augment and use natural enemies to regulate pest populations.

When an organism is transported from one geographic area to another without its complement of natural enemies, it often becomes a very destructive pest, as in the case of the cottony cushion scale in California. Finding natural enemies in the pest's native habitat and establishing them in the new area is a specialized activity known as "classical" biological control.

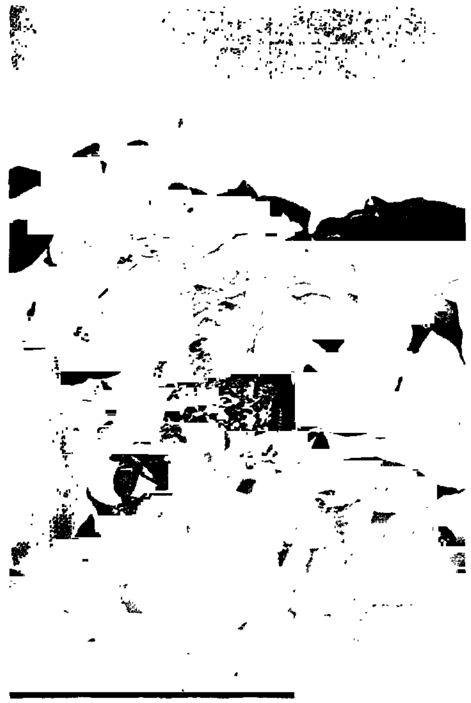
In the early 1970s, two new pests were found on cassava in Africa. Both spread rapidly and caused disastrous crop losses. The ambitious and successful project to import natural enemies into Africa to control the new cassava pests and its implications for the future of crop protection in developing nations are highlighted here.

The cassava story

Cassava is the third largest tropical food crop. It is by far the most important root crop and is a significant source of calories for an estimated 500 million people in developing countries. Cassava originated in the tropics of Latin America where it has been cultivated for 4,000 years. In the late 16th century, Portuguese traders conveyed it to Africa where it was readily adopted. Cassava was compatible with existing root and tuber cropping practises, survived in widely varying environmental conditions, and roots remained in the soil in edible condition for up to four years. The latter attribute meant that cassava could be available when other crops failed during periods of drought or locust plagues, which has earned it a reputation as a "famine reserve crop." Cassava now is grown throughout the tropics. According to FAO, estimated total world production in 1986 was 137 million tons grown on 14 million hectares.

In Africa, cassava is grown over a wide belt extending from Senegal to Angola in the west to Somalia south to Mozambique and Madagascar in the east. This area is one and one half times that of the United States. Annual cassava production in Africa is estimated to be 51 million tons grown on 7.2 million hectares. Cassava is the staple diet of more than 200 million Africans. It is grown mostly as a subsistence crop by small farmers including many who practise slash and burn or shifting agriculture. It is a 1-5 meter high woody shrub which produces edible, large elongated starchy roots. These are low in protein and vitamins and must be supplemented by other food such as vegetables, fruits, meat and fish. The roots must be used two to three days after harvesting unless dried. Farmers have developed several processes to leach, ferment, and heat cassava to remove the harmful HCN which is present in the roots, particularly in some "bitter" varieties. A fermented pulp called *garri* is produced in West Africa. The leaves containing protein and vitamins are eaten as a pot-herb in parts of Africa and help to supplement cassava root diets.

Cassava has a significant unrealized potential to feed tropical peoples because of its capacity for high yields in a wide range of ecological zones and conditions. It and other root crops are thought by some to have a far higher potential for increased production than grain crops in the tropics, even though they only recently have begun to be improved by modern agricultural technology. This potential is especially important in Africa where the human population is increasing at a rate faster than the rate of food production.



By the mid-1970s, cassava plants in Africa were showing the ravaging effects of cassava mealybug.

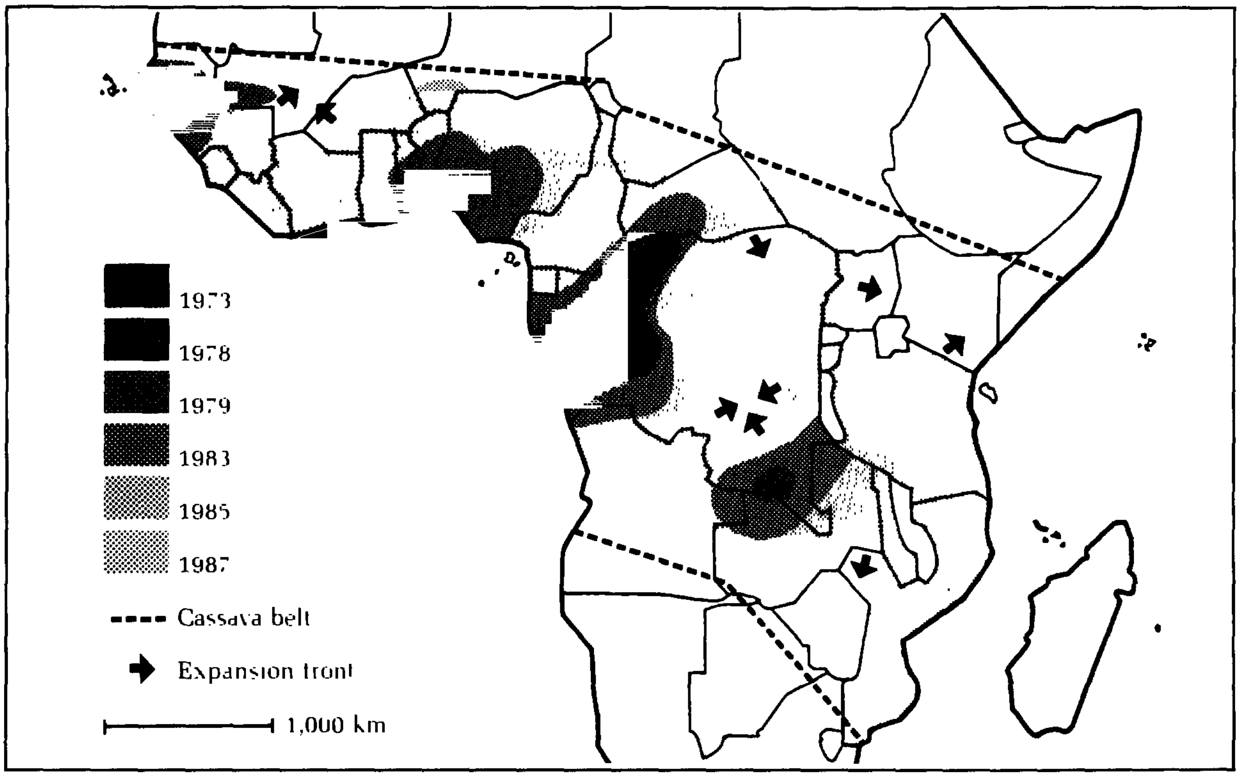
Introduction of the cassava mealybug and cassava green mite

The cassava green mite, *Mononychellus tanajoa* was first discovered in Uganda in 1971 and the cassava mealybug, *Phenacoccus manihoti* in Congo/Zaire in 1973. They have spread throughout most of the cassava belt at a remarkable rate in view of the fact that the mites and cassava mealybugs have no wings. They are now found in 31 of the 34 countries in the African cassava belt (Figures 4.1. and 4.2.). They are found together in 24 countries and are expected to spread to all cassava-growing areas within the next 2-3 years. It is thought that they are transported from place to place primarily on the stem pieces which are used for starting new plantings. It also seems very likely that they were inadvertently brought into Africa from Latin America on stem pieces on which they could survive in crevices for the relatively short time required with modern transportation but perhaps not for the slow passages made by Portuguese traders in the 16th century.

As these pests spread they cause severe yield losses of up to 80 percent. The cassava mealybug has caused the greater losses generally, but the green mite does cause severe losses under certain conditions and losses are particularly severe when both occur together.

Crop protection scientists on the scene must have been perplexed at the severe damage being caused by a mealybug which was not known to be a pest in any other part of the world. In fact, it had never been described and named prior to its arrival in Africa. The cassava green mite was known as one of a complex of spider mites which feed on the crop in Latin America, but there was no history of the severe prolonged outbreaks such as were occurring in Africa. The obvious answer was that both pests had been brought to Africa without their respective complexes of natural enemies that are present and serve to control them in the American tropics.

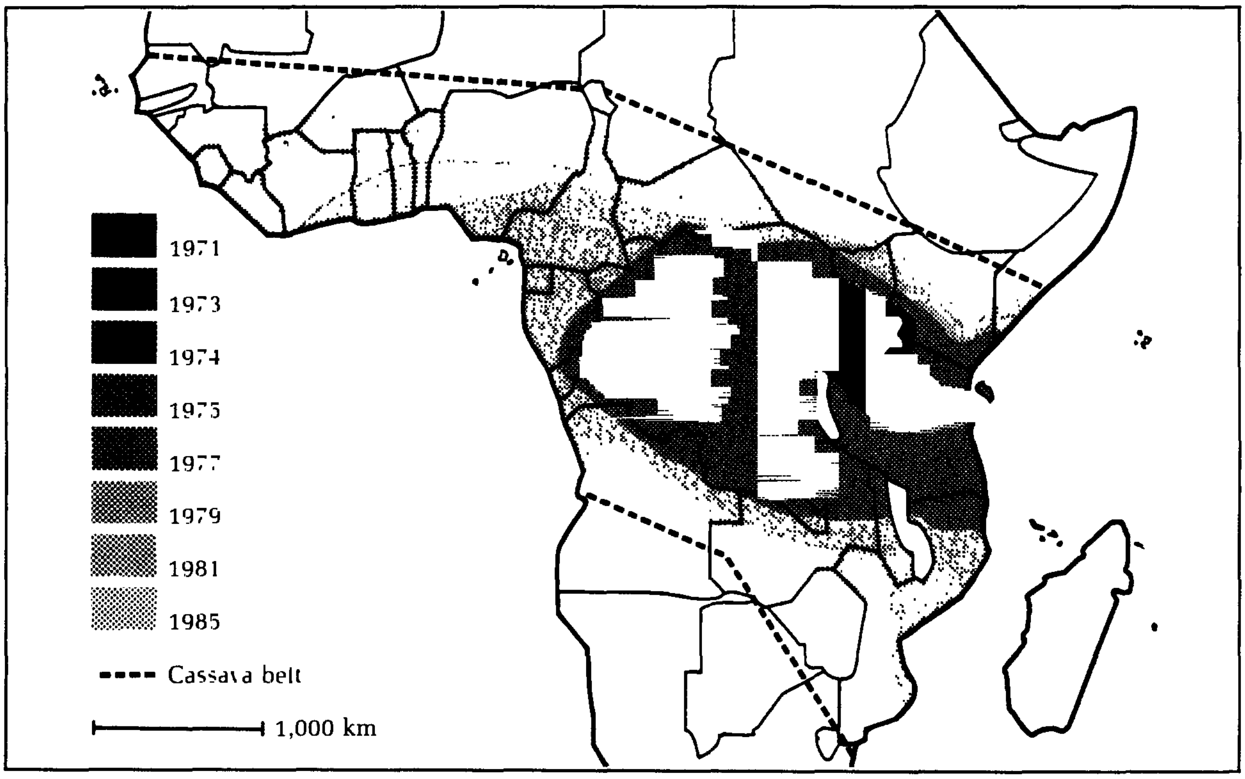
Figure 4.1. Spread pattern and distribution of cassava mealybug in Africa, 1973-87.



What was the response to this serious threat and what options were available? Pesticides were and are not considered a satisfactory response to control these pests, especially on small farms where most cassava is grown in Africa. Scientists observed that some types of cassava were less damaged than others but none seemed to have a high enough degree of resistance to offer timely relief. Likewise, modifications in farming practises (cultural controls) were not promising. Classical biological control offered the best hope for finding an appropriate and timely solution.

The Commonwealth Institute of Biological Control (CIBC), with funding from Canada, conducted explorations for beneficial insects in the Caribbean and northeastern South America from 1977 to 1980. This early campaign was hampered by lack of biological information and logistical problems resulting in high mortality of the parasitoids during transport. Because of the gravity of the situation and in response to urgent requests from affected countries, IITA initiated a classical biological control project. Its immediate objective was to find the natural enemies of the cassava mealybug and the green mite,

Figure 4.2. Spread pattern and distribution of cassava green mite in Africa, 1971-85.



which were believed to control these species in Latin America, and to introduce them into Africa.

In 1979, CIBC appointed Hans R. Herren, an entomologist from Switzerland who had training in biological control and integrated pest management in Europe and California, to head the effort. Following up on earlier CIBC efforts, he began work with a search for the cassava mealybug and its natural enemies in central and northern South America in 1980.

On the basis of these early endeavors, the first agreement for cooperation among IITA, CIAT and CIBC on the exploration and quarantine of these pests' natural enemies was signed in 1981. This activity later developed into the Africa-wide biological control project. From its inception, developments occurred at a rapid pace. Strong and generous donor support enabled the development of cooperative projects encompassing four continents and numerous institutions (Figure 4.3.). The International Fund for Agricultural Development (IFAD), which provided early funding and acted as secretariat for the project, plus support from early donors expedited its progress and success.

Magnitude and complexity of the task

The cassava biological control project, which involves vast areas of Latin America and Africa, is the largest biological control effort ever undertaken, and could move ahead only with careful preparation, and with the resolution of numerous and complex problems before the project began. The cassava mealybug was presumed to have originated in tropical America but had never been collected and described there. Thus there was the problem of finding the pest in the large areas where cassava grows in Central and South America. The cassava green mite was known as part of a complex of mite pests but there were questions about its true identity and about where in Latin America the pest in Africa had originated.

Even though identification of the pests and their natural enemies may seem to be a trivial problem, it is not. Successful biological control of the California red scale on citrus was delayed three decades because it was mistakenly identified as a closely related species. Taxonomists could not separate the species but the natural enemies could. Success was attained only when the correct species was identified and control methods using it were pursued. A similar problem plagued early explorations for cassava mealybug's natural enemies. Unraveling the taxonomy and identifying species in obscure groups of insects and mites are difficult and must be done by an expert. Often there is only one expert in the world qualified and experienced in a particular genus. Additionally, the African cassava belt is huge and encompasses a variety of ecological zones. Both pests had already spread widely and overlapped. The problem of how to distribute natural enemies over the entire belt had to be considered and resolved.

Most countries have strict laws regulating the movement of all kinds of plants and animals across their borders. Beneficial natural enemies of damaging insects are no exception. It was, therefore, necessary for all natural enemies to pass through quarantine before placement in Africa. CIBC in London provided this service.

Parasitoids and many other predators must be reared on their living hosts. Plant pests must be reared on plants and all must be done in isolation to prevent contamination of the colonies because only pure cultures can be approved for release. Such rearing is feasible in isolated air-conditioned facilities on a small scale; however, the problems are magnified manifold when scaled up to produce thousands and millions for release over large areas. Early in the project, elaborate large-scale rearing facilities were designed and eight automated prototype chambers based on the hydroponic culture of cassava were constructed.

The life span of the releasable stages of natural enemies is short: four days or fewer for some species. Thus, fast and reliable transportation was considered essential to deliver and release these fragile organisms over an area larger than the United States where access by land is often difficult and slow. A system for aerial release of natural enemies of the cassava mealybug and green mite was developed and demonstrated to be technologically feasible.

Because of the complexity and multifaceted nature of the project and the need for a quick solution, a decision was made to attack these several problems in parallel rather than one by one in logical sequence. It was also decided to find solutions on a scale commensurate with the urgency and magnitude of the assignment. With experience and the wisdom gained from new information and hindsight, some of the proposed plans exceeded needs.

Africa-wide biological control project

The initial broad objectives of the cassava project were to find and introduce natural enemies of the cassava mealybug and cassava green mite that would maintain populations below economically damaging levels and to develop national capabilities and programs in biological control. These were to be accomplished through the following activities:

- Exploration, quarantine and shipment of natural enemies to IITA;
- Evaluation of natural enemies and development of mass rearing methods;
- Rearing, release, establishment and evaluation of the effectiveness of natural enemies;
- Training national scientists in biological control to assist in the release of natural enemies and follow-up evaluations and to foster national biological control programs by providing advanced degree training for scientists from African countries.

The success of biological control with the cassava mealybug is highlighted here. Work on the cassava green mite is progressing but success is more elusive for a number of technical and ecological reasons. The major natural control agents in South and Central America are small predatory mites which have difficulty surviving during the rainy seasons in Africa when their host populations are very low. Efforts are underway to match habitats in areas of origin and release in order to find species and types adapted to their new habitat.

Following the CIBC search of the Caribbean and the northeastern regions of South America from 1977 to 1980, IITA explored the southern United States, Mexico, Central America, northern Colombia and Venezuela. Several species of parasitoids were collected from a mealybug thought to be the cassava mealybug; however, they failed to reproduce on the latter in tests in Africa. Later, taxonomists decided on the basis of minor morphological and biological differences, plus failure of

To implement biological control, the parasitoid *E. lopezi,* originating in Latin America, was introduced in Africa by IITA scientists to quell infestation of cassava mealybug.

its parasitoids to crossover, that this was a distinct new species and named it *P. herreni*. Cassava mealybug was not found in its original habitat until 1981 in Paraguay by a CIAT scientist. It has been found only in eight areas and always in low numbers. Several parasitoids, including *Epidinocarsis lopezi*, or *E.lopezi* for short, and predators were collected and sent through quarantine at CIBC in London to IITA. They were approved by the Inter-African Phytosanitary Council and passed through Nigerian Plant Quarantine. Beneficial predators collected between 1983 and 1986 by two entomologists sponsored by the Federal Republic of Germany under the umbrella of the IITA project have been sent through the same channels to IITA. Some of these have been released and a few established, but to date only *E. lopezi* has given outstanding results.

E. lopezi is a solitary, internal parasitoid from northern Argentina, first described in 1963 from an unidentified mealybug. In early evaluations, it was questionable whether or not this parasitoid would be effective in controlling the mealybug. The rate of parasitism was not high and it was not certain that the wasp could penetrate the masses of curled rosetted leaves to deposit eggs. These concerns were soon dispelled after the first field releases at IITA in November 1981 at the beginning of the dry season and the next year in a nearby large commercial planting where the mealybug pest was causing severe losses.

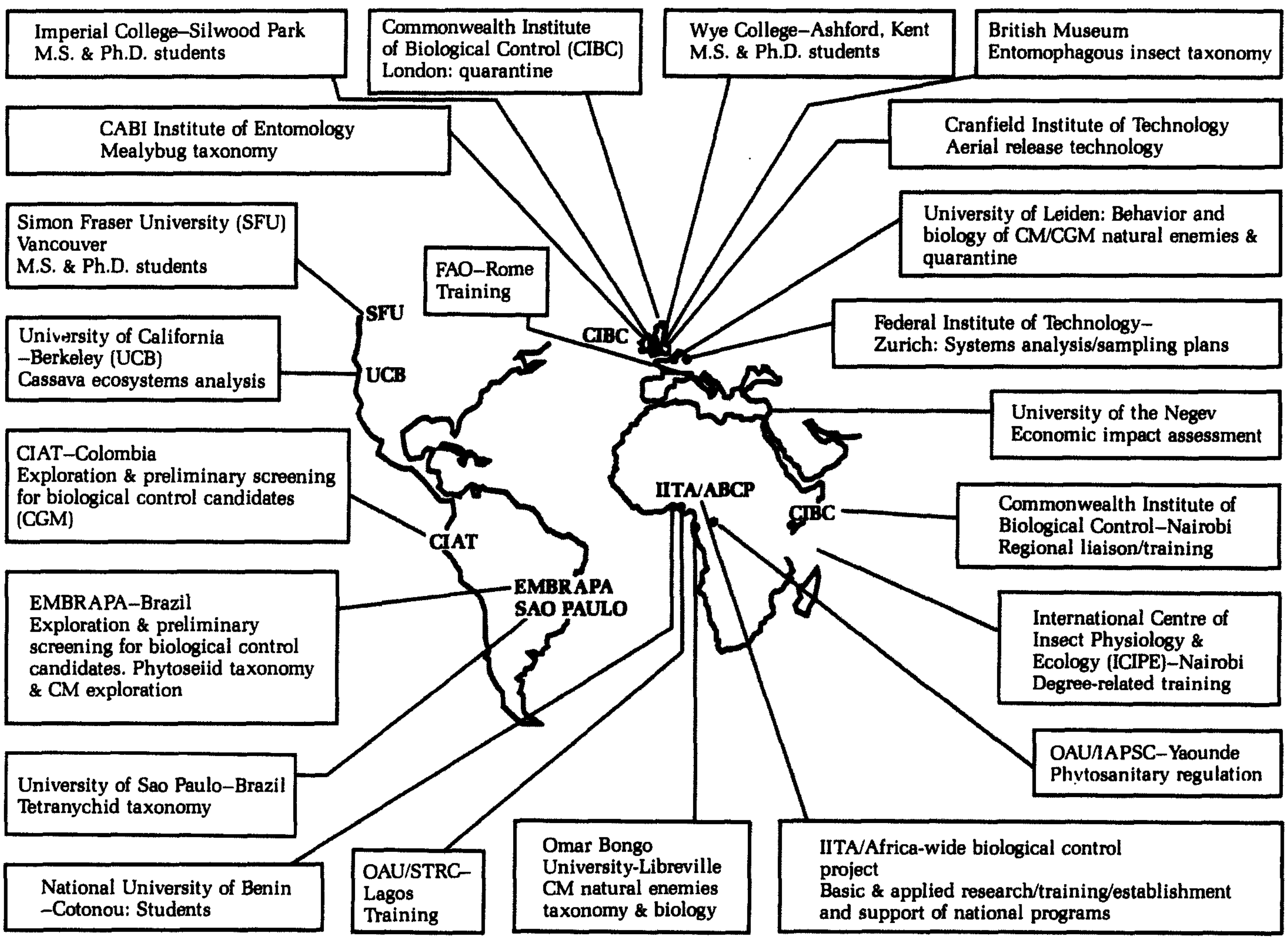
E. lopezi was considered permanently established when it was recovered after the next rainy season, the most difficult survival period because of low host populations. Not only did it survive, it spread rapidly to other plantings. A survey in March 1983 disclosed that it was present in most sampled fields within 100 km from the release sites and as far away as 170 km. After only three years, *E. lopezi* was found in 70 percent of all fields over an area of more than 200,000 square kilometers in southwestern Nigeria and to the northern limits of mealybug occurrence. It was found mostly in traditional farming environments.

More important than the rate of spread was the impact of *E. lopezi* on mealybug populations and damage to cassava. In surveys covering 200,000 square kilometers on several hundred randomly chosen fields in southwestern Nigeria, it was determined that damage symptoms declined from 88 percent of the plants at the end of the first dry season after *E. lopezi* was released to 23 percent the next year. Similar documented reductions have followed releases in Ghana, the Rift Valley of Rwanda, Bas-Zaire and in Zambia. Comparable reductions have been observed in the Gambia and Guinea-Bissau.

To establish beyond any reasonable doubt that the cassava mealybug reductions were caused by *E. lopezi* and not some other factor, physical exclusion experiments were conducted in cassava plantings at IITA. Artificially infested cassava tips were enclosed with insect-proof cheese cloth sleeve cages, some closed and some open at the end to allow the entry of the parasitoid. Mealybug populations were up to seven times lower in open cages than in the closed ones and 24-35 times lower on similarly infested, but uncovered tips. In an artificially infested field from which parasitoids were chemically excluded by insecticide applications, mealybugs averaged 200 per tip, compared to 10 on untreated plants. These results demonstrate the efficacy of *E. lopezi* in the field.

Further evidence of *E. lopezi* effectiveness as a parasitoid of the mealybug comes from the systems-analysis component of the project which was developed in collaboration with the University of California, Berkeley and the Swiss Federal Institute of Technology, Zurich.

Figure 4.3 Worldwide collaborative research and training network of Africa-wide biological control project.



The models were designed to study the dynamics of the components of the cassava agro-ecosystem, to estimate the influence of infestations on tuber yields, and to determine the effects of natural enemies on mealybug dynamics. When the biotic and abiotic parameters for the 1983/84 season at IITA were entered into the model, the predicted population curves corresponded well with recorded field populations. Further simulations indicate that *E. lopezi* rather then coccinellid (lady bird) predators was responsible for the observed small mealybug populations.

Since the early successful releases in Nigeria, IITA has responded to requests for *E. lopezi* from a number of African countries. As of early 1988, natural enemies, including *E. lopezi*, have been released on 100 sites in 14 countries (Figure 4.4.). *E. lopezi* is established in 18 countries over areas of about 1.5 million square kilometers. Monitoring surveys conducted in Ivory Coast, Ghana, Malawi, Nigeria and Zambia have determined that mealybug is being brought under control.

Biological control agents seldom, if ever, eradicate their hosts. A balance develops with some fluctuation in pest and beneficial populations. The objective of biological control is to maintain pest populations below levels which cause economic damage. Detailed experiments at IITA have demonstrated that cassava plants can tolerate up to 20 mealybugs per tip without measurable loss of storage root production. The long-term seven year survey in southwestern Nigeria shows that populations have remained below the economic damage threshold except for occasional sharp peaks of 20-40 insects per tip.

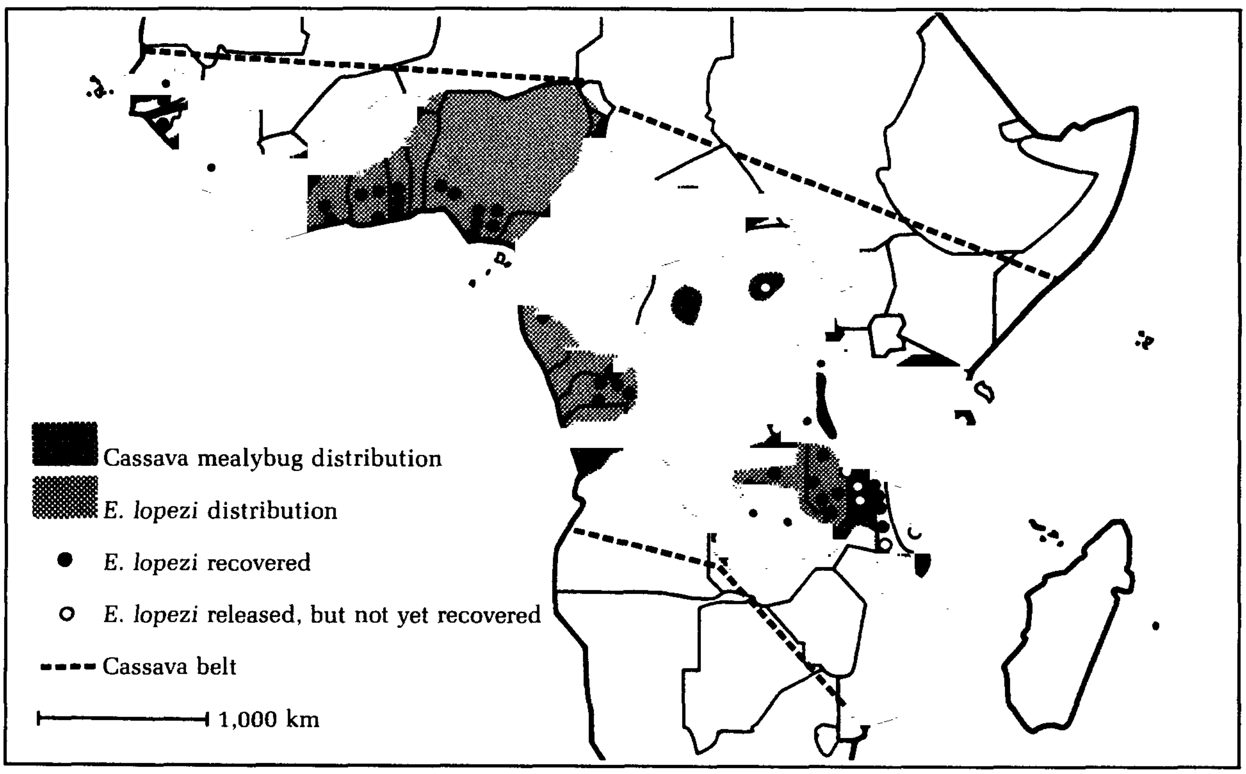
Detailed studies on the relationship between indigenous insects and the introduced *E. lopezi* demonstrate that the latter is successful despite native parasitoids which attack it. In southwestern Nigeria, native parasitoids destroyed up to 50 percent of *E. lopezi* in the first season, but the rate fell to 20 percent when populations of mealybug and *E. lopezi* remained low over the next few years. The evidence indicates that this introduced parasitoid successfully competes with native African natural enemies of its host and itself.

The biology of the adult *E. lopezi* is not only fascinating but helps to explain its efficiency in finding and controlling the cassava mealybug. Olfactory experiments conducted in the Netherlands have shown that mated females are attracted to mealybug-infested cassava leaves but not to uninfested foliage. They are also attracted to uninfested leaves from partly infested cassava plants but not to leaves from uninfested plants. Thus they are attracted to the odors from mealybug infested cassava plants. Because of this they are very efficient in locating very small host infestations. The small second developmental (instar) stage of the mealybug is preferred for host feeding. After a sting, the female often turns and feeds on the host. Almost as many hosts are killed by adults as are killed by the parasitoid larvae which develop inside the mealybug, thus contributing significantly to its efficiency.

Economic impact

Several efforts have been made to estimate the benefits accruing from the introduction of *E. lopezi*, in an attempt to determine the benefit/cost ratio. The estimates have varied widely and have caused considerable controversy. Crop losses in farmers' fields are very difficult to determine under the best of circumstances. It is next to impossible to assess losses of storage roots caused by foliage pests when there are other biotic and abiotic uncontrolled variables that are also influencing yields. The determination of the tons of cassava that have been saved by *E. lopezi* is even more difficult because it is not known what the mealybug populations would have been without the parasitoid. The careful crop loss experiments conducted at IITA and the information from simulation models provide the convincing evidence needed to assess the success of the project.

Figure 4.4. Release sites in Africa of *E. lopezi*, a natural enemy of cassava mealybug.



Experiments have demonstrated that high mealybug infestations cause 80 percent loss of root production. *E. lopezi* reduces mealybug populations below economic injury levels. Even a very conservative extrapolation from this information indicates that *E. lopezi* already has significantly reduced losses in the extensive areas where it has been established. For example, if one assumes that the mealybug and *E. lopezi* will soon be present throughout the entire cassava belt and that *E. lopezi* is reducing losses caused by the mealybug by about 20 percent (a very conservative extrapolation), the annual saving would be 20 percent of 51 million tons or 10.2 million tons. Reasoning that the benefits will continue for years, decades and even centuries, as seems likely based on the parasitoid's effectiveness against the mealybug in South America, the benefit/cost ratio of the IITA project will become very large. Recently, an economist estimated that the benefits of one year of control far outweigh the total project's cost and that the benefit/cost ratio for the project will be 149:1 in 20 years.

The benefits will continue whereas the costs to the project will cease when the parasitoid is distributed and established throughout the cassava belt. And best of all, the poor subsistence farmer pays little or nothing. She/he will not need to expend the additional labor to plant the extra land in cassava in order to provide for the family's needs. With smaller plantings the rotation time for slash and burn farmers will be increased. The benefits can also be considered in the context of a food relief program and weighed against the cost of importing and distributing equivalent calories. This project is an excellent example of providing appropriate, significant sustainable assistance for small farmers.

Significant loss of cassava roots due to cassava mealybug is evident on left, compared to normally bulky storage roots at right.

National biological control programs

From the beginning it was assumed that it would be necessary to train a few people in countries where natural enemies would be released. They would find suitable release sites, assist with the actual releases and help with follow-up studies. In practise, a few individuals from each country where releases were planned were brought to IITA for six- to eight-week intensive courses. In terms of success in establishing natural enemies such as *E. lopezi*, additional training and assistance on a continuing basis is not required. For other types of natural enemies, perhaps those that may be released against the cassava green mite, more involvement by well-trained scientists will be needed.

Because the Africa-wide biological control project was judged to offer an excellent opportunity to develop an effective biological control capability in Africa, an additional training component was incorporated into the project. It provides for the training of scientists to the M.S. and Ph.D. levels. In several instances, those involved in the release efforts have become interested and are now pursuing advanced degree studies. Students take their course work at appropriate African or foreign universities and conduct their thesis research at IITA or the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya under the direction of biological control scientists. This is a cooperative effort between these institutes and African and foreign universities. It has much potential for developing an effective and balanced crop protection capability in Africa.

Two thrusts of biological control

Biological control in agricultural development has two aspects: "classical" and "non-classical." Respectively, they involve the introduction of natural enemies of exotic pests (classical biological control) and the preservation and augmentation of natural enemies of native pests (non-classical biological control). One hundred years ago the vedalia beetle not only saved the citrus industry in California, but also gave credibility to classical biological control and prompted numerous similar efforts. It also led to the development of the theory and science of biological control. I believe that the spectacular success with *E. lopezi* will provide a comparable stimulus to the development and application of biological control in international agricultural development. It is needed.

The increasingly rapid movement of people and goods by fast ships and planes from one geographically isolated continent to another predictably will also increase the rate of introductions of insects, weeds, pathogens and other potential pests. The appearance of the mango/banana mealybug in West Africa and the greater grain weevil in Tanzania are recent introductions of serious insect pests into Africa. There is a need for an international classical biological control capability in the tropics now and for the foreseeable future.

In terms of defining the structure of such a capability, it is instructive to review the factors leading to the success of the cassava biological control project. The cooperation and coordination among the involved international centers, along with adequate funding and support by donors, were critically important. Specialized facilities and equipment for rearing and isolating pests and natural enemies were essential. Equally important were the efforts of the skilled, imaginative and dedicated scientists who unraveled the difficult problems of identification and interactions between the crop, its pests and their natural enemies. Expert peer reviews have consistently judged the work of the project to have been of the highest quality. Herren, leader of the team, received the 1986 Parasitis Award (given to recognize outstanding accomplishments in biological control) "to reward his efforts and dedicated involvement in the largest biological control programme ever conducted in the world."

An international biological capability should be in place to enable timely responses to emergencies as they occur. In the case of the cassava mealybug and cassava green mite, almost a decade passed before an adequate organized response was in place. In the meantime both had spread widely and caused great damage. It takes time to attain success with biological control, so it is important to begin operations as early as possible to avoid major crop losses.

The development and maintenance of an international classical biological control capability is too expensive to be borne by one nation. Further, its nature and international scope require facilities and cooperation in several areas of the world. In my view, classical biological control is an appropriate function of the international agricultural research centers' network wherein cooperation and coordination already exist. The specialized facilities and equipment can be put in place and maintained along with trained specialists. Appropriate linkages with other institutions can be developed as needed. The existing biological control organization at IITA is needed now and for the foreseeable future. The opportunities for application of classical biological control in other areas of the tropics should be evaluated and studied to determine how best to structure an appropriate response.

In efforts to increase agricultural production, the role of indigenous parasitoids, predators and other natural enemies has too often been neglected. We have learned the hard way the importance of natural enemies in regulating pest populations in both temperate and tropical zones. When destroyed by the unwise use of pesticides or changes in agronomic practises, severe pest outbreaks and crop losses have occurred. For example, stemborer and hopper populations on rice have exploded in some areas of Asia as a result of continuous planting of rice and/or the use of certain insecticides. Such changes have altered balances between pests and natural enemies which evolved over time with traditional agricultural practises. An understanding of the factors involved is needed in order to counteract the resulting imbalances. Solutions may be as simple as using a specific pesticide which does not harm beneficial organisms, rotating crops or interplanting. There is need for greater emphasis on biological control in pest control in the tropics, especially in terms of developing integrated pest control strategies in sustainable cropping systems.

Even though this discussion deals primarily with the control of arthropod pests, I must emphasize that biological controls operate in the regulation of other classes of pests and there have been successful examples of classical biological controls. Thus, the purview of biological control should extend beyond insects and mites.

Implications of biological control for sustainable agriculture

Among the factors limiting increased and sustained food production is the problem of losses caused by pests. Worldwide, pests are estimated to cause 30-50 percent of crop losses. They account for more fluctuations in agricultural production than any other factor except weather.

The ephemeral and/or inappropriate nature of several pest control tactics has already been discussed. Of the major components of pest control systems, natural enemies exert the most nearly "permanent" population control pressures, provided they are not destroyed by the unwise use of pesticides or changes in agronomic practises. Biological control is relatively inexpensive or free for the farmer, is non-hazardous to man, animals and the environment and, on the basis of experience, provides control over long periods of time. Biological controls are particularly appropriate for poor subsistence farmers. Even when natural enemies are only partially effective, they augment other controls such as host plant resistance, cultural controls and the judicious use of pesticides. They are the cornerstone of most integrated pest control systems. Biological control must receive greater emphasis in agricultural development if increased and sustainable food production goals are to be reached.

The Africa-wide biological control project and the network of cooperation it has established with other research centers and universities in Africa, Europe, South and North America should be continued, with modifications needed to meet the future needs and opportunities in biological control. Linkages with Asian institutions may become essential if pests from that region become established in Africa. IITA has had outstanding success with *E. lopezi*. It has helped and continues to aid in the development of national biological control capabilities. It has pursued the excellent basic research in the field and laboratory that has enabled the development of simulation models on cassava growth and the dynamics of its pests and control agents. These are basic to developing integrated pest control systems.

There is need for increased research on the role of indigenous natural enemies in regulating pest populations and ways to preserve and augment beneficial predators. Biological control along with pest-resistant crops and cultural practises that mitigate pest problems are essential components of effective and stable pest management systems which, in turn, are needed for successful, productive and sustainable agriculture.

In summary, pests are a major factor in fluctuations of crop production unless effective pest management systems are in place. Biological control is a major element in integrated pest management, which is an important cornerstone in sustainable agricultural production enterprises. Therefore, biological control should be strengthened as a component in the CGIAR's research efforts.

5. Agronomy: Strategic management of agricultural resources

Agronomy is experiencing a resurgence of interest as agricultural decisionmakers seek ways to make best use of available technology and new developments. This report emphasizes the strategic nature of agronomic research in assuring maximum benefit of crop genetic potential and a country's agricultural resource endowment.

Screening for nitrogen-efficient maize, CIMMYT researchers identify a promising plant amidst poor performers in a low-nitrogen area.

New challenges

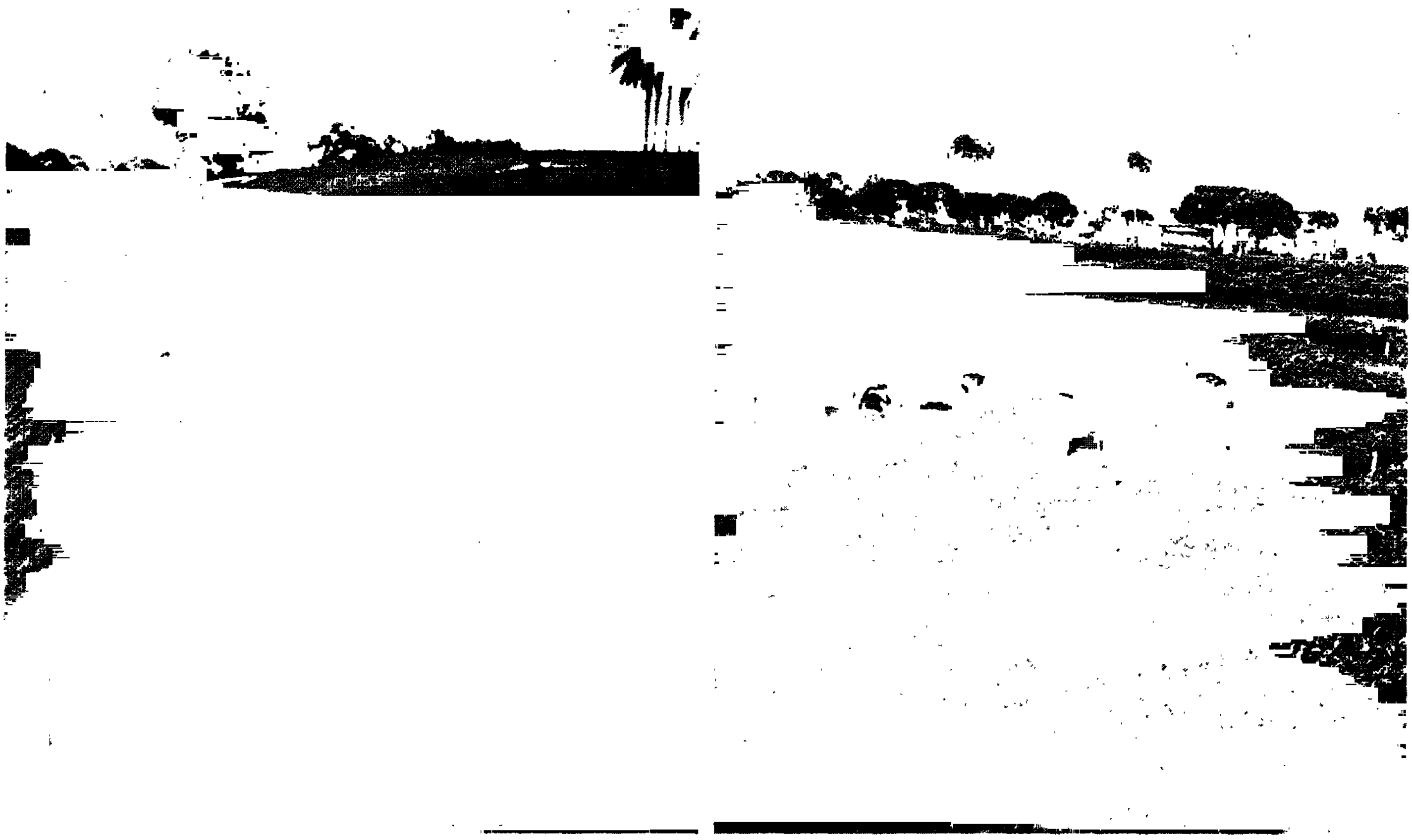
The resource base for agriculture, unless husbanded carefully and replenished continually, will dwindle in its capacity to produce at levels of global demand. While the initial challenge of averting Malthusian famine has been met, at least for the present, new ones have emerged:

- Globally, can yields be brought up to and maintained at their technical and economic potential? Can technical and economic yield be expanded?
- Can productivity be improved in less-favored areas, which of necessity have become the last frontier of agricultural expansion?
- Will production technologies maintain soil fertility and other vital resources upon which future production depends?

Potentially, the overuse of favored areas, the improper exploitation of underutilized areas, and excessive irrigation or chemical usage lead to the same unintended result: a narrower base for future production. The critical difference in outcomes—enhanced and increasing production over the long haul or accelerated depletion of resources—is dependent on the knowledge base that agricultural researchers develop. This involves describing the upper bounds for genetic potential, finding the most suitable technological package for expressing that potential, ascertaining appropriate environments for its use, and ultimately, making choices that involve compromises among the upper bound on yield, immediate demand for food, what is socially and economically feasible, and conservation for the future.

Soil, water, nutrients and energy

The availability of physical resources—soil, water, nutrients, and energy—determines whether land is cultivable or not, and whether it is typed as favored or less-endowed/marginal. Sensibly, favored areas were cultivated first, and efforts to intensify production also occurred there first. Being the backbone of agricultural production, ensuring their fertility and maintaining yields on them are paramount. Both are serious responsibilities. For small farmers on less-endowed areas, subsistence is the norm, climate harsh, resources few, and external inputs inaccessible or prohibitively costly. While the emphasis may be on low-input technology, such an agriculture is not low-tech. Rather, the application of advanced technology is the likely path to improved yields and productivity. It will entail generating seed or



CIAT researchers in Latin America are actively evaluating the effect of *Brachiaria humidicola* (right) to halt erosion of valuable topsoil.

animal stock that resist or tolerate stress as well as providing substitutes for lacking nutrients and energy. A balance is needed between affordable inputs and usable output. Management of germplasm and inputs is critical in both settings.

Due to the shrinking availability of cultivable land, gains in production will increasingly be confined to intensification rather than expansion schemes. Intensification will occur on both favorable and less-endowed lands. On favorable lands, with high-input systems, better management will be especially crucial to achieving higher yields. For less-endowed and marginal lands, pressed upon by population, a combination of new cultivars and management practises will be required to achieve both greater productivity and yields. In either case, conserving and enhancing the resource base will be vital. In high-input agriculture, degradation of the environment usually stems from soil erosion or from spoilage due to excessive use of agrochemicals or overexploitation of water. In environments where low-input agriculture predominates—the tropical forests of Latin America, open savannas in Africa, and hillsides in Asia—soil erosion and lack of replenishing nutrients tend to be the major deterrents. In fragile areas, the margin of error is already less forgiving to farmers and more devastating for the future, sometimes irreparably so, as deserts attest. Furthermore, degradation of marginal lands puts increased pressure on the favored lands, which also face urban encroachment.

Simply put, the three main challenges for agricultural science today are to:

- Maintain and increase yields in favored areas;
- Bolster productivity in less-endowed areas;

- In both settings, employ technologies that conserve or enhance the resource base.

A key requirement is to know what resources are available, before choices regarding technology and allocation of resources can be made. Therefore, underlying each challenge is the need for more data—on the ecological setting, the crop's optimal requirements for water, solar radiation, and nutrients, its tolerance or resistance to pests and disease—before better germplasm or management practises can be suggested. Without such research, the productive potential of a crop in an environment is merely a hunch, hardly the basis for an agricultural development strategy. In areas with low productive potential, characterized by instability and fragility, the need to know is even greater in order to stave off crop failure and resource degradation.

New or recombined genes can only do so much for crop yields; thereafter, gains depend on how the genetic potential is handled: here the questions are when, where, and how, and in what combinations with other plants or animals. Higher-yielding varieties of major food

Box 5.1. Mycorrhizal management and the small farmer.

Mycorrhizae, certain fungi that attach themselves to plant roots, effectively increase the root's nutrient-absorbing capacity, thereby improving the yield of food plants. They form a symbiotic association with the root cells of vascular plants, with their threadlike hyphae functioning similar to root hairs to take up minerals. Mycorrhizal associations can be especially beneficial in tropical agriculture where the major, soil-related, chemical constraints are deficiencies of nitrogen, phosphorus and potassium—the chief elements in fertilizer. Such acid infertile soils commonly are found in areas that have poor infrastructure, including roads and railways, as in the case in the vast savanna and rain forest areas of tropical America.

Mycorrhizal management, therefore, is a biological technology well-suited to the small-scale farmer cultivating marginal land. CIAT research is discovering that naturally-occurring mycorrhizal fungi benefit many crops: without mycorrhizal associations, cassava and pasture plants would not yield in acid, infertile soil, and beans would yield very little. In 34 CIAT experiments, most of them conducted on farmers' fields and using all recommended inoculum and agronomic practises, cassava yields increased an average of 20 percent, from 19.3 tons/ha to 23.1 tons/ha.

Although naturally occurring, the native, symbiotic activity of mycorrhiza can be enhanced by fertilizer, properly used pesticides, mulching, and certain cropping systems. By increasing the population of efficient mycorrhizae and using organic or inorganic fertilizers, crops can be repeatedly grown on the same land. Mycorrhizal management by field inoculation using a selected, superior, fungal species is, in reality, an induced change in the soil mycorrhizal population. One or more tested species of mycorrhizal fungi can be multiplied by the farmer in special plots to produce infected host plant roots or infected soil, which can be used as inoculum. This material can be placed, for example, under a cassava stake in the field or applied directly to the soil around plants. The manner in which the inoculum is applied is very important for the competitive growth of the introduced fungi. CIAT's research indicates that applying infected soil is the most practical inoculation method. Since the production of inoculum and its application are done by hand, the method would be suited to small farms after further development.

For warm-climate potatoes, CIP scientists are finding that a mycorrhizal fungus, *Glomus fasciculatum*, established through inoculation may enable the tuber root system to function adequately under low pH conditions. Infection of nonrooted cuttings appears to be more effective, according to the results of experiments with 15 potato clones. Native isolates of mycorrhiza have been collected over diverse soil and climate conditions in Peru for pot evaluation for infectivity and performance in various soil types, with the objective of identifying widely adaptable ecotypes.

crops are available for favored environments, and incremental improvements have been made in disease- pest- and stress-resistant varieties for less-favored environments; once again the research focus is shifting to how that germplasm is managed and with what long-term effects. With a sense of crisis behind, the timeless concern for stable production, now at higher yield thresholds, reasserts itself.

Strategic agronomy

In this year's annual report, the major concerns of agricultural research are looked at in an old but somewhat forgotten light—that of agronomy as the umbrella discipline for devising options, whether based on improved genes or better management practises, to improve production with the most economic and beneficial use of available resources.

Whereas 20 years ago improved germplasm was the shortest and most effective path to more and better food production, in 1988, more of future gains in productivity on favored and less-favored lands are expected to come from better management of the production process, including research on it and the policy environment shaping it.

Underlying strategic choices are the deceptively simple words—what, where, when and how. Separate agricultural disciplines tend to pivot on these words, yet a sense of the whole and an understanding of the interrelationships among disciplines are what is needed to guide future strategies. For example, the oft-cited distinction between the commodity-based CGIAR centers such as CIMMYT and IRRI and the zone-based centers such as ICRISAT, ICARDA and IITA reflects the differing emphasis on what and where. As their foci converge on less-endowed and marginal lands, the distinction between these centers is blurring. Both types of centers need more information on crops and on agroecological environments. With data in hand, fine-tuning of when to plant what and in what combination of plants and livestock is possible. How to get the best results, using the best seed and optimal practises, rounds out the exercise. Field constraints are fed back into the research loop for attention by scientists and technicians, while obstacles resulting from inadequate incentives, markets, infrastructure, and credit are addressed by economists and policymakers.

For the agricultural scientist, mention of a specific crop triggers a flash card of data: growth zone, length of season, yield, importance and use as food and/or forage, host of diseases and pests, best traits, priority research questions. Similarly, a depicted environment does the same: temperature, rainfall pattern, soil conditions, what crops or crop combinations best fit. Whether crop- or zone-based, the most pertinent CGIAR research today is attempting to address some of the "what-ifs." What if a trypanosomiasis vaccine is successfully developed? What if nitrogen-fixation could be improved in the common bean or groundnut? What if improved tolerance to submergence could be bred into flood-prone irrigated rice? What if a drought-resistant, early-maturing sorghum could be developed for West Africa? What if a mildew-resistant maize could be grown in sequence with cassava?

From a technological standpoint, the overriding themes—and primary impulses for strategic agronomy—are maximizing potential, stabilizing production at increasingly higher levels, and sustaining vital resources over time. For a defined environment, the underlying objective is to develop the best seed, prescribe the most judicious use of inputs, and provide the know-how for managing them best on farmers' fields.

"Most-limiting" problems take priority

Strategic research explores the scientific ideas upon which future progress in agricultural technology depends. Its fundamental question is: Where are the next likely advances in productivity and what strategies should be pursued in order to achieve those advances? Where to begin often stems from identification of the most limiting production problems, the hurdles in the way of full potential. For example, in Africa and many parts of Asia and Latin America, low levels of nitrogen in the soil and forage plants severely limit plant and animal production. The CGIAR response, shared across many centers, is to work simultaneously on identifying and developing nitrogen-efficient cultivars, exploring the nitrogen-fixing properties of legumes and plant helpers such as rhizobia and mycorrhizae, ascertaining more efficient levels of fertilizer usage, and utilizing crop residues and green manures as sources of nitrogen fertilizer, as well as experimenting with pasture production systems that use forage legumes and grasses to enhance soil fertility and animal nutrition.

Maintaining soil fertility for most crops mainly involves nitrogen and phosphorus. The main sources of nitrogen are biological inputs—animal and green manure and plants that "fix" atmospheric nitrogen—and chemical additives, such as commercial or indigenous fertilizers. Crop yield is largely a function of how much nitrogen is absorbed by the plant for growth, but too much nitrogen in the soil leads to waste and pollution. With an eye to reducing the cost and possible pollution effects of commercial nitrogen, studies to calculate the requirement for nitrogen, based on the crop, its stage of growth, season of planting, and organic matter already in the soil, are underway at several CGIAR centers.

For poor farmers, nitrogen fertilizer is expensive, so finding ways to improve biological fixation of nitrogen (converting atmospheric nitrogen into organic or inorganic forms for crop absorption) benefits them directly. Bacteria of the genus *Rhizobium* are the most efficient fixers of nitrogen; they live symbiotically in root nodules of leguminous plants and shrubs. However, many of the best rhizobia types suffer from the maladies of soil and climate where their presence is most wanted. Therefore, the CGIAR centers are actively seeking to find strains of rhizobia that combine efficacy and hardiness.

Efforts to make soil phosphorus more available is the goal of several CGIAR research projects. Phosphorus is often present in the soil, but in relatively unabsorbable form, so plant helpers such as mycorrhizae also come into play. Unlike rhizobia that are bacteria, the plant helpers involved in phosphorus-uptake are fungi that invade plant roots, form an associative relationship with the plant, and enhance phosphorus uptake.

Nitrogen-efficient cultivars

In resource-poor environments, low-cost, low-input technologies are often seen as the most efficient approach to improving production. This perception has influenced much CGIAR research; for example, CIMMYT's maize program has increased its efforts to identify maize that can be grown with limited nitrogen. Through a program of recurrent selection for improved performance under low nitrogen levels, several traits have been found that correlate with grain yield at low levels of nitrogen. Leaf chlorophyll content (an indirect measure of nitrogen status in leaves) appears particularly useful, since it can be gauged rapidly in the field with a portable photometer. (See *CGIAR 1985 Annual Report* for comparable findings in rice).

At IRRI, the ability of 37 lowland rices to support biological nitrogen-fixation was measured by acetylene-reducing activity at heading stage for three consecutive days. The degree of variation suggests that it should be possible to breed rices for high nitrogen-fixing ability. Atmospheric nitrogen was higher in the grain of IR42 than in other varieties.

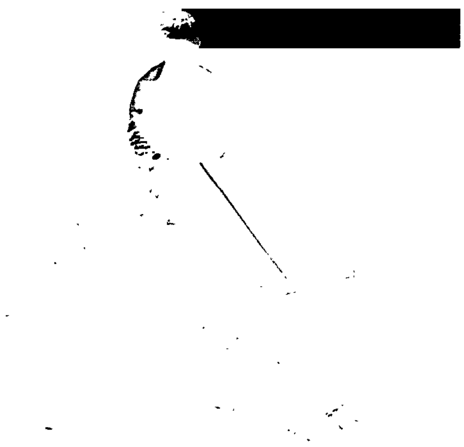
Also seeking nitrogen-efficient cultivars, CIP scientists grew 64 potato varieties on a soil that supplies 60 kg of nitrogen per season through mineralization, with additional high and low treatments of nitrogen. Some clones gave good yields at low nitrogen levels but did not respond to the higher level of treatment. Clones that responded well to low nitrogen and even better to high applications are being evaluated further.

Efficient use of commercial fertilizer

The most common nutrient deficiency in rice is nitrogen. All soils supply some nitrogen to rice, although usually not enough to meet yield potential. For most rice farmers the simplest remedy is to add nitrogen fertilizer, which can be their largest cash outlay. Once the commitment to purchase fertilizer is made, the plant's ability to use nitrogen, the most efficient form of fertilizer, for plant uptake, and the management practises that maximize its use are research concerns.

IRRI and the University of California at Davis studied the relative ability of 24 rices or breeding lines to use fertilizer nitrogen and to collect nitrogen from the soil and air. Over three seasons, two IRRI-bred lines showed consistently better nitrogen utilization from fertilizer and soil and produced superior yields. They performed better than IR42 and IR50, which other studies have shown to perform well under relatively low nitrogen.

Through the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), some 50 rice scientists in 22 countries collaborated in research on integrated nutrient management. Sulfur-coated urea, the most expensive nitrogen product, and deep-placed urea supergranules outperformed the best split application of prilled urea at 24 lowland irrigated in seven countries. Fifty-one percent less nitrogen was required to obtain a one-ton/ha yield increase from sulfur-coated urea, and 48 percent less from supergranules than from prilled urea. At 31 rainfed sites in nine countries, in 33 percent of the trials, yield responses were also significantly higher with sulfur-coated urea and supergranules, requiring 57 percent and 62 percent less nitrogen, respectively, than prilled urea.



In the Philippines, fertilizer-use efficiency has improved 20-80 percent with use of the plunger-auger injector, which is being more widely tested through INSFFER.

Earlier work at IRRI showed that fertilizer nitrogen recovery is only 30 percent or less if fertilizer is broadcast into field water, the most common practise. Incorporating fertilizer in the soil before planting can double its nitrogen efficiency. Soil incorporation of nitrogen is likely to be more important for broadcast seeded rice than for transplanted rice, according to experiments involving ammonia volatilization. Scientists from IRRI and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia compared total nitrogen loss and ammonia volatilization using simple techniques. Comparing different management and application rates, maximum volatilization occurred when urea was broadcast into floodwater and least when urea was incorporated into soil without standing water.

On calcareous soils of the arid zones of the ICARDA region, experiments involving ammonia volatilization of top-dressed urea showed that soil temperature appears to affect ammonia volatilization. With increased soil temperature, the rate of hydrolysis of urea and the rate of reaction leading to ammonia volatilization increases. In northwest Syria, for example, the temperature in February is usually low and urea appears to be a rather efficient and cheap source of nitrogen fertilizer. Losses of nitrogen applied at planting of wheat are expected to be small (5-10 percent), as are losses when nitrogen is applied as top-dressing in early February (10-20 percent).

Under contract research with the National Agrarian University in Lima, Peru, the basic fertilizer requirements for potato in diverse soils and environments are being investigated by CIP scientists. For heat-adapted potato cultivars, mulch is recommended at planting to improve crop emergence and establishment; however, mulch makes it difficult to side-dress a split application of nitrogen fertilizer. CIP experiments conducted during two seasons at separate locations in Peru indicate that a split fertilizer application is not superior. Rather, total fertilizing at planting in combination with mulching eliminates the need to build soil ridges along the rows and reduces the possible entry of bacterial wilt and other pathogens into the crop. Maximum yield was achieved at 70 days by applying all nitrogen at planting. Similar experiments during the dry season also indicated no benefit to tuber yield by splitting fertilizer applications.

Fertilizer and water-use efficiency

Based on ICARDA's regional network set up to calibrate soil tests with crop responses in cereals and legumes, it is clear that economically optimal fertilizer use depends on crop rotation, weed control, soil fertility, previous fertilizer usage and rainfall. In ICARDA's predominantly dry region, soil deficiencies, particularly nitrogen and phosphorus, are widespread. Even in harsh environments, fertilizer can improve water-use efficiency and farmers' profits can increase, as indicated by results with barley/fertilizer experiments. In on-farm trials in Syria, the use of 20 kg/ha of nitrogen and 60 kg/ha of phosphate resulted in increased farmer incomes. The benefits after only two seasons of collaboration were enough to induce the Ministry of Agriculture and Agrarian Reform to provide agricultural credit for fertilizer in low-rainfall (350 mm of annual rainfall) areas. In 11 trials harvested, mean yields ranged from 0.9 ton/ha to 3.3 tons/ha for grain and between 1.4 ton/ha and 3.9 tons/ha for straw, an important by-product where barley/livestock systems predominate.

An 81 percent increase in water-use efficiency was found by ICARDA scientists following the use of 60 kg/ha of phosphate on barley trials in Khanasser, Syria where the long-term average rainfall is 220mm. Grain and straw yields improved significantly.

Other experiments in Syria show that relative responses to soil nitrogen and phosphorus vary depending on water availability. At sites where seasonal rainfall exceeds 250 mm, the response to applied nitrogen was much stronger than to phosphate. At the driest sites, phosphate was more significant. The nitrogen and phosphate fertilizer also affected the protein content of the grain and straw—an important consideration in countries where human and animal diets are deficient in protein. The application of nitrogen fertilizer to durum wheat significantly increased protein in grain (24-51 percent) and straw (31-65 percent).

Importance of phosphate

On marginal land with low pasture productivity and overgrazing by sheep, phosphate fertilizer experiments by ICARDA scientists showed significant improvement in total herbage yield (legumes and grass); also, importantly, legume seed yield on marginal land increased by 27 and 61 percent, in response to 25 kg and 60 kg/ha, respectively.

A collaborative ICRISAT/International Fertilizer Development Center (IFDC) study in Niger confirmed that rock phosphate processed from locally available material is as good as water soluble phosphate. The local phosphate is also less expensive than imported phosphate fertilizers. Yields at least doubled with 24 kg/ha of phosphorus applied, both on the research station and in on-farm trials.

Among the inputs suggested to farmers in ICRISAT's village studies in Niger, phosphorus is being adopted by farmers and a general increase in use (up to 60 kg/ha) has been noted. An improved low-cost production package was tested on a pilot scale in farmer-managed and researcher-managed tests in four villages in Burkina Faso. The package includes runoff-reducing bunds made from field rocks, mechanically-built tied ridges, a low dose of chemical fertilizer, and the improved ICRISAT white-sorghum variety ICSV 1002. Yield increases exceeding 157 percent were obtained under complete farmer management. Results of phosphorus research on millet are consistent with earlier findings: a phosphate application of only 30 kg/ha can triple millet yields.

Crop residues and green manures

Crop residues and green manures are being used to maintain soil fertility in the semi-arid regions of West Africa where population pressures have forced farmers to change from traditional shifting cultivation and fallow systems to continuous cultivation and reduced fallow. In a two-year experiment, involving IITA and SAFGRAD (Semi-Arid Food Grain Research and Development) collaborators in Burkina Faso, six crop residue and four tillage treatments were tested in cowpea production. Crop residue treatments were established the first year and tillage methods in the second year. Before planting, all plots received 50 kg/ha of phosphate fertilizer. Due to beneficial effects on physical and chemical properties of the soil, cowpea seed yields were positively associated with the amount of crop residues left in the field, either as *in situ* mulch on no-till plots or incorporated in the soil in tilled plots. Maize residues retained *in situ* led to early flowering and maturity. No-till with *in situ* mulch was as effective as conventional tillage.

Recycling crop residues and growing and incorporating organic manures can also significantly increase nitrogen supply to crops and reduce chemical fertilizer requirements. For rice, the nitrogen accumulation of the water fern *Azolla*, which grows in association with nitrogen-fixing blue-green algae, and of *Sesbania rostrata*, a fast-growing, stem-nodulating, green manure species from West Africa that will grow in standing water, has been confirmed in IRRI experiments. Growing and incorporating *Azolla* and *Sesbania* before rice increases the soil's nitrogen content and the supply of nitrogen to rice. A long-term field experiment begun in 1985 has evaluated these biofertilizers in comparison to inorganic nitrogen fertilizer. Two crops of rice are grown per year. Before each rice crop *Sesbania* was grown for 45 days during the wet season and for 55-60 days during the dry season, and incorporated. In *Azolla*-treated plots, *A. microphylla* no. 418 was grown and incorporated three times before rice transplanting and once at 25 days after transplanting. The inorganic fertilizer treatment received 50-60 kg nitrogen/ha per rice crop. Rice yield and fertilizer efficiency of four croppings showed a significant yield increase over the control due to *Sesbania* and *Azolla*. Both biofertilizers also produced higher rice yields than the inorganic nitrogen fertilizer (see Table 5.1). Studies of long-term effects on soil fertility will be made after several more croppings.

Inorganic and organic fertilizers combined

Collaborative trials on integrated use of inorganic and organic fertilizers for lowland rice have been established through INSFFER. Inorganic nitrogen fertilizers applied alone or in combination with azolla or fresh straw were evaluated in 22 trials at nine lowland sites in Bangladesh, China, India, and the Philippines. At one site, *Leucaena leucocephala* and *Sesbania rostrata* also were evaluated. Yield response to nitrogen was significant in all trials. Deep-placed urea supergranules resulted in yields 36 percent higher than best split applications of prilled urea. Azolla plus either prilled urea or supergranules equalled inorganic sources alone; in Wanli, China, yield response to azolla plus inorganic nitrogen was higher than to inorganic nitrogen alone. *Leucaena* and *Sesbania* resulted in higher yields than prilled urea alone in Coimbatore, India.

Legumes

Legumes are viewed as a major alternative to expensive and largely unavailable nitrogen fertilizers in conditions of low soil fertility where increased cropping pressures are reducing fallow periods and depleting soil resources. The importance to smallholders is their nitrogen-fixing and often erosion-halting capacities, at low cost and risk. A major concern to subsistence farmers and other smallholders is the impact of legumes on food crops. In mixed livestock/cropping systems, and in rangeland livestock production, improved protein content of legumes for animal feed is the premium asset. In livestock production in vast areas of Africa and Latin America, forage quality and quantity are the main technical limitation to improved livestock productivity.

Over five years of experiments by IITA scientists with two legumes—*Centrosema pubescens* and *Psophocarpus palustris*—demonstrate the effectiveness of tropical legumes in adding organic matter to soil and improving soil properties at low-input levels without a long period of bush fallow. As "live mulch" ground cover in 10 crops of maize, the tropical legumes controlled weeds and contributed nitrogen to the soil, resulting in high yields. No nitrogen was applied. Yields were superior to those in conventional and no-tillage systems at low levels of inorganic nitrogen fertilizer. The live mulch also depleted weed seeds in a manner similar to cropland subjected to long bush fallow. After four years of cropping, the organic carbon content

A 45-day old crop of *Sesbania rostrata* (top) used as green manure significantly increased rice yields in IRRI experiments, due to nitrogen fixation in root and stem nodules.

Table 5.1. **Comparative effect of biofertilizers and inorganic fertilizer on lowland rice (IR54), 1985-87 (average per crop).**

Treatment	Nitrogen input (kg/ha)	Rice grain yield	Percent nitrogen recovery by rice
Control (no nitrogen)	0	4.6	—
Biofertilizer			
Sesbania	69	6.2	65
Azolla	76	6.4	55
Inorganic fertilizer Urea	52	5.9	46

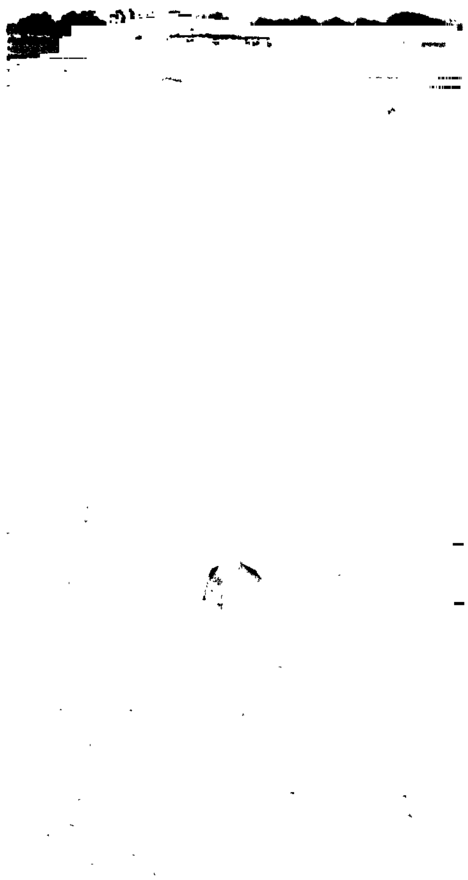
of soil in the live mulch plots approached the level in newly cleared tropical forest, while that in no-till and conventional tillage sites remained relatively low.

Data from long-term crop-rotation experiments on black soils at ICRISAT center confirm the good residual effects of grain legumes. Grain yields of rainy-season sorghum with no added fertilizer increased from 1,400 kg/ha to 3,400 kg/ha where an intercrop of pigeonpea and cowpea was grown the previous year.

At IRRI, rice and legume intercropping was evaluated in upland rice areas. Yields from the best treatments in many experiments exceeded 5.0 tons/ha; average local upland rice yields are 1.5 ton/ha. Yields from the first rice crop in the pattern were 4.0 tons/ha, with high returns above variable costs. Returns were highest for the rice and cowpea intercrop; yields were high and costs were low because fertilizer was not applied.

Dual-purpose legumes

In the Sudan savanna and Sahel ecologies of West Africa, cowpea fodder is as important to farmers as the grain, because of usual dry season shortages of fodder. A dual-purpose variety that produces 600-800 kg grain/ha and retains its foliage through the end of the season is valued, because both grain and fodder attract almost equal prices in times of scarcity. IITA scientists in collaboration with program scientists in Nigeria and Niger evaluated medium-maturing cowpeas for this purpose. Preliminary results indicate that TVX 4659-03E, a multiple resistant variety, gave grain yields of 1.7 ton/ha and fodder of 4.5 tons/ha and could be a suitable dual-purpose cultivar. In Niger, in ICRISAT/IITA work on early-maturing cowpeas, widely intercropped with millet, the best dual-purpose line gave 1,600 kg grain/ha and 2,070 of hay/ha in fewer than 70 days.



In crop rotation experiments by ICRISAT, results indicate substantial benefit to cereal crops from residual nitrogen left in soil by legumes.

ILCA's alley farming experiments in Nigeria with leguminous shrubs (*Gliricidia*) and food crops (maize) are improving the sustainability of a fragile resource base and increasing crop yields.

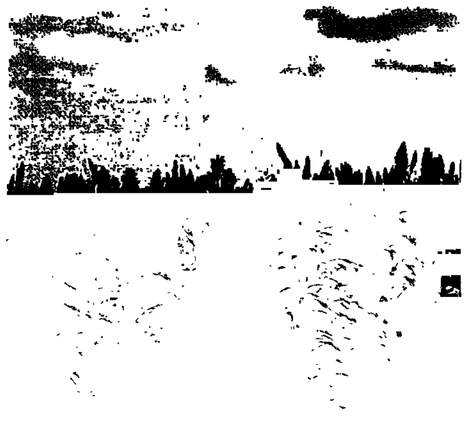
Alley cropping

The nitrogen contributions of green manures from three species of hedgerow trees (*Flemingia congesta*, *Cassia siamea*, and *Gliricidia sepium*) to a maize crop on a degraded Alfisol in Ibadan were evaluated by IITA. Phosphorus and potassium were broadcast on the plots before planting. *Gliricidia* prunings yielded a greater amount of nitrogen, equivalent to 90 kg of nitrogen fertilizer/ha. For alley cropping where labor for pruning is a major constraint, preliminary results from *Calliandra*, a fast-growing leguminous tree, intercropped with maize and cowpea suggest good maize yields from pruning alone without added fertilizer. In Kagasa, Rwanda, a harsh semi-arid environment with poor soils, yields of maize, bean and sorghum in alley cropping with leguminous shrubs were as good as yields grown without shrubs. No fertilizers were applied in these IITA trials.

IITA's farming systems program is also evaluating several leguminous species for biomass production, protection of surface soil, survival during the dry season (June-September), and blending of harvested tops as green manure into the soil. *Crotalaria* spp, *Mucuna pruriense* var. utilis, pigeonpea (*Cajanus cajan*), and *Sesbania sesban* were about equal in biomass production. *Crotalaria* provided best early ground cover and promised to reduce soil erosion during the dry seasons. Pigeonpea was most drought tolerant, followed by *Crotalaria*. Mixing pigeonpea (50 percent) with grasses also improved the quality of fodder and increased goat liveweight gains.

In the humid zone of Africa, ILCA's agronomic work in collaboration with IITA has focused on the integration of fodder trees into traditional farming systems and the development of fodder production strategies, so that livestock production can be improved and cropping practises made more stable. Food crops are grown in alleys between lines of leguminous trees (*Gliricidia* or *Leucaena*), which provide browse for small ruminants and mulch for crops while stabilizing the fragile soils found in the zone. Continuous alley farming with *Gliricidia* and *Leucaena*, and alley farming after a two-year grazed fallow produced maize yields 60 percent and 100 percent higher, respectively, than maize yields following continuous maize cropping without trees. Soils under alley farming were richer in organic material and major nutrients. The nitrogen content of maize leaves was highest in alley farming following fallow, providing improved crop residue feed for livestock. The number of alley farms under farmer management in Nigeria's humid zone increased from four in 1982 to 250 in 1987. The technique is being extended to other countries.

Other agronomic trials in the humid zone have elucidated the most effective plot designs for intensive feed gardens—small plots of leguminous trees and grasses that provide high quality feed for small ruminants kept in confinement. The highest yields of protein in feed were produced from rows of trees spaced 2.5 m apart with two rows of grasses in the alleys. The testing of alley farming and fodder bank techniques is now being extended to the sub-humid and semi-arid regions of other countries in West Africa.



Pigeonpea (tall) and sorghum have been the most productive and useful crop combination for Indian farmers in ICRISAT experiments.

Forage and pasture crops

At CIAT, grazing systems that recycle nutrients through soil microorganisms and integration of soil and plant nutrition are a priority. Forage legumes are being increasingly introduced into the traditionally grass-based pasture systems that predominate in sub-humid and humid ecosystems of Latin America. The low-input approach, using adapted germplasm and efficient use of local resources, rather than correcting soil deficiencies with large amounts of fertilizer, is a sensible choice in view of forecasts of limited availability of lime and fertilizer. Legumes in symbiosis with rhizobia are expected to contribute directly to the improved diet of animals in terms of protein (particularly during the dry season) and to improve the yield, quality and persistence of grasses due to enhanced availability of nitrogen.

In ICARDA's research on pastures and forages in rotation with cereals—to improve native pastures and animal nutrition, hence productivity, and the effective use of crop byproducts—legumes are emphasized. Analysis of a four-year series of trials to test the feasibility of replacing fallow with forage legumes such as vetch and lathyrus indicates that forage substantially increases barley's water-use efficiency. Although forage production is economically attractive, profitability depends on which forage is used. ICARDA seeks to improve the productivity and profitability of legumes, to ensure that

Table 5.2. IBPGR field collecting for forages in 1986-87.

Country	Specific collecting for forages
Argentina	*Briza, Bromus, Lycium, Pappophorum, Pitochaetium, Poa, Sorghastrum, Stipa*
Belize	*Aeschynomene, Centrosema, Desmodium, Leucaena, Macroptilium, Stylosanthes*
Brazil	Subtropical legumes and grasses
Cameroon	*Andropogon, Brachiaria, Pennisetum*
Chad	*Acacia, Pennisetum* (forage forms)
China	*Agropyron, Aneurolepidium, Elymus, Hordeum, Roegneria*
Colombia	*Centrosema, Stylosanthes*
Ethiopia	*Cenchrus, Chloris, Digitaria, Panicum, Stylosanthes, Trifolium*
Greece	*Dactylis, Festuca, Lolium, Medicago, Trifolium*
Indonesia	*Desmodium*
Italy, Portugal, Spain	*Dactylis, Festuca, Holcus, Lolium, Lotus, Medicago, Ornithopus, Trifolium, Vicia*
Mauritania	*Andropogon, Cenchrus, Pennisetum, Vigna*
Niger	*Acacia, Andropogon, Cenchrus, Panicum, Pennisetum, Setaria*
Oman	*Cenchrus, Medicago, Pennisetum, Trigonella*
Syria	*Cicer, Lathyrus, Lens, Lupinus, Medicago, Pisum, Vicia*
Turkey	*Lathyrus, Vicia*
Venezuela	*Centrosema, Stylosanthes*

farmers have economic incentives to maintain rotations that conserve soil fertility and provide valuable protein for human and animal consumption. While faba beans, lentils and kabuli chickpeas may be of minor significance in global agricultural production and trade, they are important in hard-pressed environments because of their ability to fix atmospheric nitrogen and enhance soil fertility.

Benefits for both livestock and food crops

One of the most common questions asked by farmers about pastures and forage crops is what effect will they have on a subsequent cereal crop. Based on ILCA research, Table 5.3 shows the effects of two forage legumes on subsequent sorghum and maize yields, compared to maize following oats, in the Ethiopian highlands. *Vicia dasycarpa* and *Trifolium steudneri* produced average yield increases of 72 percent in sorghum grain and of 91 percent in maize grain.

Table 5.3. Effect of previous crop on grain yield of sorghum and maize, Debre Zeit, Ethiopia, 1985-86.

	Grain yield (kg/ha)	
1984 Crop	1985 Sorghum	1986 Maize
Trifolium steudneri	2,632	2,731
Vicia dasycarpa	2,130	3,274
Oats (*Avena sativa*)	1,386	1,571

Intercropping forage legumes with cereals can produce higher total biomass and protein yields than legumes and cereals grown in pure stands. For example, intercropping the cowpea CII and maize produced 24 percent and 38 percent more dry matter, respectively, than did the two crops grown in pure stands.

In summary, the CGIAR centers carry out research on fertilizer needs and responses for their respective commodities, but cannot cover the full range of possible activities. Nitrogen and phosphorus, as major limiting factors in most developing countries, receive priority. Here the effort is more toward finding nutrient-efficient genotypes, characterizing genotypic responses to fertilizer, and improving the application and efficient use of fertilizer materials. Realizing that purchased inputs may be unavailable or too expensive in many situations, the centers also are studying legumes and other nitrogen-fixing organisms for crop use, as well as improving the usage of legumes in cropping systems and pastures. Plant helpers that improve fertilizer efficiency or uptake also receive attention.

Box 5.2. Agronomy of forage legumes.

The use of improved forages, particularly legumes, in farming systems is the special focus of CIAT, ICARDA, and ILCA scientists with their respective regions—Latin America, West Asia and North Africa, and sub-Saharan Africa. The emphasis is on soil fertility as it affects plant growth, and forage nutrition as it affects livestock production.

In conjunction with IBPGR (see Table 5.2), all three centers maintain extensive forage legume and grass collections, as part of a global action plan, initiated in 1984, to preserve high-potential forage and grasses.

CIAT. For Latin America, regional trials of selected grasses and legumes suited for major ecosystems are screened at more than 150 locations through the International Tropical Pastures Evaluation Network (RIEPT in Spanish) with 18 member countries. Similarly for sub-Saharan Africa, the Pasture Network for Eastern and Southern Africa (PANESA) was formed by ILCA in 1985, and 19 countries now participate. Studies on nutrient responses, nitrogen fixation, and agroecological zoning to increase the efficiency of germplasm screening are in progress.

After initial screening and evaluation of forage species, grass-legume associations are developed into pastures under low-input technologies and evaluated for their productivity and persistence under grazing conditions, both at major screening sites and at RIEPT sites. The improved pastures are finally exposed and evaluated under farmer-management systems on marginal lands with close-market proximity to extensive, cow-calf operations in the frontiers.

Several grasses and legumes are now being used by CIAT in various pasture combinations as part of its strategy for expanding milk and meat production in the vast, underused frontiers of the tropics. Of those, the grasses most stable in productivity are: *Andropogon gayanus* 621, *Brachiaria decumbens* 606, *B. dictyoneura* 6133, and *B. humidicola* 679, while the most stable legumes are *Stylosanthes capitata* 10280 (cv. Capica), *S. guianensis* 136 and 184 (cv. Pucallpa), *Centrosema macrocarpum* 5065, *Centrosema* sp. 5277 and 5568 as well as *Desmodium ovalifolium* 350.

More than 16 million hectares are estimated to have been planted in either *Brachiaria decumbens* or *Brachiaria humidicola* in the tropical America lowlands alone.

However, "spittlebugs," insects named after the frothy, spittlelike mass that surrounds their nymphs that feed at the base of grass, are a major threat to the future use of *Brachiaria* in Latin America and even a potential economic threat to crops. Through mass-rearing of spittlebugs and screening techniques, CIAT is identifying species of *Brachiaria* that are resistant to spittlebugs and which have antibiotic characteristics that reduce spittlebug populations.

ICARDA. The concept of using pastures to replace fallows is based on experience in southern Australia where fallows have been replaced by self-regenerating pastures whose roles are to provide livestock with year-round grazing, replenish soil fertility, and provide a disease-controlling break between cereal crops. Success of the system depends on using pasture species with the ability to produce enough dormant seed for the population to survive a year in which no seed is set.

Three years of research at ICARDA has shown that *Medicago rigidula* can regenerate naturally and form productive pasture in rotation with wheat. The experiments included 25 promising medic strains: 23 entries of *M. rigidula* and one each of *M. rotata* and *M. noeana*. Selections of *M. rigidula* originated from Algeria, Jordan, Lebanon, Libya, Syria and Turkey; the latter two entries from Turkey.

Eighty-seven percent of the more than 600 kg/ha of seed remained in the soil three years later as a long-term reserve. The final yield of seed at the end of the third year was 700 kg/ha. The amount which germinated in the third year ranged from 25 to 167 kg/ha, depending on the entry. Pasture yield in the year after wheat depended on the population of seedlings and was largely independent of other attributes. There is no short cut to selecting medics adapted to a pasture/cereal rotation: they must be subjected to the system in which they will finally be used. Several selections of *M. rigidula* are now being included in grazing experiments and on-farm trials. In the near future, it is expected that cultivars adapted to pasture/cereal rotations in Syria will be released.

ILCA. At ILCA, accessions are also tested in a range of environments, using different management techniques. *Stylosanthes guianensis* (cv. Cook) in the short term and *S. scabra* and *S. fruticosa* in the longer term have shown excellent growth and persistence under cutting and under grazing when oversown, or sown into cultivated strips, in native pastures in the middle altitude, medium rainfall, acid soil region of East Africa.

Desmodium intortum (cv. Greenleaf) grown under coffee and false banana is productive, persistent and has a high acceptability with Ethiopian farmers, as do *Stylosanthes guianensis* (cv. Cook) and *Macrotyloma axillare* (cv. Archer) planted in pure sward or established as intercrops with maize. The ready acceptance of these crops by farmers is due to their ease of establishment, their high productivity and their positive effects on the yield and quality of milk from livestock feeding on them.

6. Impact: Adaptive research links farmers and researchers

The CGIAR centers rely upon the comparative advantage of national agricultural research systems in choosing and modifying technologies to meet the needs of their farmers. While the CGIAR centers focus on the development of intermediate products, they have a keen interest in the effective application and adaptation of germplasm and management principles resulting from their research to location-specific situations. The local application of new technology is where much of the search for sustainability lies. A novel technique is seldom inherently degrading or sustainable; rather, degradation and erosion are caused by its inappropriate application on the farm within the local ecology. Thus it is national research systems, in their role of identifying principles and adapting them to solve local problems and to exploit local farming opportunities, that directly confront the challenge of sustainability. Strong national programs are also the most effective means for transmitting CGIAR "products" to their intended beneficiaries, small farmers in developing countries. Hence, the CGIAR's firm commitment to building national research capacity, an activity currently absorbing some 20 percent of the CGIAR budget.

CGIAR interest in the adaptive research process is paralleled by interest in how policy interacts with the process, and in how research institutions are best organized to manage the process. Over the past 15 years or so, efforts by CGIAR centers to develop an effective adaptive research process and to help national systems build skills and institutions to use it have had considerable impact on national research organization and management.

Adaptive research process

Research has traditionally been on experimental stations where conditions bear little resemblance to those experienced by resource-poor farmers. Often research stations resemble islands—with unique soil fertility characteristics, weed spectra and pest and disease complexes. Such physical isolation stems from years of classical experimental research at high levels of management designed to expand yield potential with new plant material and agronomic practises.

The orientation of researchers with a single commodity focus who seek maximization of physical yield per unit area is also remote from the concerns of near-subsistence farmers. With low resource endowments, such farmers operate complex systems which include a diversity of crops—often mixed in the same field—animals, and off-farm work. The priorities embodied in such complex systems, including the need to cope with vagaries of both climate and markets, and their resource limitations demand compromises in management; for such farmers, the whole is more significant than any component.

Two major developments in the research process have evolved to eliminate the gap between researchers and farmers:

- on-farm research, in which experiments are done in farmers' fields under actual operating conditions, and
- a farming systems perspective to research methods as a way to understand farmers' priority needs for new technology.

CGIAR centers have played a major role in both these developments.

On-farm research

At IRRI, yield gap studies that were started in the early 1970s methodically analyzed why yields in experiments on research stations could not, on average, be achieved on farmers' fields.

> "...average farm yields of modern varieties are far below the level demonstrated to be possible on experiment stations. Instead of reaching the experimental levels of 6-8 tons/ha, good farmers get 3-4 tons/ha and many get as little as 2 tons/ha."

IRRI's classic diagram of the yield gap concept (see Fig. 6.1) shows an irretrievable gap caused by the difference between experimental and operational conditions including plot size, and a retrievable gap caused by diverse technical and socioeconomic circumstances, varying with location.

Developments around this concept led to two important innovations in the research process, predicated on the need to do much applied and all adaptive research under farmers' conditions: first, constraints analysis, developed by IRRI out of the yield gap experience, is now accepted as a necessary part of on-farm research, and second, economic analysis of experimental results that takes into account what farmers are likely to get.

As used by CIAT, CIMMYT, CIP and IITA, among others, constraints analysis in the on-farm research sequence compares farmers' current practise with the expected best technical practise. Such experiments identify and rank individual management components, including variety, on the basis of their potential contribution to yield.

Economic analysis of experimental plot results from farmers' fields recognizes the irretrievable yield gap. Average yield in experiments must be adjusted downward to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. Without such adjustment, exaggeration of outcome, a feature of "top-down" research, jeopardizes the credibility of both research and extension in the eyes of small farmers.

The CGIAR centers in general have perceived the need for an on-farm research sequence. CIP's "farmer-back-to-farmer" approach to on-farm research has received wide attention. Exploratory trials, determining which production factors are important in local circumstances, are a first step; the second is to identify levels of those factors that are economically important. The third step is validation. Findings from the previous two steps are widely exposed to the spatial and inter-seasonal variation that farmers within a target group have to manage, to verify them as robust within the local production environment.

Unlike classical research techniques, as the sequence progresses, less and less control is imposed by the researcher; farmers' current management practise is followed except for the treatments. Farmers perform the operations across treatments and apply each treatment. At this stage, across-site and across-year analysis is used to establish the level and probability of economic differences between favored treatments and current farmer practise.

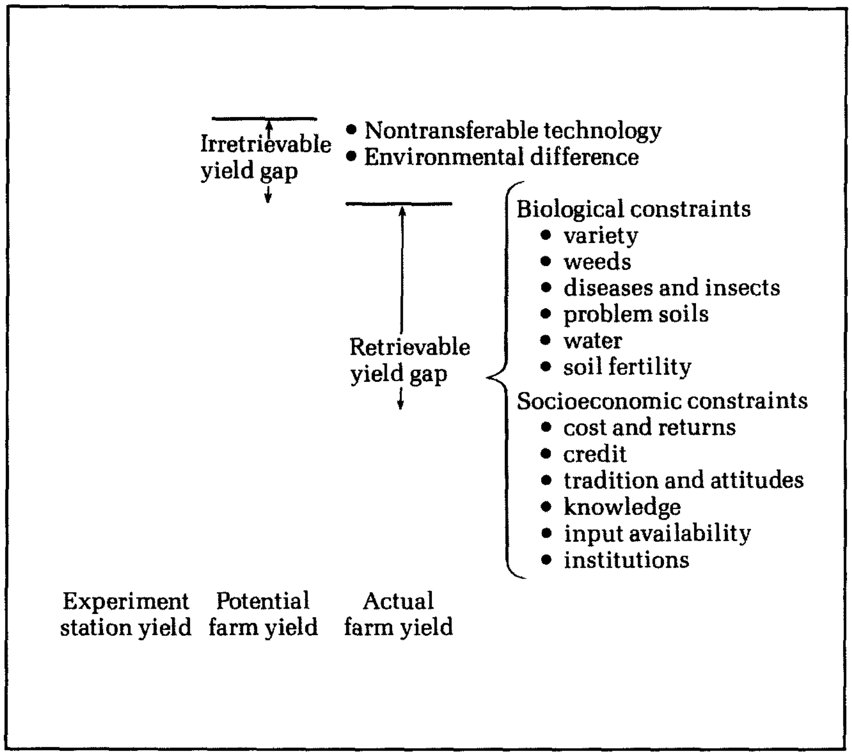
Both ICARDA and ILCA have been active in extending the principles of on-farm research to livestock. As ILCA staff have pointed out: "Small numbers of animals on small holdings often preclude adequate statistical design and analysis. Animals are more complex to work with, their mobility reduces the degree of control possible, inputs are made daily rather than seasonally, the production cycle is long and the products of an individual animal may be numerous and their inter-relationships complex." These factors make "in-herd" experiments more complicated than crop experiments on small farms.

The farmers' perspective

Based on the extensive findings of technology adoption studies of the 1960s and 1970s, the CGIAR has widely acknowledged the importance of a holistic, systems approach to technology design. IITA in 1967, ICRISAT in 1972, ILCA in 1975, and ICARDA in 1977 were, in fact, established with a systems-oriented mandate. The centers' work on methods for capturing the farmers' perspective took different directions. Each had a view on how such a perspective was best related to its mandate. ICRISAT undertook its now widely known "village studies" in the Indian semi-arid tropics, a detailed collection of data on farmers activities over 10 years, perhaps the most extensive set of micro-level data available to researchers. A similar pattern was followed by ICRISAT in its West African program. IRRI extended its physical descriptions of experimental sites to include the farm family and circumstances. ILCA undertook detailed longer-term studies, similar to ICRISAT's, at key benchmark sites in the major livestock systems of Africa.

Identifying research methods that would make an effective contribution to technology development became a major preoccupation at several centers. Much of this effort fell under the rubric of farming systems research. CIAT, CIP, ICARDA and later IITA used studies of farming systems to diagnose opportunities for their own technologies. The studies were followed with on-farm experiments designed to adapt the principles of strategic findings to location-specific situa-

Figure 6.1. IRRI's concept of yield gaps: differences between experimental yield and potential and actual farm yields.



tions. CIMMYT concentrated on the development of low-cost farming systems research methods and training national programs in their use. One CIMMYT concept—the use and refinement of target groups as "recommendation domains"—creates a framework for both policymaking and technology development and a strong awareness among researchers about who they are working for (see Box 6.1). Box 6.2 illustrates some other features of the CIMMYT process from a collaborative project with the Malang Agricultural Research Institute for Food Crops (MARIF) in Indonesia.

Understanding farming systems and farmers' strategies in allocating land, labor and cash has highlighted key facets of an effective adaptive research process for the centers:

- The ability to focus on problems which farmers regard as priorities immediately creates a commonality of purpose between researchers and their clients. It helps ensure that, if appropriate solutions are identified, farmers would be willing to allocate scarce cash or labor to their implementation. There are always 1,001 problems on any farm, hitting the one the farmer ranks as

1,000 is unlikely to raise his enthusiasm as much as hitting number one.

- The ability to shape a proposed solution to the resource and management capabilities of an existing system emphasizes the principle of sequential adoption which has taken on new importance in technology development (see Box 6.3).
- The ability to identify *ex-ante* the criteria farmers will use in evaluating innovations, so that experiments can be planned and evaluated around these same criteria. Thus, lower costs, units of cash earned per unit of cash spent, improvement in the return offered to labor employed at a peak season, the amount of water, fuel, and time required to cook a new variety, all these and more have become key criteria in adaptive experimentation.

Overall, the development of a systems-based diagnostic process has allowed center researchers to interact with small farmers. Initial diagnosis puts applied and adaptive experimentation on a track important to clients, and feedback during experimentation guides the work to an appropriate conclusion. Two examples from ICARDA and ILCA demonstrate the radical changes of direction that feedback from farmers can elicit.

Diagnostic surveys by ILCA, working in the sub-humid zone of Nigeria in collaboration with the Nigerian National Animal Production Research Institute (NAPRI), indicated dry season feed shortages as the primary constraint on increased livestock production for the zone. Researcher-managed trials on farmers fields examined ways to establish and manage small, intensive dry-season fodder banks—fenced areas planted with specialized forage species to be used as reserve feed for the dry season. The next phase was to test banks in farmer-managed trials in collaboration with the Nigerian National Livestock Projects Department (NLPD). Although these trials showed that the concept was highly acceptable to stock-owners, many of the practises for establishment and for management had to be modified. Mechanical cultivation proved impossible and further researcher-managed trials used trampling by high densities of stock as a means for fodder legume incorporation. Stock-owners needed reassurance by experience that such herding would not increase the risk of worms in their herds.

ILCA's idea had been to use the banks for the selective grazing of special animals, for example, pregnant or lactating cows. But a primary concern for many stock-owners was dry season survival of their animals and they grazed the whole herd. Further economic evaluation showed a higher internal rate of return to this use. Fodder banks spread among stock-owners who controlled land, but most did not. Researchers began to emphasize the advantages of fodder banks for non-owners by showing the benefits from maize production on the banks. The adoption of fodder banks by crop farmers increased, and the innovation continues to evolve as farmers adapt the idea to their own needs.

ICARDA had a similar experience in studying the impact of annual forage crops on the productivity of farms in northwest Syria over a six-year period. The forages studied were common vetch (*Vicia sativa*), chickling (*Lathyrus sativus*) and forage peas (*Pisum sativum*). In preference to using the crops for hay, which ICARDA had expected, the farmers chose to use the crops either for spring grazing for fattening lambs, or to allow the crops to mature for seed and straw production. Using the crops for fattening lambs maintains their growth rate after weaning so that they reach marketable weight before the dry season starts. Harvesting the crops at the mature stage gives the greatest yield of energy. The protein can be used as highly nutritious feed in winter when ewes are pregnant or lactating. This option also produces seed for sowing next season. Research priorities have been adjusted accordingly.

Small farmers in Colombia participating in a joint CIAT/national program learn from each other about successful practises in bean production.

Box 6.1. Heightened awareness of the role of women in farming.

IRRI's Women-in-Rice-Farming Program has demonstrated the strong division of labor by gender in crop production and how it varies in different subgroups within the same community. For adaptive experiments in this locality in the Philippines which focus on rice land preparation, researchers need to interact strongly with men and to assess the implications for male labor. On the other hand, for experiments on seedling quality, women are the main clients and female landless laborers a group strongly affected.

Labor participation by gender in cropping activities by farming and landless households in a Philippines locality.

Crop and activity	Participation (%)			
	Farming households		Landless households	
	Male	Female	Male	Female
Rice				
Land preparation	95	5	100	0
Pulling seedlings	6	94	9	91
Transplanting	98	2	100	0
Harvesting	76	24	69	31
Threshing	94	6	83	17
Buying inputs	82	18	66	34
Taking harvest to mills	56	44	100	0
Marketing	69	31	100	0
Glutinous rice				
Cooking	36	64	50	50
Pounding	71	29	59	41
Marketing	14	86	—	100
Total households interviewed (no.)	69		26	

Source: Census of total households, 1984.

Surprisingly, peas were not eaten in adequate quantities by farmers' lambs. This has stimulated new research on the palatability factor in peas and is an example of farmer feedback on applied as well as adaptive research in the same process. If palatable pea types can be identified, their high yield in dry areas and ability to fix significant amounts of atmospheric nitrogen gives them valuable potential.

Such feedback from farmers has proved so valuable that centers have increasingly emphasized their direct participation in the adaptive research process. As pioneering work at CIAT found, farm surveys are useful, but no substitute for the benefits of full involvement by farmers with researchers in the adaptive research effort. This insight acknowledges the mutually reinforcing expertise of each: the farmer in understanding local climate, soils and markets; and the researcher in identifying new germplasm and management principles that might apply to specific conditions. The process demonstrates the need to present a number of relevant options from the research shelf to farmers who could select what they consider the appropriate option for better, if not optimal, results.

The juxtaposition of the farming systems perspective with trials on farmers' fields has turned the process of developing recommendations for small farmers on its head. The top-down pushing of technically optimal ways of crop management from research stations to farms is receding. The new emphasis is threefold:

- drawing in management principles to location-specific farming situations;
- working with farmers to identify relevant principles and to adjust them to local needs and conditions;
- passing back key technical problems encountered in this process as an agenda for applied research on farms and on research stations at both national and international levels.

Building national capacity in on-farm research methods

The CGIAR centers' involvement with small farmers over the past 15 years has been a prerequisite for their contributions to research methods. Most learning was done in collaboration with national agricultural research systems, working with farmers. Initially, it was a mutual learning process: IRRI's Asian Rice Farming Systems Network, established in 1974, has been a most effective device for this type of partnership. More than 250 research sites in 16 countries use methodology developed by IRRI scientists and their network collaborators. CIAT, CIMMYT, CIP and ILCA play roles in networking systems for on-farm research in east and southern Africa and, recently, IITA has played a role in west Africa through the West African Farming Systems Network. More recently, collaboration has involved training programs for national systems; examples include ICARDA's Nile Valley Project and IITA's assistance to Cameroon.

Residential training in cropping systems research was started by IRRI in 1969, and having broadened its scope to take a whole farm perspective, continues today. Since 1970, CIMMYT's trainees in production agronomy have always spent a high proportion of their time laying out and managing trials in farmers' fields. From the mid-1970s, time has been increasingly spent on a farming systems perspective in planning, managing and evaluating trials.

More recently, emphasis has been placed on in-country training, including regional training workshops, in-country short courses and those courses following a "call system." In the call system, center scientists visit national trainees five or six times over one or two sea-

Box 6.2. Maize production research in East Java, Indonesia.

CIMMYT and Indonesian researchers identified four major crop production systems within Malang District in East Java. A production system with maize and horticultural crops dominant was selected for an evaluation of on-farm research techniques by MARIF researchers. Diagnosis indicated that though farmers used intensive cultivation practises, including the application of 160 kg nitrogen/ha, the maize had spindly stalks and discolored leaves and yields averaged only 1.8 ton/ha. An extraordinary feature of farmers' husbandry was an establishment density of up to 150,000 plants/ha, diseased and poor plants being thinned out, leaving a stand of about 40,000 plants at harvest. Agronomists perceived that high initial densities led to interplant competition and the heavy nitrogen application contributed to lodging. Several hypotheses on the causes of overplanting and low fertilizer efficiency were drawn up. It was vital to choosing an appropriate research focus to verify or reject these, either by survey or by exploratory on-farm experiments:

- ● Overplanting and thinning produce green fodder for livestock.
- ● Overplanting compensates for poor seedling vigor and low germination rates.
- ●● Overplanting compensates for expected losses to shootfly and other pests and diseases.
- ●● Farmers' overplanting practise reduces fertilizer efficiency.
- ● Farmers' varieties do not respond to fertilizer application.
- ●● Nutrient imbalances cause low fertilizer efficiency.
- ●● Fertilizer efficiency is low because nitrogen is applied late.

Subsequent survey and experimental work verified four hypotheses on causes (highlighted above) which were then used to plan further research. Five cycles of experiments over a two-and-a-half-year period identified an 80 percent yield improvement from shootfly *(Euxesta spp)* control, better population management and improved timing and nutrient balance in fertilizer management.

sons to take them through a full cycle of diagnosis and experimentation on farmers' fields. CIMMYT introduced this approach in Latin America and has extended it to Africa in collaboration with CIAT and ILCA.

Since 1981, European members of the CGIAR have run an eight-month course on development-oriented research in agriculture at Wageningen, the Netherlands, where the host institute is the International Agricultural Centre. The aim is to take post-academic, specialized, young scientists, and give them the tools with which to elicit the farmers' perspective, once settled into agricultural research in developing countries. The course includes three months in a developing country, using diagnostic methods to identify adaptive experiments for a designated farming system. Kenya, Malawi, the Philippines, Senegal, Sri Lanka, and Zimbabwe have hosted their field studies.

Box 6.3. Sequential adoption.

An important idea from a farming systems perspective is "sequential adoption." It emerged from studies which repeatedly demonstrated that farmers usually adopt only parts of a recommended technology package. It is also manifest in the idea that farming systems evolve in response to changing economic pressures, population density being a major source of such pressure. In this context innovations need to be relevant not only to the specific location but also to the evolutionary status of the system—appropriate in both space and time.

Researchers from CIAT, CIMMYT, CIP, ICRISAT, and IITA have all contributed to the idea of a sequence of innovations. IITA for example, has described the introduction of a new maize variety (TZSR-W) with moderate levels of fertilizer use into the intercropping system of the secondary forest zone of southwest Nigeria. In the research, all non-experimental variables were managed under farmers' practise. The improved variety TZSR-W as a single component produced more than farmers' maize at all levels of yield. In the poorest yielding fields, however, the response to fertilizer did not cover the input's costs. Further agronomic analysis showed that severe losses of plants during the season reduced the stand to between 5,000 and 30,000 plants/ha at harvest. Further research to identify the causes of these losses and solve the population problem will be a prerequisite to the viability of wide fertilizer use. In such experimentation, the use of high-level management and full crop protection on the non-experimental variables would have obscured a necessary sequencing of interventions.

To date, agricultural researchers from more than 70 developing countries have participated in on-farm related training by the centers. National programs have called for increased collaboration in training, now that a standardized process for systems-based on-farm research, robust enough to be modified to suit particular country situations, is in place.

Future institutional and policy linkages with small farmers

The centers' work in helping to build on-farm research capacity is ongoing. The centers' aim is to develop strategic management principles that can be used by the national systems. CIP, for example, has transferred principles of diffused light storage with particular emphasis on the domestic storage of potato seed, and of true potato seed through its extensive collaborative efforts in on-farm research with national systems.

At the national level, many countries are not as organized as Zambia (see Box 6.4) in integrating systems-based on-farm research with traditional station-based research. A lesson learned is that human capability, recurrent funds for operation, a niche in the research process, and support from institutions and managers must be built together. Training is wasted unless new skills are recognized as important and immediately mobilized. With a rapid rise in donor interest and commitment, the key issue has become institutional reorganization.

In 1986, ISNAR, committed to investigate key institutional issues as a basis for sounder advice to national programs, launched a set of studies of systems-based agricultural research processes, which it termed on-farm client-oriented research. It began with nine country case studies, three each in Africa, Asia and Latin America. The studies were completed by the end of 1987, and reports on them will be published in 1988. One of the key issues addressed is how to institutionalize the integration of classical station research and systems-based on-farm research—in the words of CIP, "from farmer back to farmer." The project's intentions are to provide national programs with guidance on the institutional organization of systems-based on-farm research and to offer authoritative advice in an area of management where it is urgently needed.

With institutional organization better understood, partly through ISNAR research, a new issue has seized the attention of the centers' social scientists in particular. IFPRI research has long emphasized the importance of appropriate policies in identifying and mobilizing technologies that exploit national comparative advantage, rather than policies that distort the choice of technology and set development on a false track. There is need for a process that reconciles farmers' priorities and national policies. Systems-based on-farm research is an

Box. 6.4. Zambia: 10 years of collaboration in adaptive research.

In 1976, Zambia began to analyze its agricultural research process and organization to identify why small farmers were not making use of research results. CIMMYT was invited in 1978 and 1979, to join Zambian research staff in two demonstrations of diagnostic procedures. In one, farmers in a province were divided into target groups. In a second, the farming system of one target group was diagnosed to identify key leverage points around which an on-farm experimental program was planned. A steering committee of senior research and extension staff monitored these demonstrations, and at the end of 1979, these procedures were incorporated into the organization of the research branch of the Ministry of Agriculture. An Adaptive Research Planning Team was organized on provincial lines to complement national commodity research teams already established. Each provincial team is made up of an agronomist and an economist from the research branch and a research/extension liaison officer from the extension branch, with a national coordinator based in Lusaka.

Zambia sought assistance from the donor community for the adaptive research program, and the evolution of commitment is shown below. Technical assistance staff was included from the three disciplines.

Province	Donor	First Survey	First Experiments
Central	USAID	1981	1981/82
Lusaka	ODA/CIMMYT	1981	1981/82
Western	Netherlands	1981	1981/82
Eastern	World Bank	1982	1982/83
Luapula	SIDA	1982	1982/83
North Western	IFAD	1985	1985/86

Ten Zambian professionals had been recruited by 1983 to work with technical assistance staff. CIMMYT regional staff mounted an in-country training course, covering the cycle of diagnosis and experimentation during 1983 and 1984. The course was attended by some 15 Zambian and 10 technical assistance research staff and staff from the extension branch. Some 250 trial/site combinations (a proportion of sites had two or three trials) were managed by 1985. By 1987, seven out of the nine provinces had adaptive research teams. While in the early years, provincial coordinators were donor-supported technical assistance staff, by 1987, all were Zambian professionals who had returned from masters' degree training overseas.

important source of information on farmers' priorities and could make a major contribution to such a process. CIMMYT, CIP, ILCA, and IRRI are among the centers that have begun to shift resources to research on farmers' priorities as a basis for both technology development and policy formulation. This linkage to policy and the more direct participation of small-farmer communities in the research process are perhaps the centers' two new frontiers in the development of an adaptive research approach for national systems.

In building national capacity for systems-based on-farm research, the CGIAR system faces a dilemma. It is an unfinished task: once established, this capacity will provide both national programs and the centers with strong signals from small farmers about their needs. But at the same time, the CGIAR system needs to tap strongly into biotechnology in order to help developing countries capture its benefits. It is a two-way stretch, downstream to farmers on the one hand and upstream to biotechnology on the other, which makes inter-center collaboration in building on-farm research capacity in national programs an imperative.

7. The financial situation

Contributions to the CGIAR in 1987 increased by US$7.5 million, the net result of a US$9.4 million increase in core contributions and a US$1.9 million decrease in special project contributions. Total funding amounted to US$243 million, or 3 percent more than in 1986. Overall, exchange gains against the dollar were the principal reason for the increase.

Of the more than 40 donors[1] to the CGIAR, 34 contributed to the centers' core programs in 1987. While Australia and the United States reduced their contributions in 1987, other major donors (Canada, Federal Republic of Germany, France, IDB, Italy, Japan, the United Kingdom), as well as Denmark and Finland increased their support. Most noteworthy were a doubling of Finland's contribution and a 30 percent increase by France. The Asian Development Bank did not contribute core funds, though it actively supports several special programs of the centers. The Leverhulme Trust withdrew, while Brazil, Saudi Arabia, the Kellogg Foundation and UNEP remained inactive, only contributing to a few special programs. Discussions on new memberships are underway with several potential donors.

Core funding in 1987 was US$201.6 million. After a net set-aside of US$6.7 million for the stabilization fund, the amount available from

[1]In 1987, 38 of the donors are also members.

Figure 7.1. CGIAR core funding, 1972-87 (US$ million).

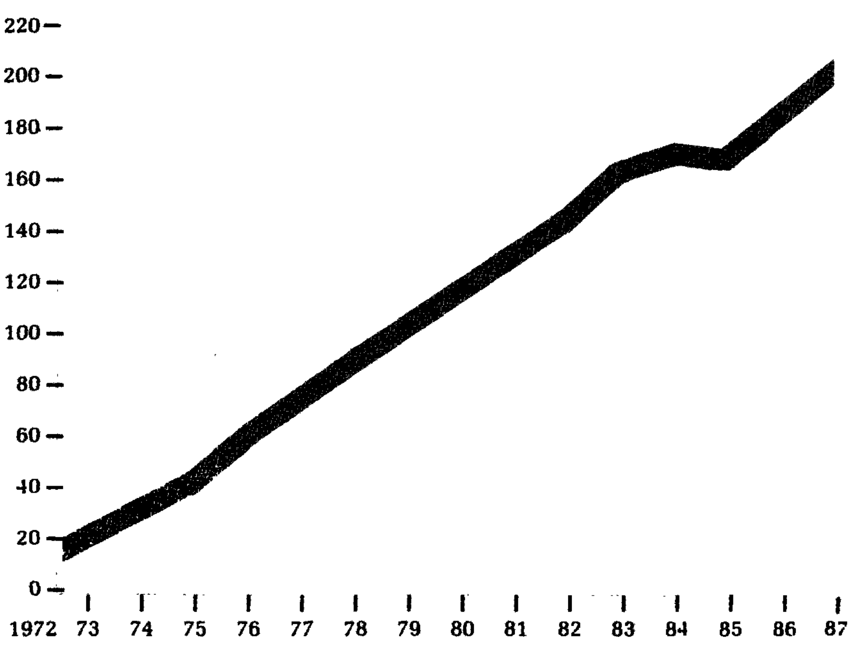


Table 7.1. CGIAR funding, 1985-87 (current US$ million).

	1985	1986	1987
Total donor core funding[a] (stabilization mechanism included)	170.2 [4.4]	192.2[c] [3.8]	201.6 [6.7]
Total core expended[b]	176.4	189.4	203.2
Operations	163.3	175.2	188.2
Capital	13.1	14.2	15.0
Non-core (special project) donor funding[b]	39.6	43.3	41.4
Total non-core expended			
Operations	35.7	41.3	40.2
Capital	13.9	1.2	2.6
Total donor funding	209.8	235.5	243.0
Percent change from previous year			
in core funding	–2	13	5
in non-core funding	32	9	–4
in total funding	3	12	3

[a]Funding represents donor contributions only; centers also finance programs from income, carry-overs, and changes in working capital. A stabilization mechanism was initiated in 1984 to buffer center budgets against exchange rate and inflation rate fluctuations.

[b]Core programs are those recommended by TAC and approved annually by the Group. Special projects are activities within the overall scope of each center, but not part of the currently approved program.

[c]Including US$3.0 million funding of capital projects for which commitments were made in 1986. Actual expenditures will be made in 1987.

donor contributions to the centers' core programs was US$194.9 million (Table 7.1). Reflecting the changed exchange rates and relative changes in donor support, the proportion of contributions made in U.S. dollars dropped below 50 percent for the first time, amounting to 46 percent of the total. This compares with 51 percent in 1986 and 58 percent in 1983. Since more than 50 percent of centers' expenditures are in dollars, this slight mismatch in currency funding and spending exposes centers to possible currency risk in the future. Donor disbursements to centers lagged in the first half of 1987, with only about 39 percent of pledged funds disbursed (compared with 51 percent in 1986). By the end of the year, 8 percent of pledged contributions remained undisbursed.

The healthy funding picture allowed most center programs to be fully financed in 1987. Furthermore, systemwide funding needs in 1987 were reduced by favorable adjustments in local currencies during 1986—the downward realignment of Nigeria's national currency in 1986 resulting in savings of US$4.9 million in 1987, and rapid devaluation in Mexico (US$0.7 million), partially offsetting the cost of a temporary stoppage of devaluation in Peru (US$1.3 million).

At ICW87, the CGIAR secretariat estimated 1988 funding at US$207 million. Subsequently, the U.S. dollar further weakened and the estimate was revised upwards. Centers have been asked to plan on the basis of full funding of approved programs. At March 31, 1988 exchange rates, the estimate stood at US$217 million. Thereafter the dollar strengthened. The outcome will depend on exchange rates and economic climate in host countries.

Expenditure trends

In aggregate, spending on operations in 1987 was very close to the levels planned at the start of the year. Centers spent US$188 million on operations, 2.8 percent more in real terms than in 1986 (Table 7.2). Moderate inflationary cost increases, 4 percent compared with 6 percent annually in the past three years, allowed for a higher real increase than the 1.3 percent which occurred in 1986. Centers also spent US$15 million on capital items, a shade more than in 1986. Funds set aside in the form of increased operating funds or reserves to cover potential liabilities amounted to about US$4 million.

In real terms, operational expenditures by CIMMYT, ICARDA and ILCA registered marginal declines from the 1986 levels. Expenditures rose relatively rapidly in the cases of ICRISAT, IFPRI, ILRAD, ISNAR

Table 7.2. Center operating expenditures, 1985-87.

	[In constant 1987 US$ million]		
Center	1985	1986	1987
CIAT	22.1	21.9	22.7
CIMMYT	23.0	22.3	21.8
CIP	12.4	12.8	12.9
IBPGR	4.6	4.9	5.1
ICARDA	17.8	18.4	18.2
ICRISAT	21.4	22.6	23.4
IFPRI	4.5	4.6	5.7
IITA	19.7	18.2	18.3
ILCA	14.9	14.7	13.4
ILRAD	9.7	9.7	10.9
IRRI	23.8	24.5	24.8
ISNAR	4.6	4.5	5.2
WARDA	2.0	3.9[a]	5.8
Total	180.5	183.0	188.2
Percent change	−2.2	1.3	2.8
Additional expenditures (current US$ million)			
Capital	13.1	14.2	15.0
Non-core expenditures	39.6	42.5	42.8

[a]WARDA's total research program. Prior amounts relate to its core research program only.

World Bank contributions

As the balancing donor to the CGIAR, the World Bank allocated its 1987 funds after other donors' intentions were known. To fund the approved programs of the centers, the Bank contributed US$23.3 million to 12 centers, with IBPGR being the only center not requiring Bank funds. Of the 12, CIP and CIAT needed less than 5 percent of their approved funding from the Bank. Only five centers required contributions larger than 15 percent of their approved funding levels, compared with six centers in 1986. The remaining five centers received contributions ranging from 5-15 percent.

Stabilization fund

The weakening of the U.S. dollar put cost pressure on centers with significant spending in currencies moving opposite to the dollar—ICRISAT for its West African operations in the CFA franc and ISNAR for its headquarters spending in Dutch guilders. ISNAR reduced the financial impact by arranging forward currency purchases in late 1986 before the downturn in dollar exchange rates. However, this was only partially possible for ICRISAT due to its more complex financing structure. Additionally during 1987, ICRISAT was required to revise its local salary scales. Consequently, ICRISAT claimed US$1.9 million from the stabilization fund. Although there were adverse changes in local inflation rates or dollar exchange rates, particularly in the case of CIMMYT, IRRI and WARDA, none appeared significant enough to warrant a call on the stabilization fund in 1987. The only other transaction was the fund's stabilization claim of US$0.5 million from ICARDA due to favorable local exchange rates. The net result of these transactions—US$1.4 million in outflow and inflows of US$6.7 million in contributions and US$0.8 million interest—was an increase of US$6.1 million to the fund during 1987. At the start of 1988, some US$18 million was available to meet future inflation/exchange rate risks

Annex 1. About the CGIAR.

The Consultative Group on International Agricultural Research (CGIAR) is an informal association of governments, international organizations, and private institutions, cosponsored by the World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP). The CGIAR first met in 1971 when members agreed to support, on a sustained basis, a well-defined and closely monitored program of research on food commodities and on food production in agroecological zones. CGIAR operates without a formal charter, relying on the consensus deriving from a sense of common purpose.

CGIAR started with a nucleus of four existing international agricultural research centers—CIAT, CIMMYT, IITA, and IRRI—established by the Rockefeller and Ford Foundations in Colombia, Mexico, Nigeria, and the Philippines, respectively. At the start, 15 donors provided about US$20 million. The number of centers has since increased to 13, supported by 38 donor members and other contributors who provided about US$243 million in 1987.

Each center supported by the CGIAR is independent and autonomous, with a particular structure, mandate and objectives, and each governed by an international board of trustees. Some centers focus on one commodity for which they have a global mandate, while others have a regional or ecological mandate with, in some cases, a global mandate for one or more commodities. Others perform specialized functions in the fields of food policy research, genetic resource conservation, and strengthening national agricultural research in developing countries.

The programs of the commodity-oriented centers vary, but common components include genetic resource conservation and classification; biological research to increase yields by genetic improvement and greater resistance to pests and diseases; farming systems studies to better understand farm-level constraints and improve traditional practises; and training and other activities to strengthen national research systems.

The CGIAR's objectives have recently been summarized by its Technical Advisory Committee (TAC) as follows: "Through international research and related activities, to contribute to increasing sustainable food production in developing countries in such a way that the nutritional level and general economic well-being of the low-income people are improved."

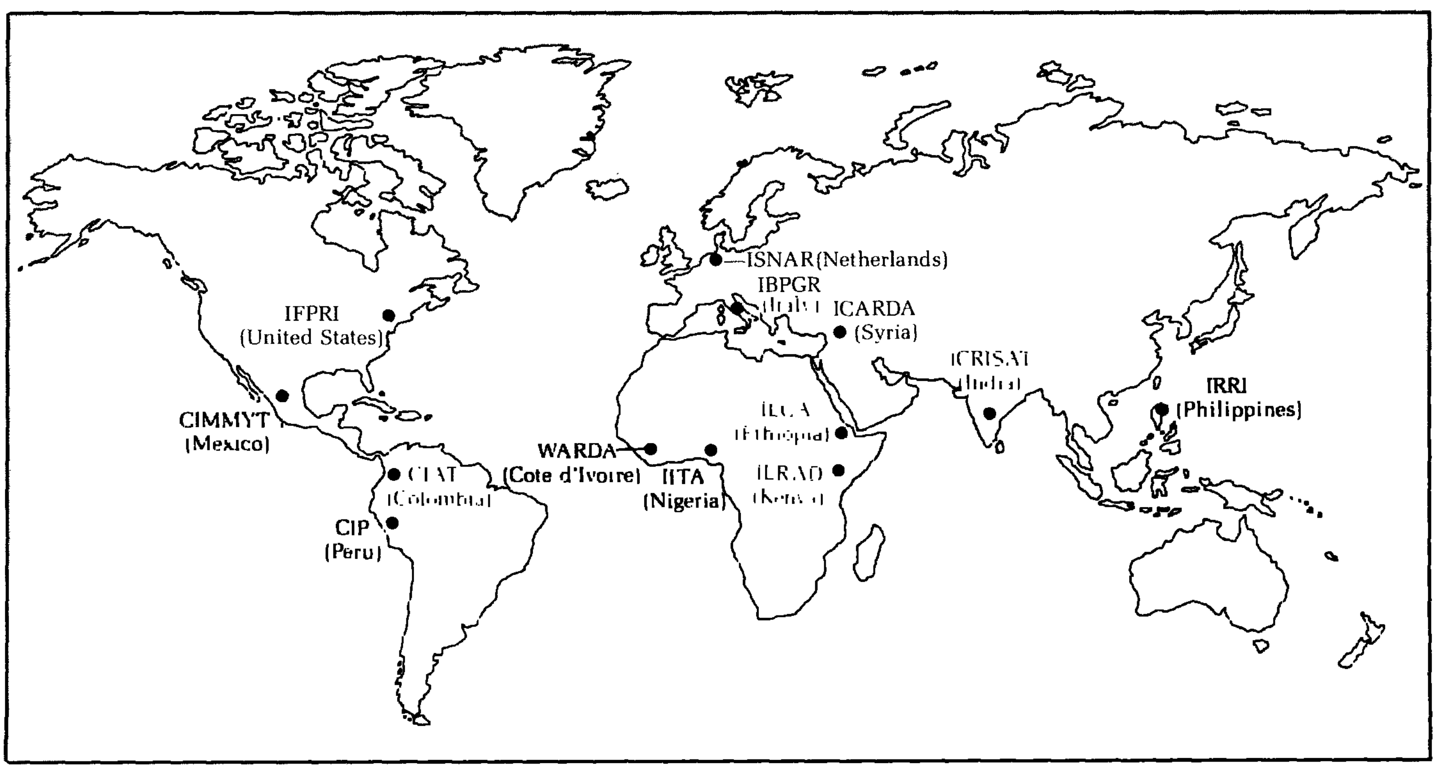
TAC comprises a chairman and 14 scientists drawn equally from developed and developing countries. The committee makes recommendations on research programs and priorities, monitors performance through program and budget reviews, and supervises periodic external reviews of the centers undertaken by panels of independent scientists. TAC is supported by a secretariat, provided by the three cosponsors of CGIAR and located at FAO headquarters in Rome.

The CGIAR is also served by an executive secretariat, located in Washington, D.C. and provided by the World Bank. The secretariat reports to the CGIAR chairman, a vice president of the World Bank designated by the Bank's president after consultation with CGIAR members. It coordinates fund raising among the donor members and organizes two meetings of the members each year. Besides providing administrative services, the secretariat helps keep donors informed about the scientific programs, finances and management practises at the centers.

Meetings of the CGIAR are held twice a year, once in Washington, D.C. in October/November and once elsewhere in May. The meetings receive and discuss recommendations on overall research strategy, programs and budgetary needs of individual centers, and management issues pertaining to the centers as a group. Critical independent reviews of center performance are presented and discussed. Developing country interests are represented by several donors from this group of countries, and by 10 delegates selected by regional conferences of FAO.

Individual donors allocate their contributions to centers of their choice. The World Bank balances the centers' finances by making up as much as possible of the difference between approved budgets and collective donor contributions.

Global location of the 13 CGIAR-supported centers.



Annex 2. CGIAR major crops and activities.

Objectives	Center	Regional focus
Barley	CIMMYT	Latin America
	ICARDA	Developing countries
Cassava	CIAT	Developing countries
	IITA	Sub-Saharan Africa
Chickpea	ICRISAT	Developing countries
	ICARDA	North Africa/Middle East
Cocoyam	IITA	Developing countries
Cowpea	IITA	Developing countries
Faba bean	ICARDA	Developing countries
Groundnut	ICRISAT	Developing countries
Lentil	ICARDA	Developing countries
Maize	CIMMYT	Developing countries
	IITA	Sub-Saharan Africa
Millet	ICRISAT	Developing countries
Pigeonpea	ICRISAT	Developing countries
Potato	CIP	Developing countries
Pastures	CIAT	Latin America
	ILCA	Sub-Saharan Africa
Phaseolus (field bean)	CIAT	Developing countries
Rice	IRRI	Developing countries
	CIAT	Latin America
	IITA	Sub-Saharan Africa
	WARDA	West Africa
Soybean	IITA	Sub-Saharan Africa
Sorghum	ICRISAT	Developing countries
Sweet potato	CIP	Latin America
	IITA	Developing countries
Triticale	CIMMYT	Developing countries
Wheat	CIMMYT	Developing countries
	ICARDA	North Africa/Middle East
Yam	IITA	Developing countries
Livestock	ILCA	Sub-Saharan Africa
Theileriosis	ILRAD	Sub-Saharan Africa
Trypanosomiasis	ILRAD	Sub-Saharan Africa
Food policy	IFPRI	Developing countries
Plant genetic resources	IBPGR	Global
National research systems	ISNAR	Developing countries

Annex 3. CGIAR organization, June 1988.

Continuing members:

Australia	Germany, Fed. Rep.	Philippines
Austria	India	Saudi Arabia
Belgium	Ireland	Spain
Brazil	Italy	Sweden
Canada	Japan	Switzerland
China	Mexico	United Kingdom
Denmark	Netherlands	United States
Finland	Nigeria	
France	Norway	

African Development Bank
Arab Fund for Economic and Social Development
Asian Development Bank
Commission of the European Communities
Food and Agriculture Organization of the United Nations
Ford Foundation
Inter-American Development Bank
International Bank for Reconstruction and Development (World Bank)
International Development Research Centre
International Fund for Agricultural Development
Kellogg Foundation
OPEC Fund for International Development
Rockefeller Foundation
United Nations Development Programme
United Nations Environment Programme

Fixed-term members of developing countries:

Africa—Guinea and Zambia
Asia and Pacific—Bangladesh and Thailand
Latin America and the Caribbean—Argentina and Venezuela
Near East and North Africa—Egypt and Turkey
Southern and Eastern Europe—Poland and Portugal

CGIAR Chairman:

W. David Hopper
World Bank
1818 H St., N.W.
Washington, D.C. 20433, United States

CGIAR Executive Secretary:

Curtis Farrar
World Bank
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Technical Advisory Committee:

TAC Chairman:

Alexander McCalla
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Department of Agricultural Economics
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TAC Members:

Michael H. Arnold
Charan Chantalakhana
C.T. de Wit
Raoul J.A. Dudal
Ola Heide
Amir Muhammed
Ibrahim Nahal
Gustavo Nores
Thomas R. Odhiambo
Ernesto Paterniani
Abdoulaye Sawadogo
Gian Tommaso Scarascia Mugnozza
E.T. York

TAC Executive Secretary:

John H. Monyo
TAC Secretariat
Food and Agriculture Organization of the United Nations
Via delle Terme di Caracalla
Rome 00100, Italy

CGIAR-supported Centers:

CIAT Centro Internacional de Agricultura Tropical
Apartado Aereo 6713
Cali, Colombia
Director General: John L. Nickel
Chair: William E. Tossell

CIMMYT Centro Internacional de Mejoramiento de Maiz y Trigo
P.O. Box 6-641
Mexico 06600, D.F. Mexico
Director General: Donald L. Winkelmann
Chair: Lucio Reca

CIP Centro Internacional de la Papa
Apartado 5969
Lima, Peru
Director General: Richard L. Sawyer
Chair: J. W. Meagher[1]

IBPGR International Board for Plant Genetic Resources
Food and Agriculture Organization of the United Nations
Via delle Terme di Caracalla
Rome 00100, Italy
Director: J. Trevor Williams
Chair: William J. Peacock

ICARDA International Center for Agricultural Research in the Dry Areas
P.O. Box 5466
Aleppo, Syria
Director General: Nasrat Fadda
Chair: Jose I. Cubero

ICRISAT International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India
ICRISAT Sahelian Center
B.P. 12404
Niamey, Niger (via Paris)
Director General: Leslie D. Swindale
Chair: Fenton V. MacHardy

IFPRI International Food Policy Research Institute
1776 Massachusetts Avenue, N.W.
Washington, D.C., 20036-1998, United States
Director: John W. Mellor
Chair: Dick de Zeeuw

IITA	International Institute of Tropical Agriculture PMB 5320 Ibadan, Nigeria Mailing address: IITA, Ibadan, Nigeria c/o Ms. Maureen Larkin L.W. Lambourn & Co. Carolyn House, 26 Dingwall Road Croydon CR9 3EE, United Kingdom Director General: Laurence D. Stifel Chair: Lawrence A. Wilson
ILCA	International Livestock Center for Africa P.O. Box 5689 Addis Ababa, Ethiopia Director General: John P. Walsh Chair: Ralph Cummings, Sr.
ILRAD	International Laboratory for Research on Animal Diseases P.O. Box 30709 Nairobi, Kenya Director General: A.R. Gray[2] Chair: Ingemar Maansson
IRRI	International Rice Research Institute P.O. Box 933 Manila, Philippines Director General: Klaus Lampe Chair: Kenzo Hemmi
ISNAR	International Service for National Agricultural Research P.O. Box 93375 2509 AJ The Hague Netherlands Director General: Alexander von der Osten Chair: M. Henri Carsalade
WARDA	West Africa Rice Development Association 01 B.P. 2551 Bouake 01, Cote d'Ivoire Director General: Eugene R. Terry Chair: Heinrich C. Weltzien

[1]Chair, Board Chair Group.
[2]Chair, Directors General Group.

Annex 4. Donor contributions to center programs, 1972-87 (in US$ million).

	Core Programs								Total (Core + Non-core)				
Donor	1972-76	1977-81	1982	1983	1984	1985	1986	1987	1983	1984	1985	1986	1987
Australia	4.00	13.28	3.77	4.06	4.00	4.18	4.52	2.92	4.11	4.03	4.27	4.85	3.50
Austria	—	—	—	—	—	—	1.00	1.00	—	—	—	1.01	1.00
Belgium	3.48	13.70	1.85	1.88	1.71	2.01	1.77	2.74	2.46	2.31	2.66	2.48	3.74
Brazil	—	—	—	—	1.00	—	—	—	—	1.00	—	0.01	0.05
Canada	17.37	36.14	8.29	9.94	10.03	9.70	10.66	11.79	10.74	11.58	12.74	14.26	14.76
China	—	—	—	—	0.50	0.50	0.48	0.30	—	0.50	0.50	0.48	0.30
Denmark	1.71	4.69	0.96	0.95	1.24	1.12	1.65	2.26	0.95	1.24	1.26	1.67	2.36
Finland	—	—	—	—	0.50	0.60	0.99	2.29	—	0.50	0.60	0.99	2.44
France	1.05	3.14	0.90	1.01	0.88	1.23	2.07	3.22	1.10	0.94	1.39	2.15	3.31
Germany, Fed. Rep.	13.27	39.06	7.84	7.89	6.67	6.15	8.03	10.38	8.68	7.39	8.14	8.90	12.17
India	—	0.50	0.50	0.50	0.50	0.49	0.50	0.50	0.50	0.50	0.49	0.50	0.50
Iran	1.98	3.00	—	—	—	—	—	—	—	—	—	—	—
Ireland	—	0.38	0.21	0.34	0.41	0.40	0.58	0.69	0.34	0.41	0.40	0.58	0.72
Italy	0.10	1.90	1.59	6.10	6.62	6.49	8.33	10.08	6.10	6.62	6.78	9.73	10.72
Japan	2.49	26.25	8.85	9.13	9.72	11.09	15.89	17.98	9.48	10.46	12.05	18.92	20.19
Mexico	—	1.45	0.10	0.15	1.22	0.37	0.20	0.10	0.15	1.44	0.47	0.25	0.10
Netherlands	4.11	11.54	3.24	3.58	3.28	3.89	6.65	5.60	4.12	3.79	4.53	7.88	6.37
New Zealand	0.11	0.14	0.02	0.02	0.02	0.01	0.01	—	0.02	0.02	0.01	0.01	—
Nigeria	1.30	5.36	1.13	1.00	1.00	0.85	0.19	0.18	1.40	1.60	1.29	0.38	0.22
Norway	3.33	9.27	1.87	2.19	1.92	2.27	3.12	3.23	2.19	1.92	2.27	3.40	3.59
Philippines	—	0.65	0.45	0.35	0.32	0.23	0.27	0.26	0.35	0.32	0.23	0.27	0.26
Saudi Arabia	1.00	1.00	—	1.50	1.50	—	—	—	1.50	1.50	—	—	—
Spain	—	0.50	0.46	0.52	0.52	0.50	0.50	0.50	0.52	0.52	0.50	0.50	0.50
Sweden	7.19	14.80	3.18	3.05	3.07	3.02	4.20	4.86	3.05	3.07	3.02	4.21	4.87
Switzerland	1.87	9.47	2.76	4.89	6.70	5.17	7.11	7.70	5.91	8.21	7.80	9.08	9.70
United Kingdom	9.02	27.51	6.34	5.92	5.66	6.32	8.40	10.27	5.98	5.74	6.33	8.55	10.27
United States	41.60	128.09	40.79	44.55	45.25	45.16	46.25	40.22	55.02	56.85	60.19	60.22	55.10
Country Subtotal	114.98	351.82	95.11	109.52	114.23	111.74	133.36	139.09	124.67	132.46	137.90	161.30	166.74
Ford	16.79	6.20	0.81	1.31	0.99	0.90	0.90	0.94	1.75	1.37	1.68	1.73	1.65
Kellogg	1.32	0.63	—	0.63	0.34	—	—	—	0.69	0.41	—	—	0.18
Kresge	0.75	—	—	—	—	—	—	—	—	—	—	—	—
Leverhulme	—	1.08	0.65	0.75	0.81	0.60	0.62	—	0.75	0.81	0.60	0.62	—
Rockefeller	17.10	6.67	0.80	0.50	0.50	0.80	0.93	0.88	0.54	0.55	0.99	1.22	1.47
Foundation Subtotal	35.96	14.58	2.26	3.19	2.64	2.30	2.45	1.81	3.72	3.14	3.27	3.57	3.30
ADB	0.30	1.20	—	—	—	—	—	—	0.17	0.45	0.64	0.71	0.92
AFDB	—	0.15	0.02	—	—	—	0.59	0.71	—	—	—	0.59	0.71
AFESD	—	1.12	0.24	0.23	0.23	0.34	0.34	0.37	0.23	0.23	0.34	0.34	0.37
EC	—	17.38	4.72	5.16	4.72	6.58	7.14	9.12	6.25	6.01	7.95	8.47	10.00
IDB	11.15	32.19	8.10	8.16	8.73	8.17	9.39	10.28	8.16	8.73	8.17	9.44	10.29
IDRC	3.95	5.68	1.20	1.80	1.01	1.30	1.18	0.81	2.45	2.78	3.12	3.51	3.02
IFAD	—	11.05	5.94	8.37	7.02	3.15	0.45	0.25	10.31	8.67	5.26	1.22	1.00
OPEC	—	1.90	3.58	2.25	2.19	1.00	0.47	0.51	2.25	2.19	1.05	0.87	0.63
UNDP	7.42	21.59	6.19	6.86	8.06	7.49	8.42	8.68	7.16	9.12	8.85	8.87	8.88
UNEP	0.94	0.49	0.18	0.13	0.03	—	—	—	0.17	0.03	0.02	0.03	0.04
World Bank (IBRD)	16.15	53.33	16.30	19.00	24.30	28.10	28.40	30.00	19.50	24.68	28.87	29.61	30.39
International Donor Subtotal	39.91	146.08	46.47	51.96	56.29	56.13	56.39	60.72	56.65	62.88	64.27	63.66	66.25
Other donors	—	—	—	—	—	—	—	—	3.29	4.60	4.37	7.01	6.77
Total	190.85	512.48	143.84	164.67	173.16	170.17	192.20	201.62	188.33	203.08	209.81	235.54	243.05

Annex 5. CGIAR-supported center expenditures, 1971-87 (current US$ million).

	Core Operating Expenditures							
Center	1971-76	1977-81	1982	1983	1984	1985	1986	1987
CIAT	24.5	61.6	17.9	20.8	21.4	20.6	21.3	22.7
CIMMYT	34.0	71.5	17.7	17.9	20.3	21.0	21.4	21.8
CIP	8.7	31.3	8.9	9.3	9.9	9.6	12.5	12.9
IBPGR	1.4	12.0	3.1	4.5	4.1	4.3	4.8	5.1
ICARDA	1.4	32.8	11.5	13.8	14.8	16.0	18.0	18.2
ICRISAT	11.7	43.0	14.0	17.7	16.7	18.8	20.6	23.4
IFPRI	—	10.3	3.1	3.8	4.3	4.1	4.5	5.7
IITA	31.6	65.4	18.8	19.0	20.0	20.2	17.4	18.3
ILCA	4.4	33.7	8.2	10.1	11.8	12.6	13.7	13.4
ILRAD	2.5	28.3	7.5	8.4	8.5	8.8	9.3	10.9
IRRI	24.2	66.9	20.3	19.9	20.5	21.6	23.6	24.8
ISNAR	—	2.4	2.3	3.3	3.3	3.8	4.4	5.2
WARDA	1.8	8.6	2.7	2.4	2.1	1.9	3.7	5.8
Total	146.2	467.8	136.0	150.9	157.9	163.3	175.2	188.2

	1971-87 Cumulative			
Center	Operations	Capital	Special Projects	Total
CIAT	210.8	20.9	21.6	253.3
CIMMYT	225.7	11.0	39.3	276.0
CIP	103.1	9.9	7.5	120.5
IBPGR	39.3	—	1.1	40.4
ICARDA	126.5	40.0	13.8	180.3
ICRISAT	166.0	43.1	31.8	240.9
IFPRI	35.6	0.9	10.2	46.7
IITA	210.7	30.4	80.9	322.0
ILCA	107.1	18.8	10.1	136.0
ILRAD	83.9	21.4	1.8	107.1
IRRI	220.0	17.8	62.1	299.9
ISNAR	24.2	1.1	4.0	29.3
WARDA	29.2	1.7	17.0	47.9
Total	1,582.1	217.0	301.2	2,100.3

Annex 6a. Regional origin of internationally recruited staff and board trustees, 1987.

Region	Staff	%	Trustees	%
Asia	164	18	34	19
Sub-Saharan Africa	110	12	30	16.5
N. Africa/M. East	24	3	8	4
Latin America/Caribbean	112	13	22	12
Europe	221	25	47	26
North America	221	25	30	16.5
Australia/New Zealand	37	4	11	6
Total	889	100	182	100

Annex 6b. Regional origin of internationally recruited staff by center, 1987.

Center	Asia	Sub-Saharan Afirca	N. Africa/ M. East	L. America/ Caribbean	Europe	N. America	Australia/ New Zealand	Total
CIAT	8	1	—	35	24	32	5	105
CIMMYT	12	6	2	23	17	39	8	107
CIP	14	2	3	37	21	18	—	95
IBPGR	2	1	1	3	10	2	4	23
ICARDA	11	3	14	3	16	11	3	61
ICRISAT	28	14	2	1	26	19	6	96
IFPRI	14	1	—	2	2	14	—	33
IITA	32	29	1	3	26	32	1	124
ILCA	3	16	—	—	29	9	3	60
ILRAD	—	8	—	—	32	11	1	52
IRRI	36	—	—	3	7	21	5	72
ISNAR	3	4	1	2	10	12	1	33
WARDA	1	25	—	—	1	1	—	28
Total	164	110	24	112	221	221	37	889

Annex 6c. Regional origin of board trustees by center, 1987.

Center	Asia	Sub-Saharan Africa	N. Africa/ M. East	L. America/ Caribbean	Europe	N. America	Australia/ New Zealand	Total
CIAT	2	1	—	7	2	4	—	16
CIMMYT	4	2	1	4	2	2	1	16
CIP	3	—	—	2	2	1	1	9
IBPGR	4	—	—	1	6	2	2	15
ICARDA	—	—	6	1	6	2	1	16
ICRISAT	4	2	—	1	4	3	1	15
IFPRI	4	1	1	2	3	4	1	16
IITA	1	5	—	2	3	4	—	15
ILCA	—	5	—	—	6	2	1	14
ILRAD	—	5	—	—	4	2	1	12
IRRI	9	1	—	1	2	2	1	16
ISNAR	2	2	—	1	4	1	1	11
WARDA	1	6	—	—	3	1	—	11
Total	34	30	8	22	47	30	11	182

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