# SCIENCE and FOOD

## The CGIAR and Its Partners

Jock R. Anderson · Robert W. Herdt · Grant M. Sco

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The Consultative Group
on International Agricultural Research

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# Foreword

The idea of doing a thorough study of how the activities of the Consultative Group on International Agricultural Research (CGIAR) have affected food production and the welfare of the poor in the developing world was suggested by the representative of Sweden, Bo Bengsston, at the Group's annual meeting in Washington, D.C., October 1982. The proposal was readily approved, although it took a year to define the scope of the study and set up the mechanism for conducting it.

The CGIAR had been founded in 1971 to coordinate policy and funding for a growing number of international agricultural research centers, and by 1982 its donors were contributing $160 million a year to the system. It was time to evaluate the returns to this investment. Clearly, striking gains had been made in wheat and rice production, beginning in the mid-1960s, through the work of the first two centers—the International Rice Research Institute (IRRI) and the Centro International de Mejoramiento de Maíz y Trigo (CIMMYT)—in cooperation with the national agricultural organizations. But the well-publicized "green revolution"—the development of new high-yielding varieties of wheat and rice—had little effect on areas that depended on other staples. A number of specialized centers had therefore been set up for other food crops and livestock. Now one of the questions for the impact study was whether in fact significant gains had been made for other commodities.

No matter how good the programs of the international centers, they must ultimately be judged by the results in farmers' fields. Success depends to a large degree on the capacity of national agricultural systems in the developing countries to absorb the products of research and to modify them for local conditions, often after additional work. Another task for the study was therefore to assess whether the work of the international centers had weakened or strengthened national research systems.

Finally, since a frequently heard criticism of the green revolution was that the new varieties of wheat and rice were prejudicial to the interests of the poor, the study was to review the evidence on the effects of the CGIAR's work on poor farmers and poor consumers. A related question was whether the research outputs helped women in farm families, who in many parts of the world not only do the bulk of farm labor but also make most of the important decisions.

Besides outlining the objectives of the study, the CGIAR had to decide whether to rely primarily on those persons and institutions who were best informed about the work of the centers and could gather information most easily or to entrust the study to unbiased observers from outside the system. The Group decided to seek objectivity, but it proved difficult to find experts in agricultural science and the role of agriculture in developing countries who were not associated in some way with CGIAR-supported centers. In the end the study depended for objectivity as much on the ability of individuals to recognize and compensate for their own biases as on the judgments of well-informed outsiders.

As part of the effort to gain objectivity and to ensure consistency and overall quality, the study was guided by an advisory committee of eminent scientists from all parts of the world. The director of the study was Jock R. Anderson of the University of New England, Australia. He, Robert W. Herdt, and Grant M. Scobie were the authors of the final report and of this book.

The general task of the study was to determine the effect that the CGIAR centers had on agriculture in the developing countries. Specifically, what had the centers done to help the developing countries improve their own agricultural research capabilities? What contributions had the centers made, directly or collaboratively with national programs, toward increasing food production? To gather the information needed to answer these questions, it was decided to conduct case studies in as many developing countries as practical and, in addition, to undertake studies of specific technical and social issues. Many of these reports have been published separately. (See "Documents from the CGIAR Impact Study," which follows the text.)

As the study progressed, it became evident that there was no way to distinguish sharply between the contributions of the CGIAR centers and their national collaborators and no way to determine what the world would have been like had specific elements of technology not been fashioned at a particular time. The authors concluded, broadly, that advances in rice and wheat production are continuing and that progress is being made in many other crops and technical areas in which the CGIAR centers are involved.

Neither the impact study nor this book based on the study make a systematic attempt to apply the conclusions to planning for the future. But that process was going on in the CGIAR before the report was published. When Frank Press, the chairman of the advisory committee, presented the study report to the CGIAR in November 1985, he called for new approaches to deal with changing circumstances. Among his suggestions were more emphasis on basic research to take advantage of the rapid development of the biological sciences, greater attention to the sustainability of agricultural production systems, and, possibly, extension of the work of the CGIAR to commercial crops.

After a day-long discussion of the impact report, the Group requested its Technical Advisory Committee to take the report into account in drawing up its statement of research priorities. Subsequently, the CGIAR determined to put greater emphasis on agricultural sustainability and on ways of generating higher rural incomes, and to give relatively greater attention to roots and tubers and somewhat less to grains. Several new commodity initiatives are being considered—for vegetables, freshwater aquaculture, and coconuts, for example.

More generally, the CGIAR is coming to grips with the issue of its relationship with the dozen or more centers for international agricultural research that are financed separately from the Group itself and with the increased capabilities of its principal partners, the national agricultural research systems. The CGIAR centers themselves are continuing and expanding their involvement in the application of new biological science to the problems of developing countries, while the donors cheer and caution in turn.

In short, the conclusions from this study, together with many other pieces of information, are being woven into the ever-changing course of international agricultural research, all with an eye to having a greater effect in the future and making the best possible use of available resources. But to tell that side of the story fully would require another book.

The CGIAR is grateful to the authors, to the members of the advisory committee, and to the many people who contributed to this investigation, not all of whom can be mentioned in this brief note. Members of the advisory committee were the chairman, Frank Press, president of the National Academy of Sciences, United States; Luís Crouch, management consultant, Dominican Republic; Yujiro Hayami, Tokyo Metropolitan University, Japan; Jonah Kasembe, at that time director general, Tanzania Agricultural Research Organization; I. G Patel (India), director, London School of Economics; Ralph Riley, at that time secretary, Agricultural Research Council, United Kingdom; and Joachim Weniger, Technical University of Berlin, Federal Republic of Germany.

The coordinators for the country case studies were Carl E. Pray (Asia), Jock R. Anderson (Middle East and North Africa), Hans E. Jahnke, Johannes Lagemann, and Georges Tacher (Sub-Saharan Africa), and Grant M. Scobie (Latin America). Contributors to the studies, in addition to the people already named, were P. K. Aiyasamy, Habib Amamou, Robert Bell, Dev Raj Bhumbla, Kevin J. Billing, Shriniwas Dattatraya Bokil, Dana G. Dalrymple, Jean-Jacques Dethier, Hisham El-Akhrass, Robert E. Evenson, Arturo A. Gomez, Ahmed Goueli, J. Gromotka, Anil Gupta, Jake Halliday, J. Brian Hardaker, John Gregory Hawkes, Peter B. R. Hazell, Fernando Homem de Melo, Rungruang Isarungkura, Alain de Janvry, Janice Jiggins, Dieter Kirschke, Kyaw Zin, Michael Lipton, Richard Longhurst, Simon Lyonga, David MacKenzie, Dev Ishwar Chandra Mahapatra, Antonio Martín del Campo, Ishwar Manwan, Jaime Matus, Eugenia Muchnik de Rubinstein, Bruno Ndunguru, Akalu Negewo, Michael Nelson, Barry Nestel, Dominic Okoro, John Onuoka, Ibrahim Firmin Ouali, E. T. Pamo, Luís J. Paz Silva, Per Pinstrup-Andersen, Rafael Posado Torres, Arturo Puente G., V. Rajagopalan, P. Roche, George Ruigu, Narendra Rustagi, Pedro A. Sanchez, Maria de J. Santiago, D. Sène, Ramesh P. Sharma, Hailu Shawel, Rigoberto Stewart, Etienne Tedenkeng, Paul Teng, Eduardo Venezian, and Teresa Weersma-Haworth.

The National Institute of Agricultural Engineering prepared a study on agricultural engineering as an in-kind contribution of the United Kingdom. The French government financed a study of the national agricultural research system of Senegal, and the U. S. Agency for International Development sponsored Dalrymple's review of the spread of semidwarf rice and wheat varieties.

Robert Herdt managed the conduct of the study itself. He was assisted by Dorothy Marschak on editorial matters and Narendra Rustagi on statistical work. Edward Sulzberger and Mary Horne helped with the publication of the supporting studies. Phillip Sawicki revised the manuscript and helped transform it from a report intended for CGIAR decisionmakers into a book that, it is hoped, will interest a wider audience.

Curtis Farrar
Executive Secretary
Consultative Group
on International Agricultural Research

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# Abbreviations

| | |
|---|---|
| AARD | Agency for Agricultural Research and Development (Indonesia) |
| BARI | Bangladesh Agricultural Research Institute |
| BBF | Broadbed and furrow system |
| BGMV | Bean golden mosaic virus |
| BNF | Biological nitrogen fixation |
| CG | Consultative Group (CGIAR) |
| CGIAR | Consultative Group on International Agricultural Research (also CG) |
| CIAT | Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture) |
| CIDA | Canadian International Development Agency |
| CIMMYT | Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center) |
| CIP | Centro Internacional de la Papa (International Potato Center) |
| CRRI | Central Rice Research Institute (India) |
| DMR | Downy mildew resistant (maize) |
| EMBRAPA | Empresa Brasiliera de Pesquisa Agropecuaria (Brazilian Agricultural Research Bureau) |
| FAO | Food and Agriculture Organization |
| FSR | Farming systems research |
| GDP | Gross domestic product |
| GEU | Genetic evaluation and utilization |
| GRU | Genetic resources unit |
| HYRV | High-yielding rice variety |
| HYWV | High-yielding wheat variety |
| IBPGR | International Board for Plant Genetic Resources |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| ICTA | Instituto de Ciencias y Tecnologías Agropecuarias (Institute of Agricultural Science and Technology) (Guatemala) |
| IFPRI | International Food Policy Research Institute |
| IICA | Instituto Interamericano de Cooperación para la Agricultura (Inter-American Institute for Agricultural Cooperation) |
| IITA | International Institute of Tropical Agriculture |
| ILCA | International Livestock Center for Africa |
| ILRAD | International Laboratory for Research on Animal Diseases |
| IMF | International Monetary Fund |

| | |
|---|---|
| INIA | Instituto de Investigaciones Agropecuarias (National Institute for Agricultural Research) (Mexico) |
| INIPA | Instituto Nacional de Investigación y Promoción Agropecuaria (National Agricultural Research and Development Institute) (Peru) |
| IPM | Integrated pest management |
| IRRI | International Rice Research Institute |
| ISNAR | International Service for National Agricultural Research |
| NARSS | National Agricultural Research System Survey (Philippines) |
| NIAE | National Institute of Agricultural Engineering (United Kingdom) |
| OECD | Organisation for Economic Co-operation and Development |
| ORSTOM | Office de la recherche scientifique et technique outre-mer (Office of Scientific and Technical Research Overseas) (France) |
| PCARRD | Philippine Council for Agriculture and Resources Research and Development |
| PRECODEPA | Programa Regional Cooperativa de Papa (Cooperative Regional Potato Program) |
| RIP | Rolling injection planter |
| TAC | Technical Advisory Committee |
| UNDP | United Nations Development Programme |
| USAID | United States Agency for International Development |
| USDA | United States Department of Agriculture |
| VITA | Volunteers in Technical Assistance |
| WARDA | West Africa Rice Development Association |

# 1 The CGIAR Centers: An Overview

The origins of the Consultative Group on International Agricultural Research (CGIAR) and the international agricultural research centers that operate under its aegis can be traced back to 1944 and the fields of Mexico. With the world's attention fixed on World War II, few people were giving much thought to the challenges of the postwar world. But the Rockefeller Foundation foresaw that large parts of the low-income world would need to increase their food production—for economic development if not simply for survival. It therefore dispatched four agricultural scientists to Mexico to help farmers grow more wheat and maize. Although those two crops are staples in Mexico, the nation was able to grow far less of them than it needed and was forced to rely on imports.

Those who addressed themselves to the question of how to increase food production in the nonindustrialized countries after 1945 agreed that certain steps were vital. The millions of peasant farmers who raised subsistence crops needed better knowledge of how to grow more food and achieve greater crop stability. Extension services therefore had to be strengthened. The farmers also needed the financial wherewithal to buy seeds and other inputs even after a poor harvest left them with nothing to plant the following year. In many cases that required credit. Their communities needed better roads, better schools, better health care, and better sanitation. And they needed community leaders who were not wedded to the past.

But there was another requirement that was not as widely recognized—the need for agricultural technology suited to the agroecological circumstances of developing countries. Improved technology not only had to be transferred; it also had to be adapted to very different environments.

The four Rockefeller scientists who went to Mexico—Norman Borlaug, William Colwell, George Harrar, and Edward Wellhausen—and their Mexican colleagues were to demonstrate just how necessary was adaptation to circumstances. What adaptation largely meant, in their view, was the use of modern plant-breeding techniques to develop varieties of cereals—particularly maize and wheat—superior to those traditionally grown in Mexico. That advance did not occur overnight. The development of high-yielding wheat varieties, for instance, took time, notwithstanding some radical shortcuts used by the Rockefeller scientists to hasten the process.

The development of advanced varieties of wheat, which became one of the tasks of the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) when it was established in Mexico in 1963, paralleled the development of high-yielding varieties of rice by the International Rice Research Institute (IRRI), which formally began operating in the Philippines in 1962. By the late 1960s, as the planting of high-yielding varieties spread to many farmers, harvests of wheat and rice in many developing countries broke all previous records by wide margins.

During the 1970s it became disappointingly clear that the gains from high-yielding grain varieties were only part of the solution to the food and development problems of many developing countries and that the benefits of modern varieties were sometimes accompanied by unwanted side effects. But as the world's population continued to grow, particularly in the developing countries, the importance of high-yielding crop varieties and other scientific advances were evident despite attacks from various quarters. Technology may not be the complete answer to the world's need to grow more food, but it is clearly a necessary part of the solution.

Between 1969 and 1971 a series of meetings and discussions took place which culminated in the establishment of the CGIAR (CG, for short). Not properly an organization, because it has no legal identity, written charter, or formal requirements for membership, the CG continues to operate as a forum for discussion and coordination. The annual funds associated with it have grown to nearly $200 million (Baum 1986).

The objectives approved for the CGIAR at its inaugural meeting in May 1971 were to examine the needs of developing countries for special efforts in agricultural research at the international level, to encourage complementarity of international and regional research through full exchange of information, to consider the financial requirements of high-priority international research, to assess the feasibility of specific proposals, and to review priorities for agricultural research in the developing countries. The donors who attend the Group's meetings make individual and independent decisions on what international agricultural research activities they will support. An advisory board, the Technical Advisory Committee (TAC), advises the Group on scientific matters and recommends support of budgets for each of the centers which the Group has agreed to include within its responsibility.

As of 1987 thirteen international agricultural research centers (including CIMMYT and IRRI) are funded by the nations, foundations, and international organizations that have joined the CGIAR. The centers, whose founding dates range from 1960 to 1980, did not come into existence as part of a comprehensive plan. Each was created to deal with certain problems that were perceived as being amenable to research. Nor were all of the centers affiliated with the CG from their beginnings. Some became CG-sponsored centers only after it was agreed that a formal relationship with the CG would be useful.

This chapter offers a brief description of the thirteen centers, presents their general characteristics and chief functions, and concludes with a discussion of the role that the centers and the CGIAR play within the larger context of world agricultural research.

## The Specialized Tasks of the Centers

All thirteen centers have the same general goal: to increase agricultural productivity in the developing countries, thereby raising farm incomes, reducing food costs, and improving human nutrition. This complex goal is a synthesis of several interrelated considerations. With few exceptions the populations of the world's developing countries have shown startling rates of growth over the past forty years and in aggregate will certainly not stop growing any time soon, although in some countries the rate of growth has diminished.

With population growth, additional food must be produced or food prices will rise sharply. Agriculture is the dominant economic activity of most developing countries, and unless it grows economic growth will be limited. Technological change has been an important source of agricultural growth in all countries that have developed successfully. Thus, agricultural research, which generates technological change in agriculture, is a crucial requirement for successful economic development and is the raison d'être of the CGIAR-supported centers, which foster and facilitate the needed work. Each center seeks to contribute by concentrating its research on one or two specific crops or on major subsistence crops within large ecological regions, or by taking on other research tasks of importance to agricultural progress in the developing countries. To put it another way, the centers approach their general goal in diverse ways.

IRRI has dealt virtually exclusively with rice since its founding. The reason is that rice is by far the most widely grown crop in Asia, which is in turn the most heavily populated region in the world. Roughly 90 percent of the world's rice is grown in Asia, and about the same percentage is eaten there. International trade in rice occurs largely among the major rice-consuming nations.

Two other centers confine their work, as IRRI does, to single crops. The Centro Internacional de la Papa (CIP), headquartered in Lima, Peru, was established in 1970 to devote greater scientific attention to the potato. Peru was chosen as the location for CIP because it is the potato's biological center of origin.

The West African Rice Development Association (WARDA), which started operations in 1973, concentrates on rice. WARDA was established as an intergovernmental association—not as an independent research institute like the other CG centers—with a commitment to the development of rice in addition to other research activities. The CG provides funding for some of WARDA's research on rice; WARDA's member countries and bilateral donors have supported the balance of its program. (In 1986–87 WARDA transformed itself into a form more like that of other centers.)

CIMMYT is best known for its work on wheat, a principal subsistence crop in parts of Latin America and throughout North Africa and the temperate regions of West Asia from Turkey to northern India. The importance of CIMMYT's contribution was recognized by the world at large in 1970, when Norman Borlaug was awarded the Nobel Peace Prize for his role in developing the high-yielding varieties of wheat that have helped to increase production by millions of tons annually in India, thus dissipating the specter of famine. But CIMMYT's work is not limited to wheat. Its research agenda and its collaborative programs with developing countries also encompass maize, a crop with an even wider range than wheat and the third most important food crop. CIMMYT's researchers also study barley and triticale, a cross of wheat and rye that has become a useful commercial grain.

Four centers in the CG family were established to study the crops and farming systems that predominate in four important agroecological regions.

The Centro Internacional de Agricultura Tropical (CIAT) in Colombia, initially sponsored by the Rockefeller and Ford foundations in 1967, does research on cassava, field beans, and rice and on animal forages for tropical pastures. Although CIAT has concentrated on how better to produce these crops under Latin American conditions, it is increasingly concerned with their problems elsewhere. The International Institute of Tropical Agriculture (IITA) in Nigeria was also established by the Rockefeller and Ford foundations in 1967 but became functional only in 1970, after the end of the Nigerian civil war. One of IITA's primary regions of interest is the high-rainfall tropical area of Africa. Maize, rice, cassava, cowpeas, soybeans, lima beans, sweet potatoes, yams, and the farming systems of the diverse areas of Nigeria and other nations of tropical Africa define IITA's province.

The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) is headquartered in India. Its task is to conduct research on the crops traditionally grown in semiarid Asia and in the large semiarid regions of Africa and Latin America—pearl millet, sorghum, chickpeas, pigeon peas, and groundnuts. The International Center for Agricultural Research in Dry Areas (ICARDA), established in 1977, has its main station in Syria. ICARDA is concerned with a region that extends from the dry areas of Morocco in the west to Pakistan in the east and from Turkey south to Ethiopia. Barley, wheat, triticale, forages, lentils, broad beans, chickpeas, and the farming systems in which they are grown dominate ICARDA's studies.

Two CGIAR centers in Africa are devoted to research on livestock. The International Livestock Center for Africa (ILCA), established in 1975, has its main laboratory in Addis Ababa, Ethiopia. ILCA analyzes traditional methods of herding and managing livestock, particularly cattle, to develop more productive alternatives. Because of Africa's great range of environmental conditions, much of ILCA's work is done in regional programs in Botswana, Kenya, Mali, and Nigeria, as well as in different environments in Ethiopia.

The International Laboratory for Research on Animal Diseases (ILRAD) is located in Nairobi, Kenya. ILRAD's chief task is narrower than that of any other center but is of vital importance to livestock production in Africa. Its researchers are seeking ways to combat two diseases that cause untold deaths and lost productivity among cattle not only in Africa but also in other parts of the developing world—trypanosomiasis, spread by the tsetse fly, and theileriosis, or East Coast fever, transmitted by ticks. ILRAD differs from most other CG centers because much of its research is advanced laboratory-based science, in contrast to the field orientation of most other centers.

All ten centers described above are located in developing countries; the other three are headquartered in industrial countries.

The International Board for Plant Genetic Resources (IBPGR) was set up in Rome in 1974. The importance of its mission has become more evident in recent years as human population growth and environmental alterations have increased concern about the extinction of plant and animal species. IBPGR's responsibility is to encourage and assist efforts to preserve the plant germ plasm of important cultivated crops and their wild relatives.

Another center whose importance is likely to increase in the future is the International Food Policy Research Institute (IFPRI) in Washington, D.C. Founded in 1976, IFPRI did not become affiliated with the CG until 1979. Its task is to conduct research that will improve understanding of how policies in all areas interact to promote or retard the production, distribution, and consumption of food.

The youngest of the thirteen centers is the International Service for National Agricultural Research (ISNAR) in The Hague, Netherlands. At the request of developing countries ISNAR provides services and advice having to do with the organization and operation of national agricultural research and extension programs. During its brief existence—it was created in 1980—ISNAR has already guided numerous developing countries in reshaping and improving their national agricultural research systems.

## Common Characteristics of the Centers

The centers, despite their diverse tasks, share certain characteristics. All (except WARDA) are independent organizations, all (with the exception of WARDA until 1987) are funded principally through the CGIAR, all have international staff and conduct operations in numerous countries, and all are devoted to solving the practical problems of subsistence agriculture in the developing countries, in most cases through a multidisciplinary scientific approach.

### *Independence*

Each center has a board of directors and an executive staff who decide what the center will do and how. The CGIAR does not control the centers, but it can—and often does—offer advice, both formally and informally. The Technical Advisory Committee (TAC), a group of some fifteen distinguished scientists, periodically oversees an examination of the operations of each center and assesses its most recent activities. The CG as a whole also offers suggestions to the centers during the two meetings normally held each year. In short, the CGIAR is not a hierarchical organization. By and large, the actions of the centers are their own responsibility.

### *Funding*

Each center receives funds for its core programs from CGIAR member donors, although most donors do not give to every center. TAC makes general recommendations regarding funding for the core programs. Contrary to the practice in most international organizations, each of the forty donors decides how to apportion its annual contribution among the centers, and most donors pay the centers directly rather than through the CGIAR. Although many factors affect the size and apportionment of each donor's contribution, the CG's goal with respect to funding is to reach a consensus among all the donors on the total budget for each center and for the entire system.

### *International Character*

The international nature of the centers is evident in many ways. The staff of each center consists of administrators, scientists, and technicians from both industrial and developing countries, and each center's board of directors also has an international membership. Many senior scientists from the centers are assigned to national programs or regional research activities in countries other than the host country of their own center. Perhaps most important of all, the centers try to find solutions for agricultural problems that can be applied as widely as possible throughout the world.

### *Technological Solutions*

The centers' principal activity is applied research—the search for new technologies that can be used in growing subsistence food crops in the developing world. Along the continuum of scientific investigation of agricultural problems—basic research, strategic research, applied research, and adaptive research—the CG centers concentrate on applied research that can be transferred across countries, although some work can be more accurately described as strategic, adaptive, or, rarely, basic. Perhaps the best way to clarify what is meant here by applied research is simply to say that the goal is to find technological answers to perceived agricultural problems in the developing countries.

The work of IFPRI and ISNAR falls into the category of applied research in a special sense. Policy questions of the type dealt with by IFPRI and organizational questions of the kind dealt with by ISNAR cannot be solved by technology as such. Nonetheless, the two organizations are concerned at least partially with technological answers in that their programs include reforming policies and institutions in ways that may result in greater attention to technological improvements.

## The Role of the Centers in World Agriculture

In 1980, a typical recent year, expenditures by all the CGIAR centers amounted to approximately $140 million.[1] The annual budgets of the centers that year ranged from about $2 million to about $20 million, and the centers collectively employed about 750 senior scientists and 6,000 support personnel.

Compared with world spending on agricultural research, the CGIAR figure was minuscule—the proverbial drop in the bucket. The total amount spent throughout the world for agricultural research in 1980 was more than $7.3 billion. That figure includes $3.2 billion spent in North America, Western Europe, Australia, and New Zealand and $1.4 billion in the U.S.S.R. and Eastern Europe. The rest of the world—the countries of Asia, Africa, and Latin America—spent about $2.6 billion, excluding expenditures by the CGIAR (OECD 1983; Judd, Boyce, and Evenson 1986).

Obviously the centers' contribution to world agricultural research does not arise merely from the size of their budgets. Even though CGIAR spending has increased since 1980, annual core expenditures were still under $200 million in 1986. Rather, the unique role of the CG and its centers derives from the nature and results of their research. The centers (along with a few similar organizations not affiliated with the CG) were the first institutions to make a concerted, sustained, and substantial attempt to utilize basic scientific knowledge as the foundation for technological innovations to improve the production of subsistence crops in the developing countries generally.

Before World War II scientific knowledge was utilized in the developing world primarily to increase yields of export crops—coffee, tea, sugar, cotton, jute, and so on. Not until the establishment of IRRI and CIMMYT and the maturation of some important national programs in developing countries did modern technology begin to be widely adapted to the production of the basic field crops of most of the developing world.

The adaptation of modern scientific methods for the purposes of food production in the developing countries continues to be the predominant function of most CG centers. Some of the largest developing countries, such as Brazil, India, Indonesia, and Mexico, have created their own agricultural research systems with large and competent staffs, but many countries in Africa, Asia, and parts of Latin America began to develop their own systems only since about 1970. That is not long enough to build a first-rate system, even with sufficient funding, highly developed educational systems, and stable political regimes—and in many developing countries those conditions do not exist.

A second function of the CGIAR centers is to offer training in research disciplines to scientists, administrators, technicians, and postgraduate students from developing countries. The centers are not educational institutions in the ordinary sense of the term, but in all of them staff spend some time giving practical instruction or educational guidance to researchers from national research systems. These educational activities are usually conducted at the centers themselves, but center staff also make many trips each year to classrooms, laboratories, and farms in developing countries to share their knowledge in formal and informal settings.

Education and training, it is commonly acknowledged, ordinarily show the best results when there is personal interaction between instructors and students. Over the past several centuries, however, most education has been self-education by means of the printed word and, in more recent times, through film, television, and computerized information systems. Since their beginnings the centers have produced thousands of technical documents to convey information about agricultural science in lieu of classroom instruction. The production of such documents, supplemented to an increasing extent by newer methods of transmitting information, continues to be an important function of the centers. An example is IRRI's pocket-size handbook, *Field Problems of Tropical Rice*, which has been printed in eleven languages. Published in 1970 and revised in 1983, this small, sturdy book is a compendium, with full-color photographs, of the hazards that befall rice crops, from cutworms and brown leaf spot to root-knot nemotodes and alkalinity. The illustrations are accompanied by brief paragraphs that provide information on such things as the environmental conditions responsible for a particular hazard.

Other functions of the CGIAR and its centers are described in later chapters. All these functions, however, are related to the basic tasks of research, training, and communication. The several roles of the centers all contribute to a common purpose: the international sharing of scientific knowledge and technological information and materials and the development of effective research capacity in the developing countries.

The book then goes on to analyze the impact of the work of the centers on agriculture in the developing world as of the early 1980s. The final chapter discusses some important questions that have been raised about the nature and scope of the work of the CG centers in the years ahead.

## Note

1. Current U.S. dollars are used throughout this book. A billion is a thousand million.

# 2 The Impact of the Centers on Agriculture in the Developing World

The thirteen international agricultural research centers that carry on their tasks under the sponsorship of the CGIAR are part of a much larger informal system of research endeavor linked by personal contacts, professional associations, and scientific publications. That system includes the agricultural research departments, universities, and private research laboratories of industrial nations, international agricultural institutions outside the CGIAR, and the agricultural research institutions and universities of the developing countries.

The CGIAR centers, through their own research programs and their collaborative activities, are an important link between agricultural research in the industrial nations and in the developing countries. In addition, the centers have increasingly become facilitators of scientific cooperation among developing countries that otherwise would be unlikely to interact because of geographic and language barriers.

Emphasis on the worldwide agricultural research system is necessary because the centers have not acted in isolation. Without the scientific expertise of the agriculturally advanced nations and the efforts of researchers and others in the developing countries the impact of the centers on agriculture in Africa, Asia, and Latin America would be limited. But in concert with those scientific institutions, much has been accomplished.

The following overview is meant to provide a succinct and accessible statement of the most significant effects of the centers on agriculture or on agricultural research systems in the developing countries. Some of these outcomes started to become evident in the mid-1960s, a few years after CIMMYT and IRRI first began operating. Most of the subsequent chapters of this book elaborate on this summary.

## The Effects of Research Collaboration with the CG Centers

The effects of collaborative research are, not surprisingly, as complex as the agricultural context around the developing world in which the work is applied and implemented. Any attempt to compile a short, segregated list of main effects thus runs the risk of oversimplification. An attempt is nevertheless made here, and for convenience the effects are grouped into four broad categories.

### *Improvement of Food Crops*

National research systems, in collaboration with the centers, have produced hundreds of new varieties of cereal, legume, and root crops. Many of these new plant varieties have proved to be well suited to local environments in many developing countries. The centers have also become the main external source of the plant germ plasm used by plant breeders in developing countries in tests designed to develop other new varieties. The breeding of new varieties is an unending process. In time successful varieties often lose their original advantages because of natural mutations in the pests and diseases that attack the plants in the field. Even where that is not the case, continuing plant-breeding endeavors may produce varieties with superior qualities.

Modern varieties of wheat (largely developed by CIMMYT and its predecessors in cooperation with the Mexican and, later, Indian national programs) are used extensively by farmers in the developing world. More than 250 of these high-yielding wheat varieties (HYWVS) have been further improved by research scientists in the developing countries. The most recent estimate (Dalrymple 1986b) was that high-yielding wheat varieties were being grown on 48.5 million hectares of land in developing countries in the 1982–83 crop year. To put it another way, by 1983 HYWVs had supplanted traditional wheats on approximately half of the land used in those countries for growing wheat. In ten developing nations—among them Argentina, Kenya, Mexico, and Pakistan—high-yielding varieties of wheat were being cultivated on more than 80 percent of the land devoted to wheat. The interchange of wheats in the global research system has benefited many other developing nations and several industrial nations. In Australia, for example, some 45 percent of the wheat-growing area is sown to varieties genetically related to materials obtained from CIMMYT.

Widespread use of high-yielding wheat varieties has brought with it a surge in wheat production in many developing countries. It is conservatively estimated that modern wheats produce average increases in yield of 0.5 tons per hectare over the increases attributable to increased use of inputs such as fertilizer and irrigation. By 1983 the use of modern varieties had increased wheat production in the developing countries by an estimated 18 million tons a year above the comparable figure for 1970.

New varieties of rice produced at IRRI and CIAT, about 300 of which have been further refined by plant breeders in the developing countries, have become dominant in the developing world's rice-growing regions. As of 1986 high-yielding rice varieties (HYRVs) were being grown on an estimated 76 million hectares in Africa, Asia, and Latin America—regions that account for 58 percent of the area used to grow rice. In several developing countries, including Colombia, Honduras, Indonesia, the Philippines, Senegal, Sri Lanka, and Venezuela, modern rice varieties were being raised on more than 70 percent of the country's rice lands. Since virtually all (some 95 percent) of the world's rice is grown in developing countries, the interchange of modern rice varieties has had much less effect on the industrial countries than has interchange in wheat varieties. Nonetheless, most of the developed countries that grow rice have obtained genetic materials through CGIAR centers and are incorporating desirable plant characteristics into their own varieties.

The spread of high-yielding rice varieties has brought about large increases in yield per hectare in extensive regions of the world and a massive rise in production. The average yield of the new rice varieties was conservatively estimated to have surpassed the average yield of traditional varieties by 0.6 tons per hectare over the increases attributable to the increased use of inputs such as fertilizer and irrigation. Accordingly, the implied increase in world rice production brought about through the use of HYRVs in the developing countries in 1983 was 23 million tons a year, using 1970 as the base year.

In combination, the increase of more than 40 million tons a year of wheat and rice brought about by high-yielding varieties, over the contributions made by complementary inputs, has made it possible to meet the annual food grain demands of perhaps 500 million people. India, Indonesia, and the Philippines, which relied heavily on external supplies of grain less than twenty years ago, have now become self-sufficient producers of their most important food grains.

The plant-breeding work of the centers, in conjunction with research in developing and industrial countries, has led to more than 200 new varieties of maize, as well as many new varieties of other food crops that are important in parts of the developing world—cassava, field beans, potatoes, pearl millet, sorghum, and cowpeas. New varieties of other food crops, including barley, chickpeas, pigeon peas, sweet potatoes, and triticale—have also been bred. Since these are crops largely associated with the newer centers, most of their new varieties have been available for only a few years and have not yet displaced traditional varieties to the extent that has occurred with wheat and rice.

Through their extensive and continuing food-crop-breeding activities the centers have substantially reduced the time needed by national researchers in the developing countries to create improved varieties. The plant-breeding achievements associated with certain centers have also persuaded researchers in some developing countries to begin work on crops once thought not worthy of research attention.

CGIAR's International Board of Plant Genetic Resources (IBPGR), in association with other agencies, has facilitated the creation of extensive collections of the germ plasm—largely seeds, but increasingly also roots and cuttings—of most food crops. Through strong and continuous encouragement and assistance the Board has helped to ensure the preservation of the germ plasm of 130 crop species in gene banks operated by about 450 organizations and agencies throughout the world. These collections ensure that genetic specimens of crop plants, including land races (distinct varieties that have evolved in farmers' fields, often at great distances from each other), and related wild species, will be preserved for future use by plant breeders.

Through their successful efforts to help their partners develop ways of producing more food, the centers have contributed to reducing food costs in developing countries and thereby to improving nutrition, particularly among the poorest citizens (who inevitably spend a large part of their scarce household resources on food). In some countries this has probably prevented much starvation and malnutrition. In others it has ensured steadier food supplies and greater consumption of food energy, protein, and other vital nutrients.

The crop improvement achievements of the centers and their national partners have had a widespread effect on the economic well-being of the poorer classes in developing countries. In particular, the adoption of modern varieties of rice and wheat has meant increased production of those grains. This in turn has kept food prices down to the benefit of low-income consumers in rural and urban areas, who spend a much larger share of their income on food than do the wealthy. The adoption of modern varieties also helped landless laborers in the beginning, since it intensified the demand for farm labor and thereby led to higher wages. In some countries, however, wage rates subsequently went down as population growth expanded the supply of labor and as mechanization displaced farm workers. Small landholders who adopted modern varieties have more grain to sell, but large landholders—who were often the first to adopt—have been helped even more.[1] In sum, new agricultural technology has eased the economic plight of the poor, but it has not dramatically raised their economic status.

### *Improvement of Other Aspects of Agricultural Technology*

The centers, often through joint efforts with scientists at research agencies in both developing and industrial countries, have devised or adapted new and improved farming techniques. Some of these techniques, not always novel in themselves, have won growing allegiance among farmers because of their superiority over previously used methods. Techniques that have had a clear positive impact include the storage of seed potatoes in diffused light, new methods of growing crops in deep black clay soils in semiarid regions, the use of azolla (an aquatic fern) to provide nitrogen for rice crops, new land-clearing methods that ensure soil stability, and nontraditional ways of growing cassava and other crops in the tropics.

As a result of research on plant protection by the centers and their partners, food crops—particularly wheat, rice, and field beans—have become much less susceptible to attacks by insects and plant diseases. This has been achieved largely through plant-breeding work and to that extent fits just as well under "Improvement of Food Crops." The introduction, with the help of IITA, of a wasp that attacks the cassava mealybug has begun to reduce damage to cassava from that source in several tropical African countries.

Work on farm mechanization is usually done in collaboration with national agricultural research and development organizations. The few centers with such programs have concentrated on the development of farm machines that are especially suitable for developing countries. Such machines offer greater labor efficiency than the alternative techniques that they replace, whether they be manual or animal-powered methods, but they are neither as large nor as energy-intensive as the advanced farm machinery commonly found in industrial countries. Centers have produced new designs for such items as lightweight power tillers, axial flow water pumps, injection seed planters, and mechanical grain threshers. Mechanical innovation is usually given a low priority because it can cause oversupplied or underemployed human labor to be replaced by machines and because it often occurs in the private sector without the need for publicly funded research.

A number of centers have conducted intensive investigations into the possibility of fertilizing food crops and providing forage through biological nitrogen fixation (BNF). Center research has shown that some natural processes that add nitrogen to soil can be enhanced through the judicious selection and manipulation of microorganisms and plants. This research has helped to lay the groundwork needed to make BNF a viable and eventually a significant substitute for manufactured nitrogen fertilizer.

Research by ILCA has brought about a better understanding of the complexities of farming and pastoral systems in Africa. Livestock are vital to the nutritional and economic well-being of millions of people in Africa's varied ecological zones, but little has been done to assist these people through science and technology. Finding solutions to such problems as cattle diseases (the concern of ILRAD) is a task of great inherent difficulty, and progress remains uncertain. Improving the quality of fodder, increasing its availability, and overcoming other obstacles to greater livestock production in pastoral systems are research objectives for several centers.

### *Improvement of the Efficiency of Agricultural Research*

As of 1983 the centers had trained more than 16,000 agricultural scientists and technicians, almost all of them from developing countries, in the methods used by center scientists and technicians to improve agricultural technology. The centers place particular emphasis on applied scientific investigation on experimental farms. The principal training methods include formal group training courses, supervision of scientific investigations performed by candidates for advanced degrees from cooperating universities, special training programs for individual students on particular topics, and supervision of postdoctoral researchers who have received appointments to conduct specialized research work of high value and priority.

The centers have been both catalysts and coordinators of agricultural research networks in the developing world for many years. Following initiatives by the Food and Agriculture Organization (FAO) and the U.S. Department of Agriculture (USDA) in the 1960s and early 1970s, IRRI, beginning in 1963, organized a regular series of rice nurseries (collections of selected plants) and offered them to participants. This made it possible to evaluate at sites in many different countries the potential for genetic improvement of rice. Similarly, CIMMYT organized and supplied the first regular series of international spring wheat nurseries. The other centers have been instrumental in the creation of networks for plant genetic research on the crops for which they have responsibility. Any bona fide agricultural researcher in the world can participate in these breeding research networks. Recently, many of the centers have played leading roles in the establishment of international networks for exchanging information on other research interests.

The centers have become important producers of books, manuals, reports, newsletters, and other materials that provide information on how to apply research methods to many problems of farming in the developing countries. This body of more than 5,000 publications (some of which have been criticized as "too glossy") is one of the chief methods used by the centers to transmit significant information to government officials, agricultural scientists and technicians, students of agriculture, and workers in agricultural extension systems.

The centers have been effective in distributing to scientists in developing countries knowledge about advances in scientific research techniques, especially techniques for crop improvement through plant breeding, and in methods for farming systems research. Many of these techniques have been developed at the centers themselves.

### *Strengthening National Capabilities in Research and Policy Analysis*

Through policy studies conducted at several centers, particularly the International Food Policy Research Institute (IFPRI), officials in the developing countries have become more aware of the close relation between changes in agricultural production and changes in national agricultural and economic policies. (Agricultural policies deal with such areas as import and export prices for food, marketing arrangements, agricultural credit, and input supply; related general economic policies are concerned with, for example, exchange rates, trade, and taxation.) The studies have helped to focus the attention of policy analysts on the potential impact of modified technology and how it can help achieve such national goals as economic growth, food security for the poor, and a healthy agricultural sector.

Through their training and educational activities, their facilitation and coordination of research networks, their publication and distribution of scientific information, and their development and dissemination of new methods of agricultural research, the centers have helped to strengthen aspects of many national agricultural research systems. Unfortunately, improvement of the capability for, say, food crop research often comes at the cost of reduced capability in other research areas such as traditional export crops. Thus in some cases the centers have perhaps pushed national research priorities too far in the direction of their own mandates.

The centers have done much to convince many developing nations and CGIAR donors that scientific research is essential to raising agricultural productivity. Put another way, the centers have helped to persuade many leaders in developing countries that agriculture cannot be ignored as they seek to build industrial economies. National expenditures on agricultural research and extension services—and presumably also the effectiveness of these activities—rose impressively in many developing countries between 1959 and 1980, with much of the increase going toward research on food crops.

As national agricultural research systems have developed over the past fifteen years or so (or have been drastically altered following independence), many have adopted the general operating procedures of the centers. These include a multidisciplinary approach, emphasis on the solution of real-life agricultural problems, and day-to-day work in farmers' fields. Some national systems have gone further in structuring themselves after the centers by establishing commodity research and plant-breeding programs similar to those of the centers.

Several national agricultural research systems have begun a process of extensive reorganization after seeking assistance from CGIAR's International Service for National Agricultural Research (ISNAR). That center analyzes overall institutional structure and offers suggestions on how it might be improved.

Women constitute perhaps more than half of all farmers in developing countries. The centers were slow to recognize this in formulating their research agendas, but in recent years, sometimes through formal consultation with each other, they have sought to bring about a greater awareness of the importance of women's role in agriculture and have worked on technological improvements to ease the work done by women. The centers have also sought to avoid innovations that might harm women's welfare.

The CGIAR and its centers constitute a novel form of multilateral cooperation that could be a model for similar efforts in fields such as health and engineering. The system operates by consensus among its members, and the independent and rather small centers are relatively free of the frictions that often impede the work of larger development organizations. These factors together mean that the centers operate nonpolitically and with a high degree of effectiveness that might merit study by other international organizations.

## Sources of Information about the Centers

Much of what has been written during the past two decades on the work of the centers emanates from the centers themselves. The materials are regularly compiled into extensive bibliographies (GTZ/CGIAR/IRRI 1985, 1986, 1987) to facilitate access by direct users and by librarians. This literature constitutes the first source of information about the results of the centers' work.

The general literature of agricultural development, technology generation and transfer, and the economics and sociology of agricultural innovation, agricultural policy, and related topics frequently contains discussions of the centers and of other analogous international and national agencies. These works constitute a second broad source of information. Although no explicit review of this literature is given here, such reviews form the basis for several portions of the text (particularly chapter 8).

A third source of information is a series of forty research papers written in connection with the impact study, begun in 1984, that is the basis for this book. These papers were specifically intended to assess the work of the centers in relation to agricultural productivity and the operations of national agricultural research systems. Twenty-five of the forty studies concerned the impact of the centers in individual countries selected as representative of Africa, Asia, Latin America, and the Middle East. The other fifteen ranged from revisions of the well-known Dalrymple series on the development and spread of high-yielding wheat and rice varieties to papers on gender-differentiated impacts and on the effects of the centers' work in agricultural engineering. The papers that have been published are listed at the end of this book, under "Documents from the CGIAR Impact Study."

The studies were in many ways crucial to the completion of this book. Many are referred to or quoted here, since they often provided the most current and complete information available on how the work of the centers has affected single countries or developing countries as a whole. The twenty-five country studies were designed to be as representative as possible of the views of persons affiliated with national research systems, who are in the best position to provide answers to the principal questions raised by this book. The other fifteen, depending on their subject matter, were intended either to be as comprehensive as possible or (where the subject matter was rather narrowly circumscribed) to illuminate a limited topic as clearly as possible.

The country studies, as one might expect, are not all of the same standard. This is particularly true of their discussions of the impact of the centers on crop production. Some studies offer figures on changes in production that were originally developed by the national research systems; others are content to say that production appears to have increased but that it is hard to say by how much. Still others omit any statement on production.

The differences in the studies, which extend to quantitative measurements of things other than agricultural production, can be explained to a large degree by differences in the national agricultural research systems themselves. In some developing countries—and particularly in the poorest ones studied—the system has not been in existence long enough to develop much ability to collect statistical data. In other countries the system has until recently been devoted primarily to research on export crops. As a result these countries have done a good job of keeping track of production of export crops but have generally ignored subsistence crops. Among the countries studied—and again, as might be expected—the larger countries, in general, are the ones that have made the strongest efforts to measure production of food crops.

Many of the country studies contain general assertions that the efforts of the centers have led to some change in the national agricultural research system. These assessments of the influence of the centers on the operations of the national systems are, perhaps necessarily, qualitative rather than quantitative.

How valid, it may be asked, are the generally favorable judgments of the CGIAR reported in the country studies? The operations of the centers as such go on at little direct cost to the developing countries (except for the few that have chosen to become CG donors).[2] Is it not possible—perhaps even likely—that employees of the national systems would be tempted to give only positive responses to questions about the impact of the centers on their systems? Such skepticism is certainly understandable, but we believe that it is not justified. Although the country studies present local opinion about the centers as being generally positive, the centers do not escape scot-free. There is, in our view, enough criticism in the country studies to make them credible as reasonably accurate reports of how the centers are viewed in developing countries.

## Delayed Effects

Even when the process of turning basic scientific discoveries into agricultural technologies used by farmers in developing countries works smoothly, it rarely works quickly. Although the twentieth century has been the age of technological marvels (and technological disasters), causing people in general to think that technological improvements appear at the drop of a hat, scientists and technologists know that under normal circumstances the process is frequently frustrating and lengthy. This has been true even when—as has happened frequently since World War I—the governments of large nations have spent billions of dollars and utilized the knowledge and skills of tens of thousands of workers to speed up the process. One of the undoubted high points of agricultural technology in our time, the development of semidwarf high-yielding varieties of wheat, took approximately twenty years. Borlaug and his colleagues in Mexico did in fact speed up the process by sometimes disregarding accepted wisdom about plant-breeding techniques, but it is unlikely that the spending of billions or the assignment of thousands of additional scientists to the task would have much hastened the development of HYWVs. Plant breeders, like ordinary farmers, must wait for their plants to mature before they can take their next step, and the maturing of food plants still takes time. As the plant breeder knows, the goal is to select for characteristics that make the plant desirable while modifying some of its less desirable characteristics. That is much easier said than done.[3]

Under ideal circumstances the process of technological innovation as practiced by the centers and by national agricultural research systems would operate as follows. A center becomes aware of a present or potential problem within its mandate and, in collaboration with relevant national systems, works to devise possible solutions. If the problem involves the operations of national research systems, the solution is more likely to involve a change in operating procedures than a new technology. But if the problem pertains to farming itself, the solution is likely to be a technological one or a change in operations predicated on some new technology.

If the problem is at the farm level and the national research systems confirm that the solution is a viable one for their countries, they notify the agricultural extension service in their countries. The extension agents take the new solution—let us assume here that it is a new crop variety—and facilitate its distribution to the farmers who grow that particular food crop.

The farmers, in this stylized and happy world, are already aware of their problem and are awaiting a visit from the extension agent. Soon after the agents leave, it being the right season, the farmers plant the seeds and raise healthier plants which yield larger harvests. The harvested grains or tubers are then taken to markets, where customers decide that the new variety of produce tastes as good as or better than the traditional variety they have been eating daily for thirty or forty years.

As the reader will either know or suspect, this idealized scenario (which could be extended to such things as the nutritional value of the new variety) depends on assumptions whose validity cannot be taken for granted. To try to deal with all of the scenario's underlying assumptions would be exhausting and unnecessary. Instead, we will simply point out how the country studies demonstrate that such assumptions are often hollow in reality.

One important assumption is that the centers have a firm understanding of the problems for which they help to devise solutions. Some country studies, however, show that the centers have occasionally exhibited an incomplete grasp of a particular problem and, in the case of plant breeding, can sometimes only send out solutions like buckshot in the hope that some will find the target. The national agricultural research system of Cameroon, for example, tested 130 varieties of maize from CIMMYT to find two that were deemed likely to do well in that country. That should not be taken as criticism of CIMMYT. Agricultural science and technology—like all science and technology—often involve the testing of many potential solutions to a problem before a useful answer is found. Our point here is that the centers are often only a place where the work of finding a solution may begin.

Our ideal scenario also rests on several assumptions about the national systems themselves—that they are well funded, that they have scientists of high caliber in all the important areas of study, and that they are well managed. If our country studies are representative (as they were intended to be), many developing countries have been slow to realize the importance of emphasizing research on subsistence food crops.

Funding was noted as a problem in the studies on Bangladesh, Colombia, Ecuador, and Ethiopia. In Bangladesh, Brazil, Cameroon, Colombia, and Guatemala the national system had only recently changed, or was in the process of changing, from a system heavily dominated by research on export crops (coffee, tea, sugar, jute, and cotton) to a system that did not neglect domestic food crops. In Chile, Ethiopia, and Peru the agricultural research systems were still undergoing reconstruction following, among other complex changes, the upheaval of agrarian reform. The studies on Colombia, Ethiopia, Nepal, and Peru all reported that the research systems were still hampered by poor management. According to the Peruvian study,

> The structure of the government agricultural sector results in many regional institutions, with no unity of command. There is virtually no planning or coordination of activities among these institutions, and because of lack of consistency in agricultural policy and a small, ineffective planning system, each institution sets its own priorities independently from the programs of other institutions. The poor organization of the government agricultural sector prevents clear assignment of responsibilities. (Paz Silva 1986, p. 133.)

In the ideal system outlined above, information on technological advances is passed along to farmers by a sizable force of effective agricultural extension agents. But in the real world—at least in the world as reflected in the country studies—extension agents are usually said to be far too few in number, even in countries in which agriculture is said to be in good condition.

The farmer, in our ideal scenario, is eager to learn how to improve crop production and ready to accept innovation. But the farmer in the developing countries, as the following quotation from the study of Thailand illustrates, frequently has different views (and sometimes for good reason).

> Poverty and little cash available at the farm level prevent farmers from adopting expensive technology. The education level is generally low, mainly grade 4, presenting difficulties for understanding technology. Culture and tradition can be limiting factors in technology adoption. Southern rice farmers continue to harvest their rice with traditional tools. Even though the practice causes relatively high harvesting loss, they do not change it, for religious reasons. Many northeast farmers continue to grow glutinous rice, with limited market access, because they are used to it. Because of poverty, low education, and generally low standards of living, formation of farmers' organizations has been difficult . . . [But] fruit growers, tobacco growers, and sugarcane growers have been able to form organizations. They are the ones for whom technology transfer has not presented difficulties. (Isarangkura 1986, p. 86.)

In short, improving the production of food crops in the developing countries with the help of agricultural technology is rarely easy. Farmers are clever and have for a long time been making their own technological adaptations for their complex and usually uncertain circumstances. People in the remote countryside of many developing countries who live a hand-to-mouth existence have often declined to adopt "improved" methods or have done so reluctantly. Traditional methods may guarantee little more than survival, but they are perceived to do at least that.

In time, perhaps, circumstances will compel more and more farmers in the developing countries to recognize the value of "modern" ways of doing things as long as the new is really better. The useful effects of the work of the centers and their national partners that have been delayed by natural human caution—and by more concrete obstacles such as lack of credit—will then become more evident. Despite all the words spoken about the green revolution, now almost two decades old, the transition from traditional to modern agriculture has (except, largely, for well-favored wheat and rice farmers) only begun in many countries.

## The Transformation of Agriculture: The Compelling Factors

As a whole, the developing countries have been losing ground in their efforts to raise enough food to feed their growing populations. Although it is true that some developing countries (including some of the largest) have become virtually self-sufficient producers of the principal food grains, and although it is also true that yields per hectare of all food crops have been rising in recent years at an unprecedented average annual rate of nearly 2 percent, the rise in the demand for food in the developing world has been even greater. The result has been substantial growth in shipments of food from the industrial countries to the developing countries. During 1968–70 the developing countries imported slightly more than 9 million tons of food staples, or 2.4 percent of production. In 1978–80 net imports rose to more than 36 million tons, or 7 percent of total production (Paulino and Mellor 1984). By 1985, we estimate, the developing world's food imports had risen to almost 10 percent of production.

The aggregate figures obscure important regional differences. In Asia net imports declined between the end of the 1970s and the end of the 1980s. The largest increase in food imports occurred in North Africa and West Asia, while the smallest occurred in Central America.

Table 2-1 suggests that, at least as of 1980, Asia was on its way to resolving its food problems. It also suggests that for many years the countries of southern South America have done a good job of producing staples.

**Table 2-1. *Net Imports of Basic Food Staples by Developing Countries***
(millions of tons)

| Region | 1968–70 | 1978–80 | Change |
|---|---|---|---|
| Asia | 9.9 | 7.7 | −2.2 |
| North Africa and West Asia | 4.2 | 19.0 | 14.8 |
| Sub-Saharan Africa | −0.3 | 6.1 | 6.4 |
| Central America | 1.1 | 6.6 | 5.5 |
| Northern South America | 2.9 | 9.9 | 7.0 |
| Southern South America | −8.7 | −12.9 | −4.2 |
| All developing countries | 9.0 | 36.3 | 27.3 |

*Note:* Data are rounded and may not add to totals.
*Source:* Paulino and Mellor (1984), p. 296.

For the other regions—North Africa, West Asia, Sub-Saharan Africa, Central America, and northern South America—the situation with respect to staples was different. All four regions were importing larger quantities of staple foods in 1978–80 than in 1968–70. But the reasons were not always the same. North Africa, for example, was importing more food because of higher incomes—the result of huge increases in the price of oil—in several countries. Much of Sub-Saharan Africa, however, was importing more because of a reduced ability to produce more staples.

Regardless of the reason for increases in net imports, many developing countries have implicitly thought that economic progress would inevitably require greater imports of food. This may be why so many of them continued to concentrate on their export crop sectors after they achieved independence. It is only more recently that many of these countries have come to see clearly the importance of strengthening their food crop sector as well. If food crops fail and food must be imported, the costs of those imports reduce the amount of foreign exchange earned through exports. The logical consequence of this realization should be stronger attempts in most developing countries to bolster the production of food crops.

Some countries still have land that is not used for any immediate economic purpose and that is now being transformed into agricultural land. But there is often an ecological penalty to be paid for expansion of farmland, and that fact will eventually be widely realized. For most developing countries the most appropriate solution will be to grow more food on the same or even a reduced amount of land. Generally speaking, that can only come about through the adoption of new agricultural technologies.

The green revolution showed that, under the right circumstances, it was possible to avert widespread starvation. Economic progress, however, requires more than avoidance of starvation; it requires sufficient amounts of more nutritious food, on a mass scale, to improve the health of minds and bodies. Here again technology must be an important part of the answer.

The green revolution did not show—nor has the slow spread of agricultural technology in many developing countries yet shown—that it is possible to eradicate poverty or to raise the incomes of subsistence farmers much above current levels, except in isolated instances. Among those who look with dismay on the adoption of modern technology on the farms of developing countries, this "failure" is deemed indicative of the failings of technological societies in general. But the fact is that modern technology has made very slow headway among the rural-dominated societies prevalent in much of the developing world. Rising incomes among farmers and rural laborers will come only when farmers and laborers increase their economic value by performing economically valuable tasks. The rural household will have to raise enough food for, say, five families, rather than one before it will achieve a significantly greater income. The rural poor will have to work in agricultural processing plants and packaging plants, commercial slaughterhouses, and other rural and nonrural industries if they are to earn more. There are few other ways to raise rural incomes permanently.

In sum, agriculture in the developing countries can take one of two directions. It can stagnate, or it can gradually be transformed in a manner analogous to the transformation of Western agriculture over the past century and a half. Whether one likes it or not, some of the leading developing countries have chosen to transform. The course they have chosen seems likely to be adopted by more and more developing countries as time goes on.

## Notes

1. Moreover, farmers have been able to benefit from new varieties only in areas with a relatively stable water supply from irrigation or with reliable rainfall patterns.
2. As of 1987 they include China, India, Mexico, Nigeria, and the Philippines. Others have contributed occasionally.
3. New biological technology which has recently become available does offer possibilities for speeding up some aspects of the breeding process.

# 3 Producing More Food through Plant-Breeding Techniques

The term green revolution, first used in 1968, quickly became a convenient—perhaps too convenient—way of referring to the rapid changes in agricultural technology that spread over many parts of Asia, Latin America, and North Africa, beginning in the mid-1960s. In more prosaic terms, the changes led to remarkable increases in the wheat harvests of India and Pakistan and to larger rice harvests in many of the developing countries of Asia where rice, not wheat, is the "staff of life." At the time the words green revolution were coined, the most significant evidence of a "revolution" was the rise in wheat harvests in India. After years of static wheat production of 10 million to 11 million tons a year, India's 1968 wheat harvest reached 16.5 million tons, roughly 40 percent above the previous year's 11.3 million tons. That increase, however, was far from enough to make India self-sufficient in wheat. The country still imported 3 million tons of wheat in 1968, and even so, average food energy intake remained well below 2,000 calories a day.

What the 1968 jump in production chiefly did was to raise the hope that someday India and the rest of Asia might no longer fear mass starvation. From the fourteenth century through the first half of the twentieth century Asia had been the scene of many of the world's worst famines. The most recent brush with disaster had occurred in 1965–67, when drought afflicted more severely than usual the crops in the state of Bihar, India. Intensive relief efforts by other countries helped to keep the death toll to the thousands. Without outside help the death toll would have been much higher.

The great increase in India's wheat production in 1968 was largely a triumph of modern plant-breeding techniques. The semidwarf varieties of wheat that Norman Borlaug and his colleagues had developed in Mexico produced far more grain than the varieties then available to Indian farmers, even when the traditional varieties got enough water and fertilizer.

While Borlaug and his colleagues at CIMMYT continued to work on wheat in the early 1960s, IRRI began the equally arduous process of developing higher-yielding varieties of rice. Its first success was the semidwarf variety IR8, introduced in 1966. As might be expected, IR8 made its first impact in the Philippines, where IRRI is located, but within a few years the new varieties were being used extensively in such other Asian countries as Indonesia, Sri Lanka, and Viet Nam. Like wheat production in India and Pakistan in the late 1960s, rice production in a number of Asian countries began to rise with unusual vigor in the early 1970s.

Because of his leading role in developing the new strains of wheat, Borlaug was awarded the Nobel Peace Prize in 1970. Not many years afterward IRRI received several prizes from international organizations for its work on rice.

Borlaug and other scientists at both CIMMYT and IRRI were often uncomfortable about references to the green revolution. Although the term was a boon to journalists and broadcasters, those who made plant breeding their life's work often felt that "revolution" was far too strong a word.

The fact is that the world of plant breeding is one of evolution rather than revolution. The ancestors of modern high-yielding varieties of wheat and rice could be found in Asia in the nineteenth century. Semidwarf wheat and rice were in existence for decades before relatively cheap manufactured fertilizer made it advantageous to cross them with traditional varieties. And the process continues. The wheat varieties created at

CIMMYT have been replaced in many developing countries by newer varieties even better adapted to local conditions and developed chiefly by scientists in national research systems. The rice variety IR8, once hailed as a potential savior, soon proved unable to defend itself against pests whose mutations into new forms made it more vulnerable to attack. Over the years IRRI and national scientists have had to work constantly to produce newer varieties as existing ones lost resistance to natural stresses and became less productive. IR8 gave way to IR20, which in turn was succeeded by IR26 and then IR36. In the late 1970s IR36 was said to be "the world's most popular rice," but by 1980 it was beginning to prove defenseless against a new strain of the brown plant hopper. In the meantime IRRI and its partners had fortunately developed IR56.

Plant breeders are also quick to note that the creation of improved types of plants was only the first step in raising food production in Asia. As a 1981 ICRISAT report put it, "The spectrum of improved agriculture and life styles is made up of many vital inputs—improved seeds, essential fertilizers, effective soil management, better utilization of rainfall, appropriate cropping systems, supplementary irrigation, motivation for adoption of technologies, and the elimination of socioeconomic constraints."

The new varieties of wheat and rice that were largely developed at the centers and later refined by national scientists have led to some spectacular results, especially in Asia. In 1983, for example, India's estimated wheat production was 42.5 million tons (FAO 1984), an increase of about 235 percent over average annual production in 1966–69. Indonesia, which has the third largest population in Asia after China and India, has become a self-sufficient producer of rice—and even an exporter—after having been a net importer for many years. India and China have both become self-sufficient in rice, while Pakistan (a specialty rice exporter) and Turkey have greatly increased their production of wheat. In the developing world as a whole between 1966 and 1978 wheat output steadily increased faster than population growth (FAO 1978).

Yet it is important not to be deceived by success stories. Although high-yielding varieties of wheat have led to extraordinary production increases in the Punjab, Haryana, and western Uttar Pradesh, in other parts of India where soil, water, and fertilizer conditions are less favorable the newer varieties have had little impact. And in India and China virtually every arable hectare of land is now being used intensively. As the populations of those countries continue to grow (even though more slowly) there will eventually be only two alternatives: to obtain even greater yields per hectare, not only of wheat and rice but of every other staple, or to spend large amounts of foreign exchange to buy food from foreign producers.

Finally, it must be remembered that neither wheat nor rice is the main staple in large parts of the developing world. Northern Africa is heavily dependent on wheat, but Sub-Saharan Africa relies mostly on sorghum and millet and on root crops such as cassava and yams. In Central America and parts of South America many people rely more on maize, beans, and potatoes than on wheat and rice. Depending on the physical environment in different countries, still other foods are important sources of nutrients: barley, plantains, and such legumes as pigeon peas, cowpeas, and chickpeas.

Because many developing countries depend on crops other than wheat and rice, various centers are conducting research on these as well: CIMMYT on maize, CIP on potatoes and sweet potatoes, CIAT on beans, cassava, and animal forage species, IITA on cassava, maize, yams, and legumes, ICRISAT on sorghum, pearl millet, and several food legumes, and ICARDA on barley, chickpeas, lentils, and forage. This chapter discusses in detail the achievements of the eight centers at which plant breeding is an important activity.[1]

## The Work of the Plant-Breeding Specialist

Ever since the human race turned from hunting to agriculture, peasants and farmers have saved the seeds of the plants they prized. But that informal method of plant selection began to be displaced in the late nineteenth century. Today even amateur gardeners have some knowledge of the technical methods used to improve domesticated plants.

The professional breeder does not wait to see whether nature will produce a useful variant of a plant. Instead, the plant breeder deliberately sets out to improve existing varieties, using a knowledge of breeding principles and also relying on intuition, experience, and luck.

Scientific plant breeding begins with the collection of different varieties of a single plant species. Some of these may be wild varieties whose relation to cultivated varieties is far from obvious, while others will be closely related to the cultivar.

The breeder's general purpose is to incorporate one or more desirable new characteristics into an existing variety by mating (crossing) distinctively different plants. The breeder selects the most desirable plants from the first generation of offspring, grows them, and selects from their offspring the most desirable individuals. Over several generations this process can greatly change both the genetic structure and the economic value of a species. For example, the incorporation through plant-breeding techniques of the characteristic of semidwarfness made wheats and rices more productive. Since the improved varieties were shorter and stronger, they could be fertilized more heavily and thus produce larger wheat and rice panicles without becoming top-heavy and falling over (lodging).

Although plant breeders have sometimes found it possible to speed up the process—high-yielding semidwarf rice, for example, was developed in only four years—it ordinarily takes anywhere from nine to twenty years before a new variety is ready to be released to farmers for widespread cultivation. The process is lengthier where only one generation of plants a year can be grown because of highly seasonal rainfall or temperatures.

In both industrial and developing countries plant breeders have much the same goals. One goal is to increase the yield from individual plants, which can be done in several ways. A method that has already been mentioned is to develop plants that respond more efficiently to water, sun, and soil nutrients. Another way is to develop varieties that mature more quickly than existing ones, thus allowing two and sometimes even three crops to be grown in the time previously needed to grow only one.

Yields can also be increased by reducing the susceptibility of food crops to insect pests, plant diseases, weeds that compete for soil nourishment, and animal predators, such as birds and rats. During the past thirty years or so plant breeders have often been able to rearrange the genetic structure of food crops to make them stronger in their contest with various enemies. Breeding as a way of making crops more pest resistant is especially important in tropical developing countries. Where warm weather lasts throughout the year, plant pests tend to be much more abundant than they are in Europe, North America, and northern Asia, where cold weather reduces many pest populations.

As important as yield is plant quality, including such characteristics as nutritional value, palatability, storage properties, and forage value.

From the standpoint of health, nutritional value is the most important aspect of quality, but it is also the least obvious to consumers. Since wheat, rice, maize, sorghum, and barley all lack one or more essential human nutrients, plant breeders have tried in recent years to improve the nutritional value of these crops, particularly by increasing their content of lysine and other amino acids, the building blocks of proteins.

Palatability is the characteristic of greatest concern to most consumers in developing countries, as it usually is everywhere. Plant breeders have therefore been frequently criticized for failing to satisfy local opinion on how food should look and taste. A new rice variety, for example, may produce larger yields and have better nutritional value, but if it fails to look and taste like the traditional variety, its acceptance is not guaranteed. IR8, for example, was far from popular in many parts of the developing world and as a result usually had a lower market price. Subjective factors may play a large part in determining whether a new variety will be widely grown.

Another goal of plant-breeding specialists that is especially pertinent to agriculture in the developing countries is to improve the ability of food crops to tolerate environmental stresses such as drought, low temperatures, and high levels of salt or aluminum. Breeding for tolerance is difficult because the reactions of plants to environmental insults are determined by a large number of genes.

## The Plant-Breeding Activities of the Centers

The centers that carry out plant-breeding activities, especially the older ones, are well equipped and staffed for such work. As figure 3-1 shows, breeding begins with the collection of a wide range of different varieties of the same plant, including wild varieties, unusual mutants, and land races. These plants and succeeding generations may be allowed to grow under entirely natural conditions (except perhaps for high levels of certain inputs), or they may be subjected to stresses of

**Figure 3-1.** ***Stages in the Development of Crop Varieties***

Collection and characterization of germ plasm
(one to four years)
↓
Selection of germ plasm for breeding material
(one to three years)
↓
Generation of segregating lines through crossing
(one season)
↓
Screening of segregating lines against stresses
(three to six seasons)
↓
Selection of elite lines
(two to four seasons)
↓
Preliminary and advanced yield testing
(two to four seasons)
↓
Distribution in international trials

*Period required for development: six to fourteen years* various kinds—deliberate exposure to plant diseases or insects, poor soil conditions, or insufficient water.

Breeders select parent plants, which are crossed to produce the first generation of progeny. Succeeding generations "segregate" as individual plants, each with its own genetic constitution, react differently to given stresses. Subjecting plants to one or more types of stress for a number of generations reveals which plants are able to endure such stresses.

After five to seven generations of screening against various types of stress, the best of the lines that have been retained are designated "elite" lines, and testing is begun to assess their yields. If a line survives preliminary and advanced yield tests at a center, it may then be tested in multilocational trials, which allow breeders to observe plant performance in a wide variety of local situations.

Multilocational testing is done at center substations in various countries and at research stations operated by national systems. Promising materials that are selected by national researchers from international and more localized trials undergo testing (figure 3-2) along with locally developed materials. On occasion efforts are made to shorten the process by growing promising new lines in farmers' fields rather than at research stations. There is a limit to how much of this can be done, however, since farmers are more interested in growing their own crops than in participating in plant-breeding experiments.

**Figure 3-2. *Steps in the National Testing of Varieties before Release***

Elite materials from national and international sources
↓
Preliminary national trials
(two to four seasons)
↓
Advanced national trials
(two to four seasons)
↓
Farmers' field tests
(two to four seasons)
↓
Consideration by varietal release authority
(one to three meetings)

*Period required for testing and release: three to six years*

*Note:* In many cases a crop can be grown in only one season each year. Progress can sometimes be accelerated, however, by growing multiple crops each year at a site or by growing successive crops in different environments. For example, crops may be grown in different hemispheres—say, in the United Kingdom and in New Zealand—or at different altitudes and latitudes, as is done in Mexico by CIMMYT and the Instituto de Investigaciones Agropecuarias (INIA).

After a new line has successfully gone through national testing, it may be "named." Until 1975 IRRI named its rice varieties, but now IRRI materials, like those of the other centers, are named by national seed registration boards. These seed boards ordinarily ask individuals or institutions that have submitted new varieties for naming to provide documented evidence of performance. The boards also usually ask for enough seed to conduct some tests of their own.

Table 3-1 shows how many center-related seed varieties had been named (or simply released for farmers' use) by national authorities in developing countries through 1983. As might be expected, wheat, rice, and maize accounted for the largest numbers.

It is important to remember that the new varieties developed at the centers are not the only ones used in the developing countries. As the national systems have refined their skills, they have developed breeding capacities of their own. That, of course, is eminently desirable, since it would take the centers alone an inordinate amount of time to develop the specialized varieties needed for all of Africa, Asia, and Latin America. The number of different ecosystems in the developing world is huge, and for each food crop grown in each ecosystem there will be varieties that are particularly appropriate but that will, for reasons already explained, eventually become less advantageous. Hence many developing countries have produced their own new varieties with varying levels of assistance from the centers. In Indonesia, to give only one example, the number of named rice varieties exceeds 500. Of these, only 18 are center related and are therefore included in the rice variety total for Asia in table 3-1.

The term "center related" here means that a center had a direct hand in the development of the plant variety. It can therefore refer to any of the following:

- A variety developed by a center itself (that is, all steps in figures 3-1 and 3-2 are completed by a center)
- A variety obtained from one country and sent to another country with a center acting as the intermediary and making the decision on sending out the variety
- A variety selected by a national program from among crosses made at a center and distributed to national systems as "promising materials"
- A variety selected by a national program from early-generation segregating materials supplied by a center (that is, selected by a national program early in the process of figure 3-1).

Two types of new varieties are excluded from the list in table 3-1 even though the contribution of the centers to their development is not necessarily negligible. These are a variety that results from crosses

**Table 3-1. *Number of Center-Related Varieties Released by National Authorities in Developing Countries through 1983***

| Crop | Sub-Saharan Africa | Asia | Latin America | Middle East and North Africa | Total |
|---|---|---|---|---|---|
| Barley | 0 | 2 | 0 | 8 | 10 |
| Beans, field | 4 | 2 | 90 | 0 | 96 |
| Cassava | 26 | 5 | 32 | 0 | 63 |
| Chickpeas | 0 | 1 | 0 | 2 | 3 |
| Cowpeas | 14 | 2 | 12 | 1 | 29 |
| Maize | 61 | 49 | 126 | 2 | 238 |
| Pasture species | 0 | 0 | 12 | 0 | 12 |
| Pearl millet | 5 | 3 | 0 | 0 | 8 |
| Pigeon peas | 5 | 2 | 0 | 0 | 7 |
| Potatoes | 31 | 16 | 12 | 2 | 61 |
| Rice | 31 | 140 | 129 | 2 | 302 |
| Sorghum | 8 | 18 | 5 | 0 | 31 |
| Sweet potatoes | 6 | 0 | 0 | 0 | 6 |
| Triticale | 2 | 2 | 7 | 0 | 11 |
| Wheat, bread | 40 | 44 | 114 | 66 | 264 |
| Wheat, durum | 5 | 3 | 13 | 20 | 41 |

*Note:* Excludes varieties developed by national programs from sources similar to those used by the centers.

made by scientists at a national program from parent material supplied (perhaps only in part) by a center and a variety resulting from more complex forms of cooperation—for example, a cyclical process in which a center and a national system alternate in selecting and evaluating each generation of plants in a breeding cycle until a desired variety is obtained.

## The Spread of New Wheat and Rice Varieties

As Dalrymple (1985) points out, high-yielding varieties of wheat and rice "have spread more widely, more quickly, than any other technological innovation in the history of agriculture in the developing countries." He estimates that as of 1983 high-yielding varieties of wheat and rice were being grown on about 50 percent of the land devoted to each crop in the developing countries.[2] The carefully qualified data in Dalrymple's updated studies are, for many countries, rough estimates but are perhaps as good as any estimates of coverage, since most (although not all) high-yielding wheat and rice varieties are semidwarfs and are relatively easy to identify by observation.

Tables 3-2 and 3-3 present data prepared on the basis of Dalrymple's estimated percentages of national areas planted to new varieties. As Dalrymple notes (1986b, p. 87), our tables differ from his because he uses USDA statistics as the basis for his estimates of total wheat and rice area, whereas FAO statistics are used throughout this study. These two sets of statistics often differ significantly.

Despite Dalrymple's energetic efforts, complete time series that would show the spread of semidwarf wheat and rice varieties in all countries are not available. For many countries the data show only a few scattered years, although it is clear that the semidwarf varieties continued to be grown and, indeed, to spread. To derive a consistent estimate of the total area planted to semidwarfs we used an interpolation procedure, making the assumption that adoption took place smoothly between the first known plantings and the maximum reported level, which is taken as the maximal asymptote. It is thus assumed that during the years for which data are not available the area planted followed the path of adoption observed in the sparse data. The parameters of the fitted trend were estimated from Dalrymple's updated data, but the fact that he did not use the interpolation introduces another source of difference between his estimates and those reported here.

The world averages tend to obscure substantial differences among regions. Although high-yielding wheat varieties are believed to be grown on almost 80 percent of Asia's wheat lands, modern wheat varieties are used on only about 30 percent of the wheat lands of the Middle East and North Africa. Similarly, as of 1983 high-yielding rices were being raised on about 50 percent of Asia's rice lands (excluding China), compared with only about 15 percent of the rice lands of Sub-Saharan Africa.

The coverage of high-yielding rice varieties in Asia rises above 50 percent if China is included. There,

**Table 3-2. *Area under Semidwarf Wheat in Developing Countries, 1970 and 1983***

(thousands of hectares)

| | *1970* | | *1983* | |
|---|---|---|---|---|
| *Country* | *Area* | *Percent* | *Area* | *Percent* |
| China | 14.7 | 0.1 | 5,126.0 | 17.8 |
| India | 6,480.0 | 39.0 | 18,550.0 | 80.1 |
| Other developing Asia | 3,467.9 | 40.2 | 7,797.1 | 68.8 |
| Afganistan | 232.0 | 10.5 | 400.0 | 13.3 |
| Bangladesh | 9.3 | 7.7 | 498.0 | 96.0 |
| Nepal | 98.3 | 49.2 | 377.6 | 92.1 |
| Pakistan | 3,128.3 | 50.3 | 6,521.5 | 88.2 |
| Sub-Saharan Africa | 69.8 | 5.0 | 556.3 | 52.1 |
| Ethiopia | 60.4 | 5.7 | 384.0 | 51.2 |
| Kenya | 7.9 | 5.3 | 83.8 | 72.9 |
| Nigeria | 1.0 | 33.3 | 10.0 | 71.4 |
| Sudan | 0.0 | 0.0 | 46.5 | 35.8 |
| Tanzania | 0.0 | 0.0 | 10.0 | 43.5 |
| Zimbabwe | 0.5 | 4.2 | 22.0 | 62.9 |
| Latin America | 794.5 | 10.8 | 8,878.0 | 82.5 |
| Argentina | n.a | n.a | 6,490.4 | 95.0 |
| Bolivia | 1.9 | 2.5 | 6.0 | 9.2 |
| Brazil | 56.1 | 3.1 | 826.5 | 43.0 |
| Chile | 61.2 | 8.3 | 329.7 | 70.0 |
| Colombia | 9.2 | 21.9 | 42.8 | 95.0 |
| Ecuador | 0.0 | 0.0 | 8.0 | 36.4 |
| Guatemala | 11.9 | 29.8 | 39.9 | 95.0 |
| Mexico | 651.9 | 88.1 | 942.5 | 95.2 |
| Paraguay | 2.1 | 6.6 | 6.0 | 8.0 |
| Uruguay | 0.2 | 0.0 | 186.2 | 62.1 |
| Middle East and North Africa | 1,144.4 | 5.0 | 7,690.3 | 33.8 |
| Algeria | 140.0 | 6.1 | 400.0 | 30.8 |
| Egypt, Arab Rep. | 0.0 | 0.0 | 306.2 | 53.7 |
| Iran | 63.0 | 1.3 | 891.7 | 14.7 |
| Iraq | 125.0 | 6.1 | 600.0 | 50.0 |
| Libya | 4.8 | 2.9 | 97.3 | 34.8 |
| Morocco | 90.0 | 4.6 | 721.6 | 36.5 |
| Saudi Arabia | 0.0 | 0.0 | 288.0 | 100.0 |
| Syria | 28.6 | 2.1 | 601.5 | 46.6 |
| Tunisia | 53.0 | 4.8 | 344.0 | 37.0 |
| Turkey | 640.0 | 7.4 | 3,440.0 | 38.9 |
| All developing countries | 11,962.0 | 14.0 | 48,597.7 | 49.7 |

n.a. Not available.
*Note:* Data are for center-related varieties except for China.
*Source:* Adapted from Dalrymple (1986b).

modern varieties were being used on 95 percent of the rice lands as of 1983. Although in recent years China has utilized IRRI rice lines, it initially developed semidwarf rice varieties without assistance from IRRI and used its own for many years before deciding to work with the center.

As Dalrymple makes clear, determining the coverage of high-yielding wheat and rice varieties in the developing countries is extremely difficult. Some developing countries do a good job of collecting statistical information on agriculture, but most have not yet been able to create the organizational capability necessary to collect accurate information on varietal use. That fact will be apparent in the discussions that follow.

### *High-Yielding Wheat Varieties*

In Asia new high-yielding wheat varieties were first grown in India, Nepal, and Pakistan, and the most

**Table 3-3. *Area under Semidwarf Rice in Developing Countries, 1970 and 1983***

(thousands of hectares)

| Country | 1970 Area | 1970 Percent | 1983 Area | 1983 Percent |
|---|---|---|---|---|
| China | 26,848.0 | 77.3 | 32,265.2 | 95.0 |
| India | 5,588.0 | 14.8 | 22,180.0 | 54.1 |
| Other developing Asia | 4,545.3 | 10.6 | 19,734.1 | 42.4 |
| Bangladesh | 263.8 | 2.6 | 2,628.5 | 24.8 |
| Burma | 200.0 | 4.2 | 2,370.1 | 50.4 |
| Indonesia | 1,072.2 | 13.0 | 6,626.9 | 72.8 |
| Korea, Rep. of | 2.7 | 0.2 | 418.6 | 34.1 |
| Lao PDR | 53.6 | 6.0 | 9.7 | 1.4 |
| Malaysia | 164.6 | 23.3 | 254.8 | 36.4 |
| Nepal | 67.4 | 5.6 | 478.9 | 37.1 |
| Pakistan | 550.0 | 4.6 | 915.7 | 45.3 |
| Philippines | 1,565.4 | 49.3 | 2,757.0 | 83.5 |
| Sri Lanka | 73.6 | 11.2 | 749.7 | 81.0 |
| Thailand | 30.0 | 0.4 | 1,200.0 | 12.8 |
| Viet Nam | 502.0 | 20.1 | 1,324.2 | 50.0 |
| Sub-Saharan Africa | 41.1 | 4.1 | 241.9 | 14.8 |
| Cameroon | 0.2 | 0.9 | 7.9 | 35.9 |
| Cote d'Ivoire | 2.1 | 0.7 | 32.7 | 7.1 |
| Ghana | 36.8 | 89.8 | 35.0 | 43.8 |
| Nigeria | 1.0 | 0.4 | 60.0 | 10.0 |
| Senegal | 1.0 | 1.1 | 72.4 | 96.5 |
| Sierra Leone | n.a. | n.a. | 33.9 | 8.5 |
| Latin America | 180.2 | 3.0 | 1,831.7 | 27.8 |
| Argentina | 0.0 | 0.0 | 27.3 | 33.7 |
| Brazil | 0.0 | 0.0 | 729.1 | 14.3 |
| Colombia | 41.0 | 17.4 | 364.3 | 91.8 |
| Ecuador | 15.7 | 10.5 | 40.3 | 53.1 |
| Guatemala | 0.0 | 0.0 | 3.5 | 29.2 |
| Guyana | 0.0 | 0.0 | 43.5 | 59.5 |
| Haiti | n.a. | n.a. | 11.0 | 22.0 |
| Honduras | 0.9 | 4.7 | 21.4 | 89.2 |
| Mexico | 51.1 | 27.6 | 154.2 | 83.4 |
| Nicaragua | 9.1 | 33.7 | 37.1 | 78.9 |
| Panama | 40.6 | 31.2 | 55.2 | 69.0 |
| Paraguay | 0.2 | 1.5 | 21.9 | 64.4 |
| Peru | 16.9 | 12.8 | 140.7 | 74.1 |
| Suriname | 4.7 | 13.1 | 48.7 | 69.6 |
| Venezuela | 0.0 | 0.0 | 133.5 | 79.9 |
| Middle East and North Africa | 2.1 | 0.3 | 80.7 | 11.0 |
| Egypt, Arab Rep. | 2.1 | 0.4 | 20.7 | 4.9 |
| Iran | 0.0 | 0.0 | 60.0 | 19.2 |
| All developing countries | 37,204.7 | 30.3 | 76,333.6 | 58.5 |

n.a. Not available.
*Note:* Data are for center-related varieties except for China.
*Source:* Adapted from Dalrymple (1986a).

comprehensive statistics on the spread of new varieties are available for those three countries and for Bangladesh. By the crop year 1983–84 (given as 1983 in table 3-2) high-yielding varieties were being raised on an estimated 18.5 million hectares in India, or some 80 percent of all of India's wheat lands. Although India first relied on new varieties developed in Mexico, its large agricultural research establishment soon developed other varieties based on advanced Mexican breeding lines. From the late 1960s two of these varieties, Kalyansona and Sonalika, were the dominant high-yielding varieties in India, with Sonalika eventually becoming the most favored variety because of its early maturity, high yield, and amber color. Dalrymple (1986b) states, however, that a replacement will have to be found for Sonalika because it is susceptible to a new type of leaf rust.

In Pakistan, the second-largest producer of wheat on the Indian subcontinent, high-yielding varieties had spread to 6.5 million hectares by 1983, or some 88 percent of Pakistan's wheat land. Dalrymple notes that leaf rust was a serious problem in Pakistan in 1975 and 1978. In both years Pakistan imported large amounts of varieties that were less susceptible to rust. Many farmers, however, continue to plant rust-susceptible varieties such as Yecore, Pavon, and Mexipak, leaving open the possibility that rust could again become a serious problem.

Bangladesh and Nepal have far less land planted to wheat, but the new wheat varieties are grown on higher percentages of wheat land in those two countries than anywhere else in Asia—in 1983, 96 percent (498,000 hectares) in Bangladesh, where rice remains by far the chief food crop, and about 92 percent in Nepal. Over the years both countries have relied heavily on high-yielding wheat varieties imported from India, although Bangladesh has also made substantial and successful attempts to develop its own varieties. Dalrymple (1986b) notes that the contribution of the new varieties to wheat production in Nepal is "unclear," since the wheat is grown largely in rainfed (rather than irrigated) fields, with little or no fertilizer, and the production data are contaminated by undocumented trade with India.

Wheat production in China increased nearly sixfold between 1950 and 1984, making China the largest wheat producer among all developing countries. Fertilizer use is heavy in comparison with that in other countries, and about 50 percent of the country's wheat lands are irrigated. Many foreign cultivars (including some from CIMMYT) have been used since 1950, but China has also done extensive wheat-breeding work of its own. Since 1970 a number of semidwarf wheat varieties have been developed by the Chinese for commercial use.

The spread of high-yielding wheat varieties in China is difficult to ascertain, however, since "official statistical estimates are scarce at the national level" (Dalrymple 1986b, p. 34). Our estimate is about 18 percent for 1983, but Dalrymple estimates that, depending on the definition of high-yielding wheat variety, by 1984 such varieties may be grown on 33 to 56 percent of China's total wheat area.

The use of new wheat varieties in countries outside Asia is variable and sometimes difficult to ascertain, but table 3-2 shows the best available data. After Asia wheat is most important in the Middle East. About 39 percent of all land devoted to wheat in Turkey in 1983 was planted in high-yielding varieties.

In the Arab Republic of Egypt, where wheat is the leading winter cereal, about 306,000 hectares were planted in high-yielding wheat varieties in 1983. In Libya the area devoted to high-yielding wheat varieties was about 97,000 hectares and in Morocco it was perhaps 720,000 hectares in 1983, or about 36 percent of that country's wheat lands. In Saudi Arabia, it appears, most of the country's wheat area (which had increased to almost 290,000 hectares by 1983) was planted in high-yielding strains. For some countries in the region—Afghanistan, Algeria, Iran, Iraq, Jordan, Lebanon, the People's Democractic Republic of Yemen, and the Yemen Arab Republic—little information is available on the years after 1980, although there is no doubt that farmers in all these countries grow some wheat.

In Latin America, Argentina uses high-yielding varieties of wheat almost exclusively. There, where a temperate climate and large arable tracts of land have made wheat farming a traditional way of life, semidwarfs were increasingly adopted in the late 1960s and the 1970s. By 1983 semidwarfs were being grown on about 95 percent of the country's 6.5 million hectares devoted to wheat.

Latin America's second-largest producer of wheat is Brazil. In contrast to Argentina, semidwarf wheat varieties were grown on only about 43 percent of Brazil's wheat area in 1983. Despite its substantial wheat harvests the country must import large quantities of wheat, and it is logical to suspect that the percentage of land devoted to high-yielding varieties has continued to increase.

Latin America's most important wheat-growing countries, other than Argentina and Brazil, are Mexico, Chile, and Uruguay. In Mexico, the home of CIMMYT, semidwarf varieties account for virtually all of the wheat harvest. Yields there are among the highest in the developing countries, partly because approximately 90 percent of Mexico's bread-wheat farms are irrigated. The area planted to wheat increased by nearly 300,000 hectares between 1970 and 1983, to almost 1 million.

In Chile, where the Rockefeller Foundation helped to create a wheat improvement program as early as 1955, there has been substantial interest in new semidwarf wheat varieties, a large number of which have been released since 1978. Dalrymple reports the estimates of a regional CIMMYT official to the effect that semidwarf varieties were raised on about 70 percent of Chile's wheat land in 1983. In Uruguay semidwarf wheat varieties were grown on more than 60 percent of the wheat area by 1983.

Wheat is a significant crop in only a few Sub-Saharan African countries. In West Africa and in parts of East Africa wheat production is unlikely to expand until varieties are created that are much more tolerant of high temperatures. "There is considerable interest in expanding wheat production in many African nations, but relatively few technical and scientific resources are generally available for the needed research" (Dalrymple 1986b, p. 56).

From a plant-breeding standpoint Kenya and Zimbabwe are notable. An interest in new varieties of wheat was first demonstrated in Kenya in 1908, when the Kenyan wheat grower Lord Delamere hired an English plant breeder to develop varieties more resistant to stem rust. Between 1908 and 1978, according to CIMMYT, 132 improved varieties of wheat were released in Kenya, and 25 of them were still being grown commercially in 1978. CIMMYT has also reported that as of late 1977 seventeen wheat varieties of Mexican origin were being used in Kenya. By 1983 two of the sixteen varieties recommended for use in Kenya were of CIMMYT/Mexican origin, and most of the others had Mexican strains among their ancestors. Kenya's wheat-growing regions in 1983 exceeded 100,000 hectares.

Zimbabwe's wheat-growing area is small, and it fluctuates, but irrigation and the use of semidwarf varieties have made its wheat yields per hectare among the highest in the world. Between 1980 and 1983 the average yield was 5.15 tons per hectare.

Wheat's greatest economic and nutritional importance in Africa is in Ethiopia, where about 750,000 hectares of land were used for growing wheat in 1982–83. Approximately half of that area (about 384,000 hectares) was planted in improved varieties that had been released since 1974. Although Mexican varieties were not totally absent from Ethiopia, the preferred high-yielding varieties originated either in Ethiopia itself or in Kenya.

### *High-Yielding Rice Varieties*

ASIA. Rice is the dominant food crop in South Asia, East Asia, and Southeast Asia. In South Asia an average of 54 million hectares was devoted to rice production during 1978–80. In East Asia rice covered 39 million hectares during the same period, and in Southeast Asia, including Oceania, the corresponding figure was 54.7 million hectares. The total rice area in all Asia amounted to 148.4 million hectares, compared with 22.9 million hectares in the rest of the world.

About 90 percent of the world's rice is harvested in Asia, and very little of the grain leaves the continent. By 1985 most of the high-yielding varieties in cultivation in Asia were semidwarfs (80–120 centimeters), although there are also improved varieties of intermediate height and even a few described as tall (more than 140 centimeters).

Since rice has historically been the chief food in Asia, many countries began their efforts to improve rice yields quite early in this century. In Burma, for example, the first rice experiment station was created in 1907. Rice-breeding work got under way in Indonesia in 1905, in what is now Bangladesh in 1911, and in Korea in 1906. Thus when IRRI came into existence many Asian countries were well positioned to adapt its advances in rice breeding to their own circumstances.

In China, the world's largest producer of rice, IRRI rice varieties were used as early as 1968, although this was not known in the West until several years later. China's own development of semidwarf rice varieties got under way in the mid- to late 1950s, and that early start helped the country achieve unusually quick progress in making use of improved rice strains. Dalrymple (1986a) suggests that the use of semidwarfs had spread to about 90 percent of China's total rice-growing area by 1974 and has continued at or above that level since then. Because IRRI materials include many that are highly resistant to insect pests and disease, they have been used increasingly in China's breeding program since 1971.

Rice-breeding work also started early (1929) in India. The Central Rice Research Institute (CRRI) was established there in 1946. By the mid-1950s Indian scientists were working on the development of stiff-strawed varieties able to utilize large amounts of fertilizer without lodging, and IRRI used these in its earliest days. Experiments with small amounts of seed from IRRI began in 1964. The amount of land planted in high-yielding rice varieties rose from 7,000 hectares in 1965–66 to 888,000 hectares a year later. Since then the use of improved rice varieties has spread fairly rapidly, and by 1983 over half (22.2 million hectares) of India's rice area was devoted to the newer strains.

Modern varieties are also widely used in Indonesia, the Philippines, and Sri Lanka. In 1970 an estimated 13 percent of Indonesia's land was planted with new rice varieties. Thirteen years later that figure had risen to more than 70 percent. During the early 1980s a cross made in Indonesia (with a heritage stemming partly from IRRI varieties) became the second most commonly planted rice variety in Indonesia. The leader was PB36, the semidwarf called IR36 elsewhere and first used in Indonesia in 1977.

The adoption of better varieties in the Philippines, the home of IRRI, occurred as rapidly. By 1983 over 83 percent (about 2.7 million hectares) of the rice lands in the Philippines were occupied by the newer varieties. The quickest increases occurred between 1967 and 1970, when the proportion devoted to high-yielding varieties reached 50 percent. Growth in coverage since then has been steady.

In Sri Lanka the pattern was similar to that in the Philippines. After a very quick rate of adoption during the first years that the new varieties were available (from less than 2 percent in 1968–69 to 48 percent of the country's rice lands in 1973–74), the proportion slid to 42 percent in 1975 before rising to 81 percent by 1983.

The adoption of improved rice strains elsewhere in Asia seems to have occurred at a much slower pace. Information about the recent use of new varieties in Democratic Kampuchea, the Democratic People's Republic of Korea, the Lao People's Democratic Republic, and Viet Nam is sparse. In Taiwan rice growing is dominated by the traditional varieties known as *ponlai*, which were introduced by the Japanese in the 1920s. In Malaysia, as of 1983, high-yielding rice varieties (most of them Malaysian varieties developed from IRRI ancestors) covered 36 percent of the rice regions, which are centered in West (Peninsular) Malaysia. In Burma preliminary data indicate that in 1983 high-yielding varieties were grown on 2.4 million hectares, or 50 percent of the country's rice area. Newer varieties were adopted quite slowly in the 1960s and through the 1970s; they were used on only 15.7 percent of available rice land as recently as 1979, but thereafter adoption was rapid.

The Republic of Korea and Nepal each devote roughly 35 percent of their rice lands to high-yielding varieties, but there are significant differences in rice cultivation in the two countries. Irrigation is used extensively in Korea, and fertilizer use is intensive. In Nepal few rice growers except those in the Kathmandu valley use fertilizer. The greatest share of Nepal's rice is grown on the *terai* (the southern plain), and the lack of fertilizer there has, according to Dalrymple, "muted" the impact of newer rice varieties.

Modern varieties were introduced into Thailand in 1969 but had spread only to about 13 percent of the available land by 1983. Thailand has large rice-growing areas that are subject to deep flooding in some years, and some authorities believe the country needs new varieties that would stay short in shallow water but elongate when deep flooding occurs. Work on developing such varieties continues.

Although Bangladesh is more dependent on rice than most other Asian countries, the newer varieties have spread at only a moderate pace. First introduced in 1966, they were being grown on barely one-quarter of the country's rice lands by 1983. Like Thailand, Bangladesh has extensive deep-water rice areas.

AFRICA AND WEST ASIA. In Sub-Saharan Africa rice is grown far more extensively on relatively dry uplands than in standing water. Although many countries of the region grow some rice, in only seven is it an important crop: Burkina Faso, Ghana, Madagascar, Mali, Nigeria, Senegal, and Tanzania. Many other African countries want to increase rice production and have either made some use of high-yielding varieties or have considered doing so. In Madagascar rice is the staple food and is cultivated on about 1.3 million hectares, making that country by far the region's largest producer. Yet yields per hectare are low, and in the mid-1970s Madagascar began to import rice after having been an exporter for many years (Dalrymple 1986a).

Information on the actual use of modern varieties in the region is fragmentary. The countries that have made the greatest use of modern varieties, according to Dalrymple, are Côte d'Ivoire, Ghana, Nigeria, Senegal, and Tanzania. As of 1984 two IRRI varieties were being grown on about 75 percent of Tanzania's total irrigated rice area of 15,000 hectares. IITA reported that in Nigeria in 1984 two modifications of IRRI varieties had been planted on more than 60,000 hectares in the states of Anambra and Kwara (Dalrymple 1986a). During the 1983 season in Senegal more than 70,000 hectares were planted in modern varieties. Both Nigeria and Senegal have carried out intensive investigations of potential new strains from Asia.

In Egypt from about 1954 to 1974 the most favored variety of rice was a local variety of Japanese parentage, Nahda. After it became susceptible to rice blast, Nahda was gradually replaced by other local varieties. Meanwhile a collaborative endeavor by the Egyptian Ministry of Agriculture, USAID, the University of California, the University of Arkansas, and IRRI was begun in 1980. Its main objectives were to increase rice yields and to shorten the time to maturity of the local varieties. At the same time work was continuing on the adaptation of a quick-maturing variety from Japan, Reiko, which was first grown commercially in Egypt in 1982. By 1983, it is estimated, Reiko was being grown on about 100,000 hectares, or about one-fourth of Egypt's rice area. In that year, however, Reiko was decimated by a new race of rice blast. The IRRI semidwarf IR28 was grown on about 20,000 hectares in 1983, and by 1985 it and two older local varieties of

Japanese parentage were the high-yielding varieties most extensively planted in Egypt. IR28 was grown on only 1.5 percent of Egypt's rice lands in 1983 but by 1985 accounted for 10.9 percent (42,400 hectares).

LATIN AMERICA. Rice is grown in virtually every Latin American and Caribbean country. Brazil, which has the largest rice-growing area in the region, was the sixth largest producer of rice among all developing countries in 1983.

In general terms, the adoption of high-yielding semidwarf strains of rice by farmers in Latin America has occurred more quickly in the smaller countries of Central America and on some of the larger Caribbean islands than in South America. In Costa Rica, for example, semidwarf varieties were adopted early and enthusiastically. By 1975 about 96 percent (81,000 hectares) of the country's rice area was being planted in modern varieties. In 1981–82 the percentage was much the same, although rice was being grown on about 10,000 fewer hectares (Dalrymple 1986a).

In 1976 some 53,000 hectares in Brazil were planted in new high-yielding varieties. By 1983 the corresponding figure was nearly 730,000 hectares, almost a fourteenfold increase. That amounted, however, to only 14 percent of the country's rice area. As in many other countries of Central and South America, most of Brazil's rice lands (about 85 percent) are upland nonirrigated areas where new varieties thus far have little if any advantage over traditional taller varieties.

Colombia is second only to Brazil in South American rice production, and high-yielding rice varieties have been accepted rapidly there. In 1968 a mere 100 hectares were sown with high-yielding rice strains. By 1970, relying heavily on both IRRI varieties and CIAT adaptations of IRRI lines, Colombia's rice farmers planted 41,000 hectares in new varieties. By 1983 modern varieties were planted on about 364,000 irrigated hectares.

Mexico's farmers were almost equally quick to plant newer varieties—both semidwarf and intermediate height—and from 1976 through 1983 these varieties were planted on nearly 85 percent of the rice land. High-yielding modern varieties have also spread quickly in Honduras, Nicaragua, and Panama.

Among the Caribbean countries, Cuba, the Dominican Republic, and Haiti all grow substantial amounts of rice in relation to their sizes. Both Cuba and the Dominican Republic adopted modern varieties quickly. In the late 1960s Cuban rice growers eagerly adopted IR8, and by the spring of 1970 that IRRI variety was planted on about 91 percent (94,000 hectares) of Cuba's rice land. In the Dominican Republic IRRI and CIAT rice varieties and their local variants have been grown since 1966. By 1982 new varieties were being planted on about 80 percent (83,000 hectares) of the land available for rice. Adoption of newer varieties has been slower in Haiti; in 1983 high-yielding varieties were being grown on only about 22 percent of the rice land (Dalrymple 1986a).

## Maize and Other Food Crops

MAIZE. More than 200 maize varieties derived from materials supplied by the centers have been developed and released by national authorities in forty-one countries. Latin American countries have named about 100, and Africa and Asia have each accounted for about 50. One group of lines, Tuxpeño, has been of special value in making maize resistant to disease in lowland tropical areas; IITA's discovery and incorporation in maize of genetic resistance to streak virus has been particularly important for production in Africa. It is estimated that center-related varieties of maize are being grown on more than 6 million hectares in numerous developing countries, including Brazil, Burma, China, Costa Rica, Ecuador, Ghana, Guatemala, Honduras, India, Mexico, Nigeria, Tanzania, and Thailand.

Research by the centers on maize production has had less effect than has wheat or rice research. There are three main reasons for this. First, because maize is grown under highly diverse conditions, individual varieties are adapted to a narrow range of circumstances. This sets maize apart from irrigated wheat and lowland rice,which are mostly grown in relatively homogeneous environments. Second, maize is grown all over the developing world, unlike rice, which is grown chiefly in Asia, and wheat, grown mainly in West Asia, the Middle East, and North Africa. International maize researchers must thus forge larger numbers of institutional links than their wheat or rice counterparts. Third, earlier research into maize was addressed largely to yellow dent types, but consumers in developing countries prefer white flint types.

Identifying new maize varieties in the field requires close inspection. The improved maize varieties from CIMMYT and IITA often have no obvious physical characteristics, and their crosses with local varieties and their adoption by farmers are much less obvious than in the case of semidwarf wheat and rice. Even so, it is clear that there has been considerable use of center-related maize, both directly in farmers' fields and in national breeding programs.

Researchers in Brazil reported on twelve maize varieties that had been selected from crosses made with germ plasm from CIMMYT or from CIMMYT populations since the late 1970s (Homem de Melo 1986). About half of these contained Tuxpeño genes. Most were cited for their resistance to downy mildew, the fungus *Helminthosporium*, and other diseases, as well as for resistance to lodging, and one was described as drought resistant. Each was recommended for use in certain Brazilian states or portions of states. Brazilian maize breeders have also developed many varieties that are unrelated or only remotely related to center-supplied germ plasm.

Researchers in Guatemala have produced nine varieties of maize and three maize hybrids from CIMMYT-supplied germ plasm (Stewart 1985b). Nine of these have been released by Guatemalan authorities since 1978. A high-quality protein variety, Nutricta, has been released and is being grown on about 500 hectares. Guatemalan plant breeders have also selected CIMMYT varieties for use in the highlands, where hitherto no imported materials had been successful.

Scientists in Costa Rica estimate that 10–15 percent of their country's 1984 maize area was planted to two varieties developed by the Ministry of Agriculture from materials supplied by CIMMYT (Stewart 1985a).

In the sierra region of Ecuador the Andean Maize Improvement Agreement among CIMMYT and several countries has resulted in the identification, testing, and release of highly adapted varieties. Some have already been adopted by farmers (Posada Torres 1986).

Zimbabwe has an advanced maize-breeding program which began in 1930 and in 1949 released the first commercial hybrid maize produced outside the United States (Billing 1985). A significant achievement of the program is its widely grown 150-day hybrids. Zimbabwe's researchers are also backcrossing elite inbred lines with streak virus resistant material from IITA. Kenya, like Zimbabwe, grows hybrids extensively and is using center germ plasm to develop new inbred lines.

Nigeria has made good use of two maize populations, TZB and TZPB, which were developed in the early days of IITA. TZB originated from African and Latin American sources, while TZPB is derived from Tuxpeño Planta Boja Cycle 7, from CIMMYT. The two populations were released by Nigeria's National Cereals Research Institute under the names FARZ 27 and FARZ 34. Both have good resistance to tropical rust and lowland blight. In 1981 they were the most widely grown varieties of maize in Nigeria, covering a total of 200,000 hectares. As of 1984 the two varieties were grown on an estimated 1 million hectares in Nigeria (Okoro and Onuoka 1985).

CIMMYT has been supplying Malawi with maize germ plasm since 1969 (Billing 1984). One of the first improved varieties released, Chitadze Composite A (CCA) was 80 percent local materials and 20 percent material imported from other African countries. About 60 percent of the second, CCB, consisted of CIMMYT materials, but it was not sufficiently resistant to disease. Breeders are now working on a third variety, CCC, which has a higher percentage of CIMMYT materials and produces higher yields under drier conditions.

Tanzanian plant breeders used germ plasm from the CIMMYT and IITA maize populations to obtain streak virus–resistant varieties that were released in the early 1980s (Ndunguru 1984).

Researchers in Cameroon have tested more than a hundred composites of center maize and have released a number of them (Lyonga and Pamo 1985). As in Nigeria, TZB and TZPB have proved attractive to farmers in Cameroon, where these two varieties cover 10,000–15,000 hectares.

Thailand has been the center of an inter-Asian maize improvement program since 1959, when the Rockefeller Foundation stationed a field staff member there (Isarangkura 1986). Plant materials imported from Guatemala were crossed and evaluated in Thailand and other Southeast Asian countries, and the first improved variety was released in 1969. The program cooperated closely with CIMMYT and with other countries in Southeast Asia to develop downy mildew resistant (DMR) maize, and DMR Suwan No. 1 was released in 1975. National authorities reported in 1984 that virtually all the maize planted in Thailand (about 1.7 million hectares) used materials derived from the program.

Indonesian farmers also have obtained benefits from CIMMYT-related maize varieties which, together with improved cultural practices, helped raise average yields from 1.1 tons per hectare in 1973 to 1.7 tons per hectare in 1983 (Nestel 1985). DMR varieties have been less successful in the Philippines.

In 1978 the government of Burma initiated a maize production program with the assistance of the United Nations Development Programme (UNDP) and the FAO. The project obtained germ plasm from other countries in Southeast Asia and from CIMMYT to test for local adaptability, drought tolerance, and early maturity (Kyaw Zin 1986). Six varieties have been released by the program and have been well accepted by Burmese farmers.

CASSAVA. Twenty-six varieties of cassava related to IITA germ plasm have been named and released by six African countries; thirty-two varieties related to CIAT germ plasm have been released by ten Latin American and Asian countries. The spread of improved cassava has been slowed by weak demand in Latin America, but demand in most African countries has been growing rapidly.

IITA researchers have come up with varieties that are resistant to a number of pests, including the green spider mite, the cassava mosaic virus, and the cassava mealybug. Researchers in Nigeria and Cameroon collaborated with IITA by supplying materials for evaluation and by conducting preliminary, advanced, and uniform yield trials (Okoro and Onuoka 1985). Kenya began to test IITA materials in 1983 (Ruigu 1985) and Tanzania has been testing IITA materials for tolerance to major pests (Ndunguru 1984).

Until the early 1980s cassava was a minor food crop in Zimbabwe (Billing 1985), but migrants from Malawi have brought about an increase in demand. As a result Zimbabwe's researchers started agronomic trials on cassava materials supplied by IITA, and the University of Zimbabwe's Crop Science Department has also started a cassava research program. The range of materials available from the centers has enabled Zimbabwe to forgo creating a breeding program of its own.

IITA has also assisted Malawi in establishing a cassava research program (Billing 1984). Researchers were trained to evaluate local material before incorporating IITA material, and the center helped devise a strategy to encourage farmers to adopt the new varieties.

FIELD BEANS (PHASEOLUS BEANS). By mid-1984 eighteen Latin American countries had named more than ninety CIAT-related field bean varieties, and five countries elsewhere had also named CIAT-related beans. Many of these are Dorado ("golden") beans, a group of new varieties that are resistant to golden mosaic virus (see box 3-1). In Guatemala surveys in 1982–83 by the Instituto Interamericano de Cooperación para la Agricultura (IICA) indicated that 40 percent of the small-scale bean growers and 60 percent of the large-scale growers had switched to the Dorado varieties (Viana and Pachico 1985). In Costa Rica an estimated 35–40 percent of the bean area is planted to varieties developed in collaboration with CIAT (Ballestero 1985). In Cuba about half the bean area planted since 1981 has been planted to ICA-Pijao, a variety introduced through CIAT. A survey of farmers in the four Argentinian states that account for 95 percent of that country's black bean production indicated that improved varieties were being grown on 65 percent of the bean area in 1984 (Gargiulo 1985).

Farmers in Guatemala reported an average yield of 910 kilograms per hectare from the new beans, compared with 750 kilograms a hectare from traditional varieties, with no difference in the use of other inputs. In Costa Rica farmers reported yields of 1,050 kilograms per hectare for the new variety Talamonca, compared with 600–700 kilograms per hectare for traditional local varieties. In Argentina yields of the

**Box 3-1. *Dorado Bean Varieties: A Collaboration***

In the late 1970s bean research specialists in Costa Rica, Cuba, the Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, and Panama joined CIAT in a research network to improve field bean production in Central America, where beans supply more than 15 percent of the protein consumed. Each country agreed to assume specific responsibilities in an overall bean development program, with CIAT providing support.

Bean golden mosaic virus (BGMV) is one of the main constraints on Central American bean production, especially in drier lowand areas. Guatemala accepted responsibility for working toward virus-tolerant bean varieties. CIAT provided germ plasm and some strategic research, which included isolation of the virus. After screening its germ plasm bank for promising material, CIAT researchers surrounded the test lines with other crops that carried both the virus and its vector. Crosses were made in 1975–76 at CIAT, and the segregating lines were sent to Guatemala for selection under field conditions.

One line, DOR 41, grown without insecticides, yielded 1,340 kilograms per hectare, while the susceptible commercial variety yielded 550 kilograms per hectare. These encouraging results led Guatemalan research authorities to speed up their testing, and they released three promising lines in 1979. By 1982–83 the new varieties were growing on more than 40 percent of Guatemala's bean area.

Promising lines were sent to the other members of the network. DOR 60, which had been screened at the third, fourth, and fifth generations in Guatemala, was taken to Mexico for testing. In one trial the line yielded 1,270 kilograms per hectare, compared with 560 kilograms per hectare for the traditional variety. The new line was released by Mexico in 1981 under the name Negro Huasteco 81.

Cuba selected several lines. The first to be released has spread to more than 10,000 hectares. DOR 41 is now being evaluated and adapted to local conditions, and the Cuban researchers will pass the results back to the Guatemalan researchers who developed the line.

DOR 41 also caught the attention of Argentinian researchers, who saw it as a possible solution to another problem, bean chloritic mosaic virus. They multiplied the seed, and by 1984 farmers in Argentina were planting some 20,000 hectares to it. Researchers in Haiti and the Dominican Republic have also selected DOR lines and in 1984 were testing them on farmers' fields prior to multiplication and release of seeds.

new beans averaged 1,360 kilograms per hectare, a 26 percent increase over local varieties, achieved with no other change in production practices.

In Brazil CIAT bean varietal improvement work is beginning to make an impact. Researchers released seven varieties in 1983–84 that had been developed by selecting or crossing center-derived materials or varieties developed in other countries from center materials.

POTATOES. By 1984 twenty-three developing countries had named or released sixty-one varieties of potatoes developed from germ plasm provided by CIP. Much of the germ plasm had been obtained from potato research programs in industrial countries. In addition, national researchers in fifty-three developing countries were evaluating potato lines, developed by CIP breeders, that combined resistance to the most serious diseases of potatoes. Varieties resulting from these breeding efforts should begin to be named within the next few years.

The strategy being followed by CIP is illustrated in the highlands of central Africa, where about 1 million small-scale farmers in Burundi, Rwanda, Uganda, and Zaire plant about 120,000 hectares of potatoes each year. CIP's first step was to select improved local varieties and multiply them. The second step was to introduce some improved varieties of potatoes from other parts of the world. The third step was to select varieties grown under local conditions from among families of tubers supplied by CIP. By using this strategy CIP made large amounts of improved materials available to farmers. Since 1979 six new local varieties that were tested at experimental sites and on farms have been released. Rwanda expected to plant about 9,000 out of 45,000 hectares to these improved varieties in 1984, providing the 2 tons per hectare of seed potatoes from its own production. A further step has been to test consumer acceptance of different varieties at various price levels. Recent studies have drawn attention to variability in the flavor and nutritional quality of the same varieties grown in different ecological zones.

PEARL MILLET. The relatively small number of countries in which pearl millet is an important food crop have some of the harshest environments in the crop-growing world. Pearl millet is thus usually grown by people who have few other sources of income. India, Pakistan, Sudan, and Zambia have released six pearl millet varieties derived from ICRISAT materials, and another fifteen are in either the advanced testing or the prerelease stage. It is estimated that such pearl millet varieties covered nearly 600,000 hectares in India in 1984. Varietal development work is actively in progress in Burkina Faso, Niger, Nigeria, and other countries in the semiarid tropics.

SORGHUM. Sorghum is another crop grown under often harsh environmental conditions by many poor people. Ethiopia released its first ICRISAT-derived sorghum variety in 1980 and since then has released three others. Burma released ICRISAT-related varieties in 1981 and 1982, and by 1984 the national authorities estimated that 23,000 out of 190,000 hectares were planted to these new varieties. Burkina Faso also has released several center-related varieties in recent years. It is estimated that by 1984 thirty-one sorghum varieties derived from the ICRISAT program had been released. Kenya was yield-testing forty lines and was multiplying seed for four varieties prior to their release. Many ICRISAT lines were being used in breeding programs in Guatemala, Kenya, Malawi, Mexico, and other countries in the early 1980s.

The national research program of Sudan, in collaboration with ICRISAT, had developed a promising hybrid sorghum by early 1983, and in 1984 Sudanese farmers planted 20 tons of the new hybrid. Under rainfed conditions the hybrid yielded an average 810 kilograms per hectare, compared with 270 kilograms per hectare from local varieties. During 1984 about 350 tons of seed were produced, enough to plant 125,000 hectares.

COWPEAS. By 1984 fourteen countries, beginning with Venezuela in 1979, had released twenty-nine varieties of IITA-related cowpeas. Of these, fourteen varieties were released by African countries. In 1983 Nigeria released two cowpea varieties derived from IITA materials. Both have found ready acceptance by many farmers. In 1984 about 9,000 farmers in the Kano Agricultural Development Project were profitably growing these cowpeas as their sole crop on about 4,000 hectares. Another 2,000 hectares were planted outside the project area (Okoro and Onuoka 1985).

Zimbabwe has evaluated a wide range of IITA cowpeas, and it selected promising varieties during experiment station tests in 1981–82. The cowpeas were subsequently grown in communal farming areas, where they achieved yields of 1 ton per hectare despite rainfall as low as 200 millimeters a year. Researchers in Cameroon also reported that the seeds of several new cowpea lines were being multiplied prior to being made available to farmers.

## The Effect of New Wheat and Rice Varieties on Yields

Modern semidwarf varieties of wheat and rice produce generally higher yields than traditional varieties both under experiment station conditions and on most of the millions of hectares on which they are grown. Under some conditions, however, they are clearly less productive than traditional varieties, and then farmers continue to grow the latter. Farmers who have adopted the new varieties apparently have done so because personal observation, and perhaps also the enthusiasm of extension agents, have led them to believe they are more productive than other varieties. The contribution of new varieties to food production depends on the extent of their yield advantage over traditional varieties. It is clear that they must have such an advantage, — since farmers would not grow them otherwise— but it is not clear exactly how large it is. This question is examined below.

### Wheat Grain Yields

Under experiment station conditions the first semidwarf wheat varieties had yields of 7–8 tons per hectare, as against 4 tons per hectare for traditionals. The potential yield of modern varieties has since gradually increased to 8–9 tons per hectare. The continued improvement is illustrated by the available data. During 1980–82 comparisons of the most advanced wheat lines (Veery) with the best "local checks," most of which were also semidwarf, showed that the Veery lines outyielded the best local varieties by about 10 percent on average and outyielded the best local check in 65 percent of the locations in developing countries where these experiments were conducted (CIMMYT 1984).

Few recent comparisons of the yields of semidwarf and traditional wheats grown in farmers' fields are available, but earlier research suggested that semidwarf wheat varieties produced yields between 30 and 200 percent larger than yields from traditional varieties. In the seven-year period during which the use of new varieties spread to more than 50 percent of India's wheat-growing regions, the new wheats produced yields "from less than two times to more than three times as high as traditional varieties" (Dalrymple 1975). Farm-level data from six large-scale studies in India showed that the average yields of new wheat varieties were 80 percent higher than yields from local varieties (Vyas 1975). An analysis of farm-level data from Tunisia showed that farmers who grew semidwarf varieties with an average level of inputs obtained yields that were 20 percent higher than those of farmers who grew traditional varieties and used the same average level of inputs (Gafsi 1976). Similar data for Turkey showed that the yields from the new varieties were 40 percent higher than the yields on farms that used other varieties (Demir 1976). These studies indicate that the absolute yield advantage of the new wheat varieties has ranged from 350 kilograms per hectare in Tunisia to 1,100 kilograms per hectare in India. An average difference of 500 kilograms per hectare between new and old varieties would seem to be a conservative estimate of the impact of varietal change.

### Rice Grain Yields

The yield advantage of modern varieties of rice has been estimated from data collected in the few developing countries that keep statistics on yields. Between 1968 and 1977 the average yield advantage of modern varieties was 100 percent in India, 160 percent in Bangladesh, and 30 percent in the Philippines and Indonesia (Barker and Herdt 1985). The differences between countries may in part reflect the fact that the new varieties were initially grown under relatively favorable conditions in India and Bangladesh; in the Philippines and Indonesia they were grown under a much broader range of conditions.

Farm-level comparisons of the yields from new and traditional varieties have been carried out in many Asian rice-growing countries. One review found that the yield advantage of modern varieties ranged from 10 to 158 percent (Dalrymple 1977). Another review of studies for twenty-eight rice-growing locations showed that the new varieties outyielded the traditional ones by 10–100 percent, with the average being 40 percent (Barker and Herdt 1985). On this basis 600 kilograms per hectare would be a conservative estimate of the average yield advantage of modern rices. Farm yields of rice include the inedible hulls, which account for about one-third of the grain. In terms of edible cereal grain the yield advantage is about 400 kilograms per hectare.

## The Value of Increased Wheat and Rice Production

The new varieties of wheat and rice are usually grown on good land and provided with suitable amounts of water and fertilizer because of their potential for higher yields under good growing conditions. Traditional varieties do not respond as well to such advantageous conditions. Farmers who grow modern varieties also pay more attention to weed control—by hand or with machines or herbicides, depending on labor supply and costs. But the common notion that modern varieties require more inputs than traditional varieties is incorrect. The new varieties respond well to greater attention, but they do not necessarily demand it. Even without more inputs the modern varieties usually produce somewhat greater yields.

Since additional inputs contribute to greater production, the increases in yields discussed earlier cannot be attributed to the use of new varieties alone. Without the gains available from a combination of new varieties and increased inputs there would be little reason to use more inputs. Thus it seems reasonable to attribute the value of additional production, minus the full costs of additional inputs, to the new varieties.

Determining the value of extra production minus the costs of extra inputs is not simple. There are essentially no precise data on the inputs specifically used for wheat and rice, and the prices of inputs differ in each country. A series of calculations can be used, however, to make a rough estimate of the net contribution of new wheat and rice varieties on the basis of the data in table 3-4. Annual production of wheat in all developing countries rose from an average 72 million tons in 1961–65 to an average 156 million tons in 1979–81, an increase of 84 million tons. Annual rice production increased 139 million tons over the same period. The prices of the two commodities declined by $25 and $45 a ton in 1983 constant dollar prices, but the combined value of wheat and rice output increased by $49.3 billion.

In 1961–65 wheat and rice were planted on 23 percent of the developing world's cropland (FAO 1976). The corresponding numbers for some later periods were 28.6 percent in 1969–71, 29.7 percent in 1974–76, and 30 percent in 1979–81. On the assumption that fertilizer, machinery, and other inputs were divided among wheat, rice, and other crops in the same proportion as was land, the table shows the estimated inputs used for wheat and rice. Given estimated prices of $500 a ton for fertilizer and $20,000 a unit for machinery (probably on the high side for these inputs in the developing countries), the value of modern inputs increased by $5.2 billion in 1969–71, $12.1 billion in 1974–76, and $19.9 billion in 1979–81 over the 1965 level.

The bottom line of table 3-4 is arrived at by subtracting the estimated value of the inputs from the value of output. The annual output of wheat and rice production for 1979–81 was worth approximately $50 billion more than that for 1960–65 and the annual costs of fertilizer and machinery were about $20 billion. Hence approximately $30 billion of the increase in

**Table 3-4. *Changes in Value and Inputs, Annual Wheat and Rice Production, All Developing Countries, 1961–65 to 1979–81***

| *Item* | *1961–65* | *1969–71* | *1974–76* | *1979–87* | *Change between 1961–65 and 1979–87* |
|---|---|---|---|---|---|
| Production (millions of tons) | | | | | |
| Wheat | 72 | 97 | 129 | 156 | 84 |
| Rice (paddy) | 232 | 286 | 322 | 371 | 139 |
| Prices (1983 dollars a ton) | | | | | |
| Wheat[a] | 177 | 169 | 219 | 152 | −25 |
| Rice[b] | 308 | 300 | 388 | 263 | −45 |
| Estimated inputs, wheat and rice production[c] | | | | | |
| Cropland (millions of hectares) | 169 | 212 | 228 | 235 | 66 |
| Labor (millions of workers) | 149 | 202 | 220 | 228 | 79 |
| Fertilizer (thousands of tons) | 1,800 | 3,720 | 6,700 | 10,260 | 8,460 |
| Machinery (thousands) | 207 | 418 | 691 | 992 | 785 |
| Draft animals (millions) | 195 | 260 | 290 | 305 | 110 |
| Value of output less value of machinery and fertilizer (billions of 1983 dollars) | 79.2 | 94.4 | 96.4 | 108.6 | 29.4 |
| Rise in value from 1965 (billions of 1983 dollars) | | | | | |
| Wheat and rice production | — | 20.4 | 28.8 | 49.3 | 49.3 |
| Fertilizer and machinery inputs[d] | — | 5.2 | 12.1 | 19.9 | 19.9 |

—Not applicable.

a. U.S. no 1 soft red winter, Gulf ports.

b. Thai 5 percent broken, Bangkok, converted to paddy equivalent.

c. Computed on the assumption that wheat and rice use the same proportion of all other inputs as of land.

d. Fertilizer is valued at $500 a ton, machinery at $20,000 each.

*Source:* Derived from FAO (various years). Wheat and rice prices are from World Bank data.

the value of annual output was attributable to the additional land, labor, irrigation, draft power, and other inputs used in production, as well as to the changes in technology brought about by research and extension. This method does not give separate values for the elements listed.

Another way to analyze the change is to ask what quantity of inputs would have been needed to produce the output of 1979–81 at the input-output ratio of 1961–65. Under that constant technology assumption the requirements would have been 293 million hectares of land instead of 235 million hectares, 256 million agricultural workers rather than 228 million, 3.13 million tons of fertilizer rather than 10.2 million tons, 552,000 machines rather than 992,000, and 522 million draft animals instead of an estimated 305 million. Thus traditional technology would have used much larger quantities of traditional inputs, while the new technology saved land, labor, and the land and feed inputs that would have been needed to sustain draft animals.

## Some Criticisms of the Centers' Breeding Strategies

It has been suggested that the early success of the first two centers (IRRI and CIMMYT) in raising wheat and rice production established a less than satisfactory environment for plant-breeding work by the centers that were created later. The argument is that IRRI and CIMMYT made a particularly strong public impact because wheat and rice, which are grown in large and relatively homogeneous areas, were the easiest crops to improve through plant-breeding techniques. Their successes, it is argued, led to the mistaken notion that through intensive plant-breeding work other centers could achieve similarly large improvements in the production of other subsistence crops, such as maize, beans, potatoes, cassava, and legumes. That is, the later centers were conceived in the belief that they could achieve scientific breakthroughs similar to those experienced for wheat and rice.

This error occurred, it is held, because of an initial failure to recognize that, apart from wheat and rice, the subsistence crops of the developing countries are grown under a huge range of ecological conditions. Improved varieties of these crops developed at specific places under conditions peculiar to each location would not be very successful in dissimilar ecological zones. In other words, breeding plans tailored to limited sets of circumstances would inevitably be wrong for most other places most of the time (Simmonds 1981).

It is also argued that those who concentrate on plant-breeding work at the centers have often not been sufficiently aware of actual conditions in the farmers' fields and that this lack of awareness has often led them down blind alleys. Maize grown in Latin America as a subsistence crop, for example, often serves as a physical support for beans grown as cash crops. Farmers then naturally want tall, strong, widely spaced maize plants rather than small, slim, closely spaced ones. Such realizations on the part of plant breeders, it is implied, are often slow in coming.

Another criticism of the centers that emphasize plant-breeding activities is that they have too often been influenced by how plant-breeding work is done in the industrial countries. There plant breeders naturally tend to search for new varieties that will do well under optimal conditions because most farmers in the industrial countries have adequate access to such inputs as fertilizer, water, pesticides, and advanced machinery.

What the centers have often forgotten, the argument continues, is that the developing countries need new varieties that are suitable for use by poor farmers who cannot afford the agricultural inputs used as a matter of course by farmers in the industrial countries. To correct this defect, the environments at the centers where plant-breeding work takes place should be more typical of environments in the developing countries.

A final criticism is that in breeding for disease resistance the centers in early days followed the usual approach in industrial countries and tended to breed for very high resistance to a pathogen on the basis of a single gene (vertical resistance) rather than for a broader resistance conferred by multiple genes (horizontal resistance). Proponents of the latter approach (which to date remains a goal rather than a proven alternative) argue that although vertical resistance is often successful, after several years the pathogen may overcome the resistance and the plant may become subject to attacks of epidemic proportions. Achievement of horizontal resistance would mean some reduction in annual yields in developing countries, but it would lessen the risk of the massive crop losses that occur once a plant's vertical resistance is overcome (Simmonds 1983).

Most fairminded observers of the system would agree that there is some substance to these criticisms. They would probably also agree, however, that where these points apply, they have been taken seriously by center staffs, boards, and managements and that research programs have been adjusted to deal with the underlying problems. Considerable evidence in this direction is found in the regular reports of the centers on their work and in subsequent chapters of this book.

## Notes

1. Most of the material presented in the rest of this chapter was assembled by Robert W. Herdt with the assistance of Narendra Rustagi.

2. Much of the information in this section is based on Dalrymple (1985, 1986a, 1986b). Dalrymple 1986a and 1986b are updated versions, made specifically for this study, of a series on these subjects that began in 1969. USAID supported and published the 1986 studies as contributions to this project. In some cases material from the country studies done for this project was also used.

# 4 New Farming Methods

Chapter 3 discussed the work of the centers and the national systems in breeding improved varieties of food crops. That work has led to widespread adoption by farmers of modern varieties which, particularly in the cases of rice and wheat, have brought about substantial increases in the production of staple foods in many areas.

From the beginning the centers emphasized the breeding of improved food crop varieties because of the consensus within the scientific community that this was the most effective way to raise food production. But it was also recognized that modern varieties in themselves were only part of the answer and that to prove their worth they would have to be accompanied by better farming methods. The centers and the national systems therefore provided "packages of advice" on how to grow the new seed varieties: what soil conditions were necessary, when to plant, how much and what kind of fertilizer to use, what to do about pests, and so on. Farmers were encouraged to adopt these practices by extension agents or were offered the opportunity to participate in large-scale production programs that included subsidies for such inputs as fertilizer.

Farmers seldom adopted packaged methods in their entirety—from their viewpoint not all of the advice was valid. But the basic approach was sound, and the centers have continued their efforts to improve farming in the developing countries through the use of technological innovations as well as through modern crop varieties.

As in the development of high-yielding crop varieties, in their work on farm technologies the centers collaborate closely with the staffs of the national research systems. The centers and the national systems carry on joint research projects, as do national systems among themselves. Regional networks of researchers transmit information on new farm technologies from country to country. Staff members from the centers are often dispatched to other countries to take part in problem-solving and institution-building projects. The collaborative process has intensified as it has become ever clearer that very difficult agricultural problems are still prevalent in much of the developing world. A few examples are adverse soil and weather conditions, the reluctance of farmers to adopt new methods (especially when there is little incentive to abandon traditional ways), lack of investment capital, the high costs of imported agricultural machinery, and fragmented land ownership.

This chapter discusses a number of technological efforts, ranging from the specific—for example, work on methods for storing potatoes—to the more general, such as farming systems research (FSR). It proved much harder to evaluate the impact of the innovations discussed in this chapter than to assess the effects of high-yielding crop varieties. Quantitative data on the spread and impact of the methods discussed here are rare, and it is often difficult to determine precisely how the centers and the national systems have interacted. No attempt has been made, therefore, to estimate the aggregate effect of these innovations.[1]

## Innovations in Farming Methods

### *Deep Vertisol Technology*

ICRISAT has developed an almost completely new set of methods for cultivating deep vertisols (black clay soils more than 45 centimeters deep) in the wetter areas of semiarid India. These soils, which cover some 6 million hectares, are too sticky to be worked in the wet season and too hard when dry. As a result they are generally used for only a single crop grown on the residual moisture left after the rains.

The technology known as the broadbed and furrow (BBF) system permits the growth of a rainy-season crop in addition to the post–rainy season (rabi) crop. Its components are (a) field cultivation after the harvesting of the post–rainy season crop, (b) land leveling and shaping, construction of field and community drains, and the use of graded broadbeds and furrows, (c) dry-seeding before the monsoon, (d) the use of modern cultivars and moderate amounts of fertilizer, (e) improved placement of seeds and fertilizer, and (f) timely plant protection. A bullock-drawn wheeled tool carrier is used for most of these steps.

ICRISAT staff compared the use of these techniques with traditional methods on four sites in three states of India in 1982–83. The new techniques cost about $70 more per hectare than the traditional technology, and the average increase in profits was about $140 per hectare (Walker 1984). ICRISAT then compared the costs and returns of the new practices and of local practices when used by farmers themselves on about 50 hectares in Maharashtra State. The average increase in costs with the new techniques was $145 per hectare, while profits increased about $50 per hectare, suggesting somewhat less of an advantage than in the tests conducted by ICRISAT staff. The latter data may be taken as a conservative estimate of the immediate financial impact of the technology.

The Indian farmers who tested the new techniques encountered some problems. Their bullocks found it difficult to pull the heavy toolbar used for leveling and shaping the land. Furthermore, not all of the farmers had equal access to bullocks or to the credit they needed to buy the toolbar. (The new techniques deliberately omitted the use of a weedicide to avoid displacing the work of the women who traditionally do the weeding.)

In surveys taken at the on-farm verification sites some farmers indicated that they would continue to use the new techniques. The new practices appear to have been most widely adopted in Karnataka State and are expected to spread further in Karnataka, Madhya Pradesh, and Maharashtra states as a watershed development project is implemented. Observers in India estimated in 1983 that this new way of cultivating deep vertisols was being used on about 4,000 hectares of semiarid rainfed land, mainly on farms controlled by state governments. Assuming an increase in profits of $50 per hectare, the increase in net profits would be more than $200,000. The total area in India for which the technology seems well suited is estimated at 5 million hectares. Increased productivity valued at $125 million annually would therefore be forthcoming if the technology were adopted on just half that area.

### *The Storage of Seed Potatoes in Diffused Light*

It has long been known that storing seed potatoes in natural diffused light instead of in complete darkness reduces sprout elongation, increases the numbers of sprouts, reduces storage losses, and allows a longer storage period. Yields increase because the potatoes retain seeding vigor and more of them are available for planting. Farmers also have greater flexibility in deciding when to plant their potato crop, and they can thus try to time the harvest for when prices are high.

The diffused-light technique, promoted by CIP, is used extensively by farmers in Colombia, Peru, the Philippines, Sri Lanka, and elsewhere. Surveys by CIP identified about 3,000 farmers in these countries who were using diffused-light storage in 1984, but that is believed to be a considerable underestimate. The natural spread of this technology from farmer to farmer has been rapid in at least sixteen countries, and the technique is being used widely by government agencies to improve their seed production programs.

On-farm trials in the Peruvian highlands showed that the use of seed potatoes stored in diffused light raised yields from 8 to 20 percent. Trials in Colombia and the Philippines produced similar results. A trial on the Peruvian coast showed a yield increase of 57 percent, and one in Sri Lanka led to increases of 80–130 percent.

On average, small-scale farmers in these countries plant 2 tons of seed potatoes per hectare. A 20 percent rise in yields from, say, 10.5 tons per hectare means that output increases to 12.6 tons per hectare. Adoption of this technique on 10 percent of the potato areas in the countries where CIP is promoting this technology, using the same assumptions of a base yield of 10.5 tons per hectare and a 20 percent increase, would result in more than 1 million additional tons of potatoes and an added value of about $100 million.

### *Improvements in Seed Potatoes*

CIP and a number of national research systems are carrying out collaborative programs to improve seed potatoes. In Tunisia, for example, the following procedure was developed to improve the quality of seed potatoes sown in the late crop: (a) imported seed potatoes were desprouted and then planted as soon as possible in the early season; (b) the seed potato crop was harvested early, and unhealthy tubers were eliminated before storage; and (c) the locally produced seed tubers were desprouted before being planted in the late season. Seed potato production increased from 64 tons in 1977 to 680 tons in 1980 and to 880 tons in 1983. The higher-quality seed potatoes produced more main stems per plant, which doubled the yields per hectare in on-farm trials of the late-season crop. An analysis of the program's costs and benefits was conducted by CIP on the basis of data from the national unit responsible for seed production. The analysis showed that during the early 1980s the annual net benefit of this small program was about $250,000.

Researchers in Rwanda's national program also use simple techniques to supply farmers with better seed potatoes. Their system consists primarily of field observation of plant vigor and of the proportions of healthy and diseased plants and selection of seed potatoes from the best fields. The seed potato program now produces about 250 tons of seed a year, of which about 200 tons are distributed to seed multiplication projects throughout the country. About 50 percent of the seed potatoes consists of new Rwandan varieties selected from genetic materials assembled at CIP. The production of improved seed in Rwanda has been significantly less than the demand for it. Reports from seed projects and preliminary surveys indicate that in 1984 about 7,000 hectares (18 percent of Rwanda's total potato area) were planted with seed from the national seed program. The average increase in yields attributable to the use of improved seed is estimated at about 3 tons per hectare, a 40 percent increase over yields from traditional seed.

### *Cassava-Drying Technology*

CIAT has joined Colombian farmers to develop techniques for drying cassava chips for animal feed. Cassava roots are chipped by a power chipper modified from a machine used for the same purpose in Thailand. The cassava chips are then spread on a flat concrete surface to dry in the sun for two to three days. They must be turned six or eight times a day to ensure uniform drying. Drying ceases when the moisture content of the chips is about 14 percent.

This process was introduced in 1980 on the northern coast of Colombia, where the land is dry and infertile, and only cassava and a few other crops grow well. CIAT worked with a small producers' cooperative which was also receiving assistance from an integrated rural development program. By 1982 the cooperative was operating on a semicommercial basis, and it sold its entire production of 39 tons to a feed company in Cartagena. In 1983 its output was 270 tons. Seven plants were in operation by 1984, and twenty other plants were being established. The government hoped to establish 200 by the end of 1988.

### *Managing Cassava Production*

The Cubans have extensively adapted the Colombian system of cassava production to conditions in Cuba, using methods learned at CIAT. Having selected the best local varieties, they taught agronomists from the state agricultural enterprises the new management methods, which include (a) good soil preparation, with construction of ridges taller than those used for sugarcane, (b) selection and treatment of 30-centimeter stakes from the basal part of mature plants to reduce the problem of cassava bacterial blight, (c) vertical planting on top of the ridges, (d) timely weed control, and (e) reduced irrigation. (Before the training Cuban farmers had planted short stakes horizontally on the bottoms of small ridges and had irrigated heavily.)

Cuban cassava production increased from 24 kilotons in 1974–76 to 330 kilotons in 1981–83. CIAT estimated that 10,000 of the 50,000 hectares in cassava used the Colombian system. According to the Cuban minister of agriculture, yields on the state farms increased from 7 to 20 tons per hectare. If the area on which the new methods are used included at least 10,000 hectares of state farm lands, the increase in output was 130 kilotons of cassava, valued at about $4 million.

### *Land Clearing and Management*

One way in which food production has been increased in the humid and subhumid tropics has been to clear forested land and bring it under cultivation. But if such projects are not carefully planned and executed, the lush tropical forests are soon succeeded not by productive farms but by barren land. This degradation occurs because organic matter in tropical forests breaks down rapidly rather than being stored in the soil. The topsoil layer is thin, often infertile, and easily exhausted. IITA scientists, after investigating methods of clearing tropical forests and the effects of clearing on subsequent crop production, concluded that if land clearing is unavoidable, it should be done in a way that minimizes soil disturbance, since soil that is disturbed and then exposed to tropical rains is vulnerable to erosion. Thus the use of heavy machinery should be avoided, and any mechanized clearing operation should take care not to remove litter, roots, or stumps, scrape off topsoil, compact the subsoil, or drag trees or stumps over long distances. After clearing is completed, mulch should be kept on the soil surface and mechanical tilling should be kept to an absolute minimum. These recommendations have been adopted by the Sumatra-Indonesia Transmigration Scheme, by World Bank–funded agricultural development projects in Cameroon, Côte d'Ivoire, and Nigeria, and by land development projects in Peru and Thailand.

## Mechanization

The results of recent agricultural engineering research and development at IRRI, IITA, ICRISAT, ICARDA, WARDA, CIMMYT, ILCA, and CIAT are sketched below. Engineering is not part of the programs of the other centers, except that CIP conducts some work on the storage and processing of potatoes.

### *Agricultural Engineering at IRRI*

IRRI is unique among the centers in that it has a strong and distinct agricultural engineering department with a staff that during 1970–85 included four agricultural engineers, one senior economist, and a number of associate and junior members. The department identifies problems in rice cultivation which might be solved by the introduction of new mechanical technology or by better use of existing technology. Equipment developed at IRRI has been tested on farms in many developing countries.

IRRI's courses in agricultural engineering have been attended by researchers from national systems, workers in extension programs, and representatives of manufacturers of agricultural machinery. This industrial extension program in Southeast Asia is strongly supported by USAID and the Canadian International Development Agency (CIDA). In addition, IRRI has supplied equipment, drawings, and specifications to research and extension agencies in many African and Latin American countries.

IRRI's agricultural engineering work began in 1962 with the evaluation of tractors and other agricultural machines produced in the West and the study of the mechanization needs of rice farmers in the Philippines. By 1967 the department had begun to develop machinery that was more appropriate to small rice farms than the equipment designed and built for farms in industrial countries. A wide range of machines has been investigated, and some have achieved commercial success, the most noteworthy being hand tractors, threshers, and power weeders.

LIGHTWEIGHT HAND TRACTORS (POWER TILLERS). The first important machine developed at IRRI was an imported lightweight power tiller that was modified so that it could be manufactured in small local workshops. The first models were released in the Philippines in 1972 and were rapidly adopted both by small companies and by larger manufacturers, using mass production methods. Local manufacture of the IRRI power tiller had a catalytic effect, and a number of manufacturers produced their own variants, some simpler and some more complex than the IRRI design. Monge (1980) states that only 24 percent of the 1,400 power tillers sold in the Philippines before the mid-1970s were manufactured locally. By 1978, however, 70 percent of the 9,300 power tillers sold in the Philippines were produced there.

Local manufacturers who agree to collaborate with IRRI must submit prototypes to the center for testing, tell IRRI how many machines they make annually, and refrain from patenting modifications of their equipment. Because of these conditions some manufacturers do not formally acknowledge collaboration with IRRI. Collaborators made more than 40 percent of the power tillers manufactured in the Philippines in 1975 and 1976 but by 1978 the figure had fallen to 12 percent. In 1981 the collaborators made 1,100 power tillers, but in 1982, when an improved version was introduced, they produced 2,300 units. The jump implies that collaboration with IRRI is valued most highly when a new machine is introduced. Thus the number of acknowledged IRRI-designed hand tractors produced in the Philippines understates the center's impact.

After its adoption in the Philippines the IRRI power tiller was introduced in Thailand, where several manufacturers adopted the design. Despite some initial success the manufacturers eventually decided that the design was not entirely suitable for conditions there and developed alternative models. Some 20,000 of these machines were manufactured in Thailand in 1983.

The Bangladesh Machine Tool Factory manufactured approximately 200 hand tractors to an IRRI design in 1982. Few of the machines were sold, however, because they turned out to be unreliable and because farmers in Bangladesh prefer a hand tractor with a powered rotary cultivator. Subsequent work by an IRRI consultant solved the immediate problem, but production has not been resumed.

IRRI-type power tillers have been made in India by the National Engineering Company of Madras for about five years. Production is believed to be 2,300 a year. A few IRRI hand tractors have been introduced in Belize, Cameroon, Liberia, Nigeria, Sierra Leone, and Tanzania, but there is no record of commercial manufacture.

Although the chassis design for the IRRI hand tractor has been accepted in many countries, nearly every country reported that the wheels were unsuitable for local conditions and that redesign had been necessary.

Typically such redesign was carried out in an ad hoc manner.

AXIAL FLOW THRESHER. The axial flow thresher was developed at IRRI during 1967–72 to meet the need for a mobile lightweight thresher as an alternative to labor-intensive manual methods or to the large and capital-intensive McCormick thresher. The IRRI thresher has been outstandingly successful in the Philippines, where more than 25,000 have been sold. Since none of its parts require a good surface finish for oil seals, and since the machine has few precise critical dimensions, it is well suited to production in small workshops.

In the Philippines the machine is especially attractive because it pays for itself in a short time. The payment for use of the machine for threshing and cleaning is a share of the crop. A similar practice applies in Sumatra, where the machine was recently introduced.

Where farmers traditionally pay wages to labor for manual threshing and cleaning, a comparable cash rate is usually charged for machine threshing. But since machine threshing takes substantially less time than hand threshing, it reduces the farmer's threshing costs by approximately 20 percent. In addition, the farmer (but not the traditional gleaners) may also benefit because the thresher reduces crop losses. This savings has been estimated at 40 kilograms per hectare by Toquero and others (1977) and at 290 kilograms per hectare by the IRRI experiment station.

The IRRI thresher was introduced in Sri Lanka in 1980 by the National Research Station at Maha Iluppallama. Two manufacturing companies were interested in the machine and spent the next two years modifying it to make it more suitable to conditions in Sri Lanka. There many farmers thresh by spreading the crop on a threshing floor and rolling a wheeled tractor over it. In 1983 unseasonable rain made threshing by this method difficult and subject to heavy losses. This led to a sudden demand for axial flow threshers, and approximately 800 were sold in 1983–84. The machines threshed about one-third of the crop in the southwestern zone, which was most seriously affected by the wet conditions. Many operators also migrated with their machines to thresh the slightly later harvest in the intermediate wet zone. There are no accurate records of the amount threshed, but reports indicate that the average was 30 hectares per machine per season, or roughly 120 tons per season. Since about 500 machines were in use over the two critical seasons, it is likely that the machines threshed more than 100,000 tons of rice and that their use under the adverse weather conditions saved perhaps 10,000 tons or more.

The IRRI-type thresher and its local derivatives are widely used in Thailand, which had about 20,000 threshers in the mid-1980s, many of them modified for other crops as well. In Indonesia the introduction of the axial flow thresher has had a particularly significant impact in West Java and West Sumatra. In Pakistan the IRRI thresher has been superseded by a larger multicrop thresher developed under the IRRI-Pakistan program. More than 1,000 of these machines have been sold, but many farmers consider it unsuitable for wheat because it does not shred straw for animal feed (*bhusa*). The IRRI thresher has not been adopted in Bangladesh, where manual and animal-based methods are still dominant.

Data on the proportion of all threshing done by IRRI-type machines are not available, but estimates are, for instance, at about 23 percent in the Philippines and 17 percent in Thailand.

MULTIROW TRANSPLANTER. For many years IRRI has been working on a manual rice transplanter to be used in combination with a regime that includes the preparation of plant beds, production of nursery plants of standard size in a suitable medium, and control of water levels. The first transplanters were very sensitive to variations in planting conditions; more recent models are less sensitive.

One of the few areas where the device has been successfully adopted is Libmanan, Camarines Sur, Philippines. There an irrigators' association bought a number of the machines after seeing a demonstration. The equipment has been used for several seasons, and demand is growing. In Burma the transplanter has not won acceptance, apparently because the machines failed to work correctly. Two machinery companies in Sri Lanka have conducted trials of modified versions of the transplanter and plan to start production when conditions are favorable. Adoption of the transplanter requires substantial extension work, since it is a markedly different way of doing things and does not produce dramatically more profitable results.

INDUSTRIAL EXTENSION. IRRI is a source of agricultural engineering information for other research stations in Asia. In Pakistan the establishment of the IRRI-Pakistan agricultural machinery program led directly to the establishment of the Agricultural Machinery Research Programme of the Pakistan Agricultural Research Council and to the founding of the Pakistan Society of Agricultural Engineers. The transfer of technologies to other countries through IRRI's extension programs for agricultural machinery has had modest effects, as indicated by the cases cited above and by experience with axial flow pumps, rice driers, and rotary power weeders.

### *Agricultural Engineering at IITA*

In the late 1960s the agricultural engineering section at IITA tackled a wide range of problems. The most striking developments have involved tillage and harvesting.

MINIMUM TILLAGE CROPPING. Minimum tillage involves the use of live and dead mulches and of alley or avenue cropping. Such techniques work better for maintaining or improving soil structure, fertility, and moisture than do conventional tillage practices, but they require large financial investments, and adoption has been slow.

To facilitate the use of mulches it was necessary to design equipment that could plant through mulch. An early American "walking stick" planter was modified to become the IITA hand-held jab planter, which was later fitted with an automatic feed. Drawings of the improved version were made freely available in 1976, but there is no evidence that it has been widely adopted. This reflects in part the limited use of mulches as such on West African farms.

The principle of the rolling injection planter (RIP) was brought to IITA by a Volunteer in Technical Assistance (VITA) worker, the late George Banbury, in 1977. The machine was then developed and simplified by IITA engineers. It is clearly the simplest and most effective means of planting through mulch or surface trash, and it can be used for maize, rice, wheat, sorghum, or cowpeas. Designs and prototypes have been widely distributed in Africa and have been evaluated by IRRI for Asian conditions. It is estimated that approximately 3,500 single-row RIP units have been produced in Nigeria.

Samples or drawings of the planter have also been supplied to other international centers, and multirow versions have been produced, including two-, three-, and four-row versions for hand operation and three-to-six-row versions pulled by animals or hand tractors. Prototypes of larger units pulled by four-wheeled tractors are being tried. Whether the multirow version has been successful is not known, since nearly all were produced to fill a single government order for 350 four-row machines and there have been no further sales.

The Technology Consultancy Centre of the University of Science and Technology in Kumasi, Ghana, became interested in the rolling injection planter in 1977. Realizing that prolonged and effective demonstrations would be needed to persuade farmers of the value of the planter, the center established a special farm for demonstrating the machine and for training farmers in its use. The center also published a handbook on no-till planting. Meanwhile Kenya's Ministry of Agriculture has sponsored the production of several thousand planters.

Adoption of the rolling injection planter has been held back by its poor quality. Feedback from users indicates that the seed-metering device needs to be improved and that some way should be found to reduce the amount of effort required to push the machine. Successful use of the planter in a no-till situation also requires herbicides to control weeds. This information does not appear to have been passed on to users very effectively.

CASSAVA-HARVESTING MACHINERY. In the late 1970s agricultural engineers at IITA tested three proprietary cassava lifters operated by tractor and a root-loosening device for cassava that had been designed at CIAT. The trials indicated that two of the proprietary implements were inherently unsound, that the third had some mechanical defects, and that considerable effort was needed to operate the CIAT device. The work was well conducted but did not lead to any resolution of the problems that were identified.

A lightweight, simple, low-cost aid for hand-pulling cassava tubers was developed in 1978, and one company made 300 units. The tool is apparently being used on several large cassava farms in Nigeria. Some transfer of information has led to the manufacture of similar devices in Thailand, but it has not been possible to ascertain to what extent the tool has been adopted there.

### *Agricultural Engineering at ICRISAT*

ICRISAT's farm power equipment subprogram has emphasized the development and improvement of equipment used with the broadbed and furrow system—for example, animal-drawn wheeled tool carriers and implements for cultivating, seeding, fertilizing, and weeding. This associated equipment may be used with equal ease on flat land or on ridges. Wheeled tool carriers of the type sponsored by ICRISAT are being tried in Mali, Niger, and other countries.

ICRISAT has also been concerned with the threshing, drying, and storage of cereal grains. Projects to investigate machinery and cultivation systems as components of improved crop production packages for local agriculture are well formulated, but significant results cannot yet be measured.

### *Agricultural Engineering at Other Centers*

In 1983–84 ICARDA engaged a mechanical engineer to help develop a lentil harvester under a German technical aid program. At the same time ICARDA collaborated with the Syrian Ministry of Agriculture to offer training courses in the mechanical harvesting of cereals and legumes and the mechanical planting of field crops. A survey and economic analysis of food legume crops showed a need for better weed control and for mechanization of harvesting (the present high cost of which is a major constraint on increased production of lentils) and found that soil degradation is a major problem. Mechanization work is also being done on the precision planting of chickpeas and faba beans (broad beans) and the threshing of medics (leguminous pasture herbs) and dry faba beans.

Trials of 6-horsepower hand tractors at WARDA's Mangrove Swamp Rice Station over a three-year period indicated that plowing by hand tractor can provide good weed control and is economical if undertaken at the right time. Only a very light tractor can be used, since it is necessary to transport the tractors in small boats. Arrangements have been made for small groups of farmers in Sierra Leone to share the use and costs of a tractor and plow.

ILCA is concerned with improving the efficiency of draft animals, including crossbreeds. Studies on matching implements to pairs of animals and on alternative harnessing to permit the use of single animals instead of teams are too recent to have had any effect. Work to improve the ancient plow and make it more suitable for use with single animals is likely to be directly useful in the local area. With ILCA's help Ethiopia has started to promote the use of ox-drawn scoops to build small-scale water storage areas.

Research on agricultural mechanization is controversial because of concerns about displacing rural labor and because some think this work should be left to the private sector. It is a diminishing activity, but one that has had some significant and successful effects.

## Crop Protection

The centers have made resistance breeding the keystone of their approach to plant protection. This has permitted the distribution of modern varieties as a self-contained "technology package" without the need for accompanying pest control methods and materials. But in the past decade there have been significant developments in several areas other than plant breeding that may also contribute to crop protection.

### *Components of Contemporary Crop Protection*

Agronomists and plant pathologists have come to recognize that there is rarely a single solution to the problem of crop protection. Increasing emphasis is being placed on "mixing and matching" crop protection strategies to address such issues as pest variability and the response of plants to the environment. Contemporary crop protection includes the following approaches.

RESISTANCE BREEDING. Efforts by the centers to breed new varieties that are more resistant to pests have often been successful. But in other cases (probably a minority) genetic variation in the pest population has broken down a plant variety's resistance. This "boom and bust" cycle has led to a search for better ways to protect crops from pests.

DURABLE RESISTANCE BREEDING. Considerable research has been devoted to the definition and possible application of a postulated durable, or horizontal, resistance to pests. Most professional opinion, however, still regards durable resistance as only a theoretical construct. Its existence has yet to be convincingly demonstrated, although there is some evidence for such resistance in rice and wheat.

BIOLOGICAL CONTROL. Most research into biological control has focused on insect pests. Limited research efforts in North America, Europe, India, and Australia have led to the production of biological controls for commercial use.

CHEMICAL CONTROL. Chemical herbicides, fungicides, nematocides, and insecticides have proved to be effective in controlling plant and animal pests, at least in the short run. The centers have paid little attention to chemical controls except where such controls directly affect their work (an example is the sensitivity of improved cultivars to herbicides).

CULTURAL CONTROL. There is renewed interest in how land cultivation practices can be altered to improve crop protection. Improved practices include crop rotation, the use of green mulches to control weeds and soil fungi, and management of water levels to control soilborne plant pathogens.

INTEGRATED CONTROL. Some pest control procedures are complementary. For example, various forms of resistance bred into potato plants complement each other, making it possible to control late blight while using smaller amounts of fungicide than were needed in the past.

INTEGRATED PEST MANAGEMENT (IPM). IPM researchers are trying to get a more comprehensive view of the system of pests that afflicts a particular crop. Most are entomologists who hope to find combinations of insect controls that will reduce the amount of insecticides needed.

PEST SURVEILLANCE. Pest surveillance and monitoring provide much information that is useful for crop protection. A well-known example is USDA's surveillance program for North American wheat rust.

PEST FORECASTING. Patterns disclosed by pest surveillance, weather monitoring, and the like sometimes make it possible to forecast pest infestations. But so far efforts to predict outbreaks of pests have been much less successful in tropical than in temperate regions.

ECONOMIC THRESHOLDS. The economic threshold is the point at which pest damage has serious economic consequences at the farm level. Thresholds are being defined for a number of important crop pests. Knowledge about the economic consequences of insect infestations far outdistances knowledge about the effects of other pests.

POPULATION DYNAMICS. A thorough understanding of the population dynamics of insects and of the epidemiology of plant diseases is crucial to designing crop protection systems. Significant advances have been made in some aspects of these subjects, but much of this information awaits application.

CROP LOSS ASSESSMENT. Crop loss assessment is the attempt to determine the economic loss caused by pests at the regional level. Originally it was thought that assessments could be made by merely aggregating losses at the farm level, but this is no longer believed to be the case.

BIOTECHNOLOGY. Biotechnology, a rapidly emerging field of research and development, may make it possible genetically to engineer crops that are better protected from pest attack. How this new technology will interface with crop protection remains to be seen.

### *The Centers' Contributions to Plant Protection*

The semidwarf wheat varieties produced by CIMMYT were designed from the start to carry resistance to stripe rust, stem rust, and leaf rust, the major diseases of wheat. This resistance was developed by selecting successive generations of the wheat varieties after they were exposed to pathogens at different locations. When the success of the first modern wheats in Mexico inspired interest elsewhere, sites in India, Kenya, and Turkey were used for screening experiments to broaden the range of resistance. Most of the semidwarfs grown today carry disease resistance inherited from those early lines.

IRRI's first semidwarf rice variety, IR8, was notorious for its susceptibility to insect and disease pests. Staff members were aware of this and, even as IR8 was being distributed by the Philippine government, were conducting an intensive breeding program to protect modern rices against tungro virus, its vector the green leafhopper, bacterial blight, and other pests (Chandler 1982). As a result, IR20 was ready when an outbreak of tungro virus swept the Philippines and forced most farmers to abandon IR8.

Subsequent attacks by pests made it necessary for IRRI researchers to develop varieties with a broader range of resistance. The researchers were unable to deal with pests not native to the Philippines, such as gall midge, but that problem and others were addressed by researchers in India. These efforts were directed at incorporating significant single-gene resistance into rice, in contrast to what is now called durable resistance. Nonetheless, the resistance of new rice varieties to most rice pests has been rather durable, the main exception being resistance to the brown plant hopper.

Breeders working on other crops at other centers have followed similar strategies (see table 4-1 and box 4-1). Since the area planted to varieties of other crops is much less than the area in wheat and rice, the impact has been smaller.

The global mandates of the centers have prevented them from trying to deal with every single factor that causes stress to wheat and rice. Some problems are less severe under certain conditions. For example, semidwarf rices grown under flooded conditions are seldom significantly attacked by rice blast, whereas similar varieties grown on uplands are highly susceptible.

### *Criticism of the Centers' Contributions to Plant Protection*

Some observers have commented that the centers' research on plant protection methods other than pest resistance is limited. Much criticism of the centers' crop protection research refers to "sins of omission"—too little effort toward developing better cultural and biological controls, too little attention to the assessment of crop loss and to surveillance methods, and a general neglect of the problems caused by rats and birds. Another complaint is that the centers have failed to pursue marginal but nonetheless measurable increases in crop production by devising ways to control minor pests on major crops and major pests on minor crops.

**Table 4-1. *The Farm-Level Impact of Center Plant Protection Research***

| Strategy | Rice | Wheat | Maize | Sorghum | Pearl millet | Potatoes | Cassava | Sweet potatoes | Cow-peas | Chick-peas | Beans |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Resistance breeding | **** | **** | *** | *** | *** | * | ** | ** | * | ** | **** |
| Biological control | (.) | (.) | (.) | (.) | (.) | * | *** | (.) | (.) | (.) | (.) |
| Chemical control | *** | (.) | (.) | * | * | * | * | (.) | (.) | * | * |
| Cultural control | (.) | (.) | (.) | (.) | (.) | (.) | * | (.) | (.) | (.) | (.) |
| Integrated control | * | * | (.) | (.) | (.) | * | (.) | (.) | (.) | (.) | (.) |
| Integrated pest management | ** | * | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Pest surveillance | ** | ** | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Pest surveys | ** | * | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Pest monitoring | ** | * | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Pest forecasting | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Economic thresholds | ** | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Population dynamics | * | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Crop loss assessment | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) | * |
| Biotechnology | (.) | (.) | (.) | (.) | (.) | * | (.) | (.) | (.) | (.) | (.) |

**** Large visible impact at the farm level.
***, **, * Descending sizes of impacts.
(.) No visible impact at the farm level.

**Box 4-1. *Controlling Cassava Pests***

Cassava green spider mites were first reported in Uganda in 1971, and the cassava mealybug was identified by an IITA research team in Zaire in 1973. It is believed that these pests were introduced accidentally from Latin America. They are now found in more than 60 percent of the cassava-growing areas of Africa, from Mozambique on the east coast, through Zaire and the Central African Republic, to Senegal and Guinea-Bissau on the west coast. It has been estimated that these two pests cause economic losses of nearly $2 billion a year in Africa.

IITA's conventional breeding program has identified genetic sources of resistance to the two pests that are being incorporated into cassava lines. Meanwhile, natural enemies from the pests' area of origin are being introduced to reduce pest populations to tolerable levels. One such natural enemy is the wasp *Epidinocarsis (Apoanagyrus) lopezi,* which parasitizes the cassava mealybug. Between November 1981 and the end of 1984 approximately 50,000 wasps were released in ten African countries—Congo, The Gambia, Ghana, Guinea-Bissau, Nigeria, Rwanda, Senegal, Togo, Zaire, and Zambia—and the species has been reported as established in eight of these countries. (The wasp is considered established if it survives the rainy season, when the mealybug population is low.) A significant reduction in the number of mealybugs has been observed in every zone colonized by *E. lopezi.* The mealybug now reaches peak population densities of only ten to twenty per terminal cassava shoot, compared with a peak population of more than 1,500 per shoot before the introduction of the wasp.

Despite the considerable emphasis on resistance breeding, some critics have charged that the centers produce improved cultivars with little natural resistance, which leads to a general increase in the use of chemicals (especially herbicides) for plant protection. It is noted that pesticide use has increased faster in developing than in industrial countries (the application of pesticides per hectare, however, is far lower in the developing countries). Other critics have accused the centers of neglecting to study chemical controls.

Finally, the centers have been criticized for failing to develop effective methods of distributing knowledge about crop protection to farmers in the developing world and for having had little discernible impact on crop protection at the farm level. Pointing to the USDA's Cooperative Extension Network, critics ask why the centers have not developed a similar network. Some charge the centers with having failed to build a "knowledge synthesis" that would lead to the practical application of discoveries in crop protection. Such objections may fail to take proper account of the centers' collaborative methods.

### *Opportunities for Increased Activity*

Many of the centers were created to investigate one or a few food crops in multidisciplinary fashion. The focus on commodities exacts a price: that is, concentration on some problems to the detriment of other areas. The importance given to plant breeding at the centers often results in a strong emphasis on breeding for resistance at the expense of other crop protection strategies. The centers should ensure that all aspects of crop protection will eventually be studied. Meanwhile, however, the long-standing emphasis on breeding for resistance offers an opportunity for more basic research on, among other things, the genetics of durable resistance. There is a need to define, to identify, and to develop methods for applying this form of resistance, and the centers are the logical choice for conducting such research.

Although research on plant epidemiology and the population dynamics of pests has made significant advances in temperate environments, tropical epidemiology lags far behind. There are fundamental differences between epidemics interrupted by seasonal crop cycles and epidemics in a continuous crop cycle. Effective monitoring, as exemplified by the FAO Intercountry Integrated Pest Control Program, which works closely with IRRI, is important (Kenmore and Mochida 1984).

More extensive evaluation of pesticides is another task that should be undertaken by the centers. Leaving this important research entirely to pesticide corporations and hard-pressed national programs does not seem wise.

The effects of pest stresses on production also need further study. This information would be useful for research planning as well as for crop forecasting. International nursery testing programs could provide the information needed to begin this important research activity, which should be conducted in such a way that national participants understand the importance of data collection and can see how they might reap long-run benefits.

It is generally believed that increasing the resistance of cultivars would make it possible to decrease the use of pesticides. Although this proposition seems reasonable and the objective noble, some authorities speculate that such a strategy will have only a marginal effect on yields. Increased dependence on pesticides may be an inevitable consequence of tomorrow's food production systems in developing countries, just as it is in industrial countries today. That likelihood should be recognized, even though in many parts of the industrial world efforts to limit the use of pesticides are being made. Clearly economic considerations are involved in such research, in addition to the biological and ecological matters that are the focus here (see, for example, Herdt, Castillo, and Jayasuriya 1984). Meanwhile, research into naturally derived pesticides, which may be more ecologically acceptable and less hazardous to health, should not be ignored and indeed is being pursued vigorously (for instance, at IRRI).

## Farming Systems Research

Although farming systems research attracted little attention until the 1970s, it has been the subject of much debate since then and has collected many opponents as well as supporters. But the impression that this kind of research is a sudden and revolutionary development is somewhat misleading. Farming systems themselves have existed ever since farming began, and it can be argued that much successful agricultural research has been strongly (although perhaps not consciously) oriented toward improving them. Nonetheless, institutional research specifically organized around farming systems is relatively new, dating from no earlier than the 1930s. And it is only in the past decade or so that farming systems research has gained significant formal recognition through budget appropriations and designated programs within research agencies.

Farming systems research is the attempt to understand and devise improvements for the overall operation of farms. As with all agricultural research, the objective is to improve productivity—through intensification, new investments, or new types of capital (see box 4-2). Basic to this type of research is an appreciation of the farm as a system in which the farmer and the farm household are integral parts. The farming system is the arrangement of farming activities within the physical, biological, and socioeconomic environment in accordance with a farm household's goals, preferences, and resources. Every farming system is part of larger systems (for example, the local community) and can be divided into subsystems (for example, cropping systems).

Farming systems research is holistic; it is both multidisciplinary and interdisciplinary. It includes research on farms and at experiment stations, and on occasion it trades control for relevance to an extent that is unusual in traditional research.

Farming systems research is useful to the degree that it compensates for the tendency of traditional research to concentrate on individual commodities or specific farm tasks rather than on the productivity of the farming system as a whole. Traditional research has

**Box 4-2. *Crop Intensification***

Short-duration crop varieties and improved management practices have enabled farmers in certain regions to increase the intensity of their farming systems. A good example is the expansion of wheat cultivation in Bangladesh.

Until the early 1970s about 60,000 hectares of land were planted to wheat during the winter season, an almost insignificant area compared with Bangladesh's 10 million hectares of rice, which is mostly grown at other times of the year. About 45 percent of the land was double-cropped each year, but the fraction cropped in wheat was limited because the wheat and rice seasons overlapped.

With the introduction and rapid adoption of short-duration semidwarf wheat, the area planted to wheat increased to about 0.5 million hectares. The area in other nonrice crops also increased, from 11.3 million to 12.3 million hectares. The additional land planted to wheat was an outcome of increases in multiple cropping, not of reductions in other crops. The average number of crops per cultivated unit of area increased from 1.45 in 1972–73 to 1.54 in 1981–82 (Bangladesh Bureau of Statistics 1984). During the same period the area of land single-cropped in Bangladesh fell by 0.5 million hectares, while the area double- and triple-cropped increased by 1.9 million hectares. The increased food production from the added wheat land was conservatively valued at $200 million a year, with additional profits to farmers amounting to perhaps $40 million a year.

generally emphasized biological potential and plant yields and has not given much attention to financial capacity and the interrelations of activities. But it is precisely a systems approach that is needed to speak to the needs of small-scale farmers in developing countries, who have limited resources and generally sustain themselves by using complex combinations of crop and livestock activities. For example, in much of Asia paddy rice is the predominant main-season crop, but farmers may add to their food supply and incomes by growing a legume in the second season. The legume cannot be planted until the rice is harvested, even though it might benefit from being sown earlier. Rice breeders who recognize this dimension of Asian farming systems may be able to develop shorter-duration rice, to the advantage of legume yields.

### *Methods*

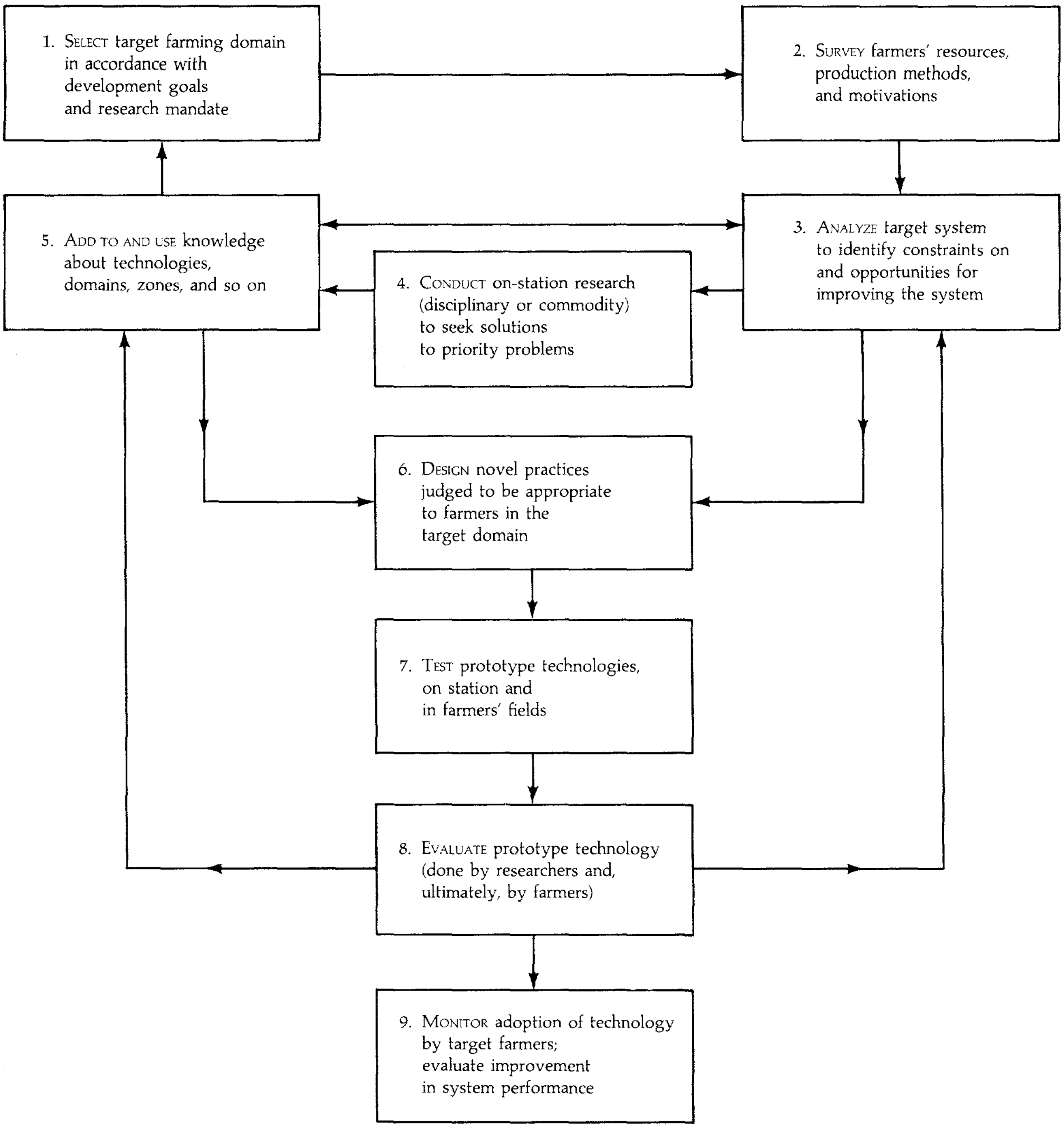
The nine principal activities that are part of the farming systems research method are identified in figure 4-1. Particularly in the initial stages, these activities may be sequential. After a research program is established, however, it is likely that several activities will be going on simultaneously.

A target domain is selected, depending on the development goals of a specific country or region and the mandate of the institution conducting the research. The target domain should be chosen to give a fair chance of obtaining tangible results in a reasonable time. It should also be large enough to allow the costs to be widely spread (Perrin and others 1976). The most satisfactory domain is likely to be one in which farms are relatively homogeneous or are all part of the same edaphoclimatic (soil and climate) region.

The next step is to study farms in the target domain to identify farmers' resources, production methods, priorities, and criteria for making decisions. Two methods have been developed for such investigations: reconnaissance (or exploratory) surveys and formal surveys. Reconnaissance surveys are relatively quick and inexpensive. They typically involve a week or so of travel through the target area by a small multidisciplinary team (consisting, for example, of an agronomist and an economist) which meets with representatives of policymaking and extension agencies, community leaders, and, above all, farmers and their families. The disadvantages of such studies are that only limited types of information can be collected, and that some of the data may be biased. Reconnaissance surveys are most useful as a way of defining the target domain and identifying issues.

Formal surveys typically involve carefully designed questionnaires and adherence to statistical standards of accuracy. Typically, formal surveys are used to construct profiles of labor availability, cash flow, work demands, prices received, and so on. If the surveys are conducted over a long enough period, variability in farms' responses to natural hazards such as flood, drought, or fire can also be quantified. Formal surveys are likely to be time-consuming and costly, particularly if the survey involves several visits by groups of researchers. Multiple visits are usually necessary to obtain accurate records of production processes, household transactions, allocation of time, and the like, as in ICRISAT's village-level studies in India and ICARDA's farming systems village studies in Syria. Anthropological components of surveys have led to insights that are useful for technology design, as in the case of diffused-light potato storage.

**Figure 4-1. *Steps in Farming Systems Research***




The primary purpose of survey information is to gain an understanding of farmers' constraints (edaphic, biological, or financial) and opportunities (defined in terms of underutilized resources, such as labor surpluses or fallow land, or in terms of the possibilities of overcoming significant constraints; see, for example, Flinn, Jayasuriya, and Labadan 1982). Opportunities for improvement exist when farmers' methods or activities differ greatly from current knowledge about the most advantageous production processes.

This appraisal of constraints and opportunities is intended to generate suggestions for improved practices that can be tested at experiment stations and on farms. It also identifies problems (for example, animal diseases or marketing difficulties) that need further research. Before research is attempted, the feasibility and the potential benefits of resolving the problems should be established. The research may be oriented to one component of a farming system or to several related components. Box 4-3 offers a concrete example of how problems can be uncovered by this kind of research.

A crucial stage in farming systems research is the testing of possible changes through experiment station trials and on farms. Generally, the greater the stock of knowledge pertinent to the system under study, the shorter will be the time required for this stage. Prototype technologies may be tested first at the experiment station before being tested in farmers' fields. Often, however, on-farm testing of technologies chosen as "best bets" can be initiated hand in hand with on-station work.

Farm-level evaluation is a vital element of farming systems research. The performance registered by an improved technology will usually drop when it is moved from the artificial conditions at an experiment station to the real conditions on farms, particularly when the technology is tested by farmers for compatibility with the existing system. The experimental designs and procedures used in on-farm work are usually much simpler than those used on-station.

Farm trials managed by researchers can cover more aspects of a new technology than can farmer-managed trials. Their objectives should be to screen proposed technologies, alter them to fit local conditions, and evaluate their potential value. All this may take several years, especially in areas of great year-to-year or farm-to-farm variation.

The process of designing and testing prototype technologies involves ongoing economic assessment, initially to cull less promising suggestions and later to determine the value of the methods on the basis of trials in farmers' fields. The main factors that must be considered in such an economic assessment of prototype technologies are indicated in figure 4-2 and have been discussed by, among others, Banta (1982), Ghodake and Hardaker (1981), Anderson and Hardaker (1978), and Ryan, Sarin, and Pereira (1979). The analyses should be based on predictions, if not observations, of performance under farmers' management and should use the farmers' criteria of value. Because of the difficulties in identifying and quantifying these criteria, the ultimate test is the willingness of farmers to adopt the technology and their success in using it.

An important feature of farming systems research is feedback about the performance of the prototype technologies from experiment stations and, more relevantly, from farms and farmers. This feedback leads to the constructive redesigning of practices until they are well suited to the needs and circumstances of the target group of farmers.

**Box 4-3. *Potato Storage and the Household Economy***
(From CIP 1984, pp. 109–10)

The contribution and role of each discipline of CIP's postharvest team is best understood by studying the team member interaction over time. Initially, an anthropologist studied postharvest activities and storage problems facing highland potato farmers in the Mantaro Valley of Peru's central Andes. Biological scientists at first restricted their activities to research with both consumer and seed potato storage on the experiment station in the same region.

Soon the social scientist and technologists found themselves in an intrateam debate over the concept of "storage losses." This was a critical point because the potato as a vegetable tuber is a highly perishable item. Storage specialists were logically concerned with designing a system to reduce both pathological and physiological losses since these are major technological problems.

The anthropologist, on the basis of a two-months' village-level survey, argued that central Andean farmers did not necessarily perceive small, shriveled, or spoiled potatoes as "losses" or "waste." All potatoes were used by farm families in some form. Potatoes not sold or used for seed or immediate home consumption were fed to animals, mainly pigs, or processed into dehydrated potatoes (*chuno, papa seca*) storable for as long as three years. In addition, some wives said the shriveled, partly spoiled potatoes were sometimes preferred for certain dishes.

These observations, as one biological scientist later put it, were "the beginning of understanding that we scientists often perceive technical problems through different eyes than farmers. Potato losses as we saw them were not necessarily losses to farmers."

One team technologist, in reflecting on the experience, explained: "I was not totally convinced of the anthropologist's argument, although he certainly made me think about what I was doing. We biological scientists hadn't even really talked to a farmer about the problems we were working on. We were doing research from a distance, not research to solve a problem. When I finally went with him to visit farmers I could see he was right, but only partially."

### The Social Scientist's Role

In the posteuphoric phase of the industrial and green revolutions the importance of human, social, and economic factors in farming systems is so widely recognized that it requires little elaboration here. Research administrators, whether in regional, national, or international organizations, are generally responding by ensuring that social scientists are represented, at least to some degree, in research structures. The form of their participation varies widely, reflecting such things as the prejudices of the administrators and of their influential scientific (especially from other than the social sciences) advisers and the availability of social scientists with relevant backgrounds and interests in agriculture. The range extends from one or two token and peripheral appointments, through specialized service divisions, to complete integration of social scientists into multidisciplinary research and problem-solving teams. The institutional incorporation of social scientists generally appears to be more haphazard the more local the level of organization. Thus, for example, social scientists are commonly involved in the centers but can be almost completely absent from the regional agricultural research stations of developing countries, where priority has usually been given to training and appointing people in biological research.

Social scientists contribute to farming systems research by collecting and interpreting information to help design policies and activities that are both effective and acceptable to the target groups. Such information includes (a) the social milieu in which farm decisions are made, (b) the institutional setting and policy environment in which farming is conducted, especially with respect to landownership, credit, and taxation, (c) the economic environment of farms, including long-term market prospects for inputs and outputs and, most important, the opportunity costs and transaction costs faced by farmers, and (d) the ideas, attitudes, and personal constraints of farmers, including their desire (or lack of desire) for change, for leisure, for education, for different foods, and so on and the human and other capital available to them. The days of the quick technological fix are all but over. Progress must now usually be won through better understanding of the full reality of farming systems.

### The Centers' Role

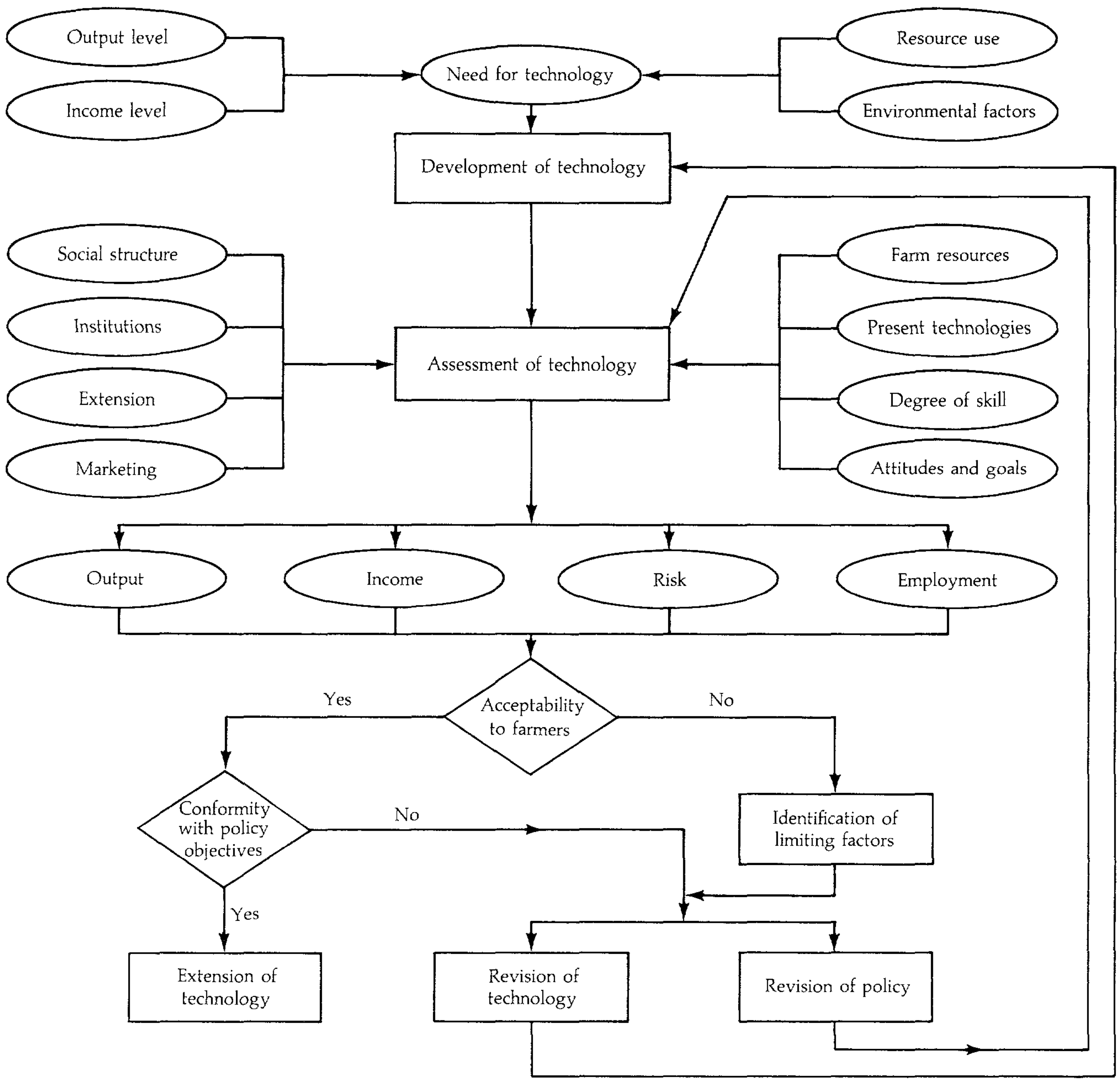
Farming systems research tends to provoke controversy, in part because of skepticism among practitioners of traditional research and in part because many different activities are conducted under that name. Although there is reason to believe that the level of controversy is diminishing, differing views on the propriety of the centers' involvement in farming systems research persist. The examples of "successful" farming systems that have been developed at the centers are still too sparse and new to provide much for either view to fasten onto. Only a few, such as ICRISAT's deep vertisol technology, can be evaluated as yet.

Since farming systems research concentrates on relatively small numbers of farmers at one time, it seems clear that most of it should be carried out by national agricultural research systems. Neither the present nor the potential resources of the centers are sufficient to allow them to study the huge number of agricultural domains throughout the world, and any attempt to do so would contradict their broad mandate. Rather, it can be argued, the centers should concentrate on expanding the knowledge on which farming systems research by national programs heavily depends.

Another view, however, is that the work of the centers must be relevant and that such relevance can best be ensured through feedback from farming systems research. Furthermore, national programs often need reinforcement in their efforts to conduct farming systems research. National agricultural research agencies constantly confront constraints in personnel and other resources, and they naturally look to the centers for guidance and help. In this view farming systems research by the centers is desirable, but it should be consonant with the aims of the national programs. Thus the centers could provide technical assistance and training, supply prospective technologies for on-farm testing, and sponsor collaborative activities, such as farming systems research networks. Many of these activities are already being carried out at several centers, but the degree of commitment varies, as will be seen below.

DEVELOPMENT OF METHODS. In collaboration with national programs CIMMYT has refined its methods of conducting farming systems research through more than a decade of field experience. These methods are usually described as "on-farm research with a farming systems perspective." Other centers, including CIAT, CIP, ICRISAT, IITA, and IRRI, have also contributed significantly to progress in research methods. While there are many similarities in approach among the centers, there are also differences, such as ILCA's pastoral orientation, ICRISAT's emphasis on soil and water conservation, and IITA's interest in developing new farming systems for the humid tropics. Such differences are useful. The evaluation of alternative approaches at different centers presumably makes it possible to identify the best research methods for particular circumstances.

**Figure 4-2. *Technology Assessment in a Farming Systems Research Context***




TRAINING PROGRAMS. In 1982 Zimbabwe established a farming systems research unit in its Department of Research and Specialist Services. The creation of this unit can be traced to a 1980 demonstration by CIMMYT of its approach to on-farm research. CIMMYT's 1980 work was one of the first evaluations of small-scale farming in Zimbabwe. The large amount of useful data generated rapidly and at low cost by the evaluation impressed Zimbabwean officials and helped them to understand the value of a farming systems approach. CIAT, ILCA, IITA, and ICRISAT have also promoted the farming systems approach in tropical Africa.

A number of national systems have become more interested in the systems approach because of center training programs. For example, the establishment in Malawi of adaptive research that uses a systems approach owed much to the ready access to training courses afforded by CIMMYT's regional and in-country programs. Three types of training are offered: orientation sessions of three to ten days, regional training workshops that last five weeks, and a series of brief in-country sessions under the "call" system. Under that system a center sends instructors in response to a call from a national center for training assistance at critical stages of the crop cycle. The material covered in the sessions, which go on over, say, fifteen to eighteen months, evolves to match the growing experience of the participants.

FARMING SYSTEMS RESEARCH PROJECTS. Farming systems research demonstrations have been offered by IITA, ICRISAT, and ICARDA, but these efforts to portray interdisciplinary collaboration have not always been exemplary. The demonstrations appear to require more financial resources than are ordinarily available and have sometimes led to reluctance to apply the methodology. But they have also given centers the opportunity to show that commodity-oriented research need not be confined to mandate crops. ICRISAT's farming systems program, for example, has included research on eleven crops besides the five in the center's mandate.

DIRECT SUPPORT OF NATIONAL PROGRAMS. CIMMYT, ISNAR, and others have stressed the need for a flexible and pragmatic approach to the development of farming systems research in national programs. Installing such research in institutions organized along commodity or disciplinary lines (and with limited professional and technical resources) presents obvious difficulties. Because of recurrent revenue crises in most developing countries, national systems often find it difficult to obtain the budgetary allocations necessary to establish and sustain farming systems research on a scale commensurate with the problems to be tackled. Even when embryonic national farming systems research programs are established, consistent financial backing often does not materialize. Since centers lack the funds to fill this void, farming systems research is unlikely to meet expectations unless other funding becomes available.

COORDINATION OF RESEARCH NETWORKS. IRRI has made a noteworthy contribution to the development and coordination of a farming systems research network. Since land scarcity is the principal obstacle to expanded rice production in South and Southeast Asia, the cropping systems program at IRRI concentrated on developing short-duration rice varieties, on improving farming techniques to permit double cropping of rice or of rice and a secondary crop, and on integrating other activities such as livestock into the farming system. National agricultural research programs within the network adjust the technologies designed with IRRI to the specific circumstances of farmers in selected domains, and feedback from the national programs is used in setting priorities for research at IRRI. Other centers have networking activities, such as the *Farming Systems Newsletter* published by CIMMYT's East Africa Economics Program.

OVERALL ASSESSMENT. Advocates of farming systems research are firm in their conviction that the approach works. They point, for example, to more than ten years of work in East Africa and to the substantial progress made there in Kenya, Malawi, Sudan, Swaziland, Zambia, and Zimbabwe. Despite a few false steps it appears that the centers have done a good job of developing farming systems methods that work and that are transportable to different settings. Difficulties in implementing the approach remain, and further adaptation and improvement are needed. But the main challenge facing the centers now is to extend the approach to other countries, farm environments, and research institutions.

Some skeptics still point to the differences among farming systems research activities at various centers (see, for example, Simmonds 1985) and to the difficulty of extending the approach to national programs. They note that national systems have fewer resources for this purpose than do the centers and are often organized in ways that are at variance with a farming systems approach. Some see farming systems research as bad science that diverts resources from more important and potentially more useful fields of enquiry. Others argue that the main task lies ahead and that some dimensions of farming systems work remain to be developed (see box 4-4). It is too early to judge whether the intuitively appealing idea of research on farming systems can be implemented on a global scale. Certainly most of the benefits of this approach lie in the future, making assessment at this time difficult.

## Research on Biological Nitrogen Fixation (BNF)

Modern farmers rely heavily on fertilizer to grow more productive crops. The most widely used fertilizers are nitrogenous chemical compounds, usually made from natural gas.

Some developing countries that are endowed with deposits of natural gas or other usable raw materials make their own nitrogenous fertilizer, but they are a minority. Most developing countries must buy manufactured fertilizer from foreign sources at considerable cost. In addition, the roads, bridges, trains, trucks, and other infrastructure needed to distribute the fertilizer have often been unavailable. This situation has brought about a continuing interest in biological nitrogen fixation.

**Box 4-4. *Women and Farming Systems Research***

Like agricultural research in general, farming systems research has often failed to recognize the importance of women to the farm enterprise. There are several reasons.

- Researchers tend to see agriculture as the primary component in the livelihood of the farm family. They have concentrated on improving food production and have generally failed to integrate household tasks into their analyses of system performance. Where male and female economic activities are gender determined and women concentrate on nonagricultural activities, the contribution and potential of women's work may be overlooked. A crop, for example, becomes food only after it has been cleaned, preserved, stored, prepared, and, in most cases, cooked—activities commonly undertaken by women. Similarly, fetching water to irrigate a vegetable crop is seen as part of the farming system, but fetching water for cooking—another task essential to survival of the household—is often omitted from labor analyses.
- Partly because of the mandates of the centers and partly because of the philosophy that research resources should be spent chiefly on those crops and animal types that loom large in trade or in farming, little attention has been paid to minor crops and small animals. These are often the particular responsibility of women, whose contribution to family welfare might be appreciably increased by the diversion of some research resources to these areas.
- Most researchers are men and (naturally) see the farming system from a man's point of view. As a result, activities within the system that are controlled by women may be underestimated and undervalued. When researchers seek to identify the goals and objectives of farmers, the priorities of the male head of household take precedence. Seldom have researchers recognized that a woman's objectives are likely to differ from and may conflict with those of a man. And the traditional idea that male-managed enterprises are the typical units of production obscures the large incidence of households that are headed by women (if only because the man is working elsewhere).
- To some extent the focus on the interests of men in farming systems research reflects the dependent status of women and their relative powerlessness to make independent decisions, including decisions about the technologies that affect their lives. Ideally a program for improving farming systems would examine the total institutional and infrastructural environment within which production and household maintenance take place and might well identify a need for such things as changes in the legal status of women and greater participation by women in various types of male-dominated employment. But these are contentious matters, and farming systems research at the centers has generally not taken the broader and politically more sensitive view.

The extent to which farming systems research raises women's contribution to development will depend on the sensitivity of researchers to women's roles and perceptions. Given the paucity of data on women in agriculture and the heavy male dominance in the staffing of research teams, the immediate outlook is not good. That these problems exist and are important is now beginning to be recognized. A first step toward improvement would be to include more women in farming systems research staffs and to increase the training opportunities for women at the centers.

## *What BNF Is*

Most farmers in developing countries grow one or more legumes, chiefly as food for their households. In many countries beans, peas, lentils, and other leguminous crops are called "the poor man's meat" because of their high protein content. Farmers may also grow certain legumes—alfalfa, for instance—as field cover during fallow periods or as livestock feed. In addition to their value as food, legumes "fix" nitrogen; that is, they support nitrogen-fixing microorganisms (*Rhizobium* sp.) that grow in nodules on their roots.

In addition to herbaceous legumes, numerous trees—including acacias and *Leucaena*, which are legumes, and such nonlegumes as the alder and the casuarina—interact with soil microorganisms that fix atmospheric nitrogen. Something similar also happens in rice paddies, as the farmers of China and Viet Nam have long known. The water fern azolla, commonly grown among rice plants, is a haven for the blue-green alga *Anabaena azollae*, which fixes nitrogen and thus adds that nutrient to the water in which the rice grows.

The value of these biological processes may be investigated simply by studying what happens to soil nitrogen when, say, legumes or azolla are grown where they had not been grown before. What happens, for instance, if a farmer who regularly uses a field for maize grows peanuts instead? Does that raise the nitrogen level enough to reduce the need for inorganic nitrogen fertilizer when the land is again used for maize?

Another kind of investigation involves deliberate efforts to increase the amount of nitrogen fixed by the various species. One method is to inoculate the seed or the growing medium with one of the microorganisms (principally *Rhizobium*) responsible for the fixation of nitrogen. Thus far, however, legume inoculation remains an imperfect technology in many contexts. Producing an inoculant of good quality, distributing it in rural areas, and convincing subsistence farmers of the potential value of inoculation all present difficulties, even though the inoculation itself is simple.

Experiments have shown that under the right conditions inoculation both increases the amount of nitrogen fixed by the plants and improves plant yield. Whether this happens depends on the compatibility of the *Rhizobium* strain and the cultivars and on soil and climate conditions. If the inoculation proves successful, *Rhizobium* may survive in the soil for as long as a dozen years.

Inoculation may ultimately prove to be a way to reduce substantially the need for applied nitrogen fertilizers where legumes are grown in rotations or as intercrops, but it seems unlikely to be as useful for cereals or root crops. Even if nitrogen-fixing microorganisms are found for these nonleguminous crops, or if legumes are used in the rotation to add nitrogen to the soil, the starchy staples need much more nutrient nitrogen to produce high yields than BNF alone affords. Thus BNF is likely to provide, at best, only a small portion of the total amount of nitrogen needed to grow such important food crops as wheat, maize, and potatoes (although even that portion may be a great help in many low-income developing countries). An important potential exception may be pasture legume–cereal rotations. ICARDA and others are working on adapting to conditions in West Asia and North Africa farming techniques that have been successful in Australia (see below).

### *BNF Research at the Centers*

The BNF research programs of the several centers involved are diverse and include work in such areas as germ plasm collection, testing, and maintenance, strain selection and plant improvement, agronomic management, inoculation technology, communications, and training. Only selected aspects are outlined here.

Several biological nitrogen-fixing organisms of importance for rice cultivation are maintained at IRRI, including a number of azollas and the blue-green algae *Anabaena, Gleotrichia,* and *Nostoc.* IRRI's chief goal in BNF research has been to evaluate nitrogen fixation by heterotrophic bacteria and by phototrophic blue-green algae. Farmers in some parts of the Philippines have begun using azolla as a result of this work, but to date the main impact has been to increase scientific understanding. IRRI is also actively investigating the use of a robust leguminous green manure crop, *Sesbania rostrata,* for use in rice farming.

BNF research at IITA is focused mainly on improving soybean and cowpea yields through *Rhizobium* inoculation and on selecting host plants with good nitrogen-fixing abilities. The contribution of cowpeas and *Leucaena* to nitrogen fixation in mixed cropping and in alley cropping with maize is also being investigated. IITA maintains more than 100 strains of *Rhizobium japonica* and more than 300 strains of *Rhizobium* sp. for cowpeas. Cowpeas, soybeans, *Leucaena,* and some other species have been evaluated to determine how much nitrogen their residues contribute to the soil.

Alley cropping of a few rows of maize and other crops between densely planted rows of *Leucaena* that are cut regularly for animal fodder or for between-rows mulch has much potential as a productive and nondegrading technology in the humid zones of West Africa and other tropical areas. IITA has concentrated on the management of such novel cropping systems, whereas ILCA has explored the nutritional and economic value of the harvestable forage in the small-ruminant enterprises run by many village households.

Research, training, and collaborative activities in BNF technology are carried out in CIAT's programs for tropical pastures and beans. Work on beans was initiated in the early 1970s and on tropical forage legumes in the mid-1970s. Although these two crops are agronomically quite distinct, both beans and forages are most frequently grown in association with plants that do not have the capacity for symbiotic nitrogen fixation.

CIAT has oriented its BNF research toward three overall objectives:

- The identification of constraints that limit nitrogen fixation under field conditions
- The development of methods for evaluating and improving BNF that are appropriate for use by national program institutions in the tropics
- The integration of the microbiological aspects of BNF with the legume selection activities in each of the legume programs in the belief that improvement of BNF requires consideration of the entire symbiotic system.

Research has concentrated on the collection and selection of strains, their legume specificity and nitrogen-fixing potential, the evaluation of nitrogen fixation in the respective cropping systems, and the effect of management practices. The information and understanding gained from this work have provided the basis for the evolution of CIAT's legume programs over the past five years toward a stronger interrelation between rhizobiology and the cultivar selection activities. Within each program current research activities include evaluation and selection of bacterial strains and of plant genotypes for enhanced nitrogen-fixing potential and studies on the agronomic management factors that affect the expression of the genetic potential of the two symbionts. As the knowledge and capability of the programs have grown, CIAT has increasingly emphasized the training of personnel from national legume programs and collaborative research with these programs. CIAT coordinates an ongoing program of trials to evaluate legume–*Rhizobium* combinations in various countries in Latin America and Africa, and interest among national programs in participating in these collaborative trials is growing rapidly.

ICRISAT is conducting an extensive evaluation of BNF as a potential source of nitrogen for such dryland cereals as sorghum and pearl millet. The center is also investigating whether yields of such legumes as chickpeas, pigeon peas, and groundnuts can be further improved through BNF technology alone. This extensive program of BNF research parallels much of that noted above for IITA and CIAT. Much attention has been given to the cereals themselves as nitrogen fixers. About 200 sorghum and 100 pearl millet accessions have been screened for nitrogen-fixing activity, and a few have proved to be active and promising.

BNF research at ICARDA has two major thrusts. The first involves chickpeas, faba beans, and lentils; about 400 *Rhizobium* strains that function symbiotically with these legumes are currently maintained in the culture collection, and work analogous to that for legume crops at CIAT, ICRISAT, and IITA continues. The second is concerned with pasture and forage legumes for rotation with cereals. The pasture and forage legumes under study at ICARDA include *Medicago, Pisum, Vicia, Astragalus, Trifolium,* and *Orobrychus.* A total of 400 *Rhizobium* strains that nodulate these legumes are maintained in culture collections. If techniques analogous to those developed in southern Australia over the past few decades can be adapted to the Mediterranean zone, nitrogen fixation can have a large impact there. Leguminous pastures in rotation with cereals could double cereal yields and generate valuable forage for additional sheep and goats on nearly 20 million hectares. There are many constraints on such progress, including, most importantly, the nonadaptation of commercially available legumes to local conditions, particularly to cold winters, and the need for inoculation because of low soil populations of effective rhizobia. But research should offer many possibilities for exploiting BNF in the region.

### *Conclusion*

In spite of long-standing efforts in BNF research at the centers, the impact in farmers' fields was limited through the mid-1980s. In many instances the potential effects of the research accomplishments are masked by constraints on application. This research, however, has helped to improve greatly the quality of analogous work in national programs. Future emphases in research are likely to be more concerned with the management and utilization of fixed nitrogen than with fixation as such.

## Note

1. In this chapter, the section "Land Clearing and Management" is drawn from an unpublished study by Michael Nelson which is discussed more extensively in Anderson and others (1985), ch. 15. "Mechanization" is derived from information assembled for this study by the staff of the Overseas Division of the National Institute of Agricultural Engineering (NIAE), Silsoe, United Kingdom, and coordinated by Robert Bell. A more complete report is available from the NIAE. "Crop Protection" summarizes a review, assessment, and appraisal by Teng and MacKenzie (1986) of the impact of the centers on national research programs and on farm-level crop protection. "Farming Systems Research" is largely based on materials assembled by J. Brian Hardaker and Jock R. Anderson at the University of New England, Armidale, Australia. "Research on Biological Nitrogen Fixation" draws on an unpublished paper prepared by Jake Halliday, currently at the Battelle-Kettering Research Foundation, Columbus, Ohio, and previously director of the Nitrogen Fixation in Tropical Agricultural Legumes (NifTAL) project, University of Hawaii.

# 5 Building Human Resources for National Research Institutions

The CGIAR and its centers believe that the developing countries must steadily improve their ability to conduct agricultural research; otherwise they will not be able to take maximum advantage of the general research on food crops conducted at the centers or to exploit their own research opportunities. To help the developing countries strengthen their research capacities, the centers offer classes, seminars, conferences, workshops, publications, and other activities to enhance the knowledge and skills of the scientists and technicians who work in national agricultural research systems.[1]

## The Magnitude and Costs of Training Activities

Between 1962 and 1983 more than 16,000 agricultural specialists participated in the educational programs run by the centers. To put this figure in perspective, in 1980 there were about 60,000 agricultural researchers in the developing world (Judd, Boyce, and Evenson 1986). To a great extent the centers provide short- and medium-term training that supplements more formal education obtained elsewhere. CGIAR-trained researchers are important channels of communication between the centers and the national systems, and many have made professional contributions that have bought them national or international standing.

The directly accounted costs of the centers' educational programs in 1984 were $13.5 million, or about 8 percent of the centers' combined budgets. Total real costs (which are not known precisely) were somewhat more, since the educational programs involved the use of staff time and the physical resources of the centers, which come under other budget categories. Although financial stringency has sometimes led to restrictions on the spending of core funds for educational purposes, several centers have been able to sustain their educational spending through special projects, and there has been no reduction in the number of participants. Currently about 2,300 researchers from developing countries attend group educational programs at the centers each year.

## Types of Training

The chief types of training provided by the centers are

- General and specialized courses for groups, lasting from one week to several months (and often through a crop cycle), to acquaint the group with the methods and results of research at the centers
- Individual instruction in new research techniques, lasting from a few weeks to two years, for research workers and managers. Postdoctoral training is a somewhat similar program for persons with doctorates who wish to conduct advanced research under the guidance of a senior center researcher.
- Research, for periods of up to three years, related to the thesis requirements for a university (usually a graduate) degree. The centers are particularly suited to providing this sort of training.
- In-country group training at national or regional institutions, similar to group courses at the centers
- Workshops, conferences, and seminars
- Information and documentation services
- Publications.

## The Origins of Participants

By 1984 more than 11,000 scientists and technicians from all over the world had attended formal group courses at the centers (table 5-1). The largest number came from Africa, with Asia second. Although the centers tend to draw more participants from the region in which they are located, most also have at least a few participants from other regions. Participants from industrial countries have been relatively few.

CIAT, CIMMYT, IITA, IRRI, and WARDA have each trained more than 1,000 participants in group courses. IITA has one of the largest programs of group technical training among the centers, reflecting continued strong demand in Africa.

IFPRI does not offer formal courses and indeed does not have a designated training program. Rather, the approach taken to enhance skills in policy analysis is to develop collaborative arrangements with local and regional research organizations. Examples of this are IFPRI's relationships with Tamil Nadu Agricultural University in India and the Bangladesh Institute of Development Studies.

During 1978–83 CIP had the largest number of participants in group training. This number, however, is not quite comparable with those of the other centers because it includes participants in CIP's principal kind of group training, that given by CIP personnel outside the headquarters country of Peru.

The total number of participants in degree-related training as of the mid-1980s (table 5-2) was much smaller than the number who had attended group courses or individualized programs at the centers (table 5-3), but at more than 1,400 the number is nonetheless significant. Although the centers do not award degrees or offer courses at the university level, they do offer participants the opportunity to carry out high-level research that can help them obtain advanced degrees from other institutions. Disaggregated data from all of the centers were not available, but data for three of them showed that 58 percent of the participants were studying for master's degrees and 42 percent for doctoral degrees. Thus a conservative estimate is that by 1983 the system had helped to educate more than 500 Ph.D.s in developing countries.

IRRI has been the most active center in offering opportunities for students seeking advanced degrees, with IITA next. Both have arranged to send scholars to universities situated close to their headquarters. A higher proportion of the scholars sponsored by most of the other centers have earned degrees in industrial countries. A small proportion of the degree-related scholars have been nationals of industrial countries. Some developed country sponsors that wish to develop their own expertise and national capability in tropical agriculture have actively pressed the centers to allow their scholars to gain experience at the centers.

About 3,700 people from developing countries had participated in individualized training programs at the centers by 1983 (table 5-3). This category includes many different arrangements under which researchers gain experience in specific techniques. Tourists and even visitors with a scientific background who spend a day or a week at the center are omitted from these data. At several centers these number in the hundreds each year. The data in table 5-3 refer to those whose visits or studies were sponsored by the centers.

**Table 5-1. *Training by the Centers: Group Courses***

| | | *Number of participants from* | | | | | *Annual average (recent years)* |
|---|---|---|---|---|---|---|---|
| *Center* | *Year* | *Sub-Saharan Africa* | *Middle East and North Africa* | *Asia* | *Latin America* | *Industrial countries* | |
| CIAT | 1968–84 | 3 | 2 | 52 | 984 | 0 | 180 |
| CIMMYT | 1966–84 | 307 | 258 | 410 | 558 | 31 | 130 |
| CIP[a] | 1978–83 | 415 | 209 | 772 | 448 | 6 | 540 |
| IBPGR | 1973–82 | 23 | 39 | 246 | 62 | 26 | 130 |
| ICARDA | 1978–83 | 1 | 244 | 22 | 0 | 2 | 40 |
| ICRISAT | 1974–82 | 355 | 4 | 202 | 13 | 7 | 90 |
| IITA | 1970–83 | 1,905 | 5 | 74 | 44 | 51 | 500 |
| ILCA | 1975–83 | 153 | 0 | 0 | 0 | 0 | 110 |
| ILRAD[b] | 1972–82 | 339 | 0 | 32 | 7 | 63 | 25 |
| IRRI | 1962–82 | 68 | 7 | 1,678 | 15 | 12 | 240 |
| ISNAR | 1981–83 | 307 | 11 | 97 | 121 | 0 | 180 |
| WARDA | 1973–84 | 1,081 | 0 | 0 | 0 | 0 | 120 |
| Total | | 4,957 | 779 | 3,585 | 2,252 | 198 | 2,285 |

*Note:* IFPRI does not offer group courses.
a. Includes participants attending courses conducted by CIP regional staff in thirty-two countries.
b. Includes forty-five degree candidates or postdoctoral fellows.
*Source:* Data supplied by centers to TAC.

**Table 5-2. *Training by the Centers: Degree-Related Research***

| | | *Number of participants from* | | | | | *Annual average (recent years)*[a] |
|---|---|---|---|---|---|---|---|
| *Center* | *Years* | *Sub-Saharan Africa* | *Middle East and North Africa* | *Asia* | *Latin America* | *Industrial countries* | |
| CIAT | 1968–84 | 9 | 0 | 4 | 130 | 58 | 25 |
| CIMMYT | 1966–82 | 19 | 18 | 9 | 26 | 20 | 5 |
| CIP | 1978–83 | 2 | 4 | 5 | 67 | 3 | 10 |
| IBPGR | 1973–82 | 13 | 12 | 20 | 5 | 4 | 10 |
| ICARDA | 1978–83 | 0 | 13 | 2 | 0 | 5 | 10 |
| ICRISAT | 1974–82 | 20 | 0 | 71 | 4 | 21 | 30 |
| IITA | 1970–83 | 172 | 0 | 7 | 2 | 81 | 65 |
| ILCA[b] | 1975–85 | 28 | 0 | 0 | 0 | 0 | 15 |
| ILRAD[b] | 1972–82 | 28 | 0 | 0 | 0 | 5 | 15 |
| IRRI | 1962–82 | 10 | 0 | 492 | 13 | 30 | 150 |
| WARDA | 1973–84 | 47 | 0 | 0 | 0 | 0 | 20 |
| Total | | 346 | 47 | 610 | 247 | 227 | 355 |

*Note:* Date for most centers include master's and doctoral candidates.
a. Number in residence at the center during a year. A participant typically takes one to three years to complete research activities at the center.
b. The total number at both levels for all regions is allocated according to the 1983 geographic distribution.

**Table 5-3. *Training by the Centers: Individual Research Training Programs***

| | | *Number of participants from* | | | | | *Annual average (recent years)* |
|---|---|---|---|---|---|---|---|
| *Center* | *Years* | *Sub-Saharan Africa* | *Middle East and North Africa* | *Asia* | *Latin America* | *Industrial countries* | |
| CIAT | 1968–84 | 25 | 1 | 35 | 1,265 | 73 | 135 |
| CIMMYT | 1966–82 | 176 | 211 | 350 | 409 | 52 | 70 |
| CIP | 1978–83 | 16 | 5 | 35 | 135 | 9 | 50 |
| IBPGR | 1973–82 | 2 | 5 | 16 | 5 | 6 | 5 |
| ICARDA | 1978–83 | 1 | 48 | 1 | 0 | 4 | 10 |
| ICRISAT | 1974–82 | 3 | 5 | 9 | 2 | 0 | 15 |
| IFPRI | 1979–84 | 0 | 0 | 0 | 0 | 0 | 5 |
| IITA | 1970–83 | 212 | 1 | 17 | 6 | 17 | 25 |
| ILCA | 1975–83 | 44 | 0 | 0 | 0 | 21 | 30 |
| IRRI | 1962–82 | 28 | 6 | 405 | 14 | 25 | 100 |
| Total | | 507 | 282 | 868 | 1,836 | 207 | 445 |

Postdoctoral training activities (table 5-4) are not undertaken at all centers, according to data gathered during the study. IRRI has had by far the largest number of participants, but postdoctoral studies have also been important at CIMMYT, IITA, and ICRISAT. IFPRI, strictly speaking, defines those shown in the table not as postdoctorals but as research collaborators. The largest number of postdoctoral participants has come from Asia, with quite a few from industrial countries and a substantial number from Africa.

## General Assessment

Although people trained at the centers usually represent only a small proportion of the agricultural researchers in most countries, they are warmly praised for their work after they return home. Authorities in the developing countries want the centers to offer more educational opportunities, but the types of training they want tend to change as development proceeds, and the training offered by centers also changes over the years. It is consequently difficult for a nation to coordinate its response to the training offered by the different centers. There is a considerable demand for more study at higher levels. Unfortunately, programs at those levels are especially costly.

Often the scientific standards of the centers are so far above those of national institutions that it is difficult for students to derive full benefit from their work at the centers. But countries that have reached a higher level

**Table 5-4. *Training by the Centers: Postdoctoral Programs***

| Center | Years | Number of participants from: Sub-Saharan Africa | Middle East and North Africa | Asia | Latin America | Industrial countries | Annual average (recent years) |
|---|---|---|---|---|---|---|---|
| CIAT | 1969–83 | 2 | 0 | 3 | 17 | 34 | 15 |
| CIMMYT | 1966–82 | 3 | 6 | 13 | 18 | 48 | 15 |
| ICARDA | 1978–83 | 0 | 11 | 0 | 0 | 10 | 5 |
| ICRISAT | 1974–82 | 9 | 0 | 32 | 9 | 21 | 20 |
| IFPRI[a] | 1975–83 | 14 | 0 | 51 | 6 | 0 | 10 |
| IITA | 1970–83 | 33 | 1 | 17 | 2 | 23 | 10 |
| ILCA | 1975–83 | 2 | 0 | 0 | 0 | 4 | 5 |
| ILRAD | 1972–82 | 5 | 0 | 1 | 0 | 17 | 10 |
| IRRI | 1962–82 | 2 | 0 | 169 | 5 | 41 | 20 |
| Total | | 70 | 18 | 286 | 57 | 198 | 110 |

a. Research collaborators at the professional level.

perceive only training in connection with advanced degrees as of real value to them.

Training at the centers has clearly played a large role in strengthening agricultural research in many countries. This is especially true when research is initiated on a commodity for the first time or when a country decides to promote a particular area of research (see box 5-1).

In most cases the centers select participants who have been nominated by governments or other employers in response to an invitation from the center. This two-stage process helps to maintain standards. Some participants in degree-related programs are proposed and sponsored by donors.

One regrettable consequence of the selection process has been the small proportion of female participants. Many factors are at work, not all of which lie outside the centers. It was not possible to determine the exact percentage of female participants at each center, but the 8 percent figure for IRRI between 1962 and 1981 seems typical. The centers, in strict terms, have been engaged mainly in the development of "manpower" rather than of human resources.

Some participants initially find the new and different environment of a center difficult and startling, but these reactions soon pass. The principal continuing difficulty is language. English is the chief language at most centers, but to an increasing degree the centers are either presenting some educational programs in other languages or providing courses in English for participants who do not speak the language of the center.

Participants themselves report that training at the centers increased their knowledge and skills, intensified their willingness to engage in intellectual and physical labor, and deepened their motivation, determination, and confidence. Continuing contact with a center gives past participants a sense of their own value in the professional world.

An examination of the subsequent careers of participants suggests that their time at a center has enabled most of them to work more effectively, even though many are promoted out of active research or are required to switch their attention to commodities or disciplines out of their study area. And some past participants return as staff members to the center at which they studied.

Each center has forged training links with many countries (up to eighty in some cases), while each country contacted in the TAC study had an ongoing relation with seven or eight centers. The centers deal separately with each country, even when they are offering training in similar fields, and this can lead to duplication. The centers are aware of the problem and have taken some steps to alleviate it. For example, all of the centers in Africa that offer training in farming systems recently agreed to keep one another informed of their respective courses and to carry out joint activities wherever possible.

Because the current demand for training at the centers exceeds what the centers can offer, they have supplemented their training efforts with in-country courses. These have certain advantages but lack the benefits that come from immersion in the highly professional atmosphere of an international center.

Nor can the centers satisfy the demand among the developing countries for more openings for agricultural researchers working toward advanced degrees. Thus far the centers have made only a modest contribution to degree-related training, even though they have the potential to offer unique opportunities in advanced training. Many on the scientific staffs of the centers are dedicated to their research responsibilities

**Box 5-1.** ***How Training Helped Introduce a New Crop***

For a long time it was believed that wheat could not be grown on a large scale in Bangladesh. But Bangladesh's wheat area expanded from less than 60,000 hectares in 1965 to over 425,000 hectares in 1980, and production increased from 0.1 million to more than 1.0 million tons. Center training played a crucial part in this development.

After semidwarf wheat varieties were developed in Mexico in the mid-1960s, CIMMYT staff members reviewed wheat production in Bangladesh and recommended many changes. These included introduction of such varieties as Mexipak 69 from Mexico and Super X from Egypt, an increase in wheat prices, appointment of a technical coordinator for the wheat research program, expansion of training , initial concentration on selection of new varieties rather than on breeding, the hiring of additional research staff to conduct off-station trials, and development of a seed certification program. A training program for Bangladeshi researchers was established with funding from the Ford Foundation, which also periodically reviewed progress in wheat production. Between 1968 and 1973 five Bangladeshi researchers were trained in plant breeding, plant pathology, and production at CIMMYT, and over the next five years an additional eleven persons were trained, seven in crop improvement.

An expanded wheat research program started in May 1975. By that time the breeders, agronomists, and pathologists trained at CIMMYT were working as a team. Thus when CIMMYT researchers expressed concern in 1979 about Bangladesh's dependence on a single strain of wheat, the country had a multidisciplinary team ready to carry out important changes.

Former participants commended the CIMMYT training for fostering a team spirit and a collegial atmosphere, emphasizing learning by doing, and demonstrating professional values. But the training also had weaknesses—repetitive experiments, incomplete coverage of the crop cycle, and a lack of theoretical rigor. Many participants also mentioned the need to relate training content to the specific problems and resources of developing countries. Analytical skills were perceived to be assigned less importance than technical skills. A recent participant mentioned that while at CIMMYT he did everything with his own hands, but when he returned to Bangladesh he found it necessary to assume supervisory responsibilities. Short-term training at CIMMYT also had the drawback, under Bangladesh government restrictions, of disqualifying the participants from longer training abroad. Despite these drawbacks, some of the early participants showed a remarkable commitment to wheat research.

The reward system needs considerable improvement. Although the wheat program received special awards from the government and from private voluntary organizations in its early years, few staff members were given better pay.

A National Wheat Research Center was established in 1982 and in the mid-1980s is on its way to becoming a self-contained research nucleus on the site allotted for the purpose in northwest Bangladesh. The future role of wheat in the country will be shaped there.

and do not see supervision of degree candidates as a natural extension of these tasks. This is a question of attitudes that is unlikely to be resolved by including academic supervision in the contractual responsibilities of center scientists. If the centers are to provide more degree-related training, as some believe they should, they will need additional personnel, space, and funds. In some cases it may be useful to appoint experienced academics as sabbatical workers whose duties include academic supervision; indeed, some appointments have had this character in the past. Postdoctoral researchers may also assume part of the task, as they do at ILRAD. The centers are not universities, but they need to have some of the characteristics of universities if they are to offer more opportunities for work toward higher degrees.

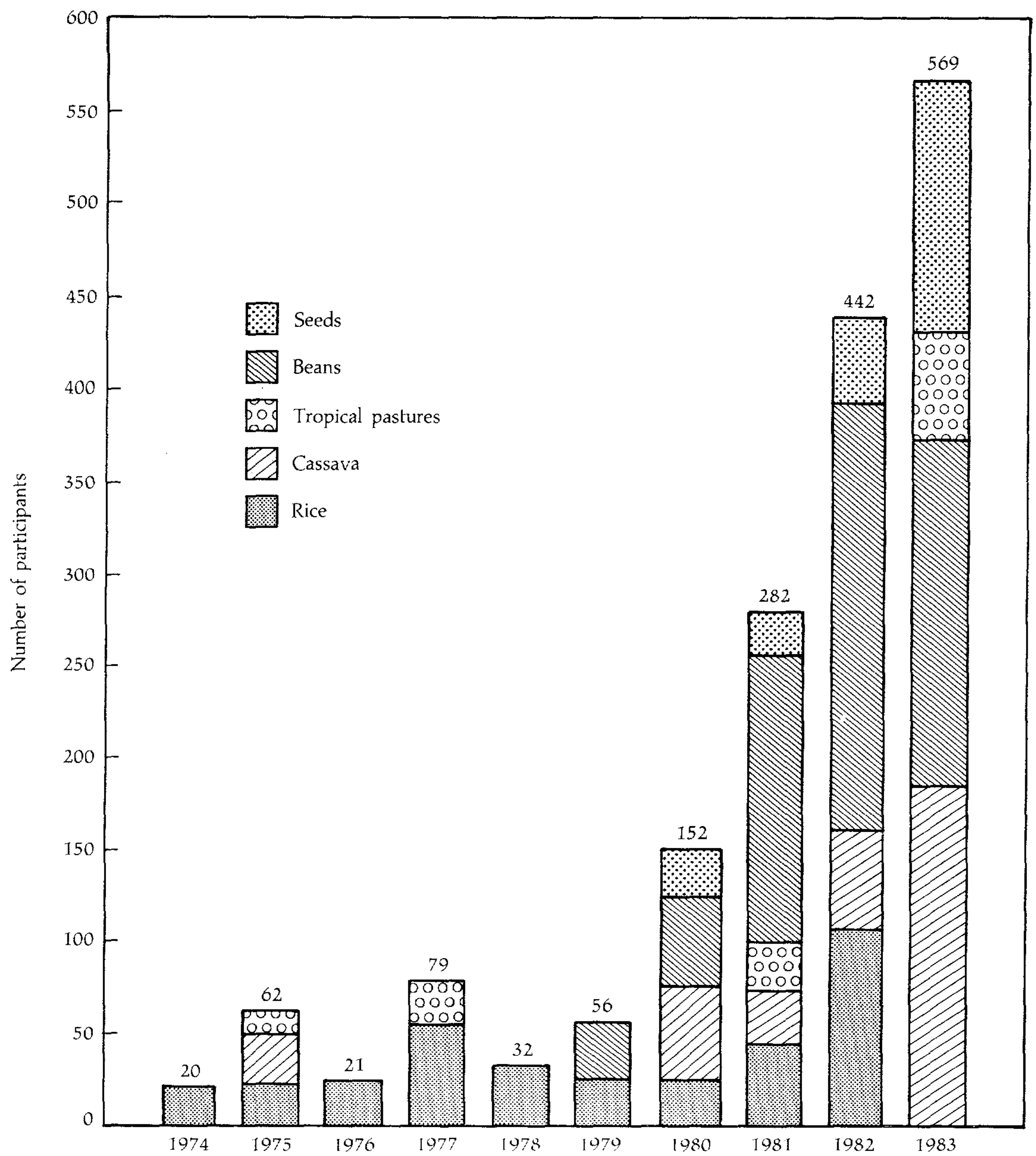
## Advantages of Center Training

Since the centers (unlike most other kinds of educational institutions, including universities) see participants as future collaborators in research, they do many things to increase the return on their investment in training. One center has set up a formal alumni association. All send much of their published material to as many former participants as they can, and some previous participants are invited back for additional training or to help in training others. These renewed contacts are helpful to the small and fragmented research communities of many developing countries, particularly where foreign exchange for books, journals, and travel is scarce.

Some countries have used training at the centers to strengthen ties among people working in different parts of the national agricultural system. Indonesia, for example, sent research workers, extension workers, and district managers, many of whom did not know each other, to study at IRRI together. This led to the creation of in-country courses in rice production, assisted by IRRI.

Assessments by past participants of the advantages of training at a center were consistently confirmed by supervisors in virtually identical language. But a few supervisors, while recognizing these benefits, suggest-

**Figure 5-1.** ***In-Country Training Courses Assisted by CIAT, 1974–83, by Specialty***




*Note:* Tropical pastures includes beef.

ed that study at a center could accustom people to techniques and equipment that could not be used or were not available at home. Similar remarks are often made about graduate students in universities in industrial countries.

An often-cited strength of the training is that much of the experience gained at the centers is practical, particularly in breeding and crop production courses. Working with a crop in the field from sowing to postharvest operations, or learning a specialized technique in the laboratory, turns theoretical knowledge acquired from reading and listening—"the study of agricultural science as a branch of literature," as one senior observer put it—into practical competence and understanding. Such an experience provides a basis for genuine confidence and produces far more effective research workers. Few people seem able to do effective research on a crop unless they also know how to grow it.

## Changes in Types of Training

It is not possible to quantify all the changes that have occurred in the training offered by the centers, but several are evident. One is a trend toward less training in production courses and more training in research methods. Another is a trend toward more training activities at places other than the headquarters of the center—that is, toward more in-country training.

Figure 5-1 shows the increase in the number of in-country training participants assisted by CIAT between 1974 and 1983. This kind of training is essential and must clearly be encouraged until the developing countries are strong enough to manage training for themselves. The call system (whereby trainers from a center respond to a call to help train national researchers at critical stages of the crop cycle) and systematic training of trainers to work in national systems can help to offset the loss of the intangible benefits of study at the centers themselves.

Many developing countries have plans to increase substantially their support for higher education, but few of these plans take account of the possible contribution of the centers. Some of the funds involved are earmarked for bilateral technical cooperation in education and training rather than for multilateral support for agricultural research. It should be possible to resolve this emerging problem, particularly if recipient countries themselves insist that the centers should offer more training for those seeking to earn advanced degrees.

## Note

1. Parts of this chapter are drawn from information assembled and papers produced by the TAC study team on training in the CGIAR system (see, for example, Bunting, Arajio, and Herz 1985). Box 5-1 is based on material collected by Anil K. Gupta during fieldwork for the impact study in Bangladesh.

# 6 Preserving Plant Germ Plasm for Future Generations

According to one source (Witt 1985) the Earth is home to an estimated 240,000 species of plants. But thus far the Earth's inhabitants have in general failed to realize the great value of the extraordinary diversity of the plant world. Only about 5,000 of the estimated 240,000 plant species have been carefully studied by scientists. Most of the rest grow, reproduce, and die with little human attention.

Given the awesome total number of plant species, one might expect that the human race by now would have found one or two thousand whose seeds, fruits, leaves, or roots are edible and nutritious. But only a few hundred of the plant species in the world are cultivated for food. All the rest—except for those cultivated for their flowers, their medicinal properties, or their value as spices—have customarily been seen (at least from an economic point of view) as worthless.

But that customary view has begun to change. Within the past twenty-five years even a part of the general public has begun to realize two things.

- The great diversity of plant life means that there is a huge and largely unknown array of plant genes, many of which might prove useful for human purposes in the future.
- It is a matter of the utmost importance to preserve as much as possible of the genetic base of food crops.

This chapter is about the second point.

## The Preservation of the Food Crop Genetic Pool

Plant genes determine the physiological characteristics of plants—in the most elementary terms, whether the skin of a ripe apple is green, red, or yellow, whether rice stalks, when ready for harvest, are short or tall, and whether maize provides the consumer with larger or smaller amounts of lysine. Genes inherited from the plant's parents determine, among other things, its ability to resist pests and diseases, to survive extreme heat or cold, and to make efficient use of plant nutrients. It was the gradual understanding of the role of plant genes and the fact that a plant's genetic constitution can be changed through conscious efforts by plant breeders that led to the beginning of widespread genetic experiments on food and industrial crop plants in the 1930s.

With the use of the germ plasm (seeds, roots, and cuttings) of traditional varieties of crop plants, of wild varieties (which are sometimes so far removed in appearance from their cultivated descendants that only specialists can tell that they are related), and of natural mutants, plant breeders were gradually able to develop more and more specialized "modern" varieties. Yet from the beginnings some fifty years ago of the intense effort to develop modern varieties of wheat, rice, maize, and numerous other plants, there were warnings that the deliberate production of modern varieties for very specialized purposes (greater yield, higher protein content, uniformity in size and color and so on) might lead to the loss of important genes found only in traditional varieties. USDA's 1936 *Yearbook*, for example, noted that Asia, Europe, and Africa all had untold numbers of traditional barleys.

> The progenies of these fields . . . constitute the world's priceless reservoir of [barley] germ plasm. It has waited through long centuries. Unfortunately from the breeder's standpoint, it is now being imperiled. When new barleys replace those grown by the farmers of Ethiopia or Tibet, the world will have lost something irreplaceable.

As time went on it gradually became evident that the substitution of modern for traditional plant varieties was not the sole reason for shrinkage of the genetic pools of food crops. Both wild and traditional varieties had disappeared or were endangered because of population pressures on farmland and countryside, widespread climatic disturbances, the natural view of many farmers that modern varieties were more profitable than traditional ones, and a general disregard of the natural environment.

By the early 1960s the threat to the genetic pools of food crop plants had become more evident—at least to the FAO, which issued foreboding notices on the subject. It was one of the many environmental and ecological problems that led in the late 1960s and early 1970s to strenuous efforts—particularly in the industrial countries—to spend much more money on cleaning up the environment and to enact more stringent laws for environmental protection. Another aspect of that renewed awareness of the importance of protecting natural resources was the creation in 1974, under CGIAR auspices, of the International Board for Plant Genetic Resources (IBPGR), with headquarters at the FAO in Rome.

IBPGR's task is to promote the collection, conservation, evaluation, utilization, and exchange of plant genetic resources. The Board is not primarily a technical assistance agency or a funding agency. Its work is largely conceptual and has been evolving toward intellectual leadership in genetic research, the development of documentation and transfer methods, and the training of plant geneticists and technicians in advanced methods.

The Board uses four criteria in determining when to encourage the conservation of a plant species: the degree of risk of genetic loss, the current and potential economic and social importance of the species, plant-breeding requirements, and the size and scope of existing collections. The crops that received priority during IBPGR's first decade were food crops, oilseed crops, a limited number of industrial and minor crops, and fuelwood trees in arid areas. Some important fruit and forage species were added in the early 1980s. Although conservation of regional and minor crops has been supported by IBPGR in some circumstances, that is generally considered the task of national programs or other organizations.

By the early 1980s the germ plasm of 138 crop species had been deposited in gene banks (IBPGR 1984). These germ plasm samples were gathered during 300 collecting expeditions in eighty-eight countries in all parts of the world. Over 550 collectors have been involved, most of them from developing countries. The material collected has been stored in gene banks operated in ninety-one countries by more than 450 organizations, including the CG centers involved in plant breeding. Many industrial countries have established gene banks as a contribution to the preservation of plant species. The gene banks now have substantial collections of most major crops and genetic materials of many other important crops (table 6-1).

A base collection consists of materials in long-term storage. An active collection, in contrast, is used for regeneration, multiplication, exchange, evaluation, and documentation. Working collections consist of materials held by breeders in their active breeding programs.

**Table 6-1.** ***Collection of Food Crop Germ Plasm***

| Crop | Accessions in major gene banks (thousands) | Distinct accessions (thousands) | Percentage of genetic materials collected[a] | | Threat to uncollected material |
|---|---|---|---|---|---|
| | | | Land races | Wild species | |
| Wheat | 400 | 125 | 95 | 60 | Medium |
| Rice | 200 | 70 | 70 | 10 | Medium |
| Maize | 70 | 60 | 90 | n.e. | n.a. |
| Barley | 250 | 50 | 40 | 10 | Medium |
| Sorghum | 90 | 20 | 80 | 10 | High |
| Phaseolus beans | 65 | 33 | 50 | 10 | Medium/low |
| Groundnuts | 33 | 10 | 70 | 50 | Low |
| Sweet potatoes | 8 | 3 | 60 | 1 | High |
| Potatoes | 42 | 30 | 95 | n.e. | Low |
| Okra | 3 | 2 | 80 | 3 | Medium |
| Cowpeas | 18 | 12 | 75 | 1 | High |

n.a. Not enough information available.
n.e. Not estimated.
*Source:* IBPGR 1984.
a. The base for the percentages is a collection that is judged to be adequate.

A base collection must have an active collection closely associated with it, since base collections are not usually involved in the exchange of germ plasm. This is not well understood, and that misunderstanding has sometimes led to unwarranted charges that restrictions have been placed on the free flow of germ plasm.

IBPGR's global network consists of base collections only, but not all gene banks with long-term storage capacity have been designated as base collections. The Board's view is that there should be at least one center (preferably two) with responsibility for holding a base collection of materials of each important crop under conditions that assure the long-term viability of the materials.

The Board believes that about fifty base collections are needed to form a reasonably complete network of some forty crops or groups of crops. The Board expects that all base collections will be in existence and duplicated by 1990.

The Board's activities and the germ plasm collection and preservation activities of the other cènters are potentially important in plant breeding and new crop development, but they will have an impact on production and human well-being only in the longer term. Accordingly, the discussion of the centers' work in this chapter primarily concerns achievements as of the mid-1980s that will be important to agricultural research programs in future decades.[1]

## The Centers' Germ Plasm Activities, by Crop

### *Wheat*

Collections of wheat germ plasm exist in forty countries, including twenty-four developing countries. The CIMMYT collection of wheat germ plasm is largely a breeders' working collection. The gene bank consists of, approximately, 15 percent land races, 50 percent developing country varieties and other advanced lines, 30 percent industrial country varieties, and 5 percent wild species. The small percentages of land races and wild species militate against a proper use of these resources in a plant-breeding program. Although the genetic base is sufficient for short-term advances, it is narrow. Thus CIMMYT cannot yet make effective use of the total genetic diversity found in wheat varieties around the world.

ICARDA's position in respect to the germ plasm of durum wheat is a little better. Its 16,500 accessions of durum consist mainly of land races, a large proportion of them from high-elevation sites. This genetic base is satisfactorily broad, and its effects on plant breeding should be positive when storage facilities are completed.

A wide crossing program (that is, a program of crossing different species or land races that differ greatly from the cultivar) was begun at what is now CIMMYT in 1959. The work was intended to develop resistance to the fungi *Helminthosporium sativum* and *Fusarium graminearum* and to produce greater tolerance of such stresses as high salt levels, drought, heat, and excessive concentrations of aluminum and copper in the soil. Some 27,000 lines from these crosses have been evaluated. Crossing success has been limited, and little use has been made of bread-wheat land races. The cereal breeders at ICARDA have begun a wide crossing program using durums and the traditional species *Triticum dicoccoides* (emmer) and *T. aestivum.*

CIMMYT's wide crossing program is designed to introgress useful genes from related genera into wheat. To date 188 intergeneric crosses have been accomplished since the program was initiated in 1979. The intergeneric crosses, together with germ plasm from CIMMYT's interspecific crossing program, should serve the variability needs of a long-term wheat-breeding program. Training in varietal evaluation, breeding, and trials has been intensive and has given a large boost to the development of national programs. Satisfactory data base systems have been developed at ICARDA, but inventories from CIMMYT were not available at the time of this review.

CIMMYT can be criticized for its lack of interest in surveys and exploration activities, for its apparent reluctance to accept global responsibility for bread-wheat germ plasm, and for its rather narrow base of gene bank material. It has preferred to draw on material from other gene banks for wide crossing. Nevertheless, its record in the breeding and release of varieties in cooperation with national programs is spectacular. But it may be difficult to maintain this record if the genetic base is not broadened considerably. CIMMYT should perhaps possess a more active gene bank rather than confine its bank almost entirely to working status. It should have a broad genetic base that includes land races and wild species of wheat as well as *Aegilops* grasses and other related genera. ICARDA's record in this respect is better.

CIMMYT has a strong program in the man-made crop triticale, a cross of wheat and rye. Triticale was conceived primarily as a food and feed crop in areas not generally suitable for wheat or maize, such as areas with acid soils and semiarid and elevated regions. Since the inception of triticale research at CIMMYT in 1968 the crop has changed from a scientific curiosity to a useful grain. Argentina, Brazil, Tunisia, and several other countries are increasing their triticale hectarage, and Poland hopes to have a million hectares of triticale in production by 1990. CIMMYT maintains in Mexico a germ plasm collection of practically all known spring triticales.

### *Barley*

Neither CIMMYT nor ICARDA has undertaken a survey of barley materials in the field or in gene banks. Instead they rely on IBPGR for this function. IBPGR and ICARDA have assembled data on world barley expeditions and have concluded that barley varieties in Ethiopia and Turkey are fairly well collected. Barley strains in most other countries are poorly collected, and little information exists on such major collections as China's. Only 12,000 land races and wild species of barley have been collected, more than one-third of them from Ethiopia and more than 10 percent by a single expedition in Greece, Iran, and Turkey. Further barley collections should be made in the ICARDA mandate area of North Africa and the Middle East.

ICARDA recently collaborated with IBPGR on a collecting mission to Morocco, where eighty-nine samples of barley were collected. ICARDA should make itself responsible, either alone or with IBPGR, for a crash program to collect land race and wild barley varieties. Otherwise much genetic diversity will be lost or at least will be unavailable to breeders. CIMMYT has a breeders' working collection of 4,630 barley accessions, while ICARDA possesses 14,215 accessions, mainly obtained from the USDA small-grains collection.

Some 8,000 accessions have been characterized at ICARDA with the use of twenty-five descriptors, of which two deal with protein and lysine content and the rest are morphological and agronomic. Drought tolerance is extremely important. Land races from China, Korea, Tibet, and the Middle East have been evaluated for this characteristic, as have 780 accessions of wild barley (*Hordeum spontaneium*). Salt tolerance is also important, and sixty-nine barley lines have shown promise in this respect. A preliminary catalog of 5,000 accessions has been produced. Varieties are needed that produce good yields in regions of low rainfall or where green-stage grazing of barley by sheep is practiced. In 1983 ICARDA initiated a genetic resources unit (GRU) to supervise and classify the center's accumulation of germ plasm.

### *Rice*

The global mandate for conserving the genetic resources of rice varieties lies with IRRI. West African rices (*Oryza sativa* and *O. glaberrima*) also fall within IITA's mandate. Between 1978 and 1983 IRRI and IBPGR jointly held two workshops to review the need for rice variety exploration and conservation. A report on Asian wild rices by the IRRI/IBPGR rice advisory committee (1983) set out priorities for exploration, conservation, and characterization.

Rice exploration activities have been well coordinated and documented, and manuals for field collectors have been published. A coordinated exploration scheme that involves fourteen countries in South and Southeast Asia has been established by IRRI. During 1971–84 some 39,200 samples were collected in Asian countries, almost a third of them by IRRI expeditions. IBPGR funds made it possible to assemble nearly 11,000 samples from seven Asian countries and Madagascar. In Africa IBPGR coordinated efforts by IITA, the French Office of Scientific and Technical Research Overseas (ORSTOM), WARDA, and others to gather nearly 9,000 samples, including 972 of *O. glaberrima* and 77 of wild species.

IRRI has an excellent program of rice conservation and regeneration (IRRI/IBPGR 1983), and as of June 1983 there were just under 80,000 entries in its long-term base collection, including 1,100 wild species. The IITA collections of nearly 9,000 entries are under medium-term storage, but a special project supported by the Italian government will provide the conditions and capacity for long-term base storage.

IRRI's evaluation program includes characterization not only for fifty morphological and agronomic features but also for thirty-eight resistance and adaptation characters. IITA uses forty-four morphological and agronomic characters and a range of pest and disease resistance features related to African conditions. Evaluation at both institutes is very satisfactory.

The movement of germ plasm that is disease and pest resistant and stress tolerant into rice gene pools is progressing actively (Chang, Adair, and Johnson 1982). Resistance to the green leafhopper has been transferred from *O. glaberrima* to *O. sativa* through hybridization. The transference of aluminum tolerance from Brazilian to Asian rices and of resistance to iron toxicity from African to Asian rices has also been noteworthy.

Training in genetic resources work and related disciplines has been good at both IRRI and IITA. IRRI has provided in-service training on gene bank management for the staffs of national research institutes, and IITA has presented two courses on genetics that were financed through IBPGR.

### *Maize*

Maize is now grown in nearly all tropical, subtropical, and warm temperate countries, and the problem of conserving its genetic diversity is more complex than for a crop restricted to a smaller and more uniform area.

The centers of diversity lie in Latin America. The CIMMYT maize bank, which contains much but not all of the maize germ plasm of Latin America, has no computerized data storage and retrieval system. Such a data base should also incorporate information from the more important national maize collections in Latin America and, if possible, in other parts of the world. IBPGR has constructed data bases for six Latin American countries, and these data are ready for incorporation into CIMMYT's data base. The lamentable lack of impact here is attributable to the low priority assigned by CIMMYT to this type of work in the past. In 1984, however, CIMMYT agreed to accept global responsibility for maize germ plasm from 1985 onward and will provide long-term storage and other facilities.

Although IBPGR believes that collections of the world's maize varieties are adequate (apart from maize varieties in the Himalayas and a few other areas), a final assessment must await the completion of surveys. CIMMYT's medium-term storage facility for 15,000 samples is less than perfect, but planned improvements should raise storage life from about twenty or twenty-five to about forty or fifty years. All materials need regeneration, and this is being carried out by CIMMYT and Pioneer Hi-Bred International, Inc., at the rate of some 500 samples a year. It has not been possible to regenerate 1,200 varieties from the original collections, and 750 varieties from Ecuador and Peru cannot be brought to the flowering stage in Mexico. Nonetheless, the CIMMYT collection is basically very valuable. The chief improvement needed is in maize relatives.

### *Sorghum and Millets*

Sorghum and millet surveys were carried out by an IBPGR/ICRISAT Advisory Committee in 1976 and 1981, and a world survey of these two crops was published on the basis of the committee's recommendations (Acheampong, Anishetty, and Williams 1984). Although good collections of cultivated sorghums exist, work is urgently needed to collect sorghum varieties in the Central African Republic and Chad. The gene banks also lack wild specimens. In 1982 only 167 samples belonging to ten related taxa were in the ICRISAT collection. Much more collecting of wild sorghum species is needed, especially in Burundi, Ethiopia, Kenya, Rwanda, eastern Sudan, Tanzania, and Uganda.

A total of 24,600 sorghum samples are held at ICRISAT under medium-term storage conditions, and a new long-term storage facility with room for 100,000 samples has almost been completed. Large collections are also stored in Argentina, Australia, China, Ethiopia, France, India, Mexico, Romania, Thailand, the United States, the U.S.S.R., and the Yemen Arab Republic. Long-term backup collections of sorghum exist at ICRISAT and at Fort Collins, Colorado.

ICRISAT stores 17,000 samples of pearl millet (*Pennisetum americanum*). Wild varieties of pearl millet are underrepresented, and cultivated or wild materials are needed from Burkina Faso, Central African Republic, Chad, Mali, Mauritania, Namibia, Niger, Sierra Leone, and Sudan. The oases of North Africa and certain areas of Ethiopia also should be explored for pearl millet types, as should parts of Burma, India, Pakistan, the People's Democratic Republic of Yemen, and Spain. There are backup collections of *Pennisetum* at ICRISAT and in Ottawa and Fort Collins.

Collections of both cultivated species and progenitor materials of finger millet need to be enlarged. Very little collecting has been done on the minor species, including foxtail millet, proso millet, little millet, barnyard millet, kodo, forio millet, and teff, although there are backup collections for finger millet (*Eleusine*) in Addis Ababa and for foxtail millet (*Setaria italica*) and proso millet (*Panicum milaceum*) at ICRISAT.

ICRISAT's evaluation work on Gramineae is confined to sorghum and pearl millets. For sorghum 20,355 lines have been evaluated according to their morphoagronomic characteristics. Disease, pest, and drought resistance have been recorded on the basis of apparent adaptation, and screening against grain mold, downy mildew, *Striga* (a plant that is parasitic on roots), and midge has been carried out. Large-scale characterization and screening of pearl millet for resistance to downy mildew, ergot, and smut has been undertaken, and 16,022 lines have undergone morphoagronomic evaluation. Introgression of genes from agronomically poor or wild material into high-yielding short-stature and daylight-insensitive material has been accomplished in both sorghum and pearl millet.

### *Potatoes and Sweet Potatoes*

By 1980 CIP had collected samples of more than 90 percent of all cultivated potato varieties, and it now has about 5,000 samples in its collection of cultivated potato germ plasm. No other center has achieved such a high level of preservation of a cultivated food crop.

The cultivated varieties are planted annually in experimental fields at high altitudes, and their progeny are stored in a controlled facility. All of CIP's samples of cultivated potato varieties have been characterized according to the CIP/IBPGR description list. The list has fifty-six morphological descriptors, ten agronomic descriptors, five descriptors for drought and heat tolerance, sixteen descriptors relating to diseases and pests (not very useful, since the pathotypes are not distinguished from each other), and four chemical descriptors.

Much work on the potato, at CIP and elsewhere, involves breaking the barriers to sexual crossing through conventional methods that use bridge varieties and through modern in vitro techniques such as protoplast fusion and embryo culture. In vitro storage has been developed, and currently twenty-six clones are being stored. Clone distribution is a problem, however, because only in vitro, pathogen-free material can be transported.

All potato evaluation results are deposited in a computerized data storage system and are available on demand. Unfortunately no inventories have been published.

Wild varieties of the potato have also been systematically collected, particularly in Argentina, Bolivia, Chile, Colombia, Ecuador, Mexico, and Peru. About 1,500 samples of ninety wild varieties are kept in the form of true seed, together with seeds of the cultivars, in medium-term storage. Progress in producing enough true seed of wild species for long-term storage has been slow. Certain wild species show resistance to potato leafroll virus, potato spindle tuber viroid, different pathotypes or races of bacterial wilt, the two cyst nematodes, and viruses X and Y.

An IBPGR survey of sweet potato germ plasm was published in 1981, and CIP has started a sweet potato survey of the Americas. Particular attention will be paid to collecting wild American varieties, since these are thought to be genetically closer to the cultivar, but wild varieties from other parts of the world should also be collected to provide as broad a genetic base as possible.

IITA holds about 1,000 clones of sweet potato in tissue culture. The varieties have been collected since 1976 on expeditions to eighteen African countries. Superior virus-free clones from the collection have been distributed to forty-nine countries. Evaluation at IITA for resistance to the sweet potato virus disease complex and the sweet potato weevil has shown promise. Of 414 lines tested, 55 have shown a high degree of resistance to the nematodes *Meloidogyne incognita* and *M. javanica*.

### *Cassava and Yams*

CIAT has accepted the mandate to preserve cassava germ plasm on a worldwide basis, but a substantial collection of cassava germ plasm is also kept at IITA. CIAT has 3,600 entries, and over 2,000 of these have successfully been put into in vitro storage. A set of forty to fifty elite lines is kept in vitro for distribution. Because of quarantine restrictions all intercontinental exchanges (and most international ones in Latin America) can now only be made in the form of in vitro materials. During 1973–84 cassava germ plasm was transferred to fifty countries in the form of stakes (699), in vitro materials (832), and seeds (321,611).

Preliminary evaluations are made to assess yield, root quality, and resistance to diseases and insects. CIAT has not yet found resistance to African mosaic virus in the cultivar, but resistance is found in the wild species *Manihot glaziovii*, and IITA has identified many resistant lines that are widely grown by farmers in Africa. There is an urgent need to intensify the evaluation of wild species. Promising levels of resistance to thrips, mites, whiteflies, mealybugs, and lacebugs have been found, as has tolerance of low soil fertility. Some work on bridge hybrids has been done to broaden the genetic base and to concentrate useful characteristics in advanced breeding lines, but few efforts have been made to introgress useful characters from wild *Manihot* species into the cultigen. Basic research on wild species and their genetic compatibility with the cultivar is still at an early stage, although IITA has made three interspecific crosses, matching its achievements with the sweet potato.

IITA has been assigned a global mandate for yam improvement and maintains a germ plasm collection for white yam (*Dioscorea rotundata*), water yam (*D. alata*), yellow yam (*D. cayenensis*), and trifoliate yam (*D. dumetorum*). The collection includes 741 accessions for *D. rotundata*, 310 for *D. alata*, and smaller numbers for the others.

After making extensive studies of flowering, seed behavior, plant physiology, and the activity of yam-pollinating agents under field conditions, IITA scientists have perfected the basic techniques of hybridization, seed germination, seedling establishment, and rapid multiplication of selections. With the use of these techniques many promising clones of the white yam have been produced.

Many water yam clones that are resistant to necrosis disease and have high yield potential (up to 40 tons per hectare if staked and 20 tons per hectare if unstaked) have been selected from the germ plasm collection. Some of these have round, uniform, thick-skinned tubers that are ideal for mechanical harvesting and processing.

### *Faba Beans and Lentils*

ICARDA has accepted the world mandate for these two crops and has collected 2,800 samples of faba bean varieties and 5,800 samples of lentils. Varieties from such countries as China, India, and Iran are seriously underrepresented in faba bean collections. ICARDA has set priorities for collecting in North Africa, West and South Asia, and Chile, regions that are also underrepresented in wild lentils.

The method adopted for screening land race samples of faba bean, since each sample is highly variable within itself, is to screen the pure lines extracted from each while retaining the original population sample. Good sources of resistance to *Botrytis* (gray mold) and *Ascochyta* blight have been identified, and selections able to grow in low-rainfall areas have emerged. Resistance to nematodes and to the parasitic plant *Orobanche* has also been found.

Wild lentils have not yet been properly evaluated. So far, features useful to breeders that have been identified include cold tolerance, height, resistance to lodging, and resistance to rust and *Ascochyta*. ICARDA collaborates with Egypt and Sudan in screening for important pests and diseases. Other objectives are higher protein content and the elimination of factors that cause favism (an acute anemia) in some people. Several training courses for Arab-speaking participants have been organized at ICARDA with the help of IBPGR. A book on genetic resources for chickpeas, faba beans, and lentils published by ICARDA in collaboration with IBPGR should facilitate further work on these species.

### *Phaseolus Beans ("True Beans")*

The genus *Phaseolus* includes many familiar edible beans as well as field beans used for fodder. CIAT has accepted responsibility for the collection, storage, and characterization of all four cultivated *Phaseolus* species and their wild relatives, but the breeding and improvement program is confined to one species, *P. vulgaris*, which includes green beans and kidney beans. The need for surveys of the genetic materials in collections is being analyzed by CIAT and IBPGR. It seems clear that more efforts are needed to collect *P. coccineus* (scarlet runner bean), *P. lunatus* (lima bean), and *P. acutifolius* (tepary bean), even though their areas of cultivation are not so extensive as that of *P. vulgaris*.

CIAT has made or encouraged expeditions, generally with IBPGR funding, to the *Phaseolus* regions of origin and primary diversity, particularly Argentina, Bolivia, Brazil, Central America, Colombia, Ecuador, Mexico, Peru, and Venezuela. Collections have been made by national scientists and by USDA and IITA teams in Africa, Asia, the Iberian peninsula, and elsewhere.

Storage conditions at CIAT are good. At present there are 17,000 samples in the active collection and 3,000 in the base collection. CIAT storage of materials from Africa, Asia, Eastern Europe, and Brazil has been hampered by quarantines, however. Six thousand samples in active storage are deteriorating because Colombia requires each sample to be grown for one season in a quarantined greenhouse.

Nearly 25,000 samples of *P. vulgaris* have been distributed to other countries. In addition, 74,900 samples have been used in the CIAT bean-breeding program. Some 12,000 accessions of *P. vulgaris* materials have been characterized according to twenty-eight of the fifty-nine IBPGR morphoagronomic characteristics, and the information has been placed in data bases. Accessions are initially evaluated for growth, adaptation, yield, and general resistance to diseases and pests. This is followed by more careful evaluation for resistance to bean golden mosaic virus, common bacterial blight, *Asochyta* leaf spot, leafhopper, and the bean weevil *Acanthoscelides*.

### *Chickpeas and Pigeon Peas*

The cultivated chickpea extends mainly through the Mediterranean Basin, the Middle East, central Asia, India, and Ethiopia but is also grown in many other countries. Of the two types, desi and kabuli, ICRISAT has responsibility for desi, while responsibility for kabuli is shared by ICRISAT and ICARDA.

ICRISAT holds over 13,000 chickpea entries from forty countries, but many of these will prove to be duplicates. In 1977 ICARDA inherited 1,798 kabuli chickpea accessions from a Ford Foundation program, and it has added 2,600 more accessions, most of which are said to be land races.

Pigeon pea materials at ICRISAT number 10,000 samples from thirty-six countries, including 46 samples of related wild species. Considerable exploration is needed for wild species in the genera *Cajanus* and *Atylosia*. Nine wild annual and six perennial *Cicer* species were assembled at ICRISAT early in its life. Annual species are being maintained satisfactorily, but the perennial species are difficult to maintain. The wild pigeon pea *Atylosia latisepala* was crossed successfully with the cultivar *Cajanus cajan*.

Some lines that are medium resistant to *Ascochyta* blight were found through screening work by ICRISAT in northern India and by ICARDA in Syria. Screening for chickpea stunt (pea leafroll virus) has not been carried out systematically. Some work has been carried out on nematodes, iron deficiency, and soil moisture stress. A few promising lines of chickpea have shown increased capacity for nitrogen fixation.

Almost the entire pigeon pea collection at ICRISAT has been screened for *Fusarium* wilt resistance, and thirty lines with good resistance have been identified. *Phytophthora* stem and leaf blight has also received attention, but the results have been less promising. Both ICRISAT's and ICARDA's complete collections of chickpeas and pigeon peas have been screened for resistance to *Heliothis* moth larvae, and a few promising accessions have been identified. At ICARDA 3,300 kabuli chickpea accessions have been evaluated for morphoagronomic characters as well as for resistance to *Ascochyta* blight, tolerance of cold and of iron deficiency, and photoperiod insensitivity. Many useful lines have been identified.

### Groundnuts

The common groundnut, *Arachis hypogaea*, is an ICRISAT-mandate crop. The other two groundnuts, *Vigna (Voandzeia) subterranea* (bambarra groundnut) and *Kerstingiella geocarpa* (Kersting's groundnut), are grown to a limited extent in Africa and have been collected by IITA.

*Arachis* is native to South America, where all the related wild species in the genus are found. Although the cultivar is fairly well explored, collection trips into the hinterlands of Brazil and adjacent regions and to Africa and Asia are still needed to discover wild species.

ICRISAT stores 11,500 accessions of cultivated material from eighty-four countries—a good representation of total genetic diversity. IITA has 1,100 accessions of bambarra groundnut but only 47 accessions of Kersting's groundnut. Large collections of bambarra groundnuts have been sent to Burkina Faso, Japan, and Zambia for testing.

Evaluation work on groundnuts at ICRISAT has been developed to a high level. Groundnut descriptors were developed in 1981 in collaboration with IBPGR; they include morphoagronomic, disease, pest, and stress descriptors. Some 9,000 accessions have been characterized.

### Cowpeas and Soybeans

IITA is responsible for the storage of a global base collection of cowpeas (*Vigna unguiculata*) and for its enlargement and improvement. It also holds a mandate for the storage and improvement of soybeans (*Glycine max*). The cowpea is indigenous to Africa, and high priority is accorded to the collection of wild relatives there. The soybean was domesticated in China, and there is little diversity in Africa. IITA has 1,350 accessions of soybeans.

The cultivated cowpea collection at IITA now stands at 11,800 accessions obtained from eighty-five countries. During 1978–83, 10,600 samples of cowpea germ plasm were distributed to over fifty countries, half of them in Africa. The genetic resources unit has characterized about 9,000 accessions for agrobotanical features and, in collaboration with the crop improvement programs, has evaluated materials for resistance to disease, pests, and stress. Sources of resistance to bruchid weevils, thrips, aphids, leafhoppers, mosaic virus, and cowpea mosaic virus have been found. General screening for agronomic characters is under way, and lines with good seed storability have been found in Indonesian germ plasm. Good root-nodulating lines have also been identified.

### Forage Grasses and Legumes

The mandate for exploration and conservation of forages from the dry regions of North Africa and the Middle East has been accepted by ICARDA, which directs most of its efforts toward *Medicago* and *Trifolium* species. CIAT has taken responsibility for tropical forage germ plasm for acid soils, with special emphasis on Latin America. ILCA is responsible for graze and browse forages (chiefly legumes) from Africa, especially *Trifolium* species. Cooperation between CIAT and ILCA prevents any excessive duplication of effort on forage grasses and legumes.

ICARDA's collection of some 16,800 samples is 90 percent legumes. During 1979–81 ICARDA received 9,476 forage samples from thirty-five countries, including some samples from existing collections, and in 1984 it collected in Cyprus, Morocco, and Syria. Between 1979 and 1984 it distributed 3,636 samples, mainly to developing countries. ICARDA has screened more than 1,800 genotypes of vetches, peas, and medics for disease resistance and for ability to produce self-regenerating pastures. *Medicago rigidula* is the most promising from the latter point of view.

ILCA began its forage program only in 1980 and has not progressed very far, but detailed collection plans that concentrate on the indigenous *Trifolium* species of the East African highlands have been worked out. ILCA lacks suitable storage facilities.

CIAT has made some attempts at surveys and has identified twenty-four grass genera of interest and twenty-five legume genera. Since 1979 CIAT has made extensive collections in Latin America, particularly of forage legumes, but the Latin American grasses are not as useful as those of Africa and Asia. The CIAT team is also collecting in Africa in collaboration with ILCA and national institutions. CIAT has no formal mandate to conserve forage germ plasm, but it does deposit such materials in its gene bank. The collection amounts to more than 13,000 accessions, of which 11,900 are legumes. The whole CIAT collection is in short- or medium-term storage, which is unsatisfactory. Distribution of samples during 1980–84 was good; 7,318 samples went to national programs.

An active breeding program is under way at CIAT, especially for resistance to *Anthracnose* fungi in the legume *Stylosanthes guianensis*. Selections of the African grass *Andropogon gayanus*, released in Colombia under the name Carimagua I and in Brazil as Planaltina, show excellent adaptation to low-fertility acid soils with high aluminum content, as well as tolerance to pests, diseases, drought, and fire.

On the whole, the exploration and collection of tropical pasture species has progressed too slowly. CIAT's programs have progressed much further than those of ICARDA and ILCA, which have had much less time to accomplish their goals. The lack of good storage facilities is unfortunate, but IBPGR has made proposals to improve storage.

## Note

1. Most of the material that follows is derived from Hawkes (1985), and the recommendations for action are his. Unless otherwise specified, the data and assessments refer to the period up to early 1984.

# 7 The Growing Importance of Policy Analysis

Earlier chapters have addressed the centers' contributions to new agricultural technology. Much has been done: new food crop varieties, improved cultivation practices, and increased knowledge and research capacity have been developed. Yet it is clear that greater production of food does not lead automatically to better distribution of food or to improved nutrition. The early 1970s, for example, were years of generally poor harvests worldwide. Nonetheless, the global supply of food energy available from basic grains alone exceeded average per capita requirements by more than 20 percent. By 1978 grain supplies exceeded world food requirements by almost 50 percent, not counting the energy available from oils, sugar, meats, fruits, vegetables, and pulses. The situation is much the same today, but millions of the world's inhabitants remain poorly fed.

Analysis of the large body of empirical evidence has shown that technological changes alone are not enough to ensure that people are fed. A broad range of economic policies influences the production, distribution, consumption, and pricing of food. The policies have a direct bearing on the demand for technological change and on the extent and impact of change. Research which leads to an improved understanding of the nature of these policies is thus an important element of global agricultural research.

## The Diversity of Policy Issues

Agricultural and food policies are the collective efforts of national and international agencies to influence the actions of producers, traders, and consumers. The purpose of these interventions is to make more effective progress toward certain social goals: improved nutrition, higher rural incomes, more rural employment, improved food security, and possibly greater national self-sufficiency in food production. Food policy research involves the identification of ways to carry out necessary policies, the quantification of the effects of policy changes on social objectives, and the development of analytical schemes, bolstered by empirical evidence that demonstrates the complementarities and conflicts among these objectives.

Food policy analysts concern themselves with such issues as current food production, the generation and diffusion of new agricultural technology, the enhancement of physical and human capital, the distribution and pricing of food, and agricultural trade. What happens with respect to any of these depends on a multitude of policy alternatives. The wide scope of the issues and the range of potential policies make food policy analysis a complex task. An example is the effect of overvalued exchange rates on agriculture.

Developing countries commonly use overvalued exchange rates as part of a strategy to accelerate economic development by speeding industrialization. Overvalued rates lower the prices of the country's tradable goods in relation to the prices of its nontradable goods. Imports are thus made cheaper (although in fact their quantities are often restricted), and exporting becomes more difficult. The implications of this policy for the production, consumption, and trade of foodstuffs are manifold.

The intent is to help low-income consumers by holding down the local price of tradable goods. But depressed prices discourage domestic production and give less incentive for investment in agriculture. (Investment is less attractive when agricultural output is undervalued.) Resource allocation between sectors responds accordingly: resources are moved out of agriculture into other sectors, and agricultural output, employment, and income are held back. This encourages farmers to leave agriculture, a tendency that is intensified by the higher urban wages that result as labor unions capture a part of the rents generated by the protection of industry.

As the urban population increases and food production remains stagnant or declines, the government begins to feel pressure to import food to hold down prices and wage costs. Continued shortages give rise to pressure for food subsidies for some or even all of the population. The combined effect of increased food imports and of subsidies for consumption is to place additional pressure on both the internal and external accounts of the country. Balance of payments difficulties are worsened by a decline in agricultural exports.

To hold down budget costs the government may compel local producers to deliver food at prices significantly below those that it pays foreign producers for imported supplies. When foreign exchange crises arise, there is little leeway to cut food imports that have been made "essential" by the other strategies being pursued. Imports of capital goods are curtailed, which reduces the growth of the capital stock, and imports of raw materials are restrained, reducing the utilization rate of installed industrial capacity. Employment and output in the industrial sector are then destabilized.

If research is to ease the task of policymakers, it must deal to some extent with all of these issues and more. There lies the challenge, if not the charm, of policy research.

## The Design of Agricultural Technology

Policy research can have a strong effect on the design, production, and diffusion of new agricultural technology and may help biological researchers to justify their work. Some examples of this role of policy research are given below.

Plant-breeding programs are sometimes directed toward enhancing the nutrient value of a crop. This may be a long and difficult task that requires tradeoffs against gains in productivity. Higher protein content in rice, for example, generally comes at the cost of lower yields. Thus the analyst must address a number of questions. Could an equal gain in nutrient intake be achieved by altering the mix of crops? How will the production of other crops be affected? Would it be better to use other instruments (maternal and child care, health services, or food subsidies) to address the nutritional needs of a specific group?

Another issue is variability in agricultural output. One reaction is to concentrate on developing plant varieties with greater ability to withstand disease, shortages of fertilizer or water, temperature extremes, and so on. But the problem calls for a much more complete assessment of the causes and magnitudes of instability and for a broad perspective on the range of possible instruments. Would other changes in the farming system enhance stability at less cost? Would readier access to fertilizer and pesticides or investment in irrigation reduce fluctuations in output? Would crop insurance be a cost-effective way to ameliorate the effects of instability? In short, policy analysis may offer a number of possible solutions to a problem that initially appears to be purely technical.

Large-scale farmers in Colombia achieved high cassava yields through monoculture while nearby small farmers who used complex multicropping systems produced small yields. The initial reaction was to call for cassava varieties tailored to the small farm. On closer inspection, however, it was learned that the small farmers used a multicropping system to reduce their need for pesticides. Because of excess demand for subsidized credit and the ensuing use of nonprice rationing methods to allocate credit, the small farmers could not borrow the money they needed to buy pesticides. It is conceivable that a nonsubsidized interest rate on agricultural loans would raise output on small farms sooner and more substantially than would the development of a new type of cassava.

These examples show that many agricultural problems may benefit from collaboration among breeders, agronomists, and economists.

## Policy Research in the CGIAR System

Since its beginnings the CGIAR has taken a strong interest in food and agricultural policy, particularly as these impinge on the generation and diffusion of farm technology. A seminar on socioeconomic research at the centers was held in 1973, and in July 1974 the chairman of the CG's Technical Advisory Committee (TAC) recommended the establishment of an international center to study key policy issues relating to world agricultural development, particularly food problems.

The International Food Policy Research Institute (IFPRI) was formally incorporated in early 1975, with funding from three donor members of the CGIAR. In 1978 the sponsors sought to have the institute's funding transferred to the CGIAR, and this was done in 1979. IFPRI's mandate is to identify and analyze policies for meeting world food needs, with particular attention to low-income countries and especially to the needs of the poor in those countries.

## Current Policy Research Activities

### *IFPRI*

Fewer than one-third of the social scientists in the CGIAR system work for IFPRI, even though it was designed to undertake most CG research on policy matters. Although the microeconomic work done at the centers has always been seen as valuable, the Technical Advisory Committee felt that many macroeconomic policy issues were not being adequately addressed. IFPRI was established largely to remedy this weakness.

The institute has five research programs: agricultural growth linkages and development policy, food data evaluation, food production policies, international food trade and food security, and food consumption and nutrition policy. IFPRI focuses on finding answers to six questions:

1. What food policy adjustments are needed to respond to rapid growth in food imports by developing countries?
2. What policies will allow technological change to play a central role in raising food production in developing countries?
3. What combination of agricultural incentives can achieve growth and equity simultaneously?
4. How much weight should be assigned to minor agricultural commodities in future production patterns?
5. What technological policies are needed to stimulate the growth of income and employment in poor rural areas?
6. How can food security be assured for poor people in the face of unequal distribution of income, fluctuating farm production, and the high costs of food storage?

### *Other Centers*

Most other centers conduct some kind of socioeconomic research. In the *systems* approach, used by ICARDA, IITA, ILCA, and IRRI, social science research is included in studies of farming systems. In the *disciplinary* approach, this work is conducted by a separate economic or socioeconomic research department. CIMMYT, CIP, IRRI, ICRISAT, and WARDA have such departments, and ILCA has a livestock policy unit. Much of the social science work undertaken by these centers is linked with farming systems research. In the *commodity* approach, adopted only by CIAT, social science research is incorporated into the work of multidisciplinary teams that address a particular subject or commodity, such as tropical pastures, beans, or cassava.

The social science work done by the centers other than IFPRI has chiefly involved studies of the technological and economic circumstances of farm producers. The centers use these studies to guide the development of new technology, estimate the payoff to alternative research strategies, collaborate in research trials on stations and farms, and document the adoption and consequences of new technology. Little has been done on food and agricultural policies in themselves; such work has generally been seen as diverting resources from biological research.

It was also felt for a long time that policy analysis was the domain of national governments and that efforts by the centers to address domestic policy questions would be an intrusion into sovereign affairs. Although the centers could collaborate with a country's scientists (and thereby influence their aims and methods), there was some concern that if the centers gave too much direct advice on policy matters, they might be accused of political meddling.

In practice, however, the centers have had to assess policy environments no less than agroecological environments. This has led some of them to examine the structure of incentives for producers and consumers of particular crops. (CIMMYT's work on maize and wheat in a number of countries is a notable example of this type of policy research.) A difficult question then arises: should a center try to improve crop technology in a country where the physical circumstances are favorable but where the structure of incentives is so unfavorable that widespread adoption of a new technology seems unlikely? There is no definitive answer. Economic climates can and do change. Policy research gives a center a better sense of where its work may have an impact, and it can thus allocate its resources more efficiently. It will also be able to discuss agricultural problems with national policymakers on the basis of concrete analyses.

Biologists and economists at the centers frequently have informal contacts with those responsible for setting national policies. These contacts arise as a logical prelude to technological advances. The introduction and spread of a new plant variety may depend heavily on a guaranteed supply of inputs, the availability of water, the provision of transport and processing facilities, and access to credit. New technical possibilities create disequilibrium—the natural consequence of technological change—and call for a whole series of actions, many of which fall directly in the domain of public policy.

These contacts have sometimes encouraged the centers to launch new initiatives, such as the livestock policy unit at ILCA. This unit has three objectives: to identify important policy questions relating to African livestock development, to conduct research on livestock issues, and to bring the results of research to the attention of policymakers. Among the topics currently being studied at ILCA are the size and composition of public expenditures for the livestock sector and the consequences of increased imports of dairy products for consumption and production in Africa. The first important study completed was an analysis of the markedly different performance of the livestock sectors in various African countries from 1965 to 1980. Information about the importance of technical and policy constraints in different settings can be of value to the center itself in setting priorities for biological research as well as to national policymakers.

Such undertakings by individual centers stimulate debate about the role and scope of policy research in the CGIAR system and the best way to conduct such research. There will always be issues that are directly linked to particular technologies or regions and that therefore lend themselves to study by an individual center. It can be argued that the future impact of the centers will be greater to the extent that both the scientific staff and the leadership are informed of changes in the social and economic climate that affect developing countries and crops in their mandates. The risk is that policy research may be limited to sporadic efforts built on an inadequate base of analytical capacity. Since certain important issues are more global than local in nature, a proliferation of policy research at the centers would also inevitably lead to a certain amount of duplication.

Both the CG Secretariat and TAC periodically sponsor studies on the allocation of research funds, the establishment of research priorities, and the impact of research. These have implications for policies within the CGIAR system, for other international agencies, and for national governments.

## The Impact of Policy Research

The introduction and spread of a new food crop variety is tangible evidence of technological advance. Identifying the impact of policy research is much more difficult; indeed, it is often hard even to ascertain the existence of a new policy. Of particular importance is the problem of attribution. To ask about the impact of policy research by the CGIAR system is to raise questions about the legitimate role of the system in relation to sovereign states. Policy research has an impact only if its findings lead to (a) changes in actual policies, (b) the avoidance of unwise policies, or (c) confirmation that existing policies should continue. But action depends on decisions by national governments. To attribute actual impact to the CGIAR could easily be construed as politically insensitive or even as evidence of meddling in national affairs. More particularly, it is seldom realistic to try to segregate the effects of policy advice or analysis from one source from all the other inputs that go into the formation of policy. For these reasons it is appropriate to view the impact of policy research as simply the contribution that such research makes to informed debate about policy decisions.

As an illustration of the mixed and subtle impacts of (a), (b), and (c), consider the case of the collaboration on crop insurance by IFPRI and Mexican analysts, which contributed to changes in the design of the insurance program for rainfed areas. A broader collaborative effort by IFPRI and the Instituto Interamericano de Cooperación para la Agricultura (IICA) resulted in a conference on crop insurance that involved analysts and policymakers from many countries. By carefully documenting the theory and administration of crop insurance and experiences with schemes in a variety of settings, the conference papers alerted policymakers to many pitfalls and encouraged a number of countries to conduct careful evaluations before embarking on potentially costly insurance schemes of their own.

### *Biological Research*

The principal influence of the commodity research centers on policy formulation has not come from direct involvement in policy research. Rather, in developing new technologies for specific areas, social and biological scientists from the centers have engaged in continuous exchange of ideas with those responsible for policy formation. This is a natural product of the collaboration of the centers with national research systems. Both the need for and the effectiveness of such activities are greater when the adoption of new technologies is impeded by constraints that could be eased by modifications in policy. When the policymakers examine the potential gains from technological advances and the redistribution of costs and benefits, they also become aware of the costs imposed by such things as the inadequacy of farmers' access to inputs, the lack of food-processing facilities, and the subsidization of food imports. For example, adoption of a new technology may be impeded if policymakers try to compel the use of certain inputs through restrictions tied to credit. Once the benefits of different inputs are established, the new technical possibilities can lead to a change in credit policy.

The development of fertilizer-responsive varieties has increased the demand for fertilizer and led a number of Asian countries to allow more fertilizer imports and to foster domestic fertilizer production so that they can capture more fully the gains from this new technology. Similarly, the creation of high-yielding cereals has increased the return to investment in irrigation and has induced changes in public irrigation policies. The introduction of new pasture species that raise the productivity of marginal acid soils has increased the return to investment in roads and has thus brought about changes in policies on infrastructure investment. All these topics are important subjects for research by the centers and their national collaborators.

Changes in policy can be accelerated by direct discussion, as in the case of policy seminars conducted by CIMMYT in Bangladesh, Colombia, the Dominican Republic, and the Philippines. These seminars focused on resolving what policymakers need to know about farms and farmers to facilitate the development and use of improved technologies.

### *Evaluation of the Rate of Return to Research*

The centers have had an indirect influence on policy through studies evaluating the return to research. These are of two types. The first is intended to improve the allocation of resources within the centers themselves to increase their productivity—that is, to ensure that a given amount of resources generates the maximum amount of useful knowledge. The national research systems may benefit indirectly in two ways. First, the centers' efficient use of their resources should allow wider and more effective collaboration with the national systems, thus improving the systems' productivity and their ability to win research funds. Second, the use of analytical methods in assessing the payoff to research has a demonstration effect, as seen, for example, in the interest expressed by the director of the Mexican agricultural research system in drawing on CIMMYT's work on research appraisal.

Both IRRI and ICRISAT have made significant evaluations of the returns to research. IRRI has examined the likely returns for different rice cultures, and ICRISAT has studied the congruence between its research and the research directions suggested by a broad range of agronomic, social, and economic indicators. CIAT, in its long-range plan, examined the expected rate of return to investment for each of its principal crop programs. In general, however, the centers do not appear to have devoted as much systematic effort to assessment of resource allocation as they might have.

The second type of assessment concerns the payoff to past research, calculated from actual costs and realized gains. The centers have underinvested in this type of assessment as well. Their own claims to resources would be strengthened by more vigorous documentation of the magnitude and distribution of benefits and costs, and the demonstration effect could help national programs to justify higher and more regular funding for their own research.

### *Nutrition*

Biological research can affect the supply of available nutrients by increasing the productivity and production of the commodities selected for study as well as by improving the nutritional quality of a given commodity. The powerful effect of research on total supplies of food staples—the essence of the CGIAR approach—has been extensively documented in chapter 3, but the question of improved nutritional quality was not explicitly addressed. Much attention has been devoted to this issue. For instance, work at ICRISAT largely allayed concern that improved cereal technology had reduced the supply of food proteins in India. The research showed that the total availability of both protein and food energy had been increased by the new varieties because the higher quantity of protein from the larger quantity of grain produced more than offset the reduction in protein caused by a shift of land from legumes to cereals (Ryan 1984).

Because of changing views on the role of protein in alleviating malnutrition, and because of the tradeoff between breeding staples for increased protein content or for yield, it is now the stated policy of the centers to give only secondary attention to protein content (Pinstrup-Andersen 1985). Implicit in this position is the argument that it is more cost-effective to achieve unit increases in the total supply of protein by focusing on high-yielding (and perhaps widely adapted) grain varieties than by breeding for a higher percentage of protein.

Notwithstanding the criticisms discussed in chapter 8, below, CIMMYT has had a substantial (although now diminished) program of research on quality-protein maize. It was an outstanding technical achievement to produce varieties with enhanced nutritional value while maintaining yield levels, and these varieties are currently being grown in Guatemala. The project was costly, however, and it is not evident that the contribution to total nutrient supply (or to intake by protein deficient groups) was greater than if the funds had been devoted to yield-increasing technologies rather than to high-protein maize.

Expenditures on nutrition-related research must be carefully scrutinized to assess their expected contribution to nutritional goals. In this CIMMYT's strategy influenced the allocation of resources by the Guatemalan national program which devoted to the testing and promotion of quality-protein maize funds that might have made an even greater contribution to nutrient supply if used in other ways. But several countries that had initiated research on a high-protein maize pioneered at Purdue University did reduce their activities and relied instead on CIMMYT germ plasm.

### *Food Subsidies*

Subsidies intended to lower consumer prices for food are widespread in developing countries, but they often have high fiscal and economic costs. IFPRI has made detailed studies of food subsidy schemes in twelve countries, including Egypt, whose rationing and subsidy arrangement is one of the most extensive and controversial of its kind. The institute's findings, which have been documented in a series of publications, have

**Box 7-1. *Collaboration on Policy Research in Egypt***

In early 1980 Egyptian officials and USAID staff held discussions concerning Egypt's food subsidy scheme. Among the questions raised were

- What are the total economic costs of the scheme?
- How widespread is access to rationed and subsidized food?
- How has the scheme affected household consumption patterns?
- How has it affected farm households?
- What effects has the scheme had on foreign trade in subsidized products and in other products?
- Who really benefits from food subsidies?

A project design team was appointed by USAID, and IFPRI was invited to participate. During a three-week visit to Egypt the team developed a research proposal and established contacts with, among others, the deputy prime minister of economic affairs, the deputy minister of economy, the deputy ministers of agriculture and planning, the minister of health, the director of the Institute of Nutrition, the director of the Institute of National Planning, and professors at the University of Cairo.

In late 1980 letters of agreement were signed with the Institute of National Planning and the deputy minister of economy after visits by the director of IFPRI, the project leader, and IFPRI researchers. Two of the researchers had previously undertaken studies related to Egyptian agricultural and trade polcies. Further discussions were held with the ministries of Agriculture and Planning and the Institute of National Planning. The deputy minister of economy proposed that all contacts with other ministries be channeled through his office, and this facilitated cooperation with the ministreis of Planning, Investment, and Economy. Contacts with the ministry of supply were also strengthened and proved to be valuable, since this ministry plays an important role in acquiring and distributing food.

From February 1981 to August 1982 two IFPRI staff members were resident in Egypt and received logistic support from the Cairo office of the Ford Foundation. Through a research contact with the Institute of National Planning a survey of 3,000 households in rural and urban areas was conducted.

Following the assassination of President Anwar Sadat in 1981 changes were made in the top echelons of the government. The project had established a wide network of contacts, however, and had sufficient support to survive the political reshuffling with no serious setbacks.

In September 1982 the main analysis began in Washington. Constant contact was maintained with key ministers and deputies, and drafts of reports were sent to them at every stage. By July 1983 the principal pieces of the project were largely complete, and the project leader and the three senior researchers visited Cairo for a series of seminars and workshops at the Institute of National Planning. A full-day presentation by the project team permitted discussion of the methods and findings with important policymakers and more than sixty people from the Egyptian and expatriate research communities. This was followed by a series of private meetings in the offices of the ministers of investment and foreign cooperation and of economy, the deputy minister of irrigation, and the undersecretaries of supply and agriculture. These meetings, which focused on the implications of the findings, reflected the policymakers' interest in the study, an interest engendered by the long series of personal contacts over the preceding three years. The questions being addressed had first been raised by the ministers and deputy ministers themselves before the analysis began. Egyptian policymakers were particularly eager to use the studies to project the likely effects on wages and income distribution of changes in subsidy policy and to investigate alternative methods for targeting.

To sum up, this project illustrates some essential elements in effective food policy research:

- Sufficient time to build a base of confidence and collaboration with national policymakers and researchers
- A core team of senior, experienced food policy analysts
- Recognition of the importance of primary data collection
- Examination of the many facets (agricultural and fiscal policy, monetary policy and exchange rates, and foreign trade) that bear on policy questions related to food
- Constant contact with senior officials
- Resident staff, with their contribution to training, project supervision, and goodwill and confidence
- The use of seminars, workshops, and private meetings to inform policymakers about the results and limitations of the research
- Flexibility to respond to the suggestions of policymakers and to conduct follow-up analyses that address policy alternatives raised by them.

provided a solid basis for assessing the Egyptian scheme. At each stage of the project IFPRI researchers maintained close contact with senior officials, and meetings were held to discuss preliminary findings, present final results, and suggest future courses of action.

Food subsidies in Egypt claim about 20 percent of government revenues, and wheat and flour subsidies account for over half of this cost. The country's capacity to import is a principal determinant of domestic wheat policies, but it is itself determined in part by wheat and cotton policies—an illustration of the simultaneous nature of policy formation. The burden of Egypt's wheat policy on both public sector and foreign sector accounts would be eased by a reduction in the quantity of wheat imported. This would require an increase in domestic output and a reduction in domestic demand. Allowing producers to respond to the import price of wheat and restricting access to subsidized bread to a somewhat narrower segment of consumers would reduce the growth in wheat imports. Steps were taken in 1980 to reduce the number of families eligible for rationed foods. Following analysis and debate (see box 7-1), further steps were taken to modify the food subsidy and rationing system. But, given the political sensitivity vividly illustrated by the riots in January 1977, the desirable changes are being phased in gradually and cautiously.

In other studies of intervention in food markets IFPRI has explored such schemes as paying people directly with food for work done in times of national difficulties. IFPRI, for example, in collaboration with the Bangladesh Institute of Development Studies, has examined the role of food-for-work schemes as a mechanism for developing rural infrastructure. This has led to a number of changes in the management of the schemes and a heightened awareness of the opportunities for using food aid productively.

### *Crop Insurance*

In 1975 D. Gale Johnson of the University of Chicago proposed extending the concept of crop insurance to developing countries at a national level, with financial support from the United States. Later, researchers at the World Bank suggested extending this approach to cover variations in both domestic harvests and world prices. In May 1981 the International Monetary Fund (IMF) introduced a plan for providing financial assistance to low-income countries that are faced with unusually high food import costs because of poor domestic harvests or abnormally high world prices. IFPRI, in conjunction with CIMMYT, sponsored an international conference to present its own and others' research results to policymakers from key national and international organizations with the aim of reaching a consensus on an international food policy.

### *Trade Policies*

A country's trade policies clearly affect its ability to meet short-run food needs, but the relation between trade policy and investments in long-term growth in food production is much less obvious. IFPRI's research has established the significant effects of a country's foreign trade regime on agricultural production, intersectoral resource allocation, and income distribution. This in turn has heightened the awareness of policymakers about the potentially depressing impact on agriculture of some commercial and exchange rate policies.

### *Research Capacity*

Given the importance of each country's agricultural sector and the widespread ramifications of national agricultural policy, improving the capacity for policy analysis within developing countries offers substantial benefits. IFPRI has established a broad network of collaborators in national ministries of planning, economic policy, development finance, and trade as well as in central banks, producer organizations, universities, and other international agencies. Collaboration is facilitated through seminars, study visits, and publications. IFPRI's research reports, which are often both a synthesis of research methods and a demonstration of their application to a particular policy problem, have established an enviable reputation for rigorous analysis and clear presentation. They are being increasingly used in graduate studies, thus contributing to the formation of human capital for food policy analysis.

# 8 The Distributional and Nutritional Impacts of New Crop Varieties

The twenty years since the introduction of modern crop varieties in developing countries have witnessed an evolution in views about the effects of these varieties on income and nutrition.[1] At first it appeared that the "miracle seeds" would solve the main food production problems in the developing countries (see, for example, Brown 1970). In the early 1970s, however, many came to believe that the green revolution had enriched the rich and further impoverished the poor in developing countries, thus creating a threat of social upheaval (Borgstrom 1974, Frankel 1971). In the middle 1970s a consensus developed that modern varieties had helped many of the poor (except farmers in neglected areas) but had helped them less than the rich. Although small-scale farmers were often the last to adopt modern varieties, they still obtained good yields. The amount of hired labor increased, but wages generally did not. Above all, modern varieties contributed to a larger food supply and thus to keeping food prices down. Most recently there have been claims that modern varieties raised the living standards of poor people faster than those of the rich, despite imperfections in the institutions of land tenure and rural credit. If poor farmers lost their land or if rich farmers replaced manual workers with mechanical threshers, modern varieties were said to be largely guiltless.

Is it merely that social science research fashions change? Is the farm reality changing, as poor farmers catch up with large landowners in the use of modern varieties? Are the latest modern varieties themselves different from early ones (perhaps more "poor-friendly") because breeders have begun to produce varieties with more drought and pest resistance and to have greater success with crops such as sorghum? Or is it, perhaps, that social science researchers have become more aware of the changing priorities of the centers and the national systems?

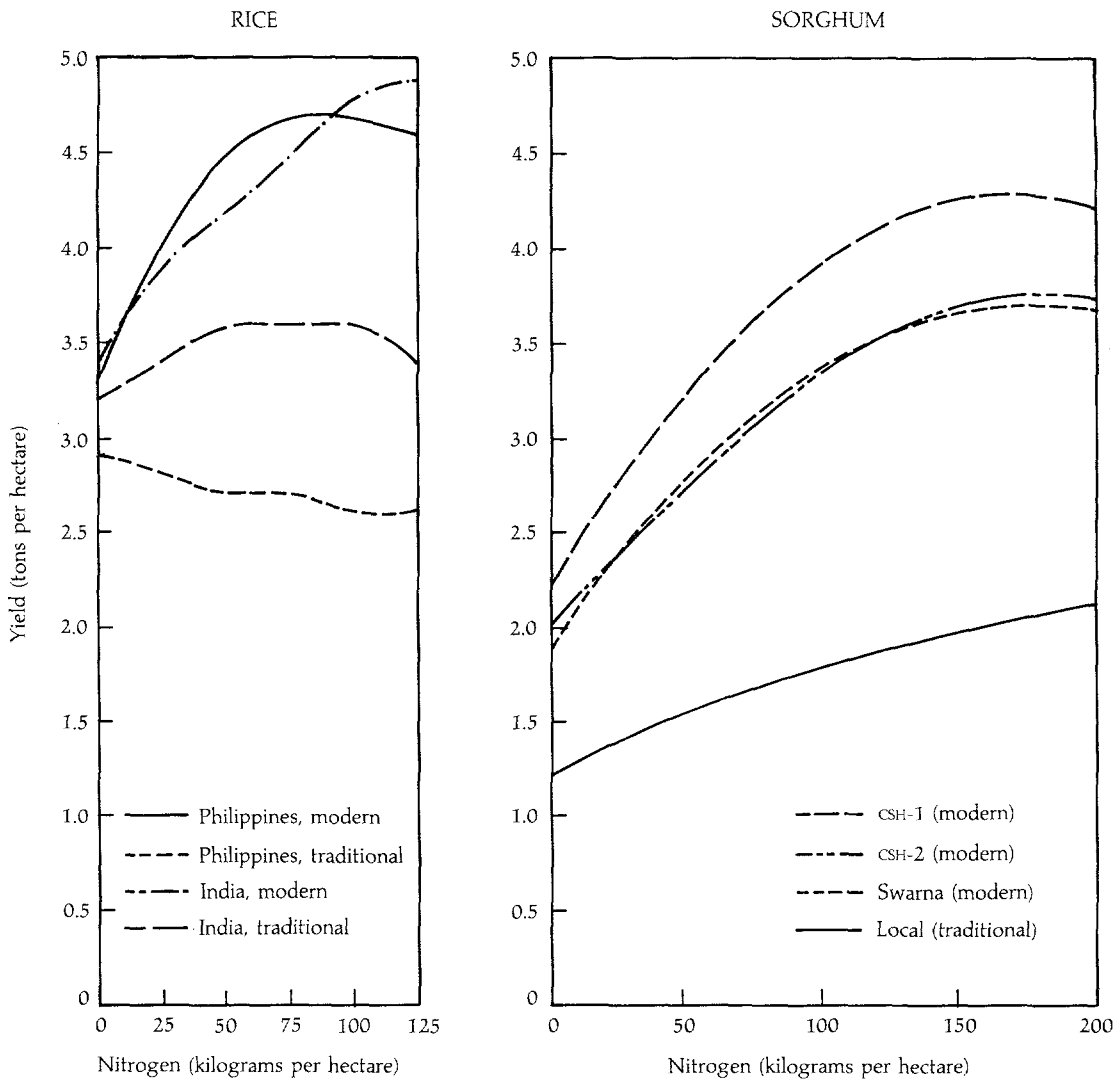
Past research concentrated on developing modern varieties that would help the poor by requiring more labor and supplying cheaper food. Socioeconomic research has documented these effects. Nonetheless, most of Africa is without modern varieties of proven usefulness and is poorer than in 1970. And modern varieties have not much changed the incidence and severity of poverty in South Asia, although many millions more are fed because of increased food production. This chapter examines what research and experience have to tell concerning the interactions between modern varieties and poverty.

## The Physical Qualities of Modern Varieties as They Affect the Poor

### *Response to Soil Nutrients*

Many critics claim that if poor farmers cannot afford to buy fertilizer they gain nothing by planting modern varieties because without fertilizer these varieties yield less than do traditional varieties. This assertion is dubious. Modern varieties are indeed designed to yield much more if provided with higher levels of the soil nutrients nitrogen, phosphorus, and potassium, but they convert the nutrients into grain weight more efficiently under any circumstances. In addition, the denser crop cover of modern varieties keeps down weeds. Thus most modern varieties outyield traditional varieties even if no fertilizer is used. This is illustrated in figure 8-1. Experiments that compared modern and traditional rices and sorghums showed that the modern varieties had higher yields whether or not applied

**Figure 8-1.** ***Yield Responses of Rice and Sorghum Varieties to Applied Nitrogen***




*Sources:* Rice (thirty experiments in the Philippines and eighteen experiments in India), Barker and Herdt, with Rose (1985); sorghum (twenty-five experiments in India), Singh, Krantz, and Baird (1970).

nitrogen was used. As newer modern varieties have been bred to resist pests and diseases, their superiority over traditional varieties at zero fertilizer has increased, even under moisture stress.

There are penalties, however, when modern varieties are grown without added fertilizer. First, because they do need extra nutrients to produce their substantially higher yields, their use may result in "soil mining"—the depletion of soil nutrients. (Many soils, however, have sufficient phosphorus and potassium to last for decades, even at high extraction rates.) Second, under some conditions modern varieties may perform worse than traditional varieties if they are given low or no fertilizer, especially if they are competing with tall weeds or are under severe moisture stress. Third, the moderate yield advantages of most modern varieties at zero fertilization may be outweighed by price discounts for traditional varieties or by the lower straw yield of modern varieties. Even with added fertilizer modern varieties bred for maximum grain-nitrogen ratios may yield less straw for fodder and thatching, may require micronutrients such as zinc to achieve high yields, may have thin husks that make storage difficult, may have higher seed costs, at least initially, and may sometimes fail to produce larger yields because of moisture stress.

Dealing with these complexities requires risk taking that may be hazardous for poor illiterate farmers. They may therefore refrain from adopting a variety even though that would seem to be in their self-interest. If poor farmers rather than laborers or urban consumers are defined as the main poverty group, researchers can help them by developing crop varieties and farming practices that make efficient use of soil nutrients even under moisture stress (perhaps at some cost to yield potential) and by concentrating on poor people's crops, such as millet, sorghum, and cassava.

### *Response to Light*

Direct breeding for greater photosynthetic efficiency (afforded by erect leaves) and for reapportioning photosynthate between stem and grain was an important accomplishment of CIMMYT and IRRI and their partners in the 1960s. The creation of modern varieties with low sensitivity to day length was another. Because such varieties often permit double cropping and a more even flow of food during the year, the poor gain most, since they can seldom save or borrow against lean seasons. But local rather than broad adaptability is sometimes needed. Where plants should mature during the late rains to permit sun drying, for example, farmers who cannot afford mechanical drying methods may want plants that are highly sensitive to day length so that the crop will flower and mature at the right time.

### *Response to Water*

Modern varieties have sometimes been criticized for raising yields only through the use of more water and for being more drought prone than traditional varieties. Actually, most modern varieties are bred to give better returns per unit of water, especially (but not only) where higher nitrogen inputs are used. This fact raises the payoff to farmers who can get more or timelier water. Fortunately, modern rice varieties mature more quickly than traditional varieties and are thereby more likely to escape moisture stress at the end of the growing season. Barley, millets, and sorghums are also bred for short maturation times and vigorous root systems.

Nonetheless, farmers in many parts of the developing world continue to plant traditional varieties. One reason is that the politics of irrigation deprives many farmers of adequate and timely water, so that the gain from switching to modern varieties is small. Another is that the centers and others have not yet achieved a dramatic improvement in the water-use efficiency of semiarid crops in Africa and of dry-season crops in Asia. Biological approaches may need to be integrated further with ecological engineering to reduce evaporation, seepage, and runoff. ICARDA's finding that the application of phosphorus improves efficiency of water use and causes barley to mature earlier offers a possibility of improvement in its mandate areas, especially if government restrictions on the use of phosphorus are modified.

More research in water-short areas (and less research on irrigated crops) could mean more income for some of the world's poorest farmers. But it would also mean slower gains through research for irrigated farms, less food or more expensive food for the poorest consumers, and smaller returns on investment in research. This dilemma can be resolved only by significant improvements in the water security of unirrigated farmlands. But large irrigation projects have become less attractive to development banks because some have been judged to be "white elephants" and because of past attempts to change farmers' use of water without understanding their problems. Modern varieties that are adapted to selective farmer-controlled microirrigation and microdrainage may be the best way to increase water-grain conversion rates in both dry and flood-prone areas.

### *Resistance to Diseases, Pests, and Weeds*

Many critics claim that modern varieties are more susceptible to pests and diseases. Some early modern varieties (for example, TN-1 and IR8) were indeed highly susceptible, but later varieties have had better resistance. IR20 rice lasted ten years before it became susceptible to a newly evolved pest; Sonalika wheat has lasted twenty. Currently, yield increases are sought mainly by raising robustness rather than by sacrificing robustness to greater yield. The centers have also helped national breeders to respond more quickly to pests—for example, to the successive brown plant hopper biotypes that attacked rice in Indonesia during the 1970s.

The centers have placed relatively little emphasis on methods to control weeds, other than to test commercial herbicides. Weeds can be very damaging to crops in dry areas, where they compete for scarce soil moisture. Some observers feel that rodent and bird pests are grossly neglected by the centers in view of the damage they do, especially in Africa. Other organizations engaged in research on these pests have also had rather limited success, however, and these problems do not seem to be readily amenable to research and human intervention.

## The Distribution of Benefits

Initial research on the relation between farm size and the adoption of modern varieties showed that large-scale farmers adopted them sooner than did small-scale farmers. This led to the misperception that small-scale farmers were not using these varieties. But the great mass of evidence shows that wherever modern varieties have been suited to the soil and climate, they have been adopted by roughly the same proportion of farmers in all farm size groups (see figure 8-2).

The relation between farm size and use of modern varieties is also illustrated by the results of a nationwide study by the National Council of Applied Economic Research of India. Data for the mid-1970s from three representative states are plotted in figure 8-3. The percentage of crop area planted to modern varieties was computed for each of five farm size categories. In Madhya Pradesh most of the land in all size groups was planted to traditional varieties; in Haryana most of it was planted to modern varieties. No positive association between farm size and the percentage of area in modern varieties was apparent in these regions. In Uttar Pradesh the relation is, if anything, inverse. Data for other states show essentially the same results. If the modern varieties are suitable, they are adopted to much the same extent on farms of all sizes.

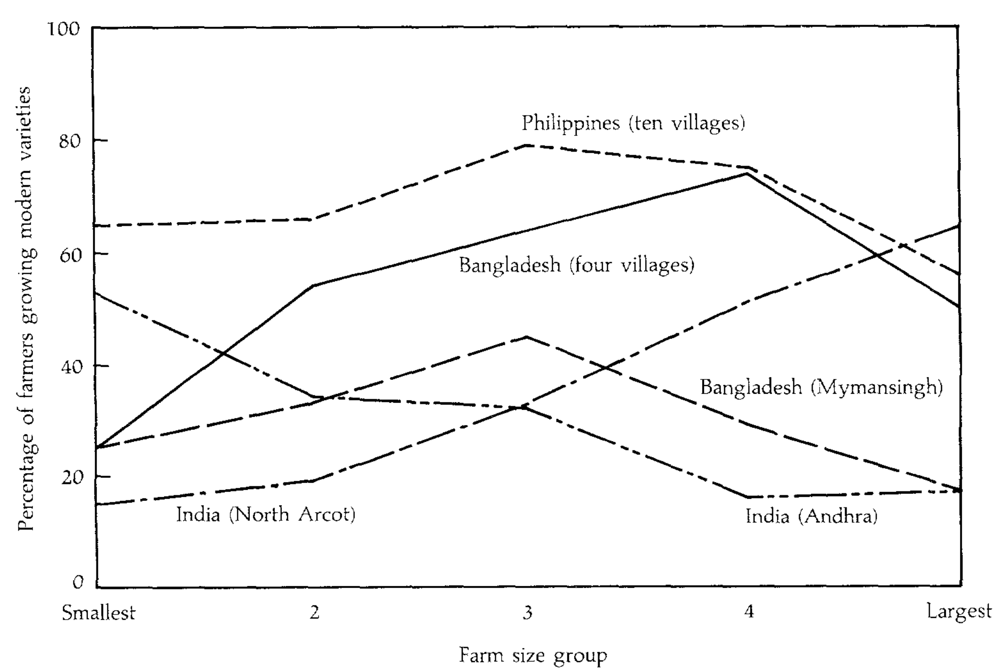
Although recent research shows that small-scale farmers are catching up with large-scale farmers, this has not been happening everywhere and is by no means automatic. Even though smallholders in the right circumstances adopt modern varieties readily, they are more often located in the "wrong" places than are richer farmers. That is, small-scale farmers are more often found in areas where no irrigation is available and the topography is unfavorable.

Because they want to avoid risk, smallholders often put off adopting modern varieties until they see whether their wealthier neighbors succeed with them. Smallholders may also delay adoption because they cannot obtain certain inputs. Lack of credit appears to be more of a constraint in irrigated areas, while elsewhere avoidance of risk is the motivation, especially if the technology has a significant fixed cost. Studies suggest that when smallholders do adopt modern varieties, they sow a bigger proportion of land to these varieties than do larger-scale farmers so as not to spread their fixed costs over too small an area.

### *Inputs and Incentives*

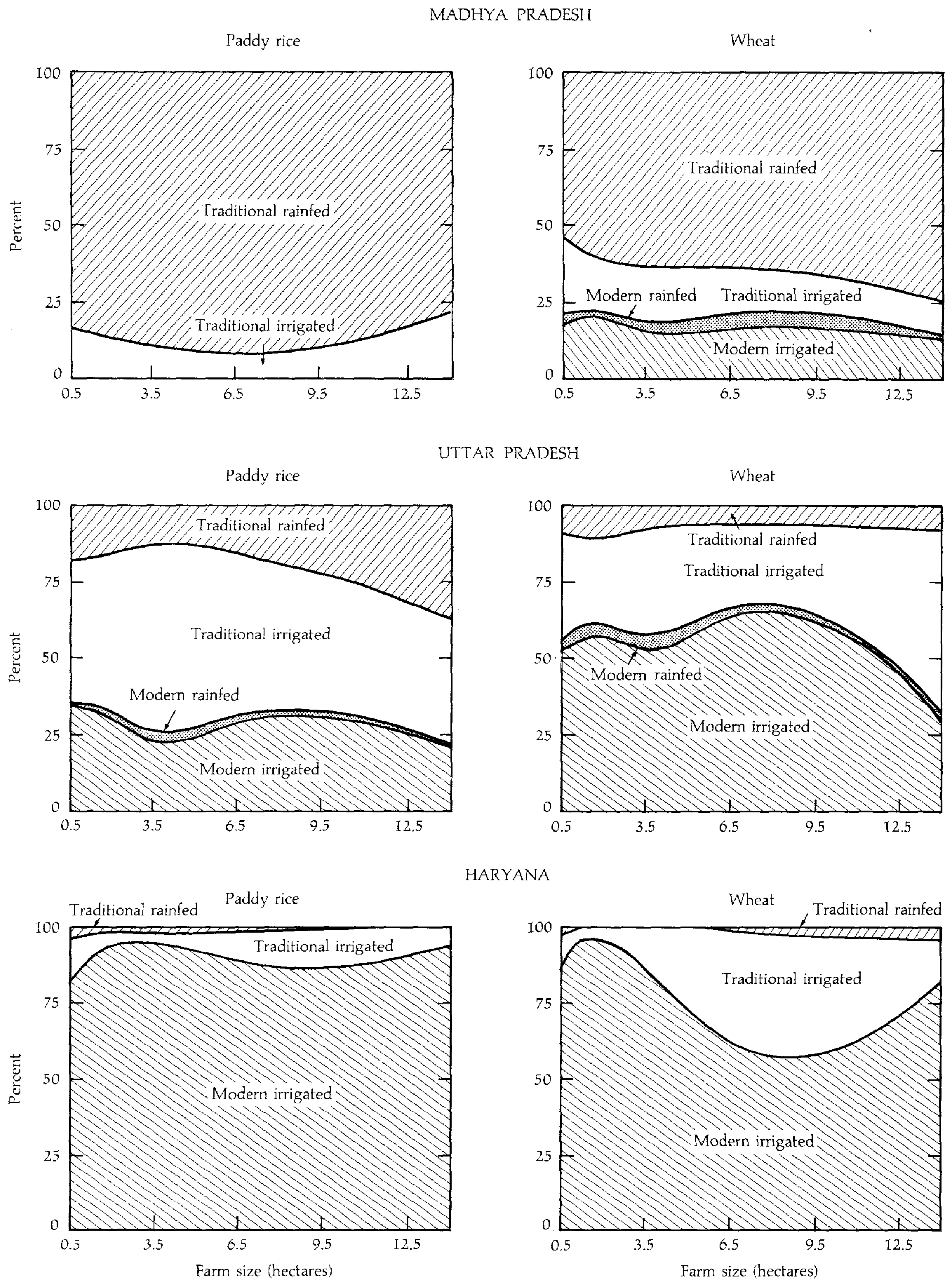
Modern rice varieties are closely linked with the use of herbicides, tractors, and threshers in double-cropping areas such as Malaysia, Philippines, and West Java,

**Figure 8-2.** ***Adoption of Modern Varieties of Rice, by Farm Size***




*Source:* Herdt and Capule (1983).

**Figure 8-3. *Percentage of Land Planted to Modern and Traditional Rice and Wheat Varieties, by Farm Size, Selected States of India, 1975–76***



Indonesia. Indeed in some locations it was the development of short-duration varieties that made double cropping possible. The net effect of these varieties on the use of labor depends on the extent to which the second crop offsets the labor-replacing effects of such inputs.

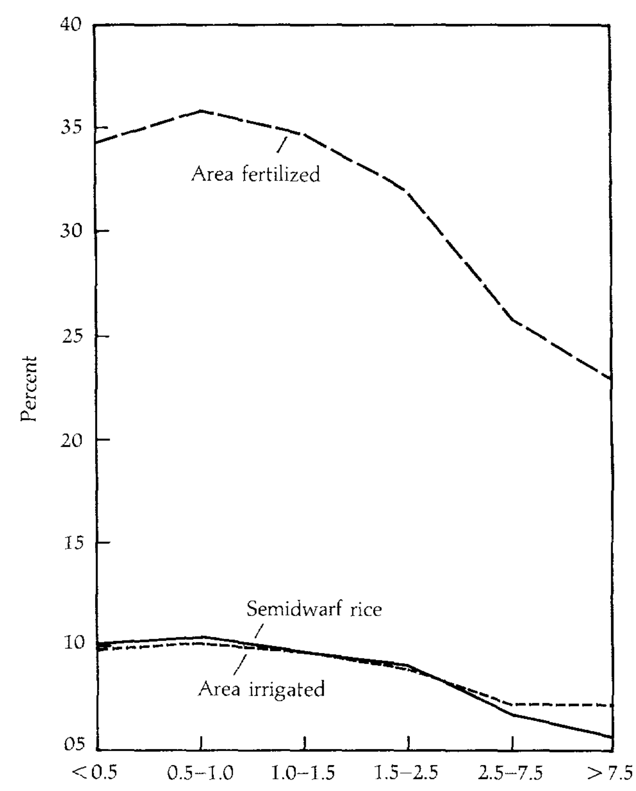
In the long term modern varieties tend to receive similarly high levels of inputs on both small and large farms. But the institutions that allocate water, fertilizers, and credit tend to be biased toward large farms, especially those owned by men. Furthermore, later adopters often receive lower prices because early adoption by their better-off neighbors has increased the supply of the crop. Richer farmers also may get better prices than the poor because of size economies in marketing, and modern varieties may increase their advantages. Resource-poor farmers can sometimes avoid this disadvantage by using most of their additional output from modern varieties for their own consumption.

### *Yields and Efficiency*

Some data suggest that modern varieties reverse the inverse relation between farm size and yield, but this does not appear to be the general case. Small-scale farmers eventually adopt modern varieties as intensively as large-scale farmers do, and they then usually get higher yields because they can utilize more family labor per hectare. At an early stage small farms may have slightly lower yields and purchase fewer inputs, but as they gradually adopt modern varieties, they get the benefits of greater crop intensity and crop value.

The relation between input and farm size in Bangladesh is shown in figure 8-4. There about 12 percent of the area occupied by farmers with 1 hectare or less is planted to semidwarf rice varieties, while a slightly smaller proportion of the area occupied by farmers with more than 1 hectare is planted to these varieties. The highest proportions of fertilized areas are in the

**Figure 8-4.** ***Farm Size and Use of Modern Agricultural Technologies, Bangladesh***




*Source:* Bangladesh Bureau of Statistics (1980).

three smallest farm size groups, and the use of irrigation closely parallels the degree to which semidwarf rices are adopted.

In recent years modern varieties have sometimes been associated with an increase in the annual variability of production. Variability in the output of sorghum, millet, and the food grains has generally risen in India, and increases in the variability of wheat and maize have been noted in many other developing countries since modern varieties were introduced. But total output has shown more variability mainly because yields and modern-variety areas tend to vary together, not because individual farm outputs vary more, and certainly not because yields are worse in bad years for modern than for traditional varieties. A better (relative) measure is the coefficient of variation of yield, and this has changed little for most countries and crops recently. By seeking greater genetic diversity and other improved agricultural methods, agricultural scientists should be able to help farmers reduce relative variability.

Thus, despite earlier gloomy assessments, most recent investigators concur that if poor people in modern-variety areas are smallholders and keep their land, modern varieties raise their average net income and consumption. For details of a specific case in India see box 8-1.

## Areas without Modern Varieties

Many observers concur that areas in which modern varieties are rarely found have often suffered negative consequences. In Madhya Pradesh, India, poor wheat farmers must sell their wheat to earn enough to buy coarser grains. Thus when the Punjab's wheat output flourishes (thanks to modern varieties) and depresses wheat prices, the wheat farmers of Madhya Pradesh suffer. In areas where modern varieties are not grown because of poor soil and poor water control, poverty tends to be worse and there is greater inequality of income.

During 1962–65, when modern varieties were first being grown in India, districts that were slow in adopting showed no worse yields than districts where modern varieties were used. (This says nothing about data for smaller areas.) But labor productivity fell behind in areas that did not use modern varieties, and the widening productivity gap has cumulatively worked against poor farmers. Even at the village level within similar semiarid environments, intervillage differences in the benefits of modern varieties far outweigh intravillage differences. Neither caste nor ethnic group appears to explain this. An additional productivity gap may be emerging between men and women. The allocation of tasks and of land is gender specific. Where male tasks become more capitalized or mechanized than female tasks, the garden and home crops to which women devote their attention are sometimes shifted to marginal or more fragile land.

The regional disparity and the known general problems suggest that one approach to research on less advanced areas would be to find out why some villages in such zones nonetheless do well with modern varieties. Do institutional factors (such as fertilizer distribution and credit) or the interaction of modern varieties with certain ecosystems explain the successes? Another tack would be to shift research priorities toward achieving greater yield stability in marginal environments.

Research on irrigated areas may have reached the point of diminishing returns, but until recently much of the centers' work has been concentrated on such research. Similarly, national research systems have in many cases emphasized improving output in irrigated areas because of the importance of these areas for production of food, especially food for middle-income urban workers. Although the centers have redirected much of their research effort toward crops in rainfed, semiarid, and dry areas, they may not have shifted enough yet to compensate for the national systems' overemphasis on "favorable areas."

## Adoption and the Research Agenda

Recent research reveals little about how modern varieties affect poverty because it has concentrated on farm size and adoption. There are several problems with this approach. First, farm size is but one factor in a farm's capacity to generate income from a modern-variety crop; terrain and the availability of water also have a great impact. Second, the effects of modern-variety crops on farmers' use of other crops and of noncrop outputs have not been intensively studied. Third, farm returns are only part of the poor household's net income from all sources, and modern-variety benefits interact, sometimes favorably, with these various sources of income. Fourth, total household income is weakly correlated with net income per person. (Larger farms may mean somewhat larger families, yet larger families tend to be poorer, and family size is often correlated with adoption of modern varieties.) Fifth, any assessment of the effects of modern varieties on net disposable income per person must take into account the increased debts or extra work that the household may have incurred in adopting new varieties.

**Box 8-1. *Modern Rice in North Arcot, India***

North Arcot, an important rice-growing district in southern India, has benefited substantially from improved rice varieties. Before the release of modern varieties average yields were growing at about 1.4 percent a year. After the release of modern varieties in the 1966–67 crop year this growth rate accelerated to nearly 4 percent a year, providing an accumulated yield increase of over 1 ton per hectare by the early 1980s.

The first modern varieties released in North Arcot were Taichung Native 1, from Taiwan, and ADT27, which was developed locally. Beginning in the early 1970s these varieties were rapidly replaced by IR8 and IR5. Of the thirty-eight paddy varieties released in the area after 1975 twenty-three had IRRI germ plasm in their parentage. The share of the paddy area planted to modern varieties increased from 20 percent in the 1970–71 crop year to 90 percent in 1981–82.

Modern varieties were the predominant source of growth in rice yields, but the sizable increases in the use of fertilizers, pesticides, and irrigation water were also important. Greater water use was achieved through increased investments in wells and mechanical pumping equipment.

Total rice production has increased faster than yields because of a concurrent but modest increase in the gross cropped area. This is attributable to a combination of increased irrigation and the shorter growing periods required by modern varieties. In a sample of villages the cropping intensity (the ratio of the area cropped each year to the paddy area) increased from 1.75 to 2.06 between the 1973–74 and 1982–83 crop years.

The widespread ramifications of these changes in rice production for the region's farm and nonfarm economy can be analyzed with the use of the detailed socioeconomic surveys conducted in 1973–74 by Cambridge and Madras universities and in 1982–83 and 1983–84 by IFPRI and the Tamil Nadu Agricultural University. A useful aspect of these data sets is that samples of households were drawn from the same representative villages.

The average household in the sample villages more than doubled the real value of its consumption of food and consumer goods and services between 1973–74 and 1983–84. Further, this gain seems to have been shared by different types of households in rough proportion to the value of their total consumption in 1973–74.

These increases in the value of per capita consumption were accompanied by a shift toward more varied diets as all household types increased their consumption of pulses, livestock, and horticultural products in relation to cereals. There were also significant increases in the proportion of household expenditures allocated to durables, medical care, transport, entertainment, house improvements, and religious and social events. Since data did not include information on intrahousehold allocations, effects cannot be differentiated according to, for example, gender and age.

In comparison with traditional rice varieties the modern varieties required a little more labor per hectare but less labor per unit of output. The labor requirements for all varieties declined after the 1973–74 crop year because of increased mechanization of irrigation pumping and paddy threshing. Mechanization of land preparation is still not widespread in North Arcot.

Total employment in paddy farming increased slightly between 1973–74 and 1983–84. The average farm increased its total labor use in paddy from eighty-eight to ninety-four days of male labor and from seventy to eighty-three days of female labor. Of these amounts about one-third of the male labor and two-thirds of the female labor were hired. There was little change after 1973–74 in the composition of labor.

Agricultural wages vary by operation, gender, and village, but there was a general pattern of increase after 1973–74. In the sample villages the average daily wage for plowing (which is performed by men) increased from 2.23 rupees in 1973–74 to 5.10 rupees in 1982–83; an increase in real terms of 24 percent. The average daily wage for transplanting (performed by women) increased from 1.17 rupees in 1973–74 to 2.45 rupees in 1982–83, an increase in real terms of 13 percent. During the same period in-kind daily wages for harvesting (performed by women) increased by 11 percent, and in-kind daily wages for threshing (performed by men) increased by 21 percent.

Initial estimates also show a strong linkage with the growth of nonagricultural employment in the local towns. The total number of full-time workers in the region increased by 30 percent between 1971 and 1981. About one-third of the additional jobs were in nonagricultural activities. If other, less important, sources of growth are ignored each 1 percent increase in the value of agricultural output was associated with a 0.6 percent increase in agricultural employment and a 0.9 percent increase in nonfarm employment.

Thus research should shift from adoption and yield issues to efforts to trace how technological changes affect real disposable income per person in poor farm households. Since poor people gain from modern varieties mainly as food consumers and lose from them in non-modern-variety areas, and since the world's poor increasingly are landless laborers, research on modern varieties should move from an emphasis on farm households in modern-variety areas to some of the issues raised in the following sections.

## Modern Varieties and Labor

When modern varieties were first introduced, wages and use of farm labor increased substantially. More recently, however, farm labor's gains from the introduction of modern varieties appear to be dwindling. Modern varieties do raise the demand for labor, especially at harvesttime. But an ample and mobile labor supply, combined with increasing mechanization in some areas, has kept real wage rates from rising much during the growing season. Furthermore, modern varieties have reduced labor demand during much of the growing season. Labor-displacing inputs, such as tractors and herbicides, used during the growing season are being joined by labor-displacing machines (threshers, for example) used at harvesttime.

### *Labor Use, Wages, and Factor Shares*

Early observers of the impact of modern varieties in developing countries found that they raised labor use per hectare-year by about a fifth. But as modern varieties spread to less favorable environments, employment benefits fell. The amount of labor used to achieve a given output has usually fallen too. The main reason—that mechanization has outpaced adjustments in the seasonal migration of farm workers—is discussed below. Other reasons include the rising costs of finding work and supervising hired labor, institutional change that destroys traditional labor arrangements, more job opportunities in nonagricultural work, government subsidies for labor-displacing inputs, and research that is addressed to reducing the per hectare costs of machinery, chemicals, and fuels, thus exacerbating the displacement of labor.

Few significant increases in real wage rates have been found in modern-variety areas in Asia. Additional demand for labor has been met by the steady increase in the work force, and wages have stayed at near-subsistence levels. But without modern varieties many of these people would have been jobless, and higher food prices would probably have pushed subsistence wages even lower, as has happened in many non-modern-variety areas. Even when modern varieties result in higher real wages, roughly 90 percent of the additional income generated by these varieties goes to farmers and landowners or for the purchase of agricultural inputs. The number of households that use hired labor has also increased, and sometimes the extra wealth obtained with the help of modern varieties enables "the village rich to turn the poor off their land" (van Schendel 1981, p. 245). Finally, although laborers as a whole gain absolutely from modern varieties, certain particularly vulnerable groups may lose. Little is known about how modern varieties affect wage rates and employment for off-farm work and non-modern-variety crops.

The impact of modern varieties on the structure of labor use can be considered by group and by timing. Since hired labor increases more than family labor, the poor in irrigated areas are helped. Modern varieties also probably increase the demand for long-term workers. Although this reduces the number of those in poverty, it makes the poverty of those without work even more intense.

Some village data suggest that both these tendencies reduce women's share of cash income. There are many documented instances, particularly in Sub-Saharan Africa, in which modern technologies have differentially affected male and female labor. A study of male and female labor roles, sources of income, and financial responsibilities among the Tiv of Nigeria showed that adoption of the recommended technologies would have raised women's labor input in relation to men's but would not have provided them with a commensurate financial reward (Burfisher and Horenstein 1985). A systematic study in India, however, found total female labor use to be positively correlated with modern-variety rice in all three states surveyed (Agarwal 1984).

Modern varieties usually help the rural poor by smoothing the demand for labor during and between seasons. Some center research such as that on threshers, transplanters, and commercial herbicides may undermine some of this benefit, but research on fertilizer placement may strengthen it. Since postharvest labor is especially at risk, the screening of modern varieties for such postharvest characteristics as suitability for labor-intensive processing may be desirable under some circumstances, although admittedly difficult.

### *Mechanization versus Manual Labor*

Tractors, threshers, and mechanized irrigation normally displace considerable labor. Claims that they avoid this by raising cropping intensity usually collapse when allowance is made for the contribution of other factors (such as the use of modern varieties and access to water) to multiple cropping. Indeed, tractors may displace more labor in double-cropping systems because animals and their care are more completely replaced. Do the centers' activities strengthen or weaken the link between modern varieties and mechanization? Machinery cannot usually be paid for out of the low returns provided by traditional varieties, whereas the double cropping brought about by modern varieties reduces down time for tractors and threshers. Reapers have been called "a very profitable investment"

(Moran 1982) because they significantly reduce the use of labor. In rare circumstances mechanized inputs can permit the farming of additional land, reduce drudgery rather than employment, or create voluntary leisure for some farmers. But deeper unemployment for the poor, with little gain in output, seems to be a more common result of mechanization in the most populous parts of the world.

Unlike mechanization, migration enables the poor to find work, especially during seasonal peaks. Experts in farm technology who work with the centers probably should know more than they do about how alternative modern-variety strategies and farm systems affect migration and hence wage rates, incentives to mechanize, and jobs. To make sure that more of the gains obtained from modern varieties go to farm laborers, farming systems ideally might spread planting and harvest times. This would attract enough migrants to prevent the development of high seasonal wage peaks and hence of labor-displacing mechanization. Admittedly this is asking much of research.

## Modern Varieties and Poor People's Nutrition

Insufficient intake of energy and protein is usually a result of inadequate "household food acquisition power." Household food acquisition power is the end result of the combination of household self-provisioning, household purchasing power, food prices, food availability, and resource control. An increase in food production because of technological change may increase the self-provisioning and purchasing power of producer households, reduce food prices (thereby increasing the food acquisition power of non-producer households), and increase the availability of food.

In low-income countries the poorest 20 percent spend 60 percent or more of their income on food and even then are able to purchase much less than the amount judged nutritionally sufficient. Thus production increases that drive down real food prices help the poor most. The relative importance of individual commodities in the food budget of the poor varies among countries. In some, one staple may account for 40 to 60 percent of food energy and expenditures, while in others no single staple is dominant.

Table 8-1 illustrates the difference in the contributions of two staple foods to the diet of the poorest and wealthiest sectors in several countries. In Sudan people in the poorest group, who consumed less than half the energy judged to be sufficient, obtained about 20 percent of this energy from sorghum; the wealthiest group obtained about 6 percent of its energy from sorghum. Both groups got a higher proportion of their energy from wheat, which is clearly a preferred staple; that is, its consumption increases as incomes rise. Thus even though sorghum is a "poor person's crop," changes in wheat prices may have a greater impact on the

**Table 8-1.** ***The Importance of Staple Foods, by Income Group***
(percent)

| | | *Lowest 10 percent in per capita income* | | *Highest in per capita income*[a] | |
|---|---|---|---|---|---|
| *Country* | *Staple* | *Share of energy* | *Share of expenditures*[b] | *Share of energy* | *Share of expenditures*[b] |
| Colombia | Rice | 17.6 | 12.4 | 14.5 | 6.1 |
| | Cassava | 7.9 | 5.6 | 4.1 | 2.0 |
| Egypt, Arab Rep. | Wheat | 47.3 | 12.6 | 38.7 | 2.1 |
| | Maize | 12.3 | 2.2 | 10.4 | 0.3 |
| Sri Lanka (urban) | Rice | 47.2 | 26.6 | 33.4 | 7.8 |
| | Coconut | 16.8 | 7.3 | 15.0 | 2.7 |
| Sudan | Wheat | 28.0 | 13.6 | 34.4 | 11.0 |
| | Sorghum | 19.5 | 6.7 | 5.9 | 2.3 |
| Thailand[c] | Rice | 89.3 | 34.5 | 48.1 | 1.8 |
| | Wheat | 0.1 | 0.2 | 2.7 | 1.1 |

a. For Colombia, average of all income groups; for other countries, highest 10 percent income group.
b. For Colombia, percentage of total food expenditures spent on each item; for other countries, percentage of total household expenditures spent on each item.
c. Consumption of millet, sorghum, and cassava and other root crops is less than 0.5 percent of total food energy.
*Source:* IFPRI Food Consumption and Nutrition Program.

nutrition of the poor than do changes in sorghum prices. Such effects are also observed in many other countries.

Because food accounts for such a high proportion of poor people's expenditures, reductions in food prices are a greater relative benefit to poor people than to the wealthy. In developing countries for which data are available a reduction in prices leads to about twice the relative increase in real income for poor households as for rich households (table 8-2).

Modern varieties have helped to keep real food prices in check, although it is impossible to say by how much. If modern varieties of rice and wheat had not replaced traditional varieties (with other inputs unchanged) in the early 1980s, annual rice output would have been 10 million to 30 million tons less and wheat output 10 million to 20 million tons less. Modern varieties of other crops have added at least 3 million to 5 million tons to available food supplies. Other inputs probably raised food output by more than 50 percent. Yet in India, with an increment of perhaps 12 million tons, the annual growth in food available per person has barely kept ahead of population growth. Apart from feeding the larger population, the additional output was used largely to replace imports and build stocks.

In some countries trade policies have fixed food imports. In Colombia the use of modern varieties increased the availability of rice and lowered its price (see box 8-2). In 1970 incomes in households with incomes below $600 rose by 12.8 percent owing to

**Table 8-2. *Impact of a 10 Percent Decrease in the Price of Food on the Real Income of Low-Income and High-Income Groups***

| Country | *Increase in real per capita income (percent)* Lowest 10 percent | Highest 10 percent | Source |
|---|---|---|---|
| Egypt | 5.6 | 1.0 | Alderman and von Braun (1984) |
| India[a] | 5.5[b] | 1.2[c] | Mellor (1978) |
| India | 7.3 | 2.9 | Murty (1983) |
| Nigeria (Funtua) | 7.7 | 6.5 | Pinstrup-Andersen and Uy (1985) |
| Nigeria (Gusau) | 9.0 | 5.7 | Pinstrup-Andersen and Uy (1985) |
| Sri Lanka | 8.5 | 4.1 | Sahn (1988) |
| Thailand | 6.0 | 2.0 | Trairatvorakul (1984) |

a. Food grains only.
b. Lowest 20 percent.
c. Highest 5 percent.
*Source:* IFPRI Consumption and Nutrition Program.

modern varieties. More than half of the increase came at the expense of producers, especially in non-modern-variety areas. Poorer producers reduce their price losses by switching to other crops if the prices of modern varieties fall much faster than the unit costs of production, or they "internalize" some gains by eating a large share of modern-variety output themselves. Poor consumers, including subsistence producers, usually gain most if technology improves crops such as cassava that are little valued by consumers with higher incomes.

But the consumption gains of the poor may be limited. If income growth favors the rich and the poor lack the purchasing power to buy more food, modern-variety output may be absorbed by the wealthy. In some cases added domestic production displaces food imports instead of reducing domestic prices. If the introduction of modern varieties restrains the prices of staples, employers can hold wages down and real purchasing power is not much improved. In non-modern-variety areas poor farmers and their employees lose consuming power as the prices of modern-variety crops fall, although in middle-income developing countries they are outnumbered by poor urban dwellers, who gain purchasing power.

Modern varieties, by moderating food prices, have been the chief factor in improving the nutrition of the poor in the developing world. Such an improvement is clearly one of the centers' main objectives. How they can help further depends on who is vulnerable to what sorts of undernutrition, where, when, by how much, and with what trends. A correct perception of undernutrition implies regional, commodity, and varietal priorities. Some research resources have been used on topics unrelated to the main causes and incidence of undernutrition. Poor consumers, at least in South Asia, need stable production of cheaper food that provides easily absorbed food energy more than they need, say, high-lysine maize. (See the discussion in the subsection on "Nutrition" in chapter 7.) Only where root crops or bananas are principal staples—and where legumes are unimportant—is it likely that research on increasing protein content can contribute significantly to improvements in poor people's nutrition.

In much of Asia modern varieties of rice and wheat have prevented mass starvation. Although wheat has often displaced pulses, wheat gives much cheaper dietary energy, and 95 percent of undernourished people lack energy more than they lack protein. But in Africa and semiarid Asia modern varieties of wheat and rice have done much less for poor consumers, who eat mainly sorghum, millet, maize, and cassava. Improved maize (including hybrids) has partly displaced sorghum, a crop less vulnerable to moisture stress, but

**Box 8-2. *Modern Rice Varieties and Human Nutrition: The Case of Colombia***

In the mid-1960s tall varieties of rice that produced yields of less than 3 tons per hectare were grown in almost all of Colombia's irrigated rice areas. Today irrigated rice production in Colombia relies solely on modern varieties, and yields exceed 5 tons per hectare. Colombia produces over 1 million more tons of rice than it would have with traditional varieties in irrigated areas. Studies have shown that the annual rate of return to investment in rice research is 80–90 percent (Scobie and Posada 1978).

Of particular interest is the impact of this increase in rice production on human nutrition. It is widely recognized that nutritional status reflects education, access to health services, distribution of potable water, and occupation, as well as food intake. To attribute changes in a particular measure of nutritional status solely to changes in food consumption would be erroneous. For the sake of convenience, however, change in energy intake is used as a measure of the impact of modern varieties.

In 1981 the Department of National Planning and the National Statistical Office conducted a survey of 9,000 households representative of more than 90 percent of the Colombian population. Information was collected about household size and age-sex composition, location (rural or urban), food expenditures, and food consumption. A twenty-four-hour food consumption survey was also conducted in 3,000 households. The first part of the study focused on the impact of rice prices on the total energy consumption of rice consumers. The consumption of each of ten major foods was expressed as a function of the price of each food, family income, family size, and the proportion of children under five years of age. From these estimates it was possible to derive a relation between changes in energy intake and the price of rice.

The introduction of modern varieties expanded output, and since rice exports were insignificant, domestic supplies increased. The rate of growth in the supply of rice was faster than the growth in demand because of rising incomes and population. Hence the real price of rice to consumers fell. Put another way, the price of rice would have been much higher had it not been for the expansion of supply engendered by the introduction of modern varieties (Muchnik de Rubinstein 1985).

This result depends crucially on the assumption that the government would, in fact, have allowed the price of rice to climb to much higher levels. Given the importance of rice in the Colombian diet, however, it is improbable that such a strategy would have been followed.

Increased energy intakes were estimated on the basis of a high and a low response to a fall in rice prices. Under the low response the total annual increase in energy intake would have been less than 1 percent per capita in an open economy (one in which rice is imported). Under the assumptions of a higher response and a closed economy (no rice imports), estimated food energy intake would have increased by 8.7 percent in urban areas and by 15.3 percent in rural areas. These represent the upper bounds of feasible estimates. The results allow for declines in the consumption of the nine other major foods when consumers respond to lower rice prices by substituting rice for other foods. In other words, the calculations reflect a net increase in total energy intake.

When a commodity represents a significant share of energy intake as does rice for the poor of Colombia (defined here as the lowest 30 percent of all households according to income), the introduction of new technology that increases supplies and lowers prices can lead to an important increase in per capita energy consumption. Given that the average per capita intake of this group in Colombia was below the FAO standard of 2,420 kilocalories per capita a day and that 42 percent of the families did not reach the Colombian standard of 1,970 kilocalories per capita a day, it is clear that increases of the magnitudes estimated here are potentially significant.

As a result of the introduction of modern varieties, the irrigated sector assumed much greater importance in Colombian rice production. Typical irrigated production in Colombia uses only about two-thirds of the labor per hectare used for traditional upland rice. This means a decline in the demand for labor, and by 1981 the income of landless workers was estimated to have been 1.03 percent lower than it would have been without the new rice varieties. This loss of income, if evenly spread among all landless workers, would mean an estimated 0.1 percent drop in energy consumption. This is the upper bound on the effect on landless laborers, since the assumption that the rice sector is large enough to affect rural wages is highly improbable and since the benefits accruing to landless laborers as rice consumers through lower real market prices were ignored. If the latter effect, which amounts to 1.2–3.8 percent in an open economy, is included, the net effect on landless workers is an increase in food energy consumed of 1.1–3.7 percent.

Finally, a group of small farmers in the uplands faced lower prices and no technological advances. As a consequence the number of such farmers who produced rice fell by about 5,000. On the basis of the fall in prices, the incomes of upland farmers were estimated to have decreased, on average, by 87 percent between 1969 and 1982 under a closed economy or by 41 percent under an open economy. When these estimates were combined with the response of energy intakes to total income changes, it was found that energy intakes among this group would have declined 2–5 percent in an open economy and 4–10 percent in a closed economy.

These results emphasize the importance of policies in determining the magnitude and distribution of benefits from new technology. A country that protects its nonfarm sector and maintains an overvalued exchange rate will

(*continued*)

**Box 8-2** *(continued)*

discourage the growth of output and productivity in agriculture. Furthermore, when new technologies are introduced into such a setting, consumers will benefit at the expense of producers, and nonadopters will be particularly disadvantaged. In contrast, in a more open economy the price effect of new technology will be less, and producers will be the primary beneficiaries. Their real income gains will result in an initial rise in total energy intake. As their spending on other goods rises, so will real income in other sectors, which will make possible increases in energy intake in the nonfarm sector.

Although improving human nutrition through increased food intake is unquestionably a desirable goal for the centers, it must be stressed that outcomes do not depend solely on the introduction of new agricultural technology. The linkages are complex. Different groups will benefit differently, and the economic policies of the country can have an overriding effect on the magnitude and distribution of any nutritional improvement.

has spread very slowly since 1970. At the time data for the impact study were collected, the adoption of improved sorghum and millet varieties had occurred in limited places and seasons, mostly in India.

Inferential evidence suggests that modern varieties of wheat and rice have substantially improved the nutrition of urban residents, farm households in irrigated areas, and the landless rural poor in Asia and Latin America. But rural Asians in unirrigated areas suffer at least as severe energy deficiencies as they did ten to fifteen years ago, and the poor rural African eats considerably less than previously. IITA's mosaic-resistant cassava will help the latter, but the use of cassava as a main staple creates the problem of insufficient protein. Since protein from legumes is more costly per hectare than protein from cereals, legume research usually has fewer nutritional benefits than is often supposed. But legumes can reduce dietary monotony and are often less vulnerable to drought than are cereals.

## Variability, Vulnerability, and Quality of the Food Supply

Modern varieties have raised cereal output. But since farmers set aside part of their output to meet family needs, the amount of food sold for off-farm consumption fluctuates more than does production, and so do prices unless reserve stocks or imports are used to moderate the fluctuations. The supply of food available to people who do not live in modern-variety areas can thus become very insecure. Reserve stocks of food become more important, and modern varieties make it more feasible to build food stocks.

Further research into the effects of modern varieties on the nutritional needs of pregnant and lactating women and of preschool children also merits attention. Higher yields and greater food stability have helped these groups by reducing intrafamily competition for food. But research has ignored the possibly special effect of modern-variety nutrients and work inputs on such things as weaning practices and disease control. Which processes could reduce the costs and time required for food preparation or lessen the risk of contamination, especially of weaning foods? Which crop mixes and modern varieties might help to improve the quantity and nutritive quality of breast milk and the energy density, nutrient mix, and digestibility of cheap weaning foods? The breeding of new plant varieties for better palatability, color, or appearance threatens the cheaper prices that make modern varieties so important to poor consumers. Such breeding efforts may make sense where many poor food producers depend for their livelihood on selling these crops to the rich, but in general it is the yield and stability of cheap food energy that are most valuable for the poor.

## Modeling the Effects of Modern Varieties

So far this chapter has dealt separately with the impacts of modern varieties on employment and nutrition. But this approach leaves some unanswered questions. Studies of consumption, for example, suggest that while consumers benefit from the price reductions induced by the greater yields of modern varieties, producers lose 50–60 percent of what consumers gain. Yet studies of production claim that modern varieties also help producers. More holistic ways of looking at modern varieties in their sociopolitical context are available and may suggest useful new departures.

Several types of models have been developed by economists to examine the consequences of production changes beyond the sectors in which the first effects of these changes occur. Some of these models are neoclassical in that they assume that all inputs are fully employed and (except for land) are freely mobile among different activities (Quizon and Binswanger 1983; Binswanger and Ryan 1977). Such models give unclear predictions of the impact of greater production on the distribution of income between labor and capital and depend on the exposure of an economy to foreign trade. Whether labor-using and land-saving technical changes such as modern varieties benefit labor depends on the effects of any new or additional equipment on employment. Research priorities could be clarified by further development of computable models of this class.

Other general equilibrium models can be used to trace how extra spending by people initially enriched by modern varieties circulates through the economy to create increased incomes for others, rich and poor. In a regional model of this kind producers in Malaysia generated some 80 cents of further income for every dollar of their additional income from modern varieties (Bell, Hazell, and Slade 1982). Further efforts of this kind seem necessary to obtain a holistic view of the impact of modern varieties.

Because in many developing countries the government is a major trader in food staples, modern varieties change the government's budgetary position. This affects demand and trade and hence prices, spending patterns, and output. Price changes caused by modern varieties also induce changes in wage rates, which affect parastatals and, again, government budgets. Both sequences can greatly alter the impact of alternative modern-variety strategies. Examination of such sequences could further illuminate the problem of dealing with rural poverty.

Apart from a few good village studies (Hart 1984; van Schendel 1981; Hayami 1978; Frankel 1971) and some work by the centers on farming systems, little research has been done on how modern varieties affect the distribution of income (let alone status or power) within rural communities. Farming systems research may contribute to such understanding, but off-farm production, consumption, and leisure activities and transactions between particular members of the community may also substantially affect the impact of modern varieties on the poor.

The approaches reviewed to this point do not explain how modern varieties interact with national wealth and power structures. Marxist analysts have hypothesized that modern varieties promote the evolution of rural societies by formalizing wage contracts, thus polarizing such societies between large-scale capitalist farmers and landless rural workers. This approach may err by assuming that large farms gain special advantages by using modern varieties. In the Punjab polarization and tractorization preceded the introduction of modern varieties, and the same was true of formalized labor contracts in Java. In the course of the long debate in India about modes of production, neoclassical economists and Marxists have explored the interaction of modern varieties and power structures and its effect on poverty. Careful scholars have argued, however, that there is no general link between modern varieties and class unrest.

## Note

1. Much of this chapter is based on Lipton and Longhurst (1985). Box 8-1 is based on work at IFPRI for the impact study by Peter B. R. Hazell, V. Rajagopalan, and P. K. Aiyasami. Box 8-2 draws on work at IFPRI for the impact study by Eugenia Muchnik de Rubinstein and Per Pinstrup-Andersen.

# 9 The Growth of National Agricultural Research Systems

National agricultural research systems in the developing countries have grown rapidly in the past quarter-century. The abilities of the national systems and the growth of their budgets and staffs, along with other important characteristics, are described in this chapter, and some of the factors associated with that growth are examined.

## Agricultural Research Capacity

### *Research Capacity in the 1950s*

Data on the progress of national agricultural research systems in the developing countries during the 1950s are scarce, but it seems to have been a period of slow growth for most. By the end of the decade, however, Argentina, Ecuador, Mexico, and Venezuela had created "decentralized, autonomous institutes generally organized on the basis of the experience derived from the experimental station system of the U.S.A." (Trigo, Piñeiro, and Sabato 1983, p. 126).

In the 1950s much of Africa was still under colonial rule. There were strong research programs for certain export crops, and food crops were being studied in some countries. Relatively little research was being done, however, on crops grown only in small-scale farming, owing to the general view that most subsistence farm households in most countries could supply their own food needs most of the time and perhaps had little to offer the economy at large.

In Asia several countries were rebuilding their research systems after having gained independence. India, Pakistan, the Philippines, and Sri Lanka inherited from the colonial era research systems that had a fair number of well-trained local agricultural scientists as well as experimental stations and an institutional research structure. Other Asian countries were less fortunate. Indonesia, for example, had very few agricultural scientists, and none with an advanced degree.

### *Growth in Research Capacity in the 1960s and 1970s*

The 1960s, unlike the 1950s, saw rapid growth in agricultural research systems. In Asia increases in budgets and in the number of staff members were accompanied by changes in institutional structures and research priorities. The systems concentrated on adapting modern varieties of wheat and rice to local conditions, building the size and abilities of staffs, and establishing central authority over fragmented institutions. Agricultural research councils were widely used as a means of centralizing research decisions. The Imperial (later Indian) Council of Agricultural Research, started in colonial India, was adopted as a model in Bangladesh, Indonesia, Malaysia, Pakistan, and the Philippines. Research priorities shifted from export and cash crops to the principal food grains. Agricultural universities in India and the Philippines became integral parts of the research systems, broadly conceived. The 1970s witnessed a continuation of these trends, with rapid growth in the research systems of some countries that had lagged in the 1960s, particularly Bangladesh, Indonesia, and Pakistan.

In South America during the 1960s Argentina's decentralization of national research programs served as a model for Chile, Colombia, and Peru. Uruguay substantially reorganized its system, and Brazil made some changes in its traditional structure before creating a completely new institution, EMBRAPA, in 1973. Semidwarf wheat and rice varieties were widely adopted in several countries, and maize and soybean output increased in others. Some critics, however, argued that new agricultural technologies were not reaching the poor. Institutional changes were implemented to direct more attention to the problems of the poor and to persuade agricultural researchers of the importance of extension and development activities. At about the same time support for many national systems started to decline, and several, including Peru's, were almost crippled.

For many African countries the 1960s and 1970s were a transitional period analogous to the 1950s in Asia. Many countries gained independence, and in some cases political instability followed. Research was disrupted by the collapse of regional research institutions, the departure of expatriate research workers, and shortages of trained local talent. In 1964 there were only three African agricultural scientists in Kenya, Tanzania, and Uganda combined.

More systematic data for the period after 1959 were assembled by Evenson and his colleagues (Judd, Boyce, and Evenson 1983, 1986; Boyce and Evenson 1975) and by Oram and Bindlish (1981), whose study covers developing countries for 1970–80. In addition, there are studies on specific regions—for example, Trigo, Piñeiro, and Sabato (1983) for Latin America. The difficulties in collecting such data and in making them comparable have led to some inconsistencies. Fortunately, inconsistent estimates of expenditures by individual countries are the exception, and the most recent available data are probably fairly accurate. Trends in the growth of expenditures are fairly consistent with trends in growth of the number of scientists.

During 1959–80 government expenditures on agricultural research increased sixfold in Asia and Latin America and more than fourfold in Africa (figure 9-1). Growth rates by region were about the same in the 1960s and the 1970s. Research expenditures in Asia increased in all countries except Sri Lanka, while in Latin America and Africa there was much more variability among countries. Although research expenditures in five Latin American countries fell in real terms during the 1970s, regional growth was rapid because several large systems, notably those of Brazil and Mexico, grew rapidly. In Africa the regional picture was dominated by growth in Nigeria, but expenditures in Kenya, South Africa, and Zimbabwe also grew significantly. Growth in these countries offset declines in a number of others.

Government research expenditures increased substantially, not only in absolute terms but also in

**Figure 9-1.** ***Agricultural Research: Public Sector Expenditures and Staffing, by Region, 1959, 1970, and 1980***

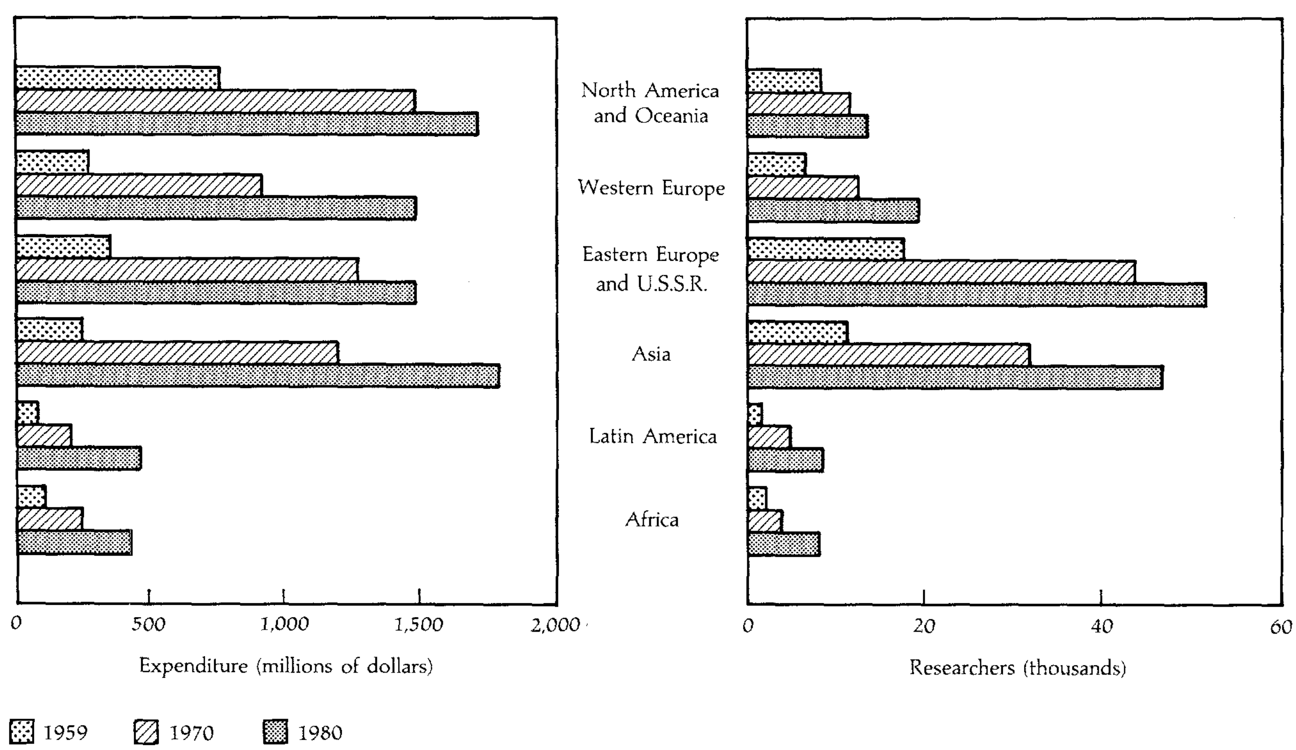
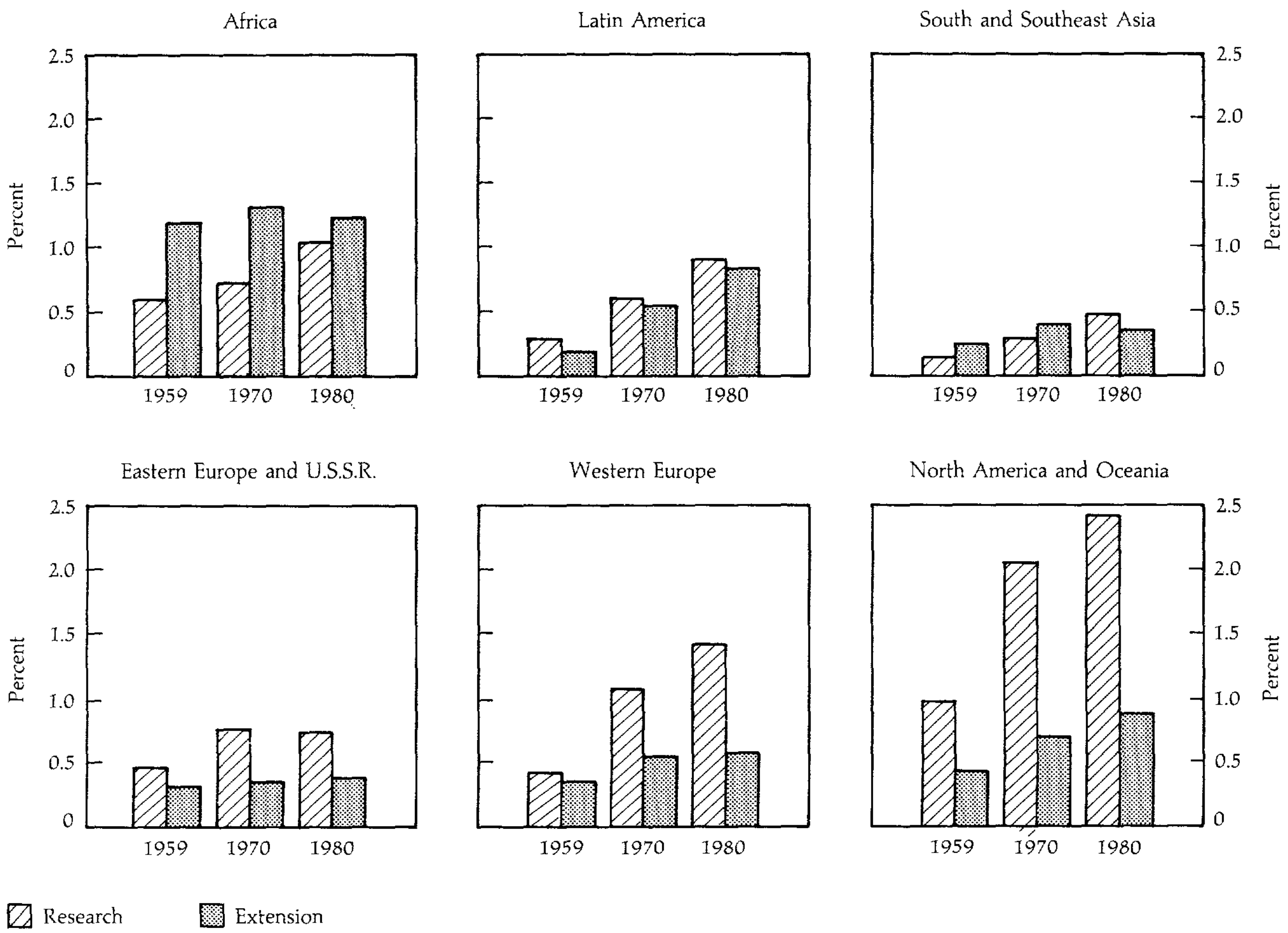


**Figure 9-2. *Agricultural Research and Extension: Public Sector Expenditures as a Percentage of the Value of Agricultural Production, 1959, 1970, and 1980***




relation to the size of the agricultural sector (figure 9-2). In the low-income countries of Africa, Asia, and Latin America 0.15 percent of agricultural gross domestic product (GDP) was spent on research in 1959. This increased to 0.5 percent by 1980. Asia invested less than 0.5 percent of agricultural GDP in 1980, while Africa spent slightly more than 1 percent. Despite the relatively high investment level in Sub-Saharan Africa, however, technological progress continued to be slow.

Research expenditures also increased in relation to expenditures on extension. The low-income countries spent the equivalent of 0.3 percent of agricultural GDP on extension in 1959 and 0.44 percent in 1980. The industrial countries spent far more on research than on extension, whereas the developing countries spent about the same amount on both.

The number of agricultural scientists grew at roughly the same rate as did expenditures in Asia and Latin America. In Africa, however, the number increased by a factor of almost seven, while expenditures increased only four times. This may reflect in part a problem characteristic of many national research systems—high turnover. The instability occasioned by migration from the research system to other sectors of the economy may ensure economical research budgets, but it is devastating to research productivity, especially in fields such as plant breeding in which gestation periods tend to be long.

In 1980 about 148,000 scientists worldwide were said to be conducting agricultural research, 43 percent of them in the developing regions of Africa, Asia, and Latin America. The world was investing $7.4 billion annually in agricultural research, 38 percent of it in the developing countries.

### *Status of National Systems in Case Study Countries*

Case studies in individual countries prepared in conjunction with the impact study showed a wide range of growth in research capacity (table 9-1). In

**Table 9-1. *National Agricultural Research Systems, Selected Countries***

| Country | Agricultural researchers, 1982 (excluding university staff) | | | | |
|---|---|---|---|---|---|
| | | | | Growth rate | |
| | Number with higher degrees[a] | Total[b] | Number per million hectares | Percent | Years covered |
| Africa | | | | | |
| Burkina Faso | n.a. | n.a. | n.a. | | |
| Cameroon | n.a. | 176 | n.a. | 5 | 1965–84 |
| Ethiopia | 50 | 123 | 9 | 9 | 1972–82 |
| Kenya | 315 | 638 | 335 | 8 | 1970–82 |
| Malawi | 21 | 76 | 33 | 6 | 1964–83 |
| Nigeria | 276 | 491 | 18 | 17 | 1970–80 |
| Senegal | n.a. | 196 | 39 | 9 | 1975–84 |
| Tanzania | n.a. | 236 | 58 | 18 | 1970–82 |
| Zimbabwe | n.a. | 214 | 79 | 1 | 1970–84 |
| Asia | | | | | |
| Bangladesh | 1,262 | 1,514 | 170 | n.a. | n.a. |
| Burma | 30 | 266 | 27 | n.a. | n.a. |
| India | 547 | 5,977 | 35 | n.a. | n.a. |
| Indonesia | 400 | 1,360 | 95 | 24 | 1975–84 |
| Nepal | 170 | 388 | 169 | 11 | 1971–80 |
| Philippines | 105 | 1,330 | 171 | n.a. | n.a. |
| Thailand | n.a. | 8,356 | 489 | 6 | 1975–82 |
| Latin America | | | | | |
| Brazil | 1,275 | 1,613 | 25 | n.a. | n.a. |
| Chile | 62 | 171 | 32 | 1 | 1970–82 |
| Colombia | 228 | 426[c] | 104 | n.a. | n.a. |
| Costa Rica | 7 | 70 | 233 | n.a. | n.a. |
| Cuba | | | | | |
| Ecuador | 75 | 337 | 187 | n.a. | n.a. |
| Guatemala | 30 | 210 | 161 | n.a. | n.a. |
| Mexico | 360 | 1,240 | 56 | 11 | 1970–82 |
| Peru | 32 | 250 | 78 | 3 | 1970–83 |
| Middle East and North Africa | | | | | |
| Egypt, Arab Rep. | 1,427 | 3,556 | 1,459 | 10 | 1979–81 |
| Syria | 55 | 500 | 95 | n.a. | n.a. |

n.a. Not available.
a. Master's and doctoral degrees.
b. Degree holders and above.
c. Includes research workers of the Instituto Colombiano Agropecuario.
*Sources*: For Nigeria and Bangladesh, Oram and Bindlish (1981); for others, country case studies; also, FAO (1984).

Indonesia the number of agricultural researchers grew 24 percent a year between 1975 and 1984, while the growth rate in Tanzania between 1970 and 1982 was an equally impressive 18 percent. Those in the middle range, with growth ranging from 8 to 11 percent, included Egypt, Ethiopia, Kenya, Mexico, and Nepal. In a few, including Chile, Peru, and Zimbabwe, the number of researchers grew little or not at all.

There is wide variation among developing countries in the number of researchers, which ranges from fewer than 50 in many small nations to about 6,000 research scientists (broadly defined) in India. The number with master's or doctoral degrees also varies widely. The number of researchers per million hectares of cropland (table 9-1) gives some idea of the range of research capacity among countries. The deflator is less than satisfactory, however, since a large country with a reasonably uniform topography does not require the research intensity needed by a small country with a highly variable topography.

### *Private Sector Research and Development*

Data on research expenditures by the private sector in developing countries are far from complete. Surveys in India and the Philippines (India 1980; NARSS 1971) showed that private expenditures were less than 10 percent of the amount spent by the government on agricultural research. Chile and Zimbabwe have long histories of agricultural research by the private sector. In these two countries and in a few others, such as Argentina, that have active private sectors the amount spent by the private sector may exceed 10 percent of government expenditures.

Two types of private institutions sponsor agricultural research: private firms, such as input supply companies or processors of agricultural commodities, and groups of farmers or plantation owners. In Asia during the colonial period private research was carried out primarily by organizations of producers of export crops. After independence many of these organizations were taken over by the government or were simply allowed to wither away. Sugar, tobacco, and rubber processors that had conducted research were nationalized in some countries but were allowed to continue operating privately in others. In the late 1960s and 1970s applied research and development by private chemical and seed companies—many of them local affiliates of multinational firms—grew rapidly in Southeast and South Asia. It is not clear whether there has been an increase or a decline in research by private organizations, but there has been a clear shift from the performance of research by private commodity organizations and processors of export crops to research by companies that supply inputs for both food grain and export crops. Apart from these overtly commercial activities, the work of nongovernmental development agencies and of religious organizations continues to be important, albeit often neglected by observers.

Research by commodity organizations also appears to have declined in Africa since independence, but the extent of the decline varies considerably among countries. During the colonial period many of these organizations were quasi-governmental and were financed out of general government revenues, whereas others had considerable autonomy. Private research by farmers' organizations remains strong in Kenya and Malawi, and is increasing in Zimbabwe. In contrast, the commodity organizations of Tanzania lost much of their strength, and their contribution to research has declined. Private input supply firms have strong research programs in only a few countries.

Private research in Latin America was conducted in the 1950s primarily by processing and trading firms, such as banana companies, and by commodity organizations, such as the coffee growers of Brazil and Colombia. Such research programs have declined in recent years, but research by input supply firms has grown rapidly in Argentina, Brazil, and Mexico. The firms have been attracted to these countries because of the similarity of their markets to those of the United States. Brazilian and Colombian coffee growers have continued to sponsor research, and several new groups of commodity producers have built strong research programs. Regional producer groups have started to invest in applied research and extension in Argentina and southern Brazil.

Individual farmers are also known to be important contributors to research in the private sector, but documentation of their role is virtually nonexistent.

## The Causes of Growth in Investment in National Research

### *The Demand for Research*

Periodic food crises were an important stimulus to national investment in agricultural research in Asia in the 1960s and in Africa in the late 1970s and 1980s. Urban groups induced governments to invest in agriculture to ensure adequate food supplies and hence economic and social stability. The food crises also led international organizations and industrial country donors to invest in food production research in developing countries.

The dramatic performance of water-responsive and fertilizer-responsive rice and wheat varieties was another factor. The global publicity surrounding the green revolution changed the perceptions in both developing and industrial countries about what research could do, while the failure of large investments in extension to achieve rapid agricultural growth led to much disillusionment with that method. In a number of countries—especially in Asia, but also in parts of Latin America—land that could be used to increase agricultural production was no longer cheap. A greater investment in agricultural research was seen as one answer to the demand for more production.

### *Public, Private, and International Interaction*

National research, private research, and international research have reinforced each other during the past twenty-five years. The international centers assembled germ plasm from existing national collections and mounted expeditions to collect more new varieties in cooperation with national programs. They hired research workers from strong national programs, such as India's, and employed expatriate researchers from industrial countries. Mexico's national program on wheat and maize, which had been greatly strengthened with Rockefeller Foundation assistance, was the basis of CIMMYT's germ plasm collection. IRRI drew on germ plasm collections from national programs in Asia and crossed Taiwanese and Indonesian varieties to develop IR8. The Indian research system's coordinated sorghum and millet improvement programs, which had been organized with the assistance of the Rockefeller Foundation, provided the bulk of ICRISAT's initial germ plasm collection and a considerable number of Indian scientists for ICRISAT and other centers.

It is clear that the international centers cannot have much impact on food production unless there are strong national systems. The centers may provide research methods and ideas, but only the national systems can adapt the technology made available through international networks to conditions prevailing in their own countries.

## The Adequacy of the National Research Systems

### *Underinvestment in National Research*

Despite the rapid growth of national research systems as a whole over the past quarter-century, the systems of many countries may be inadequate to meet their needs. There is evidence that not enough financial resources are invested in research, that the number and quality of scientists sometimes fall below minimum standards, and that available resources are not allocated efficiently.

Although there is no particular percentage of GDP and no specific sum of money that can be considered the optimal investment in agricultural research for every country, several authorities have suggested that 2 percent of agricultural GDP is an appropriate target (World Bank 1981). Figure 9-2 shows that only North America and Oceania met this goal in 1980; Europe came close.

A better measure of the adequacy of research investment is the expected rate of return. If this rate is greater at the margin than the return to alternative investment projects, more should be invested in research. There is now a considerable body of literature showing that returns to past investments in research have been much higher than returns on other kinds of investment. Some of the evidence on the return to research in selected developing countries is summarized in figure 9-3. Most

**Figure 9-3.** ***Annual Internal Rates of Return (IRR) on Investment in Agricultural Research in Developing Countries***

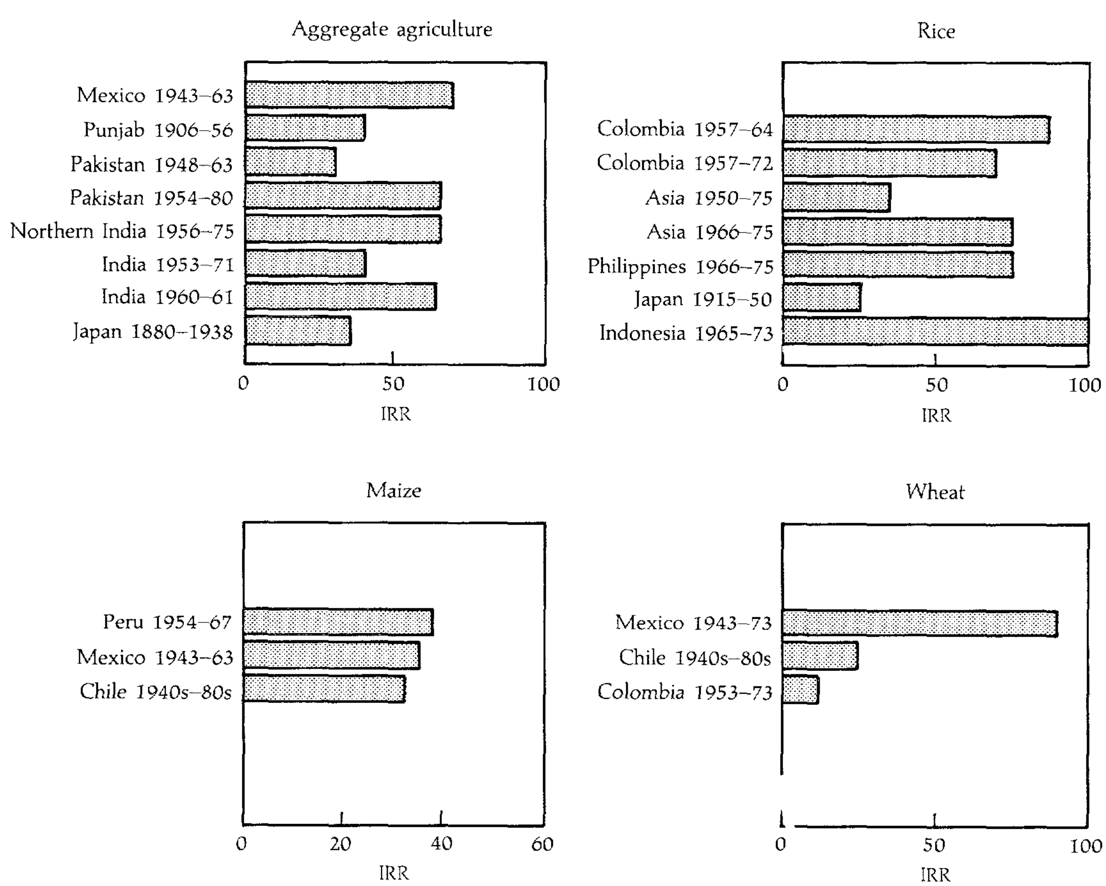


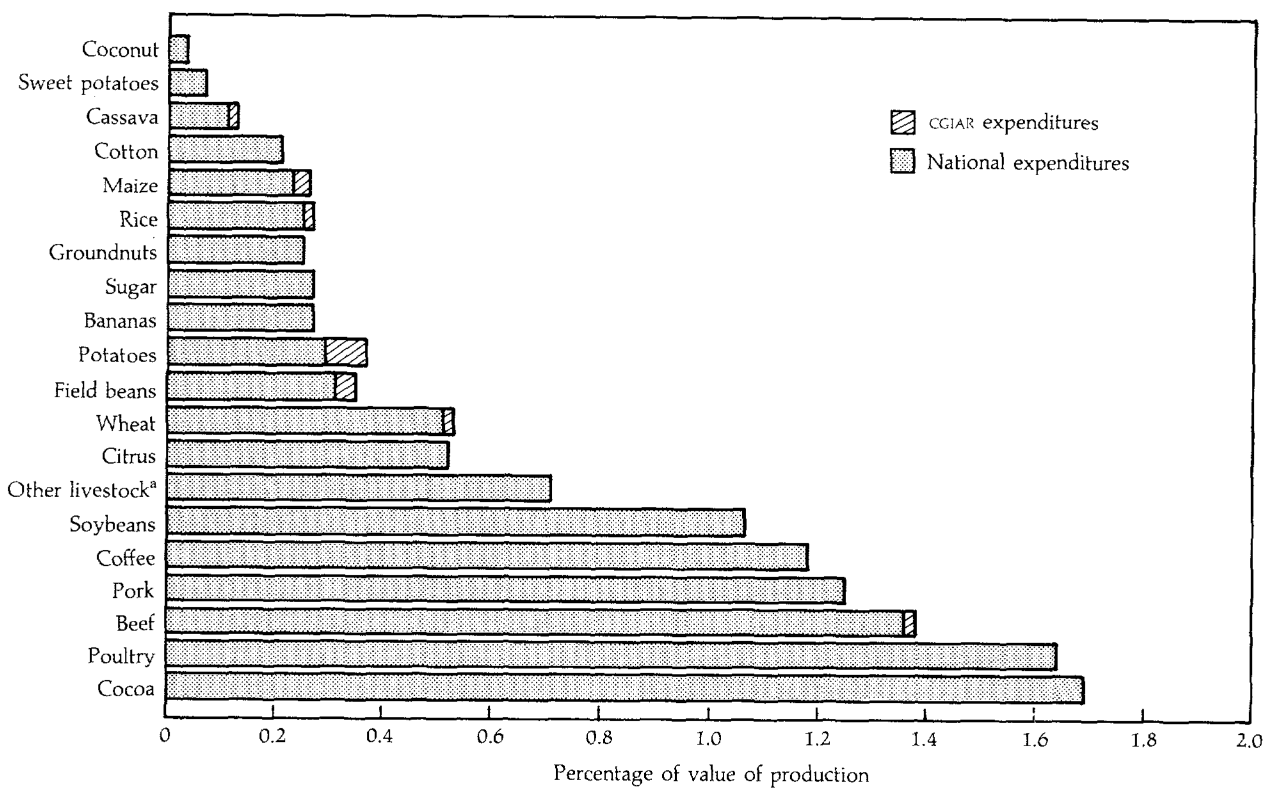
**Table 9-2. *Indicators of Research Adequacy, 1980***

| *Country or region* | *Permanent arable crop area (millions of hectares)* | *Number of agricultural scientists (thousands)* | *Scientists per million hectares* | *Research expenditures (millions of 1980 dollars)* | *Expenditure per hectare of crop area (dollars)* |
|---|---|---|---|---|---|
| India | 169 | 2.3 | 14 | 120 | 0.7 |
| China | 100 | 17.3 | 173 | 643 | 6.4 |
| Other developing Asia | 113 | 9.0 | 80 | 224 | 2.0 |
| Sub-Saharan Africa | 130 | 5.7 | 44 | 363 | 2.8 |
| Middle East and North Africa | 104 | 4.7 | 45 | 187 | 1.8 |
| Latin America | 171 | 8.5 | 50 | 463 | 2.7 |
| Eastern Europe and U.S.S.R | 278 | 51.6 | 186 | 1,493 | 5.4 |
| Western Europe | 95 | 19.5 | 206 | 1,490 | 15.7 |
| North America and Oceania | 280 | 13.6 | 49 | 1,722 | 6.2 |

*Note:* Definitional problems plague all such tabulations. For example, the number of researchers shown above for India in 1980 is considerably smaller than the 5,977 shown for 1982 in table 9-1 or the figure of 7,103 for 1980 given by Oram and Bindlish (1981). The definition used by Judd, Boyce, and Evenson (1983) is stringent: research scientists are those with some formal graduate training who are also in the *List of Research Workers* issued by the Commonwealth Agricultural Bureaux. This definition may understate the size of the large and complex Indian agricultural research system.

*Sources:* Area data, FAO; other data, Judd, Boyce, and Evenson (1983).

**Figure 9-4. *Research Expenditures as a Percentage of the Value of Commodity Production. Average 1972–79, Twenty-six Developing Countries and the CGIAR Centers***




a. Excluding beef, pork, and poultry.

estimates of the internal rate of return have been about 30–60 percent, but some research activities yield much higher returns.

Comparisons show that returns on extension tend to be lower than returns on research. In India rates of return to extension were 15–30 percent (Mohan and Evenson 1975; Evenson and Jha 1973). Rates of return to educational and infrastructural projects have typical-

**Table 9-3. *Researchers and Research Expenditures in Developing Countries 1980***

| *Country* | *Arable and permanent crop area (thousands of hectares)* | *Agricultural researchers* | | *Research expenditures (dollars per hectare)* |
|---|---|---|---|---|
| | | *Number* | *Per million hectares* | |
| *Countries with fewer than fifty researchers* | | | | |
| Cape Verde | 40 | 6 | 150 | n.a |
| Tonga | 53 | 8 | 151 | 5.4 |
| Solomon Islands | 52 | 8 | 154 | 6.4 |
| Mauritania | 195 | 9 | 46 | 4.4 |
| Lesotho | 292 | 13 | 45 | 1.0 |
| Gambia | 270 | 13 | 48 | 0.3 |
| Benin | 1,795 | 21 | 12 | 1.0 |
| Barbados | 33 | 23 | 697 | 15.2 |
| Fiji | 236 | 23 | 93 | 6.5 |
| Somalia | 1,066 | 28 | 26 | 0.5 |
| Burundi | 975 | 28 | 29 | 0.7 |
| Guyana | 380 | 35 | 92 | 4.2 |
| Haiti | 890 | 37 | 42 | 0.3 |
| Chad | 3,150 | 40 | 13 | 0.3 |
| Malawi | 1,305 | 41 | 31 | 1.8 |
| Jamaica | 265 | 41 | 151 | 1.9 |
| Trinidad and Tobago | 158 | 43 | 272 | 2.7 |
| Liberia | 371 | 45 | 121 | 1.9 |
| Mali | 2,050 | 47 | 28 | 1.8 |
| Togo | 1,420 | 49 | 35 | 0.9 |
| *Countries with fewer than twenty-five researchers per million hectares*[a] | | | | |
| Uganda | 5,680 | 58 | 10 | 0.9 |
| Ethiopia | 13,880 | 145 | 11 | 0.2 |
| Zaire | 6,314 | 97 | 15 | 0.5 |
| Nigeria | 30,385 | 491 | 16 | 2.6 |
| Niger | 3,550 | 59 | 18 | 0.4 |
| Zambia | 5,108 | 96 | 19 | 0.2 |
| Senegal | 5,225 | 105 | 20 | 1.2 |
| Sudan | 12,417 | 272 | 22 | 0.8 |
| Cameroon | 6,930 | 156 | 23 | 0.5 |
| *Others* | | | | |
| India | 169,130 | 2,345 | 14 | 0.7 |
| North America and Oceania | 280,446 | 13,607 | 49 | 6.2 |
| Brazil | 7,120 | 2,935 | 41 | 2.4 |
| Western Europe | 95,025 | 19,540 | 206 | 15.7 |
| Japan | 4,881 | 15,671 | 3,211 | 140.2 |

n.a. Not available.
a. In addition to those having fewer than fifty researchers.
*Source:* Area data, FAO (1984); other data, Judd, Boyce, and Evenson (1983).

ly been about 10–15 percent. Surface irrigation projects in India were recently estimated to have produced a return of 12–14 percent (Abbie, Harrison, and Wall 1982).

The adequacy of the links between national research systems, extension systems, and farmers has been extensively analyzed. Deficiencies in linkage slow the flow of technology to farmers, lead to inappropriate research (because researchers do not understand farmers' problems), make it difficult to develop grass-roots support for research budgets, and hold down returns on research and extension.

Comparisons of rates of return suggest that underinvestment is particularly evident in Asia, which has about half the research intensity of other regions. Studies of returns to research in Africa had not been conducted at the time of this study.

### *Adequacy of Human Resources*

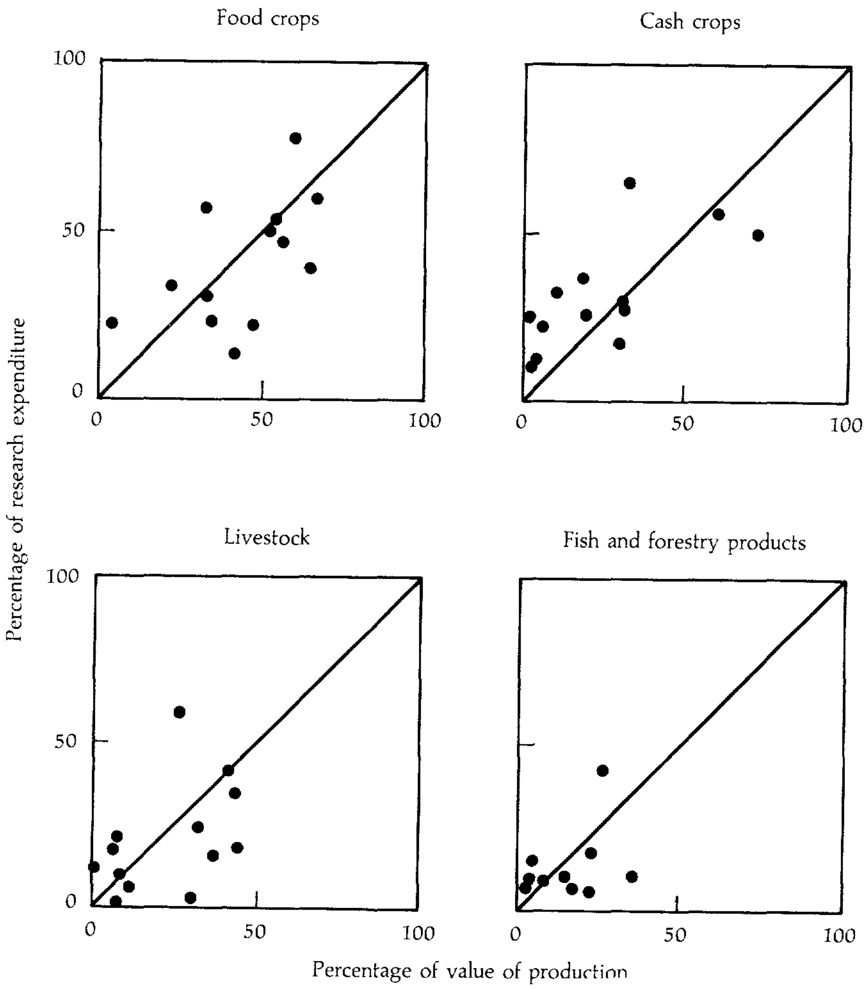
Expenditures on research may appear to be adequate when in fact they are not. In Africa, in particular, researchers are expensive and the value of agricultural output is low, which raises research intensity (the percentage of the value of production spent on research). It is thus important to look at other measures of adequacy, such as the quality of research staffs.

Larger countries need more researchers and smaller ones fewer to have the same relative capacity. Very small nations, however, may need some minimum number to achieve a critical mass—that is, to be able to make significant progress in research. Table 9-2 shows data on agricultural area and number of researchers. The industrial nations, especially in Europe, have high capacity, even judged against land area, but the developing nations have lower levels than those in figure 9-2. Countries with the lowest levels of nominal capacity are listed in table 9-3. The twenty nations with fewer than fifty agricultural researchers may be considered, somewhat arbitrarily, as having less than the number needed to achieve a critical mass. Twelve of the twenty are in Africa; the others are small island nations in the Pacific or the Caribbean. In addition to the nations that lack a minimal absolute number, several, including nine in Africa, have fewer than twenty-five scientists per million hectares of arable land. All nations in Asia have forty or more scientists per million hectares, and all in Latin America have thirty or more.

### *Adequacy of Allocation of Resources*

Research resources are divided among many different activities. Useful measures with which to judge the efficiency of allocation decisions are few; among the measures that have been used are the shares of import earnings and of government revenues derived from agriculture. Resources may be allocated by commodity or, less commonly, by input category—seeds, soil,

**Figure 9-5. *Congruence of Research Expenditures and the Value of Agricultural Output, Fourteen Developing Countries, 1980***




*Note:* Not every country is shown in all categories.
*Source:* Oram and Bindlish (1981).

fertilizer, irrigation, and so on—or by professional discipline.

A rule of thumb, known as the congruence rule, for the allocation of resources among commodities is that each commodity should have a share roughly equal to its share in the value of agricultural output. In other words, the research intensities for different crops should be equal. Figure 9-4 shows the research intensities of the principal commodities for all developing countries. Coconuts, sweet potatoes, and cassava have the lowest intensities, less than 0.1 percent. Cotton, maize, groundnuts, and rice also have comparatively low levels of investment. The commodities with relatively high levels of investment are cocoa, coffee, beef, pork, poultry, other livestock, and soybeans, each of which receives over 1 percent.

Figure 9-5 shows congruence measures for four commodity groups for fourteen developing countries. The diagonal lines indicate equal proportions of research investment and output value. Points below the line indicate less than proportional investment in research on a commodity; points above the line indicate that investment in research is more than proportional to the commodity's contribution to output. Such measures are imperfect because they take no account of variations in knowledge about different commodities or of the opportunities they present in different environments.

Other informational shortcomings have curtailed progress toward more efficient allocation of research resources. Data on the diversity of the environments in which farming takes place are often fragmentary.

National and international authorities must therefore continue to strive to improve the quality and quantity of data.

Other challenges for research planners that are not addressed here but that must be considered include criteria for allocating institutional responsibility for basic, applied, adaptive, and operational research among different levels of government and among national systems, CGIAR centers, and other international institutions.

# 10 The Impact of the Centers on the National Agricultural Research Systems

The international agricultural research centers affiliated with CGIAR have made a demonstrable impact on the agricultural research systems of the developing countries. The centers have been models, sources of inspiration, and even at times providers of basic laboratory supplies. This chapter discusses how the centers, sometimes by deliberate action and sometimes by their mere existence, have helped to shape the funding, the structure, and the activities of the national systems.

## Funding

As chapter 9 showed, national expenditures on agricultural research by the developing countries rose impressively between 1959 and 1980. Expenditures, in real terms, grew in all regions, and so did the number of scientists. Research intensity also rose, typically doubling between 1959 and 1980. Spending by the centers also increased substantially in most years between the early 1960s and 1980.

Some observers have inferred that the centers induced greater national spending. Others have argued that spending by the centers tends to displace national efforts and that the rise in spending by the developing countries would have been even more marked had it not been for the existence of the centers. The history of spending on commodity research programs in host countries is cited to support this viewpoint. A third group argues that funding for the centers did not necessarily displace national efforts but that it did come at the cost of reduced bilateral and multilateral assistance to the developing countries and that, in consequence, net spending on research did not rise.

The fact that observers use the same data to reach different conclusions suggests that a number of underlying forces are at work and that only by capturing their respective degrees of influence can the true story be known. An attempt was made to do that, but neither the data nor the theoretical constructs were completely adequate for the task. The findings given here, which are based largely on a special report (Evenson 1987) done for the impact study, must therefore be regarded as preliminary.

To understand the influence of the centers, it is necessary to disaggregate national expenditure data by commodity, since we are interested as much in the centers' influence on national spending for research on specific commodities as in overall spending for agricultural research. The centers conduct research on the main food crops, but not on all the food crops covered by national programs. Few countries, however, can provide a breakdown of research expenditures by commodity. Even where one has been attempted, the allocation to individual crops of expenditures on such things as soil conservation, irrigation, pasture, and fertilizer must be made rather arbitrarily.

The analysis here is reported in more detail in Evenson (1987). Commodity data for twenty-five countries for 1972–75 and 1976–80 were collected from abstracts of commodity-oriented publications made by the Commonwealth Agricultural Bureaux. The twenty-five countries—eight in Africa, ten in Asia, and seven in Latin America—produce over 90 percent of the total value of agricultural output in developing countries, excluding China. Since both data on actual spending on commodity research and the Commonwealth Agricultural Bureaux abstracts were available for Brazil, the abstracts were standardized in terms of cost-equivalent units of research spending, by commodity, using Brazilian data. This standardized measure was then applied to the remaining twenty-four countries to determine the intensity of spending on each food crop.

The data generated in this manner are summarized by region (they are not available by discipline) in table 10-1. Regional research expenditures are expressed as a share of the value of output. Four points emerge.

- Research intensities are very uneven among commodities.
- Research intensities for each commodity vary widely among regions.
- For almost every commodity research intensity was higher in Africa than in other regions.
- The centers' share of total research funding varies widely.

Globally, the centers accounted for 15 percent of cassava research and 21 percent of potato research but only 4 percent of wheat research. This suggests that the centers are overinvesting in research on roots and tubers in relation to cereals or that they are compensating partially for underfunding of root and tuber research by the national programs. Another possible explanation is that the perceived marginal return to center research on roots and tubers is significantly higher than the marginal return on cereals.

To analyze the influence of the centers on national spending, two sets of data were constructed. The first used observations for 1972–75 and 1976–80 for the twenty-five countries. The second set contained annual observations from 1962 to 1982 for a limited number of variables.

Twelve commodities were analyzed, ten from the centers' portfolios (rice, wheat, maize, sorghum, millet, cassava, beans, potatoes, sweet potatoes, and groundnuts) plus soybeans and sugar. The approach taken was to specify variables that might explain the level of funding for national research and extension programs. A statistical analysis was then made to determine the importance of each variable after allowing for the influence of the others.

The explanatory variables fall into three categories: economic, international, and political. The economic variables were the value of commodity production, an index of diversity among cropping patterns across geoclimatic regions, the relative costs of research and extension, and an index of land scarcity. The international variables consisted of the cumulative spending by the centers on a commodity (including an interaction effect with the total area in crops to allow for the probable complicating influence of country size), research investment by countries in similar geoclimatic regions, and a variable denoting whether a country is host to a center. The political variables included indicators of international trade, an index of farmers' terms of trade, the agricultural labor force as a proportion of the economically active population in agriculture, an index of urbanization of the population, and an index of political violence. Allowance was made for the fact that foreign assistance is influenced by the level of domestic research spending and is also a determinant of that spending.

Apparently in response to the cumulative investment of the centers in research on a commodity, national systems also invest in the commodity, generally in a manner that rapidly (in one to five years) matches the total amount invested by the CGIAR. The analogous changes in national expenditures on extension are usually an order of magnitude smaller.[1]

The influence of the centers on spending for both research and extension was found to be related to the size of the country. Since larger countries can benefit more from any given unit of research because of their greater crop area, an increase in center funding encourages them to expand their own research funding by significant amounts. Not only do larger countries increase their spending by greater absolute amounts, but their research expenditures per unit of crop area also rise. Very small countries may reduce their research efforts when the centers increase their spending.

The analysis thus far has referred to non host countries. For host countries there was no clear-cut relation between center spending and national spending. Although there was some suggestion of a positive

**Table 10-1. *Research Spending by National and International Programs: Average, 1972–79, for Twenty-five Developing Economies***

(percent)

| | *National research expenditure as a share of value of output* | | | *Spending by centers as a share of total research expenditure* |
|---|---|---|---|---|
| *Commodity* | *Africa*[a] | *Asia*[b] | *Latin America*[c] | |
| Wheat | 1.30 | 0.32 | 1.04 | 4 |
| Rice | 1.05 | 0.21 | 0.41 | 7 |
| Maize | 0.44 | 0.21 | 0.18 | 11 |
| Cassava | 0.09 | 0.06 | 0.19 | 15 |
| Beans | 1.65 | 0.08 | 0.60 | 11 |
| Potatoes | 0.21 | 0.19 | 0.43 | 21 |
| Groundnuts | 0.57 | 0.12 | 0.60 | 2 |
| Beef | 1.82 | 0.65 | 0.67 | 2 |

a. Arab Republic of Egypt, Ghana, Kenya, Nigeria, Sudan, Tanzania, Tunisia, and Uganda.

b. India, Indonesia, Korea, Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, and Turkey.

c. Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela.

*Source*: Evenson (1987).

effect, it was difficult to find a direct cause-and-effect relationship. It may be that host countries have a greater proclivity to expand their agricultural research spending. When neighboring countries increase their research efforts, a host country is induced to raise its own efforts to internalize the benefits stemming from greater research. Similarly, when exports of a commodity become more important, research and extension efforts increase. Greater output alone also induces more research spending. Typically, a 10 percent rise in the value of output was accompanied by a 6 percent increase in spending for research and extension.

A commodity-by-commodity analysis showed that spending by the centers had a significant stimulating effect on national spending on all the cereals except millet. Although the effect on the other staples as a whole was significant, only in the case of potatoes was there evidence that spending by national systems was significantly and positively related to the expenditures of the centers.

The set of annual data on commodity research in the twenty-five countries for 1962–82 was used in a further analysis of the effects of research spending on production. The value of output of particular commodities was related to measures of national research and extension, to international research spending, to the area of the crop that was harvested, and to measures of the use of irrigation and fertilizers.

It is highly improbable that the influence of the centers would be the same in all twenty-five countries, since the centers generally produce technology that is matched more closely to the environments of their host countries than to other environments. This affects each center's contribution to productivity. A variable was created to capture the extent to which a country's production of a particular crop took place in a geoclimatic zone similar to that in which the relevant center was located.

Interactions between national and center funding were generally positive for beans and sorghum and negative for wheat, cassava, and potatoes. In similar geoclimatic regions the effect was positive only for wheat. In similar regions the centers' technologies should more nearly match national requirements, and hence center funding may not interact significantly with national funding to raise crop productivity. The interaction effects between center research and national research provide general support for the notion that center research spending is a substitute for national spending in countries with an environment similar to that of a center.

Clearly, the productivity of national research and extension efforts varies tremendously among countries. It is instructive to look first at the results for cereals and other staples. In both cases national and center spending increased productivity, and the latter effect was greater where geoclimatic conditions were similar. Since total center spending as a proportion of the value of output was quite low, a small rise in cereal productivity in the twenty-five countries implied a substantial impact. Furthermore, the value of the increased output far exceeded research costs. The value of a 0.3 percent rise in global cereal output might be, say, $130 million a year, whereas a 10 percent rise in spending on cereal research by the centers would amount to only $7 million, giving an implied marginal internal rate of return of the order of 100 percent. This follows from the fact that the contribution of the centers is felt not just in one country but over entire regions. The results for individual cereals, however, were erratic. For other staple crops center spending had a significant impact on cassava, beans, and potatoes in similar regions, but cassava research has seemingly not raised productivity outside the centers' own regions.

In general, center spending on cereal research has engendered greater productivity by national systems than has research on other staples (potatoes are a notable exception). Research on noncereal staples still lacks the stock of knowledge that has been accumulated during the longer period of cereal research. Moreover, noncereal staples are often produced in subsistence conditions in remote rural areas, and the ability of subsistence producers to influence the allocation of resources at the national level is usually small. And the demand for noncereal staples does not rise as incomes increase to nearly the same extent as does the demand for cereals. The share of household budgets spent on noncereal staples falls sharply as income rises, whereas the demand for cereals for both human and animal consumption is rising rapidly in developing countries. This, combined with their greater importance in trade, leads to higher research expenditures for cereals than for other staples in most regions.

The effect on productivity of the centers' spending on noncereal staples appears to have exceeded that of their spending on cereals. This may reflect the many opportunities for improving previously neglected crops.

Finally, it should be stressed again that investment in research and extension and growth in agricultural productivity are governed by a complex interplay of economic and political forces in a wide variety of social settings. Our understanding of these forces is less than complete, and the data are less than ideal. It would thus be premature to accept these findings as definitive.

## Structure

The CGIAR centers, as was mentioned above, have created interdisciplinary teams to attack the practical problems that confront farmers in the developing countries. Ever since they were established, the centers have been urging the national research systems to adopt a similar model. To demonstrate the interdisciplinary approach in a more concrete way, the CG in 1980 created the International Service for National Agricultural Research (ISNAR) to enable developing countries to plan, organize, manage, and execute research more effectively.

### *The Work of ISNAR*

By 1984 ISNAR had carried out reviews of national agricultural research systems in eighteen countries and had recommended changes in twelve. Six countries—Costa Rica, Côte d'Ivoire, the Dominican Republic, Guyana, Kenya, and Papua New Guinea—were advised to set up new systems to tighten control over funds and programs, ensure better management of available resources, and improve interaction with policymakers (see box 10-1). Malawi and Sri Lanka were told that they could improve resource allocation and the coordination of agricultural programs by creating national research councils. Madagascar and Rwanda were urged to alter the way in which their existing systems operated, and Fiji and Morocco were advised to make more effective use of existing resources. Fiji, Madagascar, Morocco, Rwanda, and Western Samoa have all been told that they have more research stations than they need and should consolidate them.

As might be expected, ISNAR has sometimes been asked (for example, by Indonesia) to help carry out its recommendations. In other cases the national systems are implementing the recommendations without any additional help from ISNAR. One or two countries have not acted on ISNAR's report.

ISNAR has also carried out instructional programs to strengthen the managerial abilities of those in charge of national agricultural research systems. More than 130 managers, mostly from Africa, have attended these programs. ISNAR has also conducted in-depth surveys on research management in Cameroon, Sudan, and Zimbabwe.

In Kenya ISNAR, working with the National Council of Science and Technology and the Ministry of Agriculture, developed plans to bolster the agricultural research department at the University of Nairobi and thus to improve the quality of Kenyan agricultural researchers. In Thailand ISNAR helped local authorities work out a way to encourage more researchers to

**Box 10-1. *ISNAR and the Dominican Republic***

In 1982 the Dominican Republic's secretary of agriculture invited ISNAR to review that country's agricultural research system. Early in 1984 a six-member ISNAR team arrived to work on plans for a new, semiautonomous agricultural research institute to replace the existing system. What the ISNAR group and its Dominican counterparts hoped to create was an institution that would have the power to promote employees on the basis of merit and the flexibility to shift funds quickly to high-priority projects.

The proposal had to win approval from the secretary of agriculture and the top levels of the Dominican agricultural research system; it also had to be accepted by the agricultural research departments of the universities, by local extension organizations, and by external funding agencies. These tasks were carried out by the local working group. ISNAR advisers made periodic visits to provide advice on specific issues, and at the request of the secretary of agriculture ISNAR eventually sent a consultant to work full-time with the local group.

The last step was to convince the country's legislature that more intensive research was necessary to solve the food problems facing the country and that the creation of the new organization was the appropriate means for achieving this goal. The working group and other officials from the Ministry of Agriculture contacted lawmakers individually to explain to them the nature and objectives of the new research institute, and a national workshop was convened to discuss the pros and cons of the initiative. Participants in the workshop included the agricultural committees of the House of Representatives and the Senate, the current head and several past heads of research and extension, and other people connected with the agricultural sector. The workshop relied heavily on case studies that highlighted the problems of the existing research system and explained why the new organization was expected to be more effective. ISNAR helped to organize the workshop and provided the case studies, and members of the original team served as resource persons. The result was support for the new institute by the agricultural committees of both the House and the Senate.

accept assignments to research stations in rural areas rather than in the capital, Bangkok.

In certain countries to which ISNAR has sent teams (for example, Kenya and Papua New Guinea) women constitute a large number of the country's farmers. In others, such as Thailand, women also make up a large proportion of all research and extension workers. Thus far, however, ISNAR has apparently been cautious in trying to persuade national systems to strengthen their ability to help women farmers.

### *The Centers as Models*

A number of national systems have adopted the centers as models in designing their own structures. EMBRAPA, the Brazilian agricultural research company, established as the basic structure of its system commodity institutes that utilize multidisciplinary teams. Bangladesh modeled its rice research institute on IRRI, with the assistance of IRRI personnel. Guatemala's Instituto de Ciencias y Tecnologías Agropecuarias (ICTA) was organized according to the farming systems research model developed by CIMMYT and others. IITA has influenced the organization of agricultural research in Africa; its multidisciplinary approach has been adopted by many national systems, most notably those of Cameroon and Nigeria.

Some countries have imitated parts of the structure of the centers. An example is the Indonesian Genetic Evaluation and Utilization program (GEU) for rice, established in 1975. This program was formed to coordinate rice-breeding activities to respond more effectively to outbreaks of the brown plant hopper. It took both the name and the institutional structure of IRRI's GEU program.

## Activities

### *Allocation of Resources*

A key issue for national agricultural research systems is the allocation of resources among different commodities and projects. The centers were originally established because of a conviction that too little research on food production was being done in the developing countries. The activities of the centers seem to have brought about more national research on principal food crops.

The inducement effect is clearest where national research programs did not exist before they were instigated by one or more centers. Many countries, for example, had no organized research on cassava or other root and tuber crops until they came into contact with IITA or CIAT. IITA's work on cassava, yams, sweet potatoes, and cocoyam was the stimulus for the establishment of twenty-three root and tuber improvement programs in Africa since 1979. (Table 10-2 shows some aspects of CIAT's participation in a number of cassava research programs.) Only India had a national research program on cassava before the centers' programs were established. Wheat research programs in Burma, the Philippines, and Thailand were stimulated by CIMMYT's studies of tropical wheat.

Collaboration between the centers and the national systems has led to increases in the size of existing programs in many countries. Table 10-3 shows that Bangladesh's investment in rice research was smaller than its investment in jute research during the early 1960s. By the 1970s, for better or worse, Bangladesh policymakers were investing much more in rice research. Young national systems often respond enthusiastically to the dynamism of the centers and sometimes neglect their capacity to study other crops that may be critical to the nation's trade position. Syria's research establishment, for example, expanded about threefold between 1978, when it handled 144 projects, and 1986, when it handled 343 (El-Akhrass

**Table 10-2. *National Cassava Research Activities and CIAT***

| *Country*[a] | *CIAT trainees* | *Genetic material from CIAT*[b] | *CIAT lines released or grown* | *Visits by CIAT staff since 1977* |
|---|---|---|---|---|
| Bolivia | 5 | None | No | 6 |
| Brazil | 94 | S | Unknown | 34 |
| China | 2 | S, M | No | 2 |
| Colombia | 86 | E | Yes | n.a. |
| Costa Rica | 9 | M | Yes | 12 |
| Cuba | 12 | S, M | Yes | 14 |
| Dominican Republic | 20 | None | Unknown | 17 |
| Ecuador | 12 | M | Yes | 18 |
| Guyana | 4 | None | No | 1 |
| Haiti | 4 | None | Yes | 6 |
| India | 5 | S | No | 11 |
| Indonesia | 12 | S | No | 8 |
| Malaysia | 14 | S | No | 10 |
| Mexico | 31 | S, M | Yes | 27 |
| Panama | 7 | M | No | 6 |
| Paraguay | 3 | S | No | 6 |
| Peru | 10 | S | No | 7 |
| Philippines | 11 | S | Yes | 18 |
| Thailand | 24 | S | Yes | 18 |
| Venezuela | 14 | M | Yes | 2 |

n.a. Not available.
a. Most of these programs were established in the mid- to late 1970s.
b. M, meristems; S, seeds; E, stakes.
*Source:* Data from CIAT.

**Table 10-3.** ***Allocation of Agricultural Research Expenditures, Bangladesh***
(millions of current taka)

| *Crop or institution* | *1950–60*[a] | *1960–65*[a] | *1967* | *1974* | *1979* | *1980* |
|---|---|---|---|---|---|---|
| Rice | 0.2 | 0.3 | 1 | 7.0 | 28 | 40 |
| Other food crops | 0.2 | 0.2 | n.a. | 12.0 | 77 | 129 |
| Jute | 0.2 | 0.5 | 2 | 2.0 | 10 | 11 |
| Tea | 0 | n.a. | n.a. | 2.0 | 6 | 5 |
| Sugarcane | n.a. | 0.1 | 0.1 | 4.5 | 10 | 14 |
| Bangladesh Agricultural Research Council | 0 | 0 | 0 | n.a. | 5 | 11 |
| Livestock | n.a. | 0.6 | 0.3 | 2.8 | n.a. | n.a. |

n.a. Not available.
a. Annual average.
*Source:* Pray and Ahmed (1984).

**Table 10-4.** ***Personnel of National Potato Programs in 1977–78 (before the Establishment of PRECODEPA) and in 1983–84***

| | *1977–78* | | | *1983–84* | | |
|---|---|---|---|---|---|---|
| *Country* | *Full-time* | *Part-time* | *Total* | *Full-time* | *Part-time* | *Total* |
| Costa Rica | 1 | 0 | 1 | 6 | 3 | 9 |
| Dominican Republic | 2 | 0 | 2 | 12 | 5 | 17 |
| Guatemala | 2 | 2 | 4 | 11 | 20 | 31 |
| Honduras | 1 | 0 | 1 | 3 | 8 | 11 |
| Mexico | 2 | 2 | 4 | 8 | 10 | 18 |
| Panama | 1 | 1 | 2 | 4 | 5 | 9 |
| Total | 9 | 5 | 14 | 44 | 51 | 95 |

*Note:* All salaries are financed entirely from the respective national budgets.
*Source:* CIP (1984).

1986, p. 18). In 1978 Syria's research on field crops of interest to ICARDA accounted for about 42 percent of the projects; by 1984 the figure was 73 percent.

As development proceeds, national priorities are often reasserted. Again, the experience of Bangladesh is instructive. After the great expansion in rice research, national authorities and donors became aware in the late 1970s that the technological development of other crops was falling behind. The Bangladesh Agricultural Research Institute, which had responsibility for studying other important crops, was then strengthened, and by 1980 expenditures on other food crops far exceeded those on rice (see table 10-3). It could be argued that IRRI influence initially "distorted" national priorities, but an argument can also be made that the success with rice research was a strong stimulus for research on other crops.

Research by the centers is sometimes said to "crowd out" local research. Host countries face a particular challenge in determining domestic institutional responses. IRRI research appears to have been a partial substitute for national investment in rice research in the Philippines. The Philippine Council for Agriculture and Resources Research and Development (PCARRD) until recently classified rice as a priority II crop and allocated fewer resources to it than to priority I crops such as maize. The University of the Philippines Institute for Plant Breeding, the principal institution for crop improvement, undertook no rice research until recently, and the university's department of agronomy has done only a little. Two experienced Philippine rice breeders are working for IITA and IRRI. Although rice breeding at the University of the Philippines is probably weaker than it was in 1970, IRRI carries out a rice research program much larger than would be undertaken in its absence. The expressed view of the Ministry of Agriculture is that virtually all of the rice research required for the Philippines is available from IRRI. Steps have recently been taken, however, to develop a National Rice Research Center.

Rice research at CIAT in Colombia has been cited as another example of a center's replacing a national program (Trigo, Piñeiro, and Sabato 1983), but the evidence here is less clear. The share of resources going to rice increased from 5 percent in 1964 to 9 percent in 1969 and remained constant at that level until 1983. There appears to have been a substantial shift in research priorities from irrigated lowland rice to upland rice. There is also some evidence that the quality of the national rice research program may have declined because CIAT hired Colombia's most experienced rice breeders.

In general, a shift in research resources toward food crops seems to make for a more efficient allocation of resources. Some programs instituted at the behest of a center, however, have attracted comment because significant resources go to commodities that make up a small share of the value of output. Table 10-4, for example, shows the increase in potato researchers in the countries of the Programa Regional Cooperativo de Papa (PRECODEPA). (This organization is discussed in detail in box 10-2.) The tropical wheat research programs in the Philippines and Thailand and the maize research program in Bangladesh are other examples.

It is useful to remember that the centers have had little apparent effect on research priorities in a number of large national research systems and in some small ones. In Brazil, for instance, there has been a gradual shift of resources toward export crops. On balance, any negative effects of induced distortion in the developing countries as a whole have probably been offset by the stimulus that the centers' influence has given to entire national systems.

### *Changing Priorities within Commodity Programs*

The centers and their successes have influenced the structure of commodity research programs in many countries, sometimes in subtle ways, sometimes more overtly. Under the auspices of the FAO, for example, researchers in Asia in 1954 started a program to cross Japonica and Indica rice, but IRRI's production of semidwarf varieties shifted attention away from those crosses during the 1960s. The semidwarfs were tested under higher fertility levels, and fertilizer responsiveness was adopted by some breeders as a breeding

**Box 10-2.** ***PRECODEPA: A Nationally Run Regional Commodity Network***

The Programa Regional Cooperativo de Papa (PRECODEPA), formed in 1978, now includes the national potato programs of all nine Spanish-speaking countries of the Central America–Caribbean region, as well as CIP. What distinguishes PRECODEPA is its structure and function as a collaboration between equals, of which CIP is only one.

National potato programs make some commitment of resources to belong to PRECODEPA. Each national program sends two representatives—the national coordinator of potato research and the director of agricultural research—to the Permanent Regional Committee. The committee agrees on projects of regional interest and appoints a coordinator and two other representatives, who form the executive committee in charge of executing projects and arranging for periodic external reviews. CIP provides specialist assistance and training on request. A problem is considered to be of regional interest if at least two countries agree that it is a constraint on production or per capita consumption of potatoes. The regional committee assigns priorities to problems by consensus, divides research responsibilities among its members according to interest and comparative advantage, and decides on training and workshop needs and participants.

The members fund their own national staffs and projects. Under a five-year agreement the Swiss Development Corporation funds the regional component of the operating budget drawn up by the committee: travel, training, and some nonpersonnel "tooling-up" costs. This funding has averaged about $250,000 a year.

Seven of the nine projects begun in 1978 are still in operation, and others have been added. Projects originally executed in one country have spread to others as local expertise has developed. For example, Honduras has become a partner with Guatemala in the development of rustic storage. Costa Rica and Mexico, which were originally responsible for seed production, have been joined by Cuba. Other projects and their leaders include nematode control (Panama), late blight resistance (Mexico), tuber moth control (Costa Rica and Guatemala), development of potatoes for the warm humid tropics (Cuba), and a regional socioeonomic project (Guatemala).

PRECODEPA was set up to build national research capabilities and to take advantage of the possibilities of regional specialization and horizontal transfer by encouraging national initiatives in setting programs and priorities and by working with international researchers. This offsets any tendency to create a permanent dependence on the international centers (which could engender resentment against paternalism) and helps to overcome bottlenecks in moving new technology into production.

According to Manuel Villareal, coordinator of Mexico's National Potato Program and a past coordinator of PRECODEPA, "The basic philosophy underlying PRECODEPA is that countries with strong resource limitations and similar agroecological, socioeconomic, and cultural conditions can advantageously divide among themselves the task of developing technical solutions of productivity bottlenecks in food crops and share research results" (ISNAR 1981).

objective. The national rice research program in the Philippines started to breed semidwarf varieties for irrigated conditions but soon decided to concentrate on upland rice, while IRRI worked on lowland irrigated rice.

Similarly, CIMMYT's emphasis on breeding composite maize varieties rather than hybrids had a significant impact on many maize research programs in Latin America and Asia. Burmese maize breeders, for example, concentrated unsuccessfully on hybrids until they started working with CIMMYT and directed their breeding efforts almost entirely to the production of composites.

Sometimes significant changes in research programs occurred. Research on potatoes in Bangladesh changed dramatically, for example. Instead of selecting only from the best-yielding Dutch varieties, researchers started selecting from the collection of local varieties and tropical varieties available from CIP and its Indian collaborators. Completely new research on diffused light storage, true potato seed, and clean seed production was also undertaken.

### *Solving Farmers' Problems*

Perhaps the most important impact of the centers on national research priorities has been to orient national researchers toward solving farmers' problems, often under the banner of farming systems research. This shift is impossible to quantify, but people who have worked with the CG system for a long time consistently point to this as one of the most important contributions of the centers. The researchers at the centers provide prestigious role models for national research workers, and the centers provide reinforcement and reward the practical work of their national partners by holding conferences and publishing the results of applied research. The training programs at the centers also stress applied research in the field. To quote a former head of EMBRAPA, "Most of the research in Brazil . . . was not oriented to the farmers' problems . . . [Working on farmers' problems], in my opinion, is much more important than the cultivars because . . . you are teaching us how to fish instead of giving us the fish" (Alves 1984, p. 123).

### *Research Methods*

The centers have been important in improving research methods in developing countries. Many methods were devised at the centers, but others were developed elsewhere and were spread by center training programs and by staff in the field. Representative examples of these methods now in use in developing countries are described here.

One of the most important new research approaches is the high-volume crossing approach—the procedure of making a large number of crosses and exposing them to heavy attacks by pests and diseases. The standard plant-breeding approach involves growing a few carefully chosen crosses under protected experiment station conditions. The new approach has become standard in most small-grains programs around the world.

The techniques developed by many centers for screening plant lines for disease and pest resistance were among the most commonly mentioned new techniques in the country case studies. ICRISAT's technique for screening pearl millet for downy mildew, ergot, and smut in the same generation is an example. The centers have also developed new ways of multiplying pests to put heavy pressure on plants used in breeding. Techniques for mass production of downy mildew inoculum, for example, were developed by the Philippine and Thai national programs in collaboration with CIMMYT.

CIMMYT's methods for testing the milling and baking qualities of wheat have been spread to many countries by training programs, and almost all of the milling and baking laboratories in Latin America have some CIMMYT-trained staff.

Laboratory and other methods for analyzing soils and plants have been developed at IITA, and knowledge of these has been imparted to researchers through annual training courses jointly organized by IITA and the University of Guelph in Canada. The methods have been compiled in manuals that are currently used in laboratories in forty-six Sub-Saharan African countries as well as in Belize, Brazil, Canada, India, Indonesia, Malaysia, Papua New Guinea, Peru, Sri Lanka, Thailand, and the United States. Similarly, methods and instrumentation for the assessment of soil erosion and the physical degradation of tropical soils have been developed and are now being used in Brazil, Ghana, Nigeria, Peru, and Tanzania. IITA's methods for screening herbicides have been adopted in laboratories in twenty-two African countries.

On-farm research programs promoted by the centers are also being used by national researchers. Farming systems research dominates the program in Guatemala and is viewed favorably in Panama and in several East African countries, where it has had a considerable impact. There are also examples of less formal types of interaction among farmers, plant breeders, and social scientists in setting priorities. An example is the work of CIMMYT in northern India. The integration of farmer surveys and on-farm trials into

**Table 10-5. *Visits by Staff of Selected Centers to National Programs, 1983***
(number of visits)

| Center | Africa | Latin America | Asia | North Africa and Middle East |
|---|---|---|---|---|
| CIAT | 19 | 148 | 13 | 5 |
| CIMMYT | 145 | 291 | 122 | 59 |
| CIP | 16 | 99 | 48 | 16 |
| ICARDA | 19 | 0 | 20 | 83 |
| IFPRI | 16 | 11 | 31 | 8 |
| ILCA | 121 | 1 | 12 | 14 |
| ILRAD | 24 | 0 | 2 | 0 |
| ISNAR | 37 | 8 | 15 | 4 |
| IRRI | 4 | 7 | 262 | 19 |

the maize research program of the G. B. Pant University, Pantnagar, led to the revision of recommendations on pesticide and fertilizer use. The blanket recommendation that farmers spray thiodan to prevent stem borers was withdrawn, and the recommendation for nitrogen, phosphorus, and potassium was reduced from 80:60:40 kilograms per hectare to 80:0:0 kilograms per hectare. More use was made of local germ plasm, and research activity was shifted from Pantnagar, which was atypical of India's maize-growing regions, to Bulandshahr, in the maize belt of Uttar Pradesh (Biggs 1983).

One of the more important products of ILCA has been the analytical services it provides to national agencies that have large data bases on animal production but lack the human skills or computers to appraise the data. National researchers analyze the data at ILCA with the assistance of ILCA staff. These analyses allow the national agencies to make informed decisions about the continuation, enlargement, or reorientation of their livestock development programs and have also been used in preparing livestock projects funded by large donors and lenders such as the World Bank.

The need for this kind of information is clear: "Livestock numbers, yields and, a fortiori, management practices in traditional herds are usually shrouded in even denser veils of ignorance (and, worse, of self-confident assertion) than apply to smallholder crops data. Improvement upon the scandal of agricultural and food statistics in most of Sub-Saharan Africa is a necessary, and inexpensive, precondition for significant policy improvement and therefore for agricultural research design" (Lipton 1984, p. 30).

## Professional Interaction and Networks

The centers also provide professional interactions and regular services that increase the productivity of national research systems. For example, conferences on important topics sponsored by the centers enable researchers to keep current in their fields, gain recognition and prestige, and exchange ideas with colleagues.

The intensity of center involvement varies considerably among countries. In a number of cases researchers or liaison scientists from the centers have worked in a national research program over a long period. In many countries, however, no one from the centers is stationed in the national system full-time, although there are frequent visits by center staff (see table 10-5). Some national systems are almost entirely isolated from the CG system.

The international germ plasm networks provide national breeders with the best crop varieties from around the world. Other networks focus on specific research problems (see table 10-6). These include the regional research networks for potatoes, in which CIP has been instrumental, in the Andean countries, Central Africa, Central America and the Caribbean, and South Asia. A network on soil fertility and fertilizer evaluation on rice is coordinated by IRRI, as is the Asian Farming Systems Network. IBPGR coordinates an extensive network for the collection of plant genetic materials.

Typically, participants in these networks meet once or twice a year to discuss recent results and ongoing work. Leadership rotates among the participants or is provided by an elected steering committee. Centers frequently provide funds for network activities and sometimes for research, but more often the main research funds come from national sources or donors. Other centers achieve somewhat similar effects through regional programs. For example, CIMMYT has six regional maize programs, five regional wheat programs, and three additional regional programs in economics.

There has always been communication among scientific researchers, of course, and many research networks exist outside the CGIAR system. Researchers often communicate through professional organizations that hold meetings and publish journals. National research institutions, such as the USDA and the tropical agricultural research organizations of the former colonial powers, support formal and informal networks. Bilateral and multilateral aid sources have also facilitated communication through conferences and publications. But each of these alternatives is partial and intermittent, in part because the centers have assumed some of the coordinating roles once executed by others.

The centers have certain advantages in carrying out these roles. In comparison with international professional organizations the centers have more researchers who specialize in the problems of tropical

**Table 10-6.** ***International Agricultural Research Networks with Center Participation***

| *Network* | *Center participant or coordinator* | *Region* | *Number of countries* | *Year started* |
|---|---|---|---|---|
| Programa Andino Cooperativo de Investigación en Papa | CIP | Andean | 5 | 1982 |
| Programme Régional d'Amélioration de la Culture de la Pomme de Terre en Centrale Afrique | CIP | Central Africa | 3 | 1983 |
| Programa Regional Cooperativo de Papa | CIP | Central America and Caribbean | 8 | 1978 |
| South Asia Program for Potato Research and Development | CIP | South Asia | 5 | 1982 |
| Programa Cooperativo de Investigaciónes en Papa | CIP | Latin America | 4 | 1983 |
| Asian Farming Systems Networks | IRRI | Asia | 15 | 1974 |
| International Network on Soil Fertility and Fertilizer Evaluation on Rice | IRRI | Asia, Africa | 20 | 1976 |
| Africa Research Network on Agricultural Byproducts | ILCA | Africa | 18 | 1980 |
| Trypanotolerance Network | ILCA/ILRAD | Africa | 9 | 1983 |
| CIMMYT Eastern Africa Regional Economics Program | CIMMYT | East Africa | 14 | 1976 |
| West African Farming Systems Research Network | IITA/ICRISAT | West Africa | 17 | 1982 |
| West African Regional Cooperation for Research on Plantain | IITA | West Africa | 9 | 1981 |
| International Network for the Improvement of Banana and Plantain (INIBAP) | IDRC/IITA/ IFAD | Worldwide | — | 1984 |
| African Association for Biological Nitrogen Fixation | IITA | Africa | 31 | 1982 |
| On-Farm Research Network | IITA | Africa | 7 | 1983 |
| Rice Policies in Southeast Asia | IFPRI/IRRI IFDC | Asia | 4 | 1978 |
| Income and Nutrition Effects of Increasing Commercialization of Semi-Subsistance Agriculture | IFPRI | Africa, Asia, South Pacific, and Latin America and Caribbean | 13 | 1984 |
| Red Internacional de Evaluación de Pastos Tropicales | CIAT | Latin America | 22 | 1978 |
| International Rice Testing Program | IRRI | Asia | 16 | 1978 |
| | IRRI/CIAT | Latin America and Caribbean | 19 | 1978 |
| | IRRI/IITA/ WARDA | Africa | 16 | 1978 |

agricultural production, and the type of research they encourage is generally oriented toward the practical problems of farmers. In addition, the funding and activities of the centers are less influenced by political considerations than are the funding and activities of national organizations. The centers also offer greater stability than the networks sponsored by aid sources. Bilateral aid, in particular, can shift quickly with changing political winds. The concept of international centers provides some protection against such shifts.

## Note

1. Detailed interpretations of the econometric results are available in Evenson (1987) and Evenson, Pray, and Scobie (1985).

# 11 The Work of the Centers as Viewed by the National Systems

From the beginning, the work of the centers in improving agricultural production has been a collaborative effort carried out in conjunction with national agricultural research systems in the developing countries. The collaboration has not always been trouble-free; none ever is. But for the most part whatever progress the centers have helped to achieve has come through a process of give and take, negotiation, and mutual learning.

To determine how collaboration with the centers is viewed from the national perspective, the CGIAR impact study commissioned papers on the influence of the centers on agriculture in twenty-five developing countries. These country studies were designed to answer two questions:

- What has been the impact of the work of the centers on the country's national agricultural research system?
- What effect has the work of the centers had on agricultural production in the country under discussion?

The authors of the country studies relied chiefly on publications and documents provided by the government of the country and on extensive interviews with scientists and administrators in the national systems. Notwithstanding tight deadlines (one to two months), some authors managed to conduct sixty or more interviews.

Because they were produced quickly, many of the country studies are not polished works. Furthermore, even though many authors conducted a large number of interviews in the short time allotted, they were usually able to interview only a small proportion of those who work for the national systems. Some systems, India's, for example, have a force of several thousand government scientists who work on agricultural topics.

The authors of the country studies were urged to interview a representative cross-section of national researchers, but they decided on the sample. As it turned out, those who were interviewed appear to have been predominantly administrators and plant-breeding specialists. A larger sample or a sample skewed in other directions might have resulted in country studies with somewhat different conclusions. But as a whole the studies provide a comprehensive response to the first question posed above. They are primarily reportorial in nature (although often interspersed with comments and opinions by the authors) and they offer a mine of information on the successes and failures of collaboration between the centers and the national systems.

This chapter is an attempt to sum up in a reasonably balanced way the story of collaboration as told from the viewpoint of the national systems, through paraphrases or through direct quotations from the country studies.[1] It was deemed particularly important to give the national systems a platform for their views. As the reader will learn, these views cover a wide spectrum of opinion.

The country studies do not provide much new statistical evidence on how collaboration between the centers and the systems has affected agricultural production. More particularly, they often give less detail than might be hoped on the effects of the centers' efforts on food crop production. That reality may disappoint policymakers, but it will come as no surprise to agriculturalists who have worked in the developing countries and understand the impediments to accurate determination of effects.

One problem, as Billing's study on Zimbabwe points out, is the difficulty of collecting data in countries where data collection has not been habitual.

The data base on past and present agricultural practices and production is notoriously sparse in most developing countries, and Zimbabwe is no exception. This deficiency in knowledge about the pre-introduction situation [before the national system asked the centers for help] does not lend itself to an easy measurement of the overall production increases that result from the release of a new variety or technique. (Billing 1985, pp. 1-2.)

Another obvious problem is that of apportioning a total net impact among multiple causes. In the case of center-system collaboration apportionment is always difficult, if not impossible. In many countries, for example, the principal grain varieties are from the centers but are known by local names, whereas in others new lines are derived from a combination of center varieties, varieties closely related to those of the centers, varieties distantly related to center lines, and locally developed varieties. In such situations it is difficult to say how much of any increase in production should be attributed to the centers. To complicate matters further, sometimes local varieties have no center ancestors but were developed with the use of center-inspired techniques.

Notwithstanding such difficulties, some of the country studies do offer statistical data on actual increases in production or in yield per hectare that are known or believed to be directly traceable to technological innovations devised by the centers. For the most part, however, the country studies report only gross gains or losses in crop production and make no attempt to address the difficult question of the effect of center work on production. Several other country studies say that production is believed to have increased—usually because of the spread of high-yielding varieties of rice or wheat—but give no supporting statistics. In short, answers to the second question are much sparser than answers to the first.

## Factors in the Success of Collaboration

Throughout the country studies are references to the factors that have influenced the collaborative endeavors of the centers and the national agricultural research systems. Some are obvious—weather, for example. The country study on Ethiopia (to take perhaps the best-known example of weather as a crucial factor) was completed in 1984, near the end of the drought that had severely hampered agricultural production in various parts of Ethiopia since 1971.

Political considerations have also influenced progress in agricultural production in various developing countries. Where governments have been unstable, or where the chief goal in agriculture recently has been not production but agrarian reform, or where the government has focused on other priorities, agricultural technology and its value sometimes come under severe scrutiny.

Many of the more senior research administrators in Bangladesh perceive the whole agricultural research thrust to be under active threat from the government, which may be suffering some of the same "fatigues" that are purported to be held in the donor community generally. Needless to say, a military government's perceptions of priorities do not always give due attention to agricultural research, which usually claims only a rather small part of the country's budget and, given its long-term orientation, is subject to regular scrutiny as to its appropriateness vis-à-vis other issues of national development or defense. The centers really have an important role to play in maintaining credibility of the research thrust in Bangladesh, and this may well prove eventually to be their most important input, namely, helping to protect the already strong national commitment to research investment. (Pray and Anderson 1985, p. 20.)

Another factor in the success of the collaborative endeavor that is often mentioned by the country studies is the duration of the connection between one or more centers and the national system. In Indonesia and the Philippines, for example, where collaboration between IRRI and the national systems began in the mid-1960s, the spread of high-yielding rice varieties and the increases in rice production have been remarkable. In Cameroon, on the other hand, where the national system did not begin to work with any of the centers until 1980, and in Burkina Faso, which began to create an agricultural research system only in 1983, the benefits of collaboration were still slender by the time of the study.

Some anecdotal evidence in the country studies suggests that another factor in the success of collaborative endeavors is the willingness of the centers to adjust their initial premises to actual situations. The studies of Bangladesh, Chile, Colombia, and Nigeria all offer evidence on the importance of flexibility, but perhaps this quotation from the report on Tanzania provides the most concrete illustration.

Intercropping, which is the mixing or interplanting of a number of different crops on the same piece of land at the same time, is a common practice of many subsistence farmers. It provides the farmer with a variety of returns from land and labor, often increases the efficiency with which scarce resources are used, and reduces the risk of dependence upon a single crop that is susceptible to environmental and economic fluctuations. Despite its merits, this form of agriculture was considered to be primitive, and all research work and recommendations are based on monoculture. The low adoption rates by farmers can thus be understood. It is only recently that there has been a change in attitude among scientists on the importance of recognizing and understanding the constraints that farmers encounter and their rationale for conducting certain farming practices. (Ndunguru 1984, p. 70.)[2]

Although the country studies occasionally mention other factors that hamper constructive collaboration and the desired end result of greater crop production—such matters as weak extension systems, the relative importance attributed by countries to export and subsistence crops, a lack of a clear sense of priorities within the national systems, and occasional personal disagreements between staff members of the centers and the national systems—it is clear that from the national point of view the quality of collaboration is determined primarily by the capabilities of the national system. In other words, the stronger the national system, the more likely it is to be able to take advantage of collaboration with one or more of the centers. No fewer than sixteen country studies specifically refer, sometimes at length, to how the quality of a national system affects collaboration.[3] For most of the sixteen the chief obstacle to good collaboration was said to have been the weakness of the national system. These weaknesses, in general, revolve around shortages of money and qualified people.

The report on Ecuador provides illustrative details.

Three of the five doctorate-level staff were assigned to administration. For the crops of interest to the centers, only 48 researchers were available, of whom only 9 had carried out postgraduate studies. Among the support groups, the soils, plant pathology and entomology groups are the strongest, with 25 postgraduate professionals. From the standpoint of this analysis, it can be stated that there is a human resource constraint on effective interaction between Ecuador's national system and the centers.

A factor common to all research programs in Ecuador is financial constraint. This factor has to be carefully borne in mind because without it the interactions between the centers and the national system would in most cases have been much more productive. It can be stated that the financial constraint on the national system has retarded the impact of the centers by creating a situation in which, for lack of research resources, most of the best-trained professionals have left to join private enterprise. In a number of cases, imported [plant] materials are not tested with sufficient stringency, owing to scarcity of resources; for example, material may be planted in nearby localities that are not representative of the typical environment in which the crop develops. In other cases the researcher feels compelled to reduce the number of [plant] lines brought on to more advanced stages for lack of resources, and this may lead to rejection of material that has some potential for other reasons or other purposes. (Posada Torres 1986, pp. 28, 31–32.)

The report on Costa Rica testifies to similar problems.

The lack of interinstitutional coordination of the national system and the financial problems of the Ministry of Agriculture are factors that tend to reduce the potential impact of collaboration between the centers and the national system. There was at least one instance in which not enough seed of a maize variety resulting from such collaboration was available to farmers, who had accepted and were demanding the variety. This was due to the fact that the national system simply did not produce the seed after it was accepted. Later, this same variety was allowed by the national system to lose its purity and its good characteristics. With the return of a maize specialist (now head of the program) who was being trained at the graduate level by CIMMYT, it is expected that these problems will not recur. (Stewart 1985a, p. 57.)

Of the many countries where persons interviewed expressed regret about weaknesses in their agricultural research systems, Malawi was the one where officials were the most candid about the system's shortcomings.

The Malawi government is quite open about this failure to fully benefit from the services that the centers have offered. In a classic Malawian fashion, they are down-to-earth and realistic. They blame themselves for the lack of progress, and they are in the process of attempting to rectify the situation. Many senior officials feel that the inherent weakness of the national system and the lack of experienced research workers have been the major reasons for the country's failure to capitalize on the services being offered. Others blame the poor organization structure and the lack of clearly defined objectives on the part of the national system. (Billing 1984, p.46.)

To balance these reports on the weaknesses felt or perceived in many national systems, it should be noted that several country studies—notably those on Brazil, Chile, Guatemala, India, and Indonesia—portray systems that are capable of high-level collaboration with the centers. An example is the study on Chile.

The dynamics of this international [collaboration] are actually extraordinary, considering also the tremendous vicissitudes the Chilean national system and agriculture have gone through over the period of time analyzed. Probably the key factors explaining the success of this venture are the high quality of the service provided by the centers, their efficiency in delivering those services, the relatively good level of the Chilean staff and the solidity of its national system, and the close personal and highly professional contacts established among the scientists and administrators of both sets of institutions. The latter point, hinting at the lack of bureaucratic obstacles on both sides, was repeatedly stressed by all Chilean staff interviewed as a most positive feature of the center–national system relationship. (Venezian 1987, p. 81.)

## Center Location as a Factor in Effective Collaboration

Eight of the countries in which studies were conducted were also host countries for centers. The studies indicate that host country status has a limited and disparate effect on collaboration between the center and the national system of the country.

ICRISAT, established in Andhra Pradesh in 1972, is the junior partner in its relation with the Indian national system. Indian researchers had already released many varieties and hybrids of sorghum, pearl millet, pigeon peas, chickpeas, and groundnuts before ICRISAT began its plant-breeding activities. Furthermore, ICRISAT hired a large number of Indian research scientists for its own staff and was allowed to make extensive use of the national system's germ plasm collection, which had already benefited from considerable external assistance. By 1983 ICRISAT had become a highly advanced research institution, carrying out extensive plant-breeding, agronomic, socioeconomic, and farming systems research while providing training to researchers from India and many other countries. Among the Indian respondents who took part in a survey carried out for the India study (Mahapatra, Bhumbla, and Bokil 1986), 50 percent rated the quality of services from ICRISAT as very good and 40 percent rated them good.

In the Philippines, the home of IRRI since its founding in the 1960s, the relation between the center and the national system has on occasion been a matter of debate among national researchers. Some national scientists have considered their own country's rice-breeding programs too dependent on the work done at IRRI, whose mandate is to improve rice production methods not only in the Philippines but throughout Asia. At one point IRRI and the University of the Philippines at Los Baños had agreed to a partitioning of rice research activities: the university would concentrate on upland rice while, IRRI would focus on lowland rice. In the mid-1980s, however, IRRI felt that its broad-scale mandate on rice production throughout Asia meant that it too should do more work on upland cultivation.

Notwithstanding the problems of avoiding duplication of effort, the basic contribution of IRRI to rice cultivation in the Philippines has apparently not been seriously questioned. "To the question of IRRI's usefulness, Filipino scientists have no hesitation in giving an affirmative answer" (Gomez 1986, p. 41.)

IITA's relationship with national researchers in Nigeria is also given high marks.

> The national system has benefited from a number of external institutions and organizations on a wide range of topics. The most outstanding of these is IITA, which by the mere fact of its location in Nigeria naturally contributes not only as a corporate body but also through the interaction of its staff members with Nigerian scientists, even on a purely social plane, to the evolution and advancement of national programmes. (Okoro and Onuoka 1985, p. 65.)

As one example among many, the Nigerian study points to the task of devising controls for two cassava pests, the cassava mealybug and the green spider mite. "While IITA was assigned the work of biological control, the national system was responsible for work on control through breeding" (p. 65).

In Mexico, the home of CIMMYT, high-yielding wheat varieties developed in collaboration with that center have long been dominant among farmers and no doubt will continue to be. The most recent figures show that CIMMYT-related varieties are used on 90–95 percent of Mexico's wheat area. Since CIMMYT's relation with the Mexican national system has far outweighed the national system's contacts with other centers, it was perhaps natural for the authors of the country study to arrive at this verdict: "The overall conclusion reached regarding the international centers of the CGIAR is that their actions do make a favorable contribution to the activities of the Mexican [national agricultural research service]" (Matus, Santiago, and Puente 1984, p. 40). The Mexican study does mention some concerns of local researchers, the most significant perhaps being a suggestion that it may be time for the centers to give less attention to plant-breeding advances and more to basic research in genetic engineering and plant pathology (p. 42).

Ethiopia, which has the largest livestock population of any African nation, was a natural home for ILCA. That center is given credit as having been virtually the only center to have done useful work in Ethiopia during the drought years of the 1970s and early 1980s (Shawel and Negewo 1984, p. 53).

Relations between ICARDA and its host country, Syria, are reported to have been limited by the capabilities of the national system (El-Akhrass 1986, p. 30). As one of the first steps in correcting this situation ICARDA and the national system set up a collaborative research and training program in late 1981. This collaboration covers research in cereals, food legumes, and forage crops, the provision of genetic materials, and the training of Syrian researchers.

In Peru, the home of CIP, collaborative endeavors between the center and the national system are extensive. Paz Silva sums up those endeavors.

> CIP has, under agreements with the National Agrarian University and the National Agricultural Research and Development Institute, provided national programs with over 8,000

germ plasm lines, given training in advanced courses to the best-qualified professional staff of both programs, provided clones with proven resistance to frost, nematodes and late blight, and continuously provided up-to-date scientific bibliography and technical reports on potato technology. (Paz Silva 1986, pp. 96-97.)

## The Centers' Role in Plant Breeding

Even a cursory reading of the country studies makes it evident that the development of new crop varieties is still a matter of utmost interest to many of those who work in the national systems. While some skeptics may suggest that this was the natural outcome of interviews that included many national plant breeders, the new varieties nonetheless have been in the forefront of practical technological advances in food production. Time after time the country studies state or imply that the creation of better plant varieties and of advanced breeding materials has been the most significant achievement of the centers.

The view from Kenya on new wheat varieties is an example.

[The] CIMMYT wheat germ plasm bank has contributed to Kenya's wheat breeding program. The wheat breeding program has covered predominantly bread wheats . . . In 1975, CIMMYT reported that seven of the Kenyan varieties were of Mexican extraction, and by 1977 the number had reached 17 . . . Sixteen varieties were of Mexican extraction, and by 1977 the number had reached 17. [Of] 16 varieties recommended for production . . . 13 appear to have Mexican parentage. (Ruigu 1985, p. 108.)

In Cameroon, as Lyonga and Pamo (1985, p. 67) point out, "one of the major functions of the centers is to provide excellent biological materials" to the national system. Although Cameroon's productive collaboration with the centers began only in 1980, that country has received from the centers many potential varieties or lines of maize (almost 200), rice (more than 400), soybeans (50), wheat and triticale (700), and millet (400).

In Cuba rice varieties and lines from IRRI and CIAT have become overwhelmingly dominant. "Since 1967, a total of 15,027 rice varieties and lines from IRRI and CIAT have been introduced and tested in Cuba. Of these, 1,726 are in the Ministry of Agriculture's germ plasm bank, and 9 have been released as commercial varieties. The released varieties presently in use cover 100 percent of Cuba's rice area" (Sanchez and Scobie 1986, p. 77).

Twenty-one of the country studies emphasize the center's assistance in plant-breeding technology, which has allowed some countries to visualize a time when they will be fully capable of doing virtually all of their own breeding work. This is evident, for instance, in both Guatemala and Indonesia.

With a few exceptions, it was found that the pattern of division of research efforts [in Guatemala] was similar to that of other countries. This means that the international centers do the basic variety research and the crosses, and the national system tests the genetic materials for adaptation and carries out further selection. Because ICTA [the Guatemalan agricultural research organization] is so well organized and capable, there were some exceptions. For example, in beans, the collaboration of ICTA and CIAT has reached the point where they work as partners. ICTA is now doing crosses in Guatemala and is even sending materials to CIAT and to other countries. Recently CIAT received a prize for developing with ICTA a variety resistant to golden mosaic [virus]. In corn, the release of the quality protein variety Nutricta by ICTA proves that this national program is gradually doing more of the things only the centers used to do. (Stewart 1985b, p. 43.)

The Indonesian country study sums up the progress of that country's collaboration with IRRI in rice breeding.

The partnership has recently been further cemented through AARD'S [Indonesia's main agricultural research body] and IRRI'S signing a new agreement which recognizes the growing competence of the national system, whose postgraduate trained staff have increased from 42 in 1975 to 399 in 1984 (with a further 449 currently undergoing higher degree training). This agreement involved a new kind of working relationship about which AARD is very enthusiastic. It calls for IRRI to *collaborate* by filling defined and agreed gaps in AARD'S program and capability, rather than by AARD'S *cooperating* in IRRI activities. The distinction is subtle but extremely important in terms of building confidence and capability into a relatively large national system which, notwithstanding the past gains in rice productivity, envisages a key role for IRRI to play in the future in assisting AARD to move into frontier areas of research relating to upland and swamp rice, hybrid rice, and high-risk new technology. (Nestel 1985, p. iv.)

Progress is not a straightforward process. The country studies also discuss operational problems such as bureaucratic snafus and scientific differences that have cropped up over the years. The process of plant-breeding improvements is evolutionary, and sometimes that evolution can seem painfully slow. CIMMYT for example, has been sending maize germ plasm to Malawi for more than fifteen years, but "very little progress has been made if measurement is made in terms of new germ plasm [varieties] released and adopted by farmers" (Billing 1984). A 1981 survey showed that 90 percent of Malawi's maize growers were still partial to local varieties. One of the problems in Malawi has been that CIMMYT varieties grown in areas of substantial rainfall are particularly susceptible to leaf diseases. Another is the cost of seed of improved varieties, which is quite high for many of Malawi's smallholders.

Even where growers adopt a new variety, of course, they may subsequently find it unsuitable.

A problem of a fundamental nature is the rejection, in some cases, by farmers of new crop varieties released by research. This happens when the new crop does not meet the food taste of consumers, or where the costs of the inputs are high. For example, the major limitation to the adoption of the IITA sorghum package appears to be the unacceptable food quality of [the sorghum], even though the package provides very high-yield varieties. (Okoro and Onuoka 1985, p. 64.)

The country studies reveal that there is still plenty of work to do in collaboration on plant-breeding technology.

## The Training of National Researchers

In the developing countries that have been able to take maximum advantage of the agricultural research training offered by the centers, such training has been of the utmost value. That, at least, is the impression conveyed by the country studies. Perhaps none makes the point with greater force than the Indonesian study: "The responses to the questionnaire . . . make it clear that training is regarded as one of the most important roles of the centers, particularly by the senior Ministry and AARD personnel interviewed, many of whom felt that it was the single most important contribution made by the centers to Indonesia" (Nestel 1985, p. 48.)

But the studies also show that training is thought equally valuable by nations whose agricultural research systems are still quite young, such as Syria. A sense of great urgency, in fact, is found in the Syrian study.

It is generally agreed that training is one of the most important services provided by the centers. While these services are highly valued in building the national research capacity, it is believed that what is being offered is much less than what is required . . . Of course, ICARDA cannot be asked to meet all of the national system's research training requirements. However, in view of the centers' resources and organization, efforts can be intensified to enhance training activities. International help in providing post-graduate formal education is urgently needed. (El-Akhrass 1986, p. 37.)

A good description of why training is important is found in the Philippines study.

Staff development is perceived by all research administrators as a continuing concern. Due to staff turnover, training must be instituted even to maintain present strength. To young researchers, a chance to train either locally or abroad is one of the major rewards of a job well done. Thus, training is ranked as either the most important or the second most important service of the centers. . . . There are several features that are desirable about the center's training. First, training is usually given in areas where the centers have the best practical experience. Second, the sponsoring center is familiar with research work in the recipient countries, and training is designed to fit local needs. Third, trainees are selected from people already working in areas related to the training program, so that their newly acquired knowledge is readily applicable to their current job. (Gomez 1986, p. 33.)

Since the national systems have often achieved different levels of capability, it is hardly surprising that some country studies reported that some of the courses being given by centers were too elementary. No country study emphasized that point more than the report on Brazil. Brazil asserted its strong interest in bolstering agricultural research by creating EMBRAPA in 1973 and then by quadrupling, over several years, the public funds allotted to agricultural research. One result of that increase was a substantial rise in the educational qualifications of EMBRAPA's researchers. In 1976 more than 60 percent of them had only a bachelor's degree. By 1983, 70 percent had either master's degrees or doctorates. It was not surprising, under these circumstances, that a top official of EMBRAPA "expressed the opinion that the courses presently offered by the centers are not of great interest to EMBRAPA's people" (Homem de Melo 1986, p. 85.)

In some other country studies the same point was made indirectly through comments that some centers continued to offer similar courses year after year. There have been cases of scientists with doctorates taking the same courses as technicians. Yet it is also important to understand that some countries saw curriculum repetition as an answer to one of their problems, a constant inflow of new staff members. The report on Ecuador provides an illustration.

During the interviews with directors and program chiefs it became clear that the courses offered by the centers can be utilized by the national program to accomplish various kinds of purposes. Given the high staff turnover, the centers' short courses provide a means for rapid and effective training of replacement staff. This option is particularly useful when the vacancy to be filled is that of product program chief. The directors of the national system expressed their appreciation that this training was almost always available, since it helps to alleviate discontinuity in research work. (Posada Torres 1986, p. 40.)

Many of the country studies imply that the centers should be sponsoring a standing curriculum composed of elementary, intermediate, and advanced courses. The Malawi study contains a clear recommendation to this effect.

The centers tend to run courses on an annual basis and repeat the courses year after year. This means that a researcher who works in a particular field cannot progress in his or her training. The suggestion is for the centers to run a series of courses in which the training follows a sequence, with subsequent courses being more advanced. (Billing 1984, p. 81.)

Indeed, one of the strongest desires expressed in many country studies was for greater numbers of more highly qualified personnel—of practicing scientists with graduate degrees. While some countries hoped that funding for such advanced education might come from the centers, others were considering alternative sources of funding. The following two quotations illustrate the need for more researchers with high qualifications.

The chronic imbalance between the very small number of properly qualified scientists and the large number of agricultural graduate researchers impedes the process of idea and technique transfers. Building up research capacity is made more difficult. The situation cannot be corrected by short training courses oriented mainly toward tackling certain practical problems. A large-scale program of formal post-graduate education is imperative. Expanding the type of cooperation presently going on between ICARDA and Aleppo University in the area of M.S. and Ph.D. program supervision might be the answer. (El-Akhrass 1986, p. 29.)

The need for much more graduate training is deeply felt in ICTA [Guatemala's research institute]. The continued success of this agency is going to depend on its being able to keep and upgrade its personnel. Unfortunately, the highest attrition rate seems to be among those with graduate degrees. (Stewart 1985b, p. 55.)

One other suggestion for change recurred often enough—in the studies on Bangladesh, Cuba, Ecuador, Malawi, and Zimbabwe—to warrant its mention here. It was that more center courses should be given in developing countries other than the centers' host countries. Among the reasons given were the savings in travel costs and the greater possibility of adapting practices to local conditions.

## The Organization of National Systems

Ever since CIMMYT and IRRI got under way in the early 1960s the centers have often served as both models and sources of advice as to how agricultural research in developing nations might be organized and strengthened. At first the influence exerted by CIMMYT and IRRI was purely a matter of example. Once their accomplishments in raising yields of wheat and rice in a few countries through plant-breeding techniques became generally known, other countries with food production deficiencies began to pay more attention to the advances that might be achieved through more intensive attention to agricultural research.

As noted earlier, India and Pakistan were the first countries to explore these possibilities intensively, and the country study on India explains why. At the time of the green revolution, India already had a well-developed system of agricultural research organizations, and success in raising production of wheat and rice was followed by an intensive national effort to increase production of dryland crops such as sorghum, pearl millet, and chickpeas. India now has more than twenty research institutes and about 1,300 researchers working on improvement of dryland crops.

The problems of dryland agriculture are now receiving greater attention than ever before. Although doubts continue to be expressed about the availability and effectiveness of new technologies for increasing crop yields under conditions of dryland agriculture, the concerted research work of the Indian Council for Agricultural Research and ICRISAT has provided the basis for cautious optimism that, given adequate inputs and extension support, it is possible to sustain at least a moderate increase in yield of coarse grains, pulses, oilseeds, and cotton even for this type of agriculture. (Mahapatra, Bhumbla, and Bokil 1986, p. 11.)

Indonesia is another nation in which IRRI's initial successes in raising rice yields made a profound impression. As Nestel (1985, p. iv) notes, IRRI's "early successes with IR5 and IR8 are credited with demonstrating the potential impact of agricultural research, and this is believed to have helped influence and encourage the government to invest heavily in agricultural research through the establishment of AARD in 1974." At that same time, Indonesia's researchers began to adhere more closely to the institutional models provided by the centers.

Although a multidisciplinary commodity research approach has been practiced in Indonesia's transmigration programs since as long ago as the late 1950s, this type of approach has been strengthened and enhanced in the last decade through collaboration with the centers. Starting with rice in 1975, the food crop research institutes . . . have organized their work approach very much along the lines of the centers, with multidisciplinary national teams for each commodity. (Nestel 1985, p. 45.)

Some other country studies offer similar reports on institutional replication. The Bangladesh Rice Research Institute, for example, clearly reflects in its organization and operations the institutional methods of IRRI. In Cuba the cassava research program is a multidisciplinary effort "developed from contacts with CIAT" (Sanchez and Scobie 1986, p. 88). At the time the study was made the multidisciplinary team included six plant breeders, six experts on soil fertility and plant nutrition, ten plant protectionists, eight agronomists, four seed production specialists, an economist, an irrigation specialist, and a librarian.

As the national systems gradually achieved greater strength in the 1970s, it became evident that a center capable of providing intelligent advice on institutional organization and planning would be welcomed. Hence ISNAR —the International Service for National Agricultural Research— was established in 1980. The country studies on Cameroon, Costa Rica, Indonesia, Kenya, Malawi, and Zimbabwe report that these national systems have sought help from ISNAR. The results of this collaboration early in ISNAR'S existence have been mixed.

Zimbabwe appears to have benefited from ISNAR'S assistance.

> ISNAR has recently completed a study on the training needs of the Department of Research and Specialist Services. This report is still in its draft final stage but is considered a very significant contribution to the future organization development of the department. The document produced is extremely thorough and should go a long way towards the development of a viable training strategy in the department. (Billing 1985, p. 106.)

The country study for Malawi reports that officials there were skeptical of ISNAR'S recommendations and conducted their own review of their institutional apparatus. In the end, according to the study, Malawi's plan for institutional reorganization was remarkably similar to the original ISNAR proposal.

A more general way in which the centers have affected the operations of the national systems concerns export versus subsistence crops. Both Bangladesh and Cameroon credit the centers in general for influencing them to pay more attention to subsistence crops and less to export crops. In Brazil between the 1960s and the late 1970s, however, agricultural research on export crops, measured in annual research units, increased to a much greater degree than research on domestic crops. That did not mean that studies of domestic crops declined.

> With respect to domestic crops, impressive growth can be observed for cassava, maize, and, to a lesser extent, for rice and edible beans, between average 1960/69 and 1978/80. Although the overall growth for all domestic crops was about half that observed for exported crops, it is important to emphasize that maize and rice had for 1978/80 an annual research output at a level similar to the one for coffee and soybeans, the two most important agricultural exports. (Homem de Melo 1986, p. 69.)

## Agricultural Methods and Information

Apart from discussions of collaboration on plant-breeding techniques, the country studies do not offer much on the adoption of new agricultural methods. Two exceptions are the studies on Cuba and India. According to the Indian study,

> ICRISAT has developed the concept of watershed units for improved management of soil, water, and crop production consistent with good soil conservation principles. These principles have been accepted and vigorously adopted by the government of India as the basis of dryland improvement.
>
> ICRISAT has improved the methods for screening sorghum germ plasm against grain mold, downy mildew, striga and midge. The checker board technique developed for testing sorghum lines against striga resistance is now being used by national scientists. That method of screening sorghum lines against midge is a definite contribution. . . .
>
> The wilt disease of chickpea which baffled Indian pathologists for over 40 years has been demonstrated to be incited by a number of pathogens. Resistance has been identified for *Ascochyta*, *Botrytis*, anthracnose, root rots, stunt virus, wilt, [and] pod borer, either singly or in combination of two or three. (Mahapatra, Bhumbla, and Bokil 1986, pp. 42–43.)

The Cuban study reports on that country's widespread adoption of CIAT'S Sistema Colombiano, a group of rapid propagation practices that are said to have increased yields of fresh cassava from 5 tons per hectare in 1978 to 16 tons per hectare in 1984 on 60 percent of Cuba's land devoted to cassava. Among other things "major fungal and bacterial disease have been identified, and methods for their control have been established," and "rapid propagation and tissue culture techniques have been successful in eliminating bacteriosis from commercial germ plasm" (Sanchez and Scobie 1986, p. 87.)

In Nigeria researchers at the National Root Crops Research Institute developed a "minisett" technique for producing seed yams from so-called mother seed yams. This technique was later refined by IITA scientists into a "microsett technique" (see Okoro and Onuoka 1985, p. 75) whereby plants can be propagated with the use of minute amounts of vegetative material.

### *Research Information*

Nine of the country studies refer specifically to the publications of the centers. The general tenor of the comments is that although the quality of the publications is good, methods for distributing them to those who would find them most useful are often less than efficacious. Perhaps the highest praise for the publications of the centers is found in Ndunguru's study of agricultural research in Tanzania.

> The centers have been very successful in the dissemination of information, and one can cite several of the publications from these centers which are enormously useful. Examples: (a) Abstracts—CIAT'S abstracts on cassava, field

beans, tropical pastures; IITA's sweet potato and cowpea literature abstracts have done much to keep scientists informed of what is happening in these areas; (b) newsletters can be exemplified by CIAT's cassava newsletter, IRRI's newsletter on rice, and IITA's Tropical Grain-Legume Bulletin; and (c) books. Several booklets from the centers are well illustrated and greatly simplify the identification of various field problems like pests and diseases of the crops they deal with. (Ndunguru 1984.)

Sometimes, it appears, the lapses in the distribution of center publications can be traced to the centers themselves, but in other cases the problem is poor internal distribution within national systems.

### *The Conservation of Germ Plasm*

For some time the centers have given a high priority to preserving samples of plant germ plasm. These collections have been a necessity for the plant-breeding work of the commodity-oriented centers. From their banks the centers have often supplied germ plasm samples needed by developing countries.

The country study on Nepal praises CIP in this respect.

Besides research on varietal selection, Nepal has been participating in CIP programs on post-harvest storage research and studies on potato diseases, perhaps the most serious potato problem in Nepal. During 1975-79, 200 germ plasm clones were brought to Nepal from CIP for trials . . . CIP has been very responsive to requests for advice [from Nepal] at times of crisis. For instance, with a recent outbreak of bacterial wilt, an authority was dispatched very promptly to advise the government on appropriate measures. (Sharma and Anderson 1985, p. 25.)

Just as important as collections of germ plasm by the centers are collections by the developing countries, which are the last remaining source of scores of wild varieties of domesticated plant species. The CGIAR established IBPGR to encourage and assist countries to create germ plasm collections of their own. The Zimbabwe study cites the importance of this work.

A national collection of local germ plasm is a very important exercise. Its storage for possible future use in breeding programs is as important as the preservation of the national heritage. IBPGR has given assistance to Zimbabwe in this respect. A comprehensive collection was made in 1982 and it is hoped that a similar collection exercise planned for 1984 will now take place in early 1985. This collection mission involved center staff and local researchers, and is an example of how the collaboration of a center can stimulate and encourage a national system in an important but previously neglected area. (Billing 1985, p. 99.)

## National Agricultural Policy

The contributions of IFPRI were less frequently mentioned than those of the biological centers for perhaps several reasons. Because of its responsibilities for analyzing the relation of policies established by national governments to farm production, IFPRI is more likely to deal with a treasury department, a ministry of finance, or a university institute of development studies than with a ministry of agriculture, but the country study leaders concentrated on agricultural researchers. In addition, many developing countries do not yet have enough qualified personnel within their national systems to collaborate on analyses of policy. Many developing countries, for various reasons, are seriously underinvesting in social science research.

As described in chapter 7, the commodity centers gradually discovered that systematic analysis of national policies was vital to their fundamental task of raising food production. There was no point in working on a new technological approach to greater crop production if national policy made widespread adoption of that approach unlikely. Frequently the introduction and spread of a new crop variety or other agricultural innovation depends as heavily on such things as the farmers' selling price, the availability of inputs, the existence of transport and processing facilities, or the availability of credit to farmers as on the variety itself. As a result, both biologists and economists at the commodity centers have found it necessary to engage in informal discussions with the government officials who set policies in trade, transport, and allocation of natural resources. A number of centers (notably CIAT, CIMMYT, CIP, ILCA, and IRRI) now issue periodic reports on statistical trends in output, prices, trade, and consumption of the crops in their mandates.

Meanwhile, the country studies show that IFPRI and its work are becoming known within at least some of the national systems. In Bangladesh, for example, "IFPRI publications have been widely circulated as models of policy research analyses" (Pray and Anderson 1985, p. 37). The Bangladesh study also notes that "most of IFPRI's impact has been through and on organizations that are not primarily agricultural research institutions," such as the Bangladesh Institute of Development Studies, the Bangladesh Planning Commission, and the Planning Cell of the Ministry of Agriculture. The study on Indonesia offers a strong endorsement of IFPRI's work on rice policies.

This regional project is highly regarded by those who are aware of it, although knowledge of the project and its output do not seem to be widespread. However, the responsibility for this may lie with the Indonesian counterparts who have yet to produce a completion report. The work done to date, and the results from IFPRI's work in the Philippines, have encouraged the Planning Bureau of the Ministry of Agriculture to seek IFPRI participation in a follow-up project relating to investment policy in irrigation development. The local directors of the first IFPRI project felt that IFPRI had played an important role in training Indonesian planners in rationalizing their approach to policy options in making difficult decisions about large-scale investments. IFPRI's professionalism and independence were regarded as important attributes in their work in Indonesia. (Nestel 1985, p. 48.)

Some policymakers have emphasized the value of the bridge that IFPRI provides between the activities of other international centers and the national programs. Given national sensitivities, it would of course be advantageous if it were always possible to distinguish between policy analysis, exploration of policy options, and policy advice. Several national officials, however, suggested that in practice it is difficult to keep the three separate. A good policy analysis that makes issues clear was seen as tantamount to the direct offer of advice. Nonetheless those who were aware of IFPRI viewed it as a dispassionate source of independent thought on topics that often have awkward political implications.

## Agricultural Production

It is difficult—indeed, it may be impossible—to state with anything resembling scientific exactitude the effect of the work of the centers on agricultural production in developing countries. Many of the ostensibly quantifiable impacts, such as increased output stemming from the use of improved varieties, are subject to a number of qualifications. There is an intricate interplay between, say, the use of improved varieties and a host of other variables—weather, use of other inputs, availability of labor, and so on—that make pinpointing the impact of any technological advance a matter of, at best, considered judgment. Furthermore, much of the work of the centers is devoted to strengthening institutional capabilities, and these efforts are not measurable in any simple way. The best evidence available is the considered opinions of those who work in the field of agriculture in the developing countries.

Caveats aside, many of the country studies do give, in one way or another, some reasonably valid notions about the impact of the work of the centers on crop production. The Indonesian study, for example, points out that rice production in that country increased from 12.2 million tons in 1969 to 25.5 million tons in 1984 (Nestel 1985, p. iii). During that period Indonesia went from being the world's largest importer of rice to being a small exporter. By the 1983–84 crop year, according to Dalrymple (1986a), about 82 percent of Indonesia's rice land had been planted in high-yielding rice varieties, about 39 percent of it in PB36 (the local name for IR36) and 27 percent in Cisadane, a variety developed in Indonesia that has IRRI lines in its ancestry. Nestel notes that several authors have attempted to quantify the contributions of better irrigation, additional fertilizer, and new rice varieties to the higher production figures, which were in part attributable to the increase of about 1 million hectares in the wetland rice area. An unpublished USAID study for 1976–81, Nestel reports, attributed 13.5 percent of the growth in yield during the period to new varieties. The same study calculated that the internal rate of return to investment in rice research between 1974 and 1979 was more than 60 percent. Clearly, high-yielding rice varieties have not been the only reason for Indonesia's increased rice production, but they appeared to be responsible for between 1 and 2 million tons of the increase in 1983–84.

High-yielding rice varieties have made a difference in the Philippines as well. Although the amount of land devoted to rice cultivation in the Philippines remained virtually stable between 1960 and 1982, production rose from about 3.7 million tons in 1960 to about 8.1 million tons by 1982. Again, this rise cannot be attributed solely to the development of high-yielding varieties.

The country study on Ecuador offers what it readily admits is a "rough estimate, based on highly conservative assumptions" of the contribution of new technology to production.

> Estimating that, on average, the new varieties and technological packages increase farm yields by 0.5 tons/hectare, an adoption rate reaching 10 percent over a period of 5 years would raise aggregate production by some 77,000 tons for the principal crops (potatoes, wheat, rice, maize, and barley), assuming no change in the present area planted. This increase, valued at an average price of US$200/ton, would have a value of US$15.5 million. (Posada Torres 1986, p. vi.)

The Cuban study offers more detailed estimates of the impact of the centers on the production of three staples.

> In the "mature" group of crops a significant share of the total area sown in Cuba involves the use of germ plasm and technology which are products of CGIAR collaboration. It is estimated that the production of rice, beans, and cassava is a respective 73, 21, and 224 percent higher than it would be in the absence of these innovations. The annual flow of benefits from the extra production is US$40 million, $3 million, and $11 million, respectively. The internal rates of return to the Cuban research program were calculated as 54, 29, and 48

percent per year [for rice, beans, and cassava], respectively. (Sanchez and Scobie 1986, p. vii.)

Reporting on the impact of ICRISAT, the study on India prepared by Mahapatra, Bhumbla, and Bokil (1986) gives the following annual percentage increases in production for 1960–61 to 1980–81.

| | Percent |
|---|---|
| Sorghum | 0.81 |
| Pearl millet | 1.7 |
| Chickpeas | −1.2 |
| Pigeon peas | 0.7 |

But the Indian report also notes that all four crops are grown in "inhospitable and harsh environments" and that Indian scientists "have taken extensive advantage of the germ plasm bank maintained by ICRISAT" in seeking to raise production (pp. 24, 26).

The report on Nepal specifically notes something that is only implied by most of the country studies: "aggregate national level statistics do not report yields for HYVs" (Sharma and Anderson 1985, p. 34). It therefore uses reports on various small-scale studies to examine the impact of modern varieties on yields. Those studies make it evident that the advantages of modern grain varieties depend to a tremendous degree on other conditions. If the soil is good and if irrigation and fertilizer are available, rice and wheat farmers in Nepal can achieve yields that are double the national averages. In the Tarai, for example, six popular high-yielding varieties of rice produced yields of 3.6 tons per hectare, twice the national average of 1.8 tons per hectare. Similarly, wheat productivity when modern varieties are used under favorable conditions went as high as 2.35 tons per hectare in the early 1980s, far exceeding the national average of 1.14 tons per hectare. The Ministry of Agriculture's most recent figures on adoption of high-yielding varieties for the crop year 1979–80 are 25 percent for rice and 85 percent for wheat, but Sharma and Anderson suggest that the figure on rice in particular may be overstated.

Special attention is paid in the study on Syria to the production impact of high-yielding wheat varieties. Production has increased substantially owing to several factors: the approximate doubling of the country's irrigated wheat area during 1967–83 from about 83,000 hectares to 173,000 hectares, a new cropping rotation of cotton-wheat in place of cotton-fallow, and the use of additional fertilizer, as well as the planting of high-yielding wheat varieties, particularly the bread wheat Mexipak from CIMMYT. For 1967–73 the average annual production of wheat in Syria was 930,000 tons; for 1974–83 it was 1,670,000 tons (El-Akhrass 1986, p. 39).

The studies mentioned so far, along with a few others, offer statistics that show production increases. About the same number of studies, however, either ignored the subject or offered explanations of why the spread of high-yielding grain varieties has not produced larger yields or why it was not possible to trace increases in production. Venezian's (1987) study of Chile, for example, notes that while the national average wheat yield is 1.7 tons per hectare, irrigated fields can produce anywhere from 3 tons to 8 tons per hectare (p. 96). These higher yields are found mainly in regions with superior soils. But because much higher profits can be made by raising fruits, vegetables, and maize in these regions, wheat cultivation has gradually been shifted to less favorable areas.

In summary, this review of the production impacts of the centers is suggestive rather than comprehensive. It does show, however, that a much more thorough investigation would be needed to produce truly comprehensive data on the impact on production of the centers' work, even in the limited number of developing countries discussed in this project. Unlike the areal spread of high-yielding varieties of rice and wheat, which is fairly well documented, the impact of the centers on crop production, especially for crops other than rice and wheat, will probably be clear only in the distant future. The finding on total grain production in chapter 2 is believed to be conservative; it is an estimate derived from calculations using data that in many cases will obviously benefit from further refinement.

## Conclusion: The Realities of an Imperfect World

In the developing countries reported on in the country studies the centers are widely—although not invariably—regarded as sources of inspiration and of knowledge about at least many of the most important food crops. Some studies did report complaints about inadequate coverage of such things as oilseeds, vegetables, tree crops, and livestock research. Most of the studies, although they note certain difficulties in collaboration (many of which have since been resolved), conclude that there is no doubt that the centers as a whole have been a prime force for technological advance in agriculture. Many of the national research programs chiefly express regret that some weaknesses in their own operations have made it difficult to collaborate with the centers as effectively as they would have wished. Many express the hope that collaboration will improve in the future as their own national system strengthens its capabilities. A few are more skeptical.

The following quotations from the country studies illustrate the effectiveness of collaboration in many cases but also suggest that the work of maintaining effective collaboration is a day-to-day task that can never be taken for granted.

The interactions between the centers and the national system in Ecuador are complex, with the degree of interaction determined by the current situation of particular commodity programs. It is felt that, for the present study, a generalization would serve no useful purpose since the various programs are not all in the same situation. Cases exist of long-standing and well-established programs in which the theoretical division of work between the centers and the national system is functioning in practice. Programs also exist which, though similarly long-standing, are dependent on the centers both for germ plasm and for financial assistance for their operations. Evaluation is difficult in the case of commodity programs that have to serve different agroecological zones . . . In these cases the national system is compelled to carry out some of the tasks that would theoretically belong to a center. Moreover, in some cases, because of the weakness of the [national] program in all areas . . . the center has totally replaced the national system in the performance of its functions. Finally, cases exist of research programs that could have substantial potential in the future, either as intermediate or as final products, in which it has not yet become clear what the work of the centers should be. (Posada Torres 1986, p. 31.)

The collaborations have led to an overall improvement in the national system by the improvement of researchers, as reflected in the results of the interviews, which indicate improvement in research methodology and planning, better knowledge of global research activities which allows shortcuts in applied research, greater consideration of the need to treat farms as economic units, and greater concern for agroecological replicability. This improvement has been brought about with the help of training, technical information, and genetic materials services from the centers. (Isarangkura 1986, p. 66.)

The relationship between the national agricultural research system in Zimbabwe and the international centers is considered to be beneficial by all the people interviewed. The provision of biological material especially for crops programs orientated towards the communal areas and the provisions of training in specific areas has been isolated by most respondents as the activities of the centers which are the most complementary to the aims and objectives of the country's research program. Zimbabwe has benefited considerably from this relationship, the effects of which will take some time to reach fruition. The research system in Zimbabwe is moving in a new direction in its research orientation and strategy. The centers which have had experience in this type of research can help considerably. The research service is relatively inexperienced [in this new direction] but is highly competent. By realizing this and by offering genuine support and encouragement, the centers could make a significant contribution towards the continued development of research in Zimbabwe. (Billing 1985, p. 116.)

## Notes

1. Phillip Sawicki provided valuable assistance in extracting from the individual studies much of the information used in this chapter.
2. The findings of those African country studies that have not been published separately are synthesized in a summary report on tropical Africa (Jahnke, Kirschke, and Lagemann 1987). The unpublished studies are annotated in the bibliography as "processed."
3. The studies are those of Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Ethiopia, Indonesia, Kenya, Malawi, Nepal, Peru, Philippines, Syria, Tanzania, and Thailand.

# 12 A Look Ahead

Improved cropping technologies based on plant breeding and brought into existence through the work of the centers and their national partners have been the preponderant factor in growing more food in the developing world. This contribution of the centers has been heightened by more extensive use of manufactured fertilizer and by greater investments in agricultural infrastructure, particularly in irrigation systems. Improvements in wheat and rice yields have made the deepest impact on food production, and this impact will continue to expand as the centers and the national systems make further advances in matching wheat and rice cultivars with their most productive environments. The adoption of modern crop varieties themselves is essentially neutral with respect to farm size and the tenure and sex of the cultivators, but it is not neutral as far as water and soil resources are concerned.

Improved varieties of maize, beans, and cassava are also making significant contributions to the diets of people in developing countries, as will soon be reflected in increases in food production at the national level. Yields of cowpeas, sorghum, millet, and durum wheat are also rising as more and more national authorities release improved cultivars, many of which originated in part at the centers.

Research into such broad agronomic matters as crop management and crop protection has also made a noteworthy contribution to greater food production, but in this case it is much more difficult to associate better crop yields directly with center research. Many other factors in the development process, including other international agencies and national agricultural research programs, are conducting similar research, and there is no physical product (a new wheat variety, for example) by which to measure the specific contribution of the centers.

Training in applied agricultural research is a tangible and much appreciated activity of the centers, according to statements by researchers and administrators in developing countries. Assistance in building research institutions and the provision of advice and research on policy have also been widely praised as beneficial to agricultural decisionmaking.

But technological, institutional, or policy research into agricultural problems is not sufficient to solve the social ills faced by much of humankind. Although such research may help, it is a poor instrument for dealing with such realities as inequitable distribution of income, both within and among nations. Technical change is a necessary contributor to the resolution of such problems as hunger and low rural income, but it is not the only kind of change that is necessary.

Agricultural research, furthermore, cannot overcome some of the obstacles raised by nature itself. Plants cannot thrive without light, water, and nutrients. Thus there are definite limits as to what scientific endeavor alone can achieve in enlarging agricultural output economically in less-favored physical environments, especially in much of Sub-Saharan Africa. Investments in infrastructure, particularly for irrigation systems and for the manufacture and distribution of fertilizer, in combination with more supportive economic and policy environments, can help to overcome the obstacles presented by natural physical conditions, but considerable time must often pass before these investments provide a decent return. That return, of course, will also depend on whether the investment itself is adequate and well managed.

Investors in agricultural research would find their decisions easier to make if enough were known about the most effective approach to research. A simplistic interpretation of the CG experience would be that a sharp but narrow concentration on one or a few crops offers an inherently greater chance of success. Unfortunately, the answer is more complex than that; research on maize has been intensive and has been going on just as long as has research on wheat, but it has had far less effect.

What can we expect from the centers in the future? The long-range planning reports of the centers contain implicit statements about the expected returns to their research. Some may argue that predictions of the economic returns to investment in research are so fraught with uncertainties that little worthwhile can be said. By its very nature, productive research takes time. Five or ten years may be needed to develop a new technology, and more years may elapse before the technology is widely adopted and significant benefits are realized. But investment decisions must be made, and informed speculation about the likely payoff of any particular investment is seemingly the best way to separate the less promising from the more promising. (For estimates of the expected net benefits of several significant innovations, see Anderson and others 1985.)

## Better Use of Financial Resources by the Centers

Investment in research by the centers has produced advances that have clearly justified the investment. This experience is undoubtedly an important guide to the returns that might be expected from future research, and the increase in research expenditures by developing countries over the past decade is clearly a response to historical high average rates of returns. The overall record, however, conceals considerable variation in the return to past investments and can serve only as a partial guide.

Furthermore, it might be argued that future returns cannot be expected to match those achieved in wheat and rice. It may be that each successive advance will present a greater scientific challenge and that diffusion will become slower and more costly. In addition, as the CGIAR system has grown it has embraced other crops and paid greater attention to harsher ecological settings, thus raising additional questions about future advances. Given the long lags in research, commitments have to be made today to fund research whose major impact may be felt fifteen or twenty years hence. Careful consideration must be given to the size and distribution of sponsors' contributions to the centers. Lest this cautionary tone seem too pessimistic, it must be noted that the still uncertain but surely exciting prospects of research in biotechnology may dramatically change the speed and cost of advancement in biological research—perhaps especially for rice and wheat, about which so much is known that a biotechnological breakthrough may lead to rapid progress.

The CGIAR system is now investing about $200 million annually, yet little systematic attempt has been made to assess formally the likely returns to this investment. Without such analysis, which is in itself a daunting task, there is only a coincidental chance that the marginal returns to different projects will bear any relation to one another. It is possible that the expected returns on one project will exceed those on another by significant amounts under any conceivable conditions. The scarcity of research resources demands that maximal gains be extracted from any given investment, and this can be done only if investment alternatives are viewed in terms of their expected payoffs.

Clearly, measures of economic efficiency cannot be the only criterion for allocating research effort. The greatest concern may be to develop the economy of a certain region, to improve nutrition, or to alter the distribution of income among classes of producers or between consumers and producers. It does not follow that imposing these criteria necessarily implies accepting a lower economic return. But such objectives should be explicit so that the merits of research can be gauged in comparison with other policies. Redirecting research efforts to, say, an environmentally harsh setting to generate income gains for a poor community may entail considerable costs in output forgone in another region. A clearer appreciation of these tradeoffs would presumably lead to better informed judgments about the allocation of research effort.

Attempts to direct additional research funding into such areas may result in much lower returns than the resources could have generated elsewhere. Poor performance may then jeopardize future funding. It is therefore imperative that the system continually review expected future benefits with a view to making adjustments that will lead to a higher overall payoff. Indeed, in 1986 the Consultative Group charted just this role for its Technical Advisory Committee.

A first step is to estimate for a number of producing systems the added value of output attributable to research. This will identify those areas in which the contribution of research is likely to be small. For example, IRRI estimates that the annual value of extra rice from irrigated regions in South and Southeast Asia through 2000 could be $10 billion, whereas the annual value of increases from floating rice systems could be $380 million. At first glance this appears to provide an allocation rule whereby about $25 should be spent on research on irrigation for every $1 spent on research on floating rice systems. But the marginal return on research on floating rice could be many times greater (or less) than that for irrigated rice. Without more attention to estimating the changes in output in relation to different levels of research, little can be said about the efficient use of the limited funds available for rice research. The same is true of allocation of resources to other centers and programs.

Any prediction of future returns to research must recognize that too little is known about the effects of expanded food production on marginal and fragile land. Continued monitoring will be needed to ensure that the environmental consequences are adequately reflected in the design of technology and in development policy for these regions. While there have been some analyses of these questions, many questions are still unanswered, and much remains to be done to develop effective methods of measurement and monitoring before implementation can match the lip service paid to such considerations.

The challenges of assessing future returns to research are nowhere greater than in the several fields that make up biotechnology. Where knowledge is increasing exponentially and technological advances are rapid, forecasting is a problematic exercise. A difficulty that faces even the most exuberant forecaster is to pinpoint just what areas of agriculture will not benefit from the current revolution in genetic manipulation. These challenges may explain in part the rather cautious approach that most of the centers have taken to embarking on biotechnological research.

## Future Collaboration with the National Systems

Future returns from investment in the centers will depend largely on their close and effective collaboration with national programs of all types. Since returns are always sensitive to the amount of land planted in a particular crop, large developing countries will remain especially important. The centers will not be able to afford to withdraw completely from large countries with advanced and self-sustaining research systems. Excessive concentration on strengthening small, weak national programs may risk the diversion of too much of the centers' attention from the extensive geographic areas where their greatest contribution will continue to be made. Of course, there will be cases in which such strengthening is a legitimate developmental objective.

The aggregate growth of national research systems over the past quarter-century has been rapid, yet some important activities cannot readily be carried out by some national institutions, and many national programs still have weaknesses. It is in these areas that the international centers will continue to play an important role. The international testing and movement of germ plasm, for example, can be handled much more effectively by an international organization than by a national research program. Support for international networks of research workers is another activity that can often be done best through an international center.

Many developing countries are still not investing enough in agricultural research. Some systems lack sufficient human resources to carry out effective research programs and suffer from institutional inefficiencies that prevent them from making good use of available resources. The need for a critical mass of resources is clear, although the experience in colonial Africa and in many other parts of the world suggest that the resources required need not be large. The main issue is simply whether the resources are adequate in quality and quantity to meet the designated research goals, which may be quite modest—for example, the creation of a local research capacity that can capitalize on research assistance from the centers and other external sources.

The issue is especially prominent in Africa, where agricultural research into food crops thus far has had remarkably little impact. The plausible explanations for this state of affairs range from the harshness of many of the ecologies and the great variability in the natural (especially climatic) environment through poorly developed infrastructure (especially irrigation and marketing services) to general economic and political conditions and the specific environment of the national research system.

Great patience will be required of investors in research that addresses the more difficult environments, whether they be semiarid crop and pastoral areas or humid tropical forest areas with soils that are difficult to manage. Small, well-motivated, and well-supported research units with specific objectives for specific locations seem likely to be more effective than large, cumbersome, centralized systems, some of which are already in place in the developing world.

Merely investing in—some would say "throwing money at"—national agricultural research systems is not all that is required. Nations with fragile bureaucratic structures have a limited capacity to absorb new injections of human and financial resources over short periods. ISNAR and other international agencies have been helpful in making both donors and recipients aware of this problem. Similarly, nations without a rich heritage of scientific scholarship need considerable time to inculcate the new values, attitudes, and institutional responses—including a capacity for higher-level education—that are needed to create a productive research environment. Indeed, such environments are often far from ideal even in industrial countries that have long traditions of research as well as generous funding for science generally and for agricultural research in particular.

Apart from the broad cultural and sociological aspects of national development, there are immediate pragmatic matters that deserve attention. Perhaps foremost is the need to develop operational capability in a research system. There are many dimensions to this need. Potentially the simplest is the requirement for adequate recurrent funding of the nonsalary components of research budgets. Too often researchers are essentially confined to their offices because of the unavailability of fertilizer, pesticides, laboratory chemicals, glassware, computing facilities, or other supplies. They can seldom work directly with farmers for want of vehicles, fuel, or other needed inputs to research in the field. This problem can reach crisis proportions when, for example, the end of the fiscal year coincides with critical stages in the crop cycle.

The mirror image of this problem is inadequate salaries for national research staff, an issue mentioned as a major problem in several country studies. The incentives of salary and promotion are too obvious to belabor here. If salaries are so low that skilled research personnel must undertake additional employment to supplement meager incomes, observers should not be too surprised if the level of research output is low. As in all such matters there is a need to balance work incentives and encouragement, personal emoluments and operational flexibility. The international centers have been able to help somewhat by providing encouragement and flexibility, but the continuing challenge is for national authorities to provide more adequate support for the effective implementation of agricultural research.

Planning for an uncertain future is a continuing activity of the centers and the system of which they are parts. In the past there has been a heavy reliance on informed intuition. It now seems prudent to encourage planners to make the process of planning more explicit, more systematic, and more effective.

The international centers are a fact of life not found in earlier agricultural revolutions. One of their great comparative advantages lies in their relative immunity from short-run national pressures to respond to the priorities of politically powerful members of society. In continuing to sponsor research initiatives that will assist development generally and help the poor especially, priorities will necessarily be continually addressed and reappraised. The commitment and the capacity for doing so are two of the great strengths of the CG system.

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# Documents from the CGIAR Impact Study

This book is based on a series of reports produced by the impact study team under the leadership of Jock Anderson. The main study report was presented to the CGIAR in October 1985. It has been edited and produced on microfiche under the title:

Anderson, Jock R., and others. 1987. "International Agricultural Research Centers: A Study of Achievements and Potential." *Agricultural Economics Bulletin* 32. Department of Agricultural Economics and Business Management, University of New England, Armidale, N.S.W., Australia.

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*Development and Spread of High Yielding Wheat Varieties in Developing Countries.* Dana G. Dalrymple. U. S. Agency for International Development, 1986.

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