CGIAR

1986/87 Annual Report

Consultative Group on International Agricultural Research

CGIAR

Established in 1971, the Consultative Group on International Agricultural Research—CGIAR—is an association of countries, international and regional organizations, and private foundations dedicated to supporting a system of agricultural research centers and programs around the world. The purpose of the research effort is to improve the quantity and quality of food production in developing countries. The World Bank, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) are cosponsors of this effort. The World Bank provides the CGIAR's chairman and secretariat. CGIAR is advised by a Technical Advisory Committee (TAC) whose secretariat is provided by the three cosponsors and located at FAO headquarters. CGIAR has 51 members, of which 39 were donors in 1986. Total contributions were about US$235.5 million.

CGIAR-supported international agricultural research centers

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

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CGIAR Secretariat
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United States

Foreword

I write this foreword with reserve and not a little awe. As a result of the reorganization of the World Bank, I have been asked to assume responsibility for the CGIAR as part of the Bank's new Senior Vice Presidency for Policy, Planning and Research. As I believe that the responsibility for electing a new CGIAR chairman lies in a careful canvass of the views of the CGIAR members (a canvass that must take place at International Centers' Week in October), I write with the reserve of an interim chairman. Having been associated with the founding of the CGIAR system, I find myself rather awed by the turn of events that has given me the privilege of writing a foreword to this significant publication.

The honor of writing the foreword has fallen to me from S. Shahid Husain, who on June 1, 1987 assumed the responsibility of the Bank's Vice President for Latin America and the Caribbean Region. This report covers the last of his stewardship of the Group, that is, the period from mid-1986 to mid-1987. The range and excellence of the CGIAR activities that this report presents is an accurate reflection of the quality of leadership Mr. Husain brought to his exercise of the chair's functions.

At this time of transition, it is useful to review the role and work of the past chairmen of the CGIAR system. Richard H. Demuth, as the first CGIAR chairman, and Sir John Crawford, chairman of TAC, helped create an atmosphere which persists to this day: A high standard of professional judgment, an informality of discussion with an emphasis on individual participation, an enthusiasm for the common enterprise.

Warren Baum, who held the position of chairman for 10 years, saw the Group establish procedures consistent with major growth both in the number of centers and volume of funds. During his tenure, he led two reviews of the system. He is responsible for the present institutional shape of the CGIAR and for having established many of its traditions. Much of this experience is recorded in his book, *Partners Against Hunger*, which is a standard reference for those interested in knowing how the CGIAR came to be what it is.

S. Shahid Husain had a large impact on the outlook of the CGIAR. He led the Group in substantive meetings and insisted that strategic concepts be defined clearly and that hard issues be faced. He recognized the need for special action related to Africa and for a clear focus on sustainability and the issues of resource management. He will be remembered in the CGIAR for progress in these and other areas.

The next chairman will face a world circumstance that is very different from the early days of the CGIAR. In 1971, there was a specter of famine over many parts of the globe, and the need to raise the production of food in virtually all the world's developing countries was a major force in the formation of the Group. Today, in no small measure because of the extraordinary success of the research findings of the CGIAR centers, there is a global surplus of food (at prevailing market prices) coexisting with continued malnutrition of massive proportions, especially, but not exclusively, in Asia and sub-Saharan Africa. While fears of the massive famines of the 1960s have abated, there remains a nagging concern for the future. Population growth has not declined significantly and, in too many nations, growth in the need for food and better diets threatens to outstrip an increasing capacity to produce. The view of the present is one of abundance amidst want. The vision of the future is one of an uncertain capability to remain ahead of population growth while ensuring greater equity of access to all who are hungry.

This view and this vision set two broad challenges for the CGIAR:

● The **first challenge** is to discover how the CGIAR can best contribute to the enhancement of income and, through more income, the enhancement of food availability for poor people throughout the developing world. The effort must be on understanding better the policies and programs that will increase the incomes and earning opportunities of the poor, especially the rural poor, thereby opening the markets for agricultural produce to their participation. If consumer subsidies or welfare payments are not to drain the fragile development budgets of developing nations, income enhancement must rest on finding and disseminating ways of improving the economic productivity of individuals and families—a task that is both challenging and worthy of the CGIAR's affirmation.

● The **second challenge** is how best to maintain the research drive to find and exploit new technologies of producing basic food materials for growing world demand. The goal is not new; it is the reason the CGIAR was formed. The challenge now is how best to effect its accomplishment. The means we use to undertake the fundamental task of the CGIAR system must be examined in the light of the accelerating revolution in biological research findings and methodologies that has taken place over the past two decades. The frontiers of applied science have advanced more broadly and rapidly than the CGIAR centers have been able to follow. This has implications for the efficiency of CGIAR research, for the quality of the results, and, most importantly, for the centers' longer-term capacity to attract first-rate scientists to CGIAR endeavors.

The third annual report shows that much progress is being made. New successes are reported; major research results have been obtained in such specialized fields as agro-ecological analysis and food policy, and the system remains the world's unique instrument for providing hope for a future free of nutritional want. One cannot doubt, in the light of the vitality, substance and shared purpose revealed in the text that follows, that the CGIAR and the centers it supports will continue to contribute to the conquest of world hunger and poverty.

W. David Hopper

W. David Hopper
Interim Chairman,
CGIAR

Washington, D.C.
September 1987

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Editor's note:
This report covers financial information in detail for calendar year 1986, the latest available. On other matters, the report deals with events through mid-1987.

1. Agricultural research: Still a good investment?

A Commentary by G. Edward Schuh[1]

From Malthus to surplus

A little over a decade ago, the world was in the midst of one of its periodic Malthusian scares. Commodity prices were rising rapidly in U.S. dollar terms. National governments were scrambling to gain access to available supplies. Some public speakers in countries such as the United States were speaking of *triage*—the expected need to let some people die in order that others could live. Some speakers were urging Americans to eat one less hamburger a day to release the grain needed to feed starving people in faraway lands, not seeming to realize that hamburgers tend to be made from grass-fattened cattle. And predictions of doom were all around.

Today, in the second half of the 1980s, conditions could hardly be more different. If adjustments are made for inflation, commodity prices are as low as they have been since the Great Depression of the 1930s. Governments of the developed countries are spending huge sums to dispose of their surplus production. Developing countries find their export earnings shrinking as commodity prices decline. Farmers in the developed countries protest the World Bank's lending for agricultural projects and the purported harm done to their markets by bilateral foreign assistance to farmers in developing countries. And many observers question investments in agricultural research, which in their view will only aggravate the current problems of low prices.

I would like to address these issues in this essay. To anticipate my findings, the essay makes essentially four points:

- Contrary to popular belief, agricultural production is not growing at an accelerating pace in Third-World countries.
- Economic growth is the key to expanding global markets, and a more productive agriculture worldwide is the key to obtaining that expanded growth.
- Agricultural research has a long gestation period; turning the flow of resources for agricultural research off and on can be counterproductive.
- The agenda for research has broadened significantly to include such things as greater efforts for maintenance of previous productivity, the need to address emerging environmental problems, and the need to facilitate diversification and adjustment.

[1]Schuh is director of the Agriculture and Rural Development Department of the World Bank. The views expressed herein are the author's alone and in no way should be construed as official views of the World Bank or the CGIAR.

Perceptions about low commodity prices

It is widely believed today that agricultural commodity prices are declining in large part because of accelerating production in developing countries. The basis for this idea seems to rest on several perceptions: (1) that agricultural output grew rapidly in China in response to policy reforms, and in the process China virtually withdrew from international markets; (2) that India, by means of Green Revolution technology, has some 30 million tons of grain in stock and is exporting modest amounts; (3) that some former grain-importing countries such as Indonesia (for rice) have become self-sufficient; and (4) that experimental results show that cereal yield potential has increased significantly, thus the world food problem has been virtually solved.

These "facts" need to be put in perspective. The notion that agricultural production in the developing countries is growing at an accelerating pace is incorrect. In fact, in the 1980s the trend of agricultural production in the developing countries as a whole is little different from the trend that prevailed in the 1970s. During the 1970s, the volume of production in developing market economies grew at an average annual rate of 3 percent; during 1980-85, at an annual average of 2.9 percent.

Population growth rates in the developing countries have declined modestly since about 1975, and that has caused their agricultural production per capita to increase modestly. But that development has hardly been of sufficient significance to create a surplus in commodities.

The important point is that growth in agricultural production in the developing countries is on the same trend line in the 1980s that it was in the 1970s, despite the Green Revolution and the higher yields that improved varieties brought with them. This steady growth probably reflects the fact that production in many parts of the Third World is being pushed onto marginal lands. The benefits of past research may thus be doing little more than offsetting the lower returns from new areas being brought into production. The CGIAR's impact study indicated that the additional output that could be attributed to the CGIAR system was sufficient to feed 500 million people.[2] The true value of past investments in the CGIAR can perhaps best be realized by thinking about the consequences if such investments had not been made: World food prices would now be much higher, per capita incomes around the world would be much lower, and many more people would have died from starvation and the debilitating effects of malnutrition.

[2]CGIAR Secretariat, 1985. *Summary of International Agricultural Research Centers: A Study of Achievements and Potential.* Washington, D.C.: Consultative Group on International Agricultural Research.

Turning to the perceptions about rising agricultural production in developing countries as the cause of depressed international commodity prices, it is true that China's agricultural output grew rapidly as a consequence of policy reforms and that its food imports declined, in part, as a consequence. Prior to the reforms, however, China's agricultural policy had induced wasteful use of the country's agricultural resources. Especially harmful were policies that forced local self-sufficiency at the commune level. The reforms not only led to a more efficient use of China's agricultural resources, they also freed China's farmers to respond to market forces. The result was an unprecedented increase in agricultural output. But will China's agricultural output continue to grow at its recent fast pace? Probably not. Shifting from an inefficient use of agricultural resources to a more efficient use is a cheap and fairly easy way to obtain growth in output. Once the use of resources becomes more efficient, however, production tends to increase at a rate consistent with the pre-reform trend. Moreover, more efficient resource use is accompanied by a significant increase in per capita incomes. Higher per capita income raises the demand for agricultural output. And at least part of that increase in demand involves greater consumption of more resource-using commodities such as livestock products, fruits, and vegetables.

Rising demand might well have caused China to increase its imports of agricultural goods, especially feed grains, even though its domestic output was growing rapidly. However, China has faced a serious import constraint in recent years, due to trade barriers placed on its exports by other countries and sluggish economic growth worldwide, both of which have reduced its foreign exchange earnings. Thus it has not been able to import what it otherwise might have. As growth in agricultural production moves back to its longer-term trend, as per capita incomes continue to climb as a consequence of reforms in the rest of the economy, and as import constraints are eased, it is likely that China will be back in the market for agricultural imports, possibly on a significant scale.

India's recent agricultural history also has to be put in perspective. One reason India has accumulated large stocks of grains is that it has subsidized production, especially of wheat, by setting producer prices significantly above what would be market-driven levels. This is a costly way to expand output, and the stocks can be disposed of only at considerable additional cost to the government. It is doubtful whether India's fiscal resources can sustain such policies. In any case, this year's drought will probably cause these stocks to be drawn down significantly.

Despite the accumulation of large cereal stocks, India has hundreds of millions of malnourished and underfed people. If poverty were reduced and the price of wheat in India permitted to decline to near-international levels, the expansion of domestic demand would absorb the so-called surplus production in short order. The fact that the poor in India live mostly in rural areas indicates the importance of agricultural modernization and development in reducing poverty.

There is no argument with the statement that some countries are reaching food self-sufficiency. But one important reason is that they are undertaking reforms of policies that in the past discriminated against agriculture. Discrimination through economic policy was especially serious in the 1970s, when an abundance of liquidity in the international economy generated by the flood of petrodollars made it easy for developing countries to over-value their currencies. Overvaluation constituted a tax on domestic agriculture and a subsidy for imports. It is little wonder that imports by developing countries grew as rapidly as they did. The serious international debt problem of the 1980s has caused many countries to reverse these policies, and thus provide more incentives to agriculture. New production technology makes it possible for the incentives to have a stronger effect.

Economic discrimination through overvalued currencies is not in the interest of the world as a whole. In fact, the sluggish growth of the 1980s is largely a consequence of trying to undo the effects of those unwise policies. However, with policy reforms, a basis is laid for sound economic expansion in the future. Increases in demand for agricultural commodities will be a consequence of increases in per capita incomes and population growth, not of distorted economic policies.

Finally, evidence of increased cereal yields under experimental conditions is a weak basis for assuming that the world food problem is solved. In the first place, there is always a significant disparity between experimental yields and the average yield a nation's farmers obtain in their fields. This is because many farmers lag in their adoption of the new technology, and because the new technology may not be economically profitable for all farmers, despite the fact that it increases yields under experimental conditions.

A further complicating factor is that much new technology requires modern inputs such as fertilizers and pesticides to make it effective. These inputs may be unavailable to many farmers. The infrastructure —roads, communications, banks, lending agencies—and marketing arrangements may be too rudimentary to bring inputs to farmers and to accommodate increased output. What this means is that the translation of experimental yields into increased yields on farmers' fields is a difficult process, often requiring costly investments in rural infrastructure and marketing arrangements.

Genuine causes: Weak demand and policy distortions

If the above "facts" do not explain today's low commodity prices, what does? Two major factors appear to be at work: weak demand and policy distortions in industrialized countries that have led to an export-subsidy war between the United States and the European Community.

Weak demand is partly a consequence of sluggish global economic growth that has prevailed throughout the 1980s, with the exception of the rapid expansion of the U.S. economy in 1984. This problem has been complicated since 1982 by the international debt crisis. Developing countries significantly increased agricultural imports in the 1970s when the international economy was awash in petrodollars. In the 1980s, liquidity dried up, and countries with serious debt problems have had to reduce their imports in order to generate a surplus in their balance of trade in order to service debt. Associated with this development, many developing countries have had to devalue their currencies to bring their external accounts into order. These devaluations have significantly reduced their import demand in the short term.

As the international economy recovers, demand should once again increase. The chances for recovery in the relatively near future are good, since many large and severe adjustments have already been made. Policy reforms in the developing countries may reduce imports in the short run, but to the extent such reforms ultimately engender a more rapid rate of growth in countries undertaking them, demand will recover and at the same time be on a more solid economic base.

Next, consider the issue of agricultural policies in the developed countries. The great distortions created by these policies are having serious consequences for international commodity markets. The European Community, Japan and the United States all support substantial portions of their agricultural sectors by holding internal prices well above international levels. These high prices stimulate agricultural production.

In each of these economic entities, the disparity between prices paid to farmers and those prevailing in international markets is quite great. For example, the price of rice in Japan is 10 times that for Thai rice. In the United States, the target price for wheat (the basis for defining payments by the government) is US$4.28 per bushel; the international market price is around US$2.50.

The costs of these government subsidies are very large. In the United States, aid to farmers may reach US$27 billion in 1987. The 12 countries of the European Community spent US$23 billion in 1986 and Japan spent US$15 billion. Because of these policies, the European Community, for example, has shifted from being a net importer of agricultural commodities to being a net exporter—and by a wide margin.

These distortionary policies have led to a costly export-subsidy war between the United States and the European Community. Governments try to dispose of the large accumulated stocks by dumping them abroad. This is good for the consumers in importing countries, but it is devastating to producers in those countries. The important point, however, is that the low commodity prices of recent years are not a consequence of accelerating production in the developing countries. They result largely from the dumping of agricultural produce by industrialized countries.

Will these countries continue such policies into the future? There are significant pressures to reduce the high costs of these programs and to move to more liberal domestic and trade policies. Chances for liberalization look better now than they have for some time. The current Uruguay Round of Multilateral Trade Negotiations provides a critical opportunity to move in this direction.

Why agricultural research is important

For developing countries, agriculture is the foundation of economic growth since the bulk of their resources is in agriculture. Moreover, these resources are characterized by very low levels of productivity. Simply put, agricultural research is vital because it is the source of new production technology, and new production technology is the source of economic growth.

An important justification for continued investment in agricultural research is that such investments, if they are in well-managed and relevant research programs, generate large returns to society. Numerous studies consistently show rates of return that range between 25 and 100 percent a year in perpetuity—even studies that cover all of the agricultural research in a country, successful as well as unsuccessful ventures. No country that seeks to grow can ignore such high rates of return. Similarly no donor country that is seriously concerned about the welfare of those in the developing countries can fail to contribute to such investments.

To appreciate the value of new production technology for agriculture, it is useful to consider it in a somewhat different way than is currently fashionable. Most people view new production technology as a source of expanded production. Hence, they tend to think of it in the context of production programs and to see its effects only in terms of supply or output. This focus on output also frequently causes research programs to be directed toward self-sufficiency goals. (Usually this goal is not a rational policy objective, nor is it consistent with promoting a liberal international trade regime.) New production technology does tend to increase agricultural output by raising the technical efficiency with which conventional resources of land and labor are used. But it is more fruitful and insightful to think of new production technology as a source of new income streams. The fact that the rate of return to investments in agricultural research tends to be so high is another way of saying that the increased streams of income that new technology creates come at a relatively low cost. To put it more formally, new production technology is a cheap source of economic growth, and policy-makers would be wise to invest their scarce development resources in such a cheap source of growth.

These new income streams take on a variety of forms and can be found in several parts of the economy. For example, the early adopters of new production technology, such as improved varieties, receive increased incomes from their invested resources in land and labor. This is because output rises due to the gains in productivity, and in the short term the price of the commodity is unaffected.

If the new technology is not widely adopted, or if the country is a net exporter but unimportant in international markets, this flow of increased income will continue into the future and be capitalized into higher land values and into the incomes of the entrepreneurs making the production decisions. Farm owner-operators tend to capture most of the benefits. Under these circumstances, demand for labor may also expand, so landless workers may experience increased employment or higher wages. If the gains in production lead to greater exports, then the increase in foreign exchange can finance a higher rate of growth for the economy as a whole or lead to a rise in the value of the nation's currency. In either case, the new technology creates expanded income streams throughout the economy.

More commonly, however, the benefits of new production technology are passed to consumers in the form of lower prices. An increase in output tends to depress prices, and they fall to a level equivalent to the lower costs of production made possible by the new technology. This is probably the most pervasive way that the benefits of new technology are realized in an economy, but the expanded foreign exchange earnings it makes possible may still be significant.

Consider now the sense in which lower prices for agricultural commodities constitute an important source of expanded income streams. Consumers can now purchase their food or other agricultural goods at less cost. In effect, their real income increases—an increase that will continue as long as the low prices prevail. This is the true "miracle" of investing in agricultural research as the basis of economic growth. The benefits of the new technology it produces are widely distributed in the economy. Moreover, they are distributed in favor of the poor in a relative sense, since the poor tend to spend a larger share of their budget on food. Few means of economic development spread their benefits in such a broad way, and so much in favor of the poor.

The final advantage of thinking about new production technology as a cheap source of income streams, rather than as a source of expanded output, is that it underscores that the introduction of new production technology has both demand effects and supply effects. These demand effects can in fact outweigh the supply effects. Perhaps even more important, thinking about income streams rather than output conveys a different and more efficient set of research priorities, leading to faster economic growth.

Is agricultural research threatening?

Should producers in developed countries fear agricultural research in developing countries? The short answer to this question is, "In some cases yes, but in general no." A faster rate of agricultural modernization can make a country more competitive in international markets. But that problem can be reduced or eliminated by increasing the investment in research in countries that are threatened by the competition. In the final analysis, the spread of knowledge and new technology cannot be halted by political boundaries or policy actions. The only answer to such competition is to keep one's own productivity growing and to make efficient use of one's resources by reducing or eliminating distortionary policies.

More compelling, however, is the fact that agricultural modernization, as a major source of income growth in developing countries, can fuel increased demand for agricultural output. The analysis can be summarized in four propositions:

- Future foreign markets for the agricultural products of developed countries will be the developing countries, not the industrialized or centrally planned countries (China is included among the developing countries). Developing countries were an important locus of expanding markets in the 1970s. Agricultural imports by these countries grew as fast as imports by the centrally planned economies, and by the end of the decade the volumes were about equal. As discussed below, with economic advances in developing countries, their imports can be expected to resume the rapid pace of growth of the 1970s.
- Developing countries will constitute a growing import market for agricultural commodities only if they experience significant economic development. The experience of the 1970s, when developing countries' imports of wheat and coarse grains increased from 20.4 million to 58.6 million tons, provides an object lesson in this regard. Over 70 percent of the imports were by upper middle-income countries wherein rapid increases in per capita incomes were occurring. Poor countries, which exist in near-Malthusian conditions, simply do not have the means to pay for imports.
- The development of agriculture in developing countries is the key to their economic growth. The bulk of developing countries' resources are in the agriculture sector, typically characterized by low productivity. Increasing productivity (and incomes) in the agriculture sector is the fulcrum for raising per capita incomes in the economy as a whole, and in the short run often the only

means by which countries can earn the foreign exchange to further economic development.

- Rising productivity in agriculture in the developing countries need not, as a general proposition, pose a competitive threat to producers in developed countries. In most developing countries, population is growing by 2 to 3 percent per year. Given their low level of per capita incomes, the income elasticity of demand for agricultural commodities in the aggregate tends to be much higher than in industrialized countries. Assuming this income elasticity is, plausibly, 0.6, the result of a modest 3 percent growth rate in per capita income, combined with a 2 percent population growth rate, would be a 3.8 percent growth rate in demand for agricultural output. Assuming a more optimistic growth rate of 5 percent in per capita income and a 3 percent population growth rate, the growth rate in demand for agricultural output would be 6 percent.

Two points must be made about these growth calculations. First, obtaining sustained growth in agricultural output of even 3.5-4 percent per year is not easy. Few countries have done it in the past, except when there have been extensive new lands to bring into production, as in Brazil. Not many developing countries still have such stocks of land available. For those that do, the costs of bringing them into production, including the needed physical infrastructure, tend to be quite high. Evidence of this lack of available land is that in country after country population pressure is pushing cultivation onto lands that are at best marginally suited for agricultural production.

Second, increases in per capita income on the order of 3-5 percent per year are not unusual in countries that have lagged in their development and thus can play catch-up by adopting technology from abroad. Japan, South Korea, and other newly industrialized countries, such as Brazil and Mexico, have all experienced higher rates of increase in per capita income for long periods as a result of this phenomenon.

There is another feature of increases in per capita incomes in these countries that is important for developed countries. Rising per capita incomes lead not only to an upgrading in the quality of the diet, but to increased demand for commodities that require less time for household preparation. Both of these changes favor developed-country agriculture. The upgrading of diets means more rapid growth in the demand for poultry, livestock, and livestock products. This, in turn, implies an increase in the demand for feed grains, commodities for which the United States, a country whose producers have complained most about development assistance to developing countries, has an obvious comparative advantage. Increased demand for commodities that need less household preparation involves a shift away from commodities such as rice towards commodities such as wheat. In the aggregate, this change

Upland rice in Brazil is undergoing evaluation for tolerance to aluminum toxicity, a common soil problem in Latin America, to find higher-yielding varieties.

favors the United States, the European Community, Canada, Australia and Argentina.

South Korea and Taiwan provide other striking examples. Returning to the relationship between general economic development and the emergence of import markets, in 1981 alone, South Korea bought US$2.1 billion in farm products from the United States, exceeding the total value of U.S. food aid to Korea between 1955 and 1979. Similarly, in the early 1950s, Taiwan exported more grain than it imported. Although Taiwan has increased food production very rapidly since then, it now imports 60 percent of its cereals. Virtually all of these imports are feed grains, because of great demand for grain-fed livestock products.

This analysis suggests that producers in developed countries should be lobbying to increase investments in agricultural research in the developing countries, not to reduce them. But these producers have some important counter-examples. It is useful to consider some of them.

U.S. wheat farmers often view India as a lost market because of new technology used in its wheat production. The Green Revolution has been a key factor in reducing India's wheat imports, but most of the imports replaced had been subsidized by U.S. taxpayers through such programs as P.L. 480. In addition, India is now importing more oilseeds than earlier. As noted above, moreover, India's problem is weak demand associated with low incomes, and its still high cost of production make it unlikely that it will become a strong competitor in international wheat markets.

Brazil is another example of a developing country in which increased agricultural production, especially the rapid expansion of soybeans, is believed to have harmed U.S. agricultural exports. From 1970 to 1981, Brazil's agricultural production grew almost 70 percent, or 5 percent a year, one of the highest growth rates in the world. Although Brazil did emerge as a strong export competitor vis à vis U.S. soybean meal and oil, its imports of U.S. farm products as a whole increased substantially—by 15 percent per year in quantity and 25 percent per year in value. Brazil's imports of U.S. farm products also became almost 100 percent commercial (that is, private cash purchases) during the 1970-81 period, compared with earlier periods when 64 percent of imported farm products were subsidized by U.S. taxpayers through food aid.

The case of Brazil also illustrates another important point, which is the significance of international specialization. If Brazil should, in fact, have a comparative advantage in soybean production relative to the United States (and that is not yet evident), it could well make economic sense for Brazil to specialize in soybeans and the United States in maize and other feed grains, with Brazil importing feed grains from the United States. Both countries could gain from such specialization, even though specific groups of farmers in each country could be harmed.

The record of the 1970s provides another example of such international specialization in production. Those countries which at the beginning of the decade were the largest exporters of agricultural commodities were also the largest importers of such commodities. Moreover, those whose agricultural exports grew the most during the decade were also the countries whose agricultural imports grew the most. That is what international specialization is all about, and the United States is a prime example of such specialization. Although it is the largest exporter of agricultural commodities, it also tends to be the second largest importer (and on occasion the largest).

Making new production technology available to competitors is also viewed by some in developed countries as an unsound policy. The competition provided by wheat and maize producers in Argentina is often cited. But, the movement of new technology is a two-way street. Just as developed countries may lose a competitive edge from transfers of technology to developing countries, they also stand to benefit from improved technology produced by developing countries. This has already occurred in the case of some semi-dwarf wheat and rice varieties. With a growing research capability in many developing countries, the potential for such gains is increasing.

Thus, continued investment in agricultural research is vital, despite current low commodity prices, because the effect of better technology on demand can be equal to, or greater than, the effect on supply. Perhaps a more important point is that the best way to expand markets is to make the total economic pie greater, rather than to squabble over a fixed pie. Investing in agricultural research in the developing countries is the key to enlarging the economic pie.

Other important issues

Accumulation of knowledge. Man's struggle with the natural environment is interminable. No one knows when a new disease or pest will emerge that can wipe out the production of a nation's output, or have even wider effects. Some years ago the cotton industry in Brazil was virtually wiped out by an infestation of cotton wilt. An intensive research program, based on resistant lines from other countries and the advice of knowledgeable people outside Brazil, yielded locally adapted resistant varieties in a few years and revitalized the Brazilian cotton industry. The accumulation of knowledge is the only real defense against such episodic events.

Sustaining gains. A significant proportion of agricultural research is maintenance research, that is, aimed at maintaining already achieved increases in yield. Much of the research on wheat rust, for example, is of this nature. As new strains of the fungus emerge, new resistant lines of wheat have to be identified and developed. More generally, as crop yields and productivity of livestock are pushed upward, the plants and animals become more susceptible to natural pests because of more intensive cultivation conditions. Significant resources are needed to deal with these problems. In fact, there is some evidence that as yield potentials are raised, the need for maintenance research grows and tends to take up a larger share of the total research budget. Finally, insects and diseases generally can become more resistant to pesticides over time. New pesticides and new means of control continually have to be developed.

Environment. Environmental issues loom increasingly large on the agricultural scene worldwide. There are at least two important dimensions to this problem. First, the intensive use of fertilizers and pesticides can have important environmental effects. Research is needed to identify ways to reduce such environmental effects without sacrificing yield and productivity gains. Integrated pest management is one means, but research on this approach is still in its infancy. Another form of environmental damage or degradation occurs in countries where rapid population growth and limited labor absorption by the

An agroforestry nursery at ICRISAT's Sahelian Center in Niger is a testing ground for potential increases in farming system productivity.

non-farm sector forces farmers onto marginal lands. Cultivation of such lands can lead to permanent damage, or to damage that can be repaired only over a lengthy period. And the effects may harm adjacent productive areas as well. Research is needed to develop production systems that limit such environmental damage. And economic research is needed to identify policies that enhance the labor-absorptive capacity of the economy.

Diversification. Research is seriously needed to facilitate the diversification process. As economic development proceeds and per capita incomes rise, consumers shift their preferences towards commodities associated with higher per capita income levels. Eventually, the production mix needs to shift in the same direction as the consumption mix. Research is needed to facilitate the adjustment of resources in these new directions without sacrificing productivity and income.

Another diversification problem arises when there is a technological breakthrough in a commodity that has low price and income elasticities of demand. As productivity rises in those cases, consumers tend to receive the major share of benefits. If resources do not shift from this activity to other agricultural activities or to non-farm activities at a sufficiently rapid rate, producers may actually lose as a consequence of the breakthrough. The important point is that unless such adjustments are facilitated, society's benefits from the original breakthrough will not be fully realized.

Economic equity. Successful research efforts have implications for economic equity. One issue is that new production technology can significantly alter the distribution of income, both within the agriculture sector and the economy as a whole. Economic policy will have to deal with the problems associated with such redistribution, but agricultural research can also contribute by providing alternative production activities for those displaced by innovation and by changing the proportion of resources invested to offset such effects.

New production technology also tends to favor regions that have high-quality land and good climate. The disparity in incomes between these regions and marginal areas will thus tend to grow. New production technologies are needed to assist the regions that are disadvantaged, as well as economic policies to facilitate resource adjustment.

Internationally, some countries will benefit, relative to others, from particular advances in research. The disadvantaged countries will need to make concerted efforts to catch up or to develop new production alternatives. Such changes on the international scene are always occurring. Strong agricultural research programs can help keep disparities from growing.

Competence and capacity. Research is not an activity that can be turned off and on without serious consequences. The development of trained researchers is a slow process. And the development of new technologies takes time. The estimated time from the beginning of an agricultural research initiative until its benefit shows up as increased yields in farmers' fields is 7-10 years. If the research program is shut down, or even cut back, a response may not be forthcoming when a new challenge arises. A minor problem may thus become a disaster before a solution is at hand.

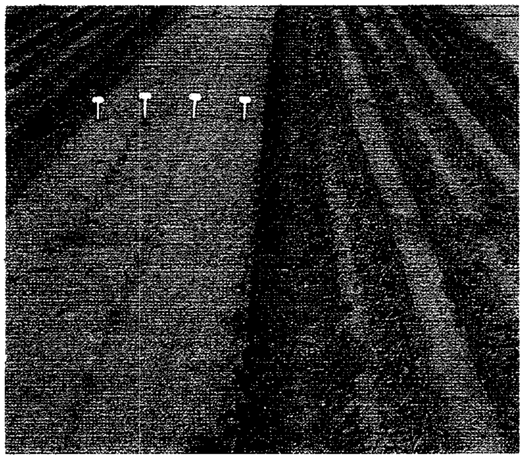
Finally, all nations of the world can benefit from additions to the stock of knowledge. The key to economic development worldwide is to maintain the flow of new knowledge. The benefits are so great, as exemplified by the high rates of return to investments in agricultural research, that it is unlikely that the costs of adjusting to new technology will outweigh the benefits.

Expansion of CGIAR research is in order

In the next three decades, the world will experience the most dramatic increases in demand for food and agricultural products in history. The only things that could keep that from occurring would be a nuclear war that destroyed a significant share of the world's population, an epidemic that did the same thing, a sustained collapse of the international economy on the scale of the Great Depression of the 1930s, or some combination of them.

Assuming that any of these catastrophies might occur is not a good basis for planning for the demands to be placed on the world's agricultural economy. That is why support for the global agricultural research system, including both the CGIAR system and national agricultural research systems, must continue, even though commodity prices are currently so low. For the CGIAR system in particular, both the scope and the scale of its programs need to be expanded. Introducing new production technology, the output of organized research programs, is an imperative if the developing countries are to experience increased and sustained rates of economic growth. The scope of the CGIAR system could productively be expanded to include a greater range of food crops, attention to the growing environmental problems around the world, making more effective use of natural resources, and the emerging problems of diversification and adjustment associated with the successes of its programs. There is also much to be gained from expanded work on cash crops, which are so important in generating the income and employment for the rapidly growing agricultural labor force around the world.

2. Research: Fitting technology to the physical environment



The ability of selected millet seeds to emerge through crusted red soil is being investigated by ICRISAT scientists in India.

Characterization of agricultural environments is a research undertaking of increasing importance to CGIAR centers. The knowledge gained through this process—often expressed as maps or computer models—promises to sharpen understanding of the different ecologies in which crops and livestock are and can be produced. It is shaping research programs, changing priorities, and in general, is a vital tool in devising more productive and stable farming systems. Moreover, the technology used is as sophisticated and demanding as any found at work in the CGIAR system.

Achieving stable production

Higher agricultural productivity on a stable and sustainable basis depends on identifying crops, livestock, and systems of production that are adapted to their environments—whether those environments are well or poorly endowed with resources. Finding the right fit of technology and environment requires detailed information about both. In the initial years of the Green Revolution, scientists labored to create broadly adapted technology, mostly for high-potential areas. The early successes of CIMMYT with wheat and IRRI with rice were based not so much on varieties that performed well in different environments, but on ones that gave good returns to water and nitrogen fertilizer under rather similar conditions in different places.

With the broadening of the commodity and geographical interests of the CGIAR system, it has become clear that environmental circumstances are so diverse that greater sensitivity to variation is required, especially as agricultural production in marginal areas, frought with adverse climate and soils, is targeted for improvement. Plant breeders and other scientists must specify the range of agroecological conditions for which a particular variety is best suited. For harsher climates and fragile soils, specially adapted varieties must be developed.

Greater attention to yield stability has been the major emphasis in activities of CGIAR centers during the 1980s. Broad adaptability and high-yield potential remain important goals, as does maintenance of yields through stronger and broader resistance to diseases and pests. But research increasingly turns to less-favored areas where the productivity revolution has reached only a fraction of farmers. Significant gaps exist in describing environments with specific needs, especially hard-pressed marginal environments. Stable production in these environments calls for stress-tolerant varieties, whose growth requirements must closely match temperature and available moisture. However, data on temperature, length of growing season, rainfall, and soil characteristics in marginal environments are lacking, thereby making it difficult to classify environments and to identify ecological stumbling blocks to increased production.

In Senegal, West Africa, pearl millet and sorghum are intercropped among *Acacia albida* to enhance productivity and maintain soil fertility in a harsh environment.

It may not be possible to moderate uncertainty and risk in all marginal environments. In areas subject to large swings in weather, extreme difficulties are customarily resolved by movement of people and animals and by storage of water, food, and marketable valuables. In such environments, the concept of sustainable or stable yields may not be supportable, and there may be no alternative except to cease relying on them for production.

Potential uses of characterizing agricultural environments

Agroecological characterization aims at systematically describing a region's resource endowment and its potential use. The goal is to determine where crops and livestock can be grown, in what production context, with what inputs and constraints, and at what levels of yield or productivity. The first task is to develop an inventory of environmental resources for agriculture and to understand how the resources are being used. The second task is to broaden knowledge of the potential uses of the resources and to suggest how the potentials might be achieved.

To be cost-effective, the commodity programs of the CGIAR centers require systematized information about their target environments in three main phases of research activity: formulation of research strategy, evaluation of technology and its potential for transfer, and improving the efficiency of international networks.

Among its numerous potential uses, therefore, the CGIAR centers are chiefly interested in applying agroecological characterization to:

- Define broad research priorities and breeding strategies;
- Identify comparable environments for the transfer of technology;
- Improve the design of international trials and collaborative research networks and the interpretation of results from them.

The centers' special competence and comparative advantage lie in sustained research on commodities and production systems in developing countries, and in analyzing and interpreting—across many locations —the adaptation of crops and livestock to their environments. Standard terms and methods of observation and measurement are required. For crops, the tools encompass eco-physical and analytical agronomy, including studies of phenology (crop growth patterns) and the development of plant structure over time, and the estimation of the so-called genetic coefficients for use in computer models of growth and yield.

Compiling an agroecological inventory

A vast quantity of data is needed to provide an integrated picture of diverse production environments. The data fall into four main groups:

- Edaphic factors—topography, terrain, soils, and hydrology.
- Aerial factors—weather and climate.
- Vegetation factors.
- Human factors—land use, farming systems, societal organization.

The data become more complex—and less stable—in that order. Except for catastrophic erosion, soil tends to stay in place year after year. Although weather fluctuates, and over long periods may change, its broad characteristics are repeated year after year in most regions. Vegetation and other biological factors may differ radically within short distances and can undergo substantial change quickly. Land use and farming systems are highly location-specific. They may be altered suddenly and dramatically in the face of population increase, improved communications, or enhanced economic opportunity.

The inherent instability and complexity of such data suggest that the compilation of an agroecological inventory is a formidable task, but major advances by international institutions have made global

Box 2.1. An environmental catalogue: climate, soil, water and vegetation.

The CGIAR centers, with varying methods and degrees of intensity, assemble data on weather and climate, soils and vegetation, crop characteristics, distribution and production of crops, and ancillary socioeconomic data. The essential weather components are solar radiation, maximum and minimum temperature, and rainfall. Data on humidity and movement of the air are desirable, but they can often be interpolated or estimated. Although monthly averages or totals are published for many collection stations, daily data are needed for agroecological purposes (including yield forecasting and tactical management of crops).

For data on the physical and chemical properties of soils, the nutrient status and physical conditions of the soil profile penetrated by roots and even the plow layer itself are significant. Complementary information on hydrology, including effects of land form and properties of the soil surface, to support calculations of water balance are also required. A world soils map on a scale of 1:5,000,000 has been published, and the international soils community is compiling descriptors and soil mapping units, taking into account soil, land forms, and terrain, appropriate to a scale of 1:1,000,000, including indications of diagnostic horizons and other critical features. To better fit agricultural technologies to land resources, more detailed maps will be required.

Information about wild or spontaneous vegetation can also provide valuable clues about climatic or edaphic constraints to crop production when other data are sparse. And wild vegetation is often a resource in its own right, as in savanna and tropical forests—environments that are of interest to CIAT in Latin America and IITA and ILCA in Africa.

The centers' data are derived from ground surveys, aerial photographs, remote-sensing images (from aircraft or satellites), and administrative statistical records. CIAT, in its work in Latin America, is refining methods for converting administrative data to agroecologically defined areas. One difficulty is that most environmental information is collected at individual sites (except when derived from maps and remote sensing), but most uses of the information relate to larger areas. Better methods of deriving information applicable to an area from data gathered at many points (mainly weather and research stations) are of particular importance to the centers.

In collecting weather data, for example, averages are invaluable, but it is the distributions about the means that lead to disappointments, difficulties, and disasters for farmers. Therefore, some estimates of the variability of weather become a vital need.

Brazil's tropical rain forest, with high inherent fertility, is being increasingly cleared for cultivation. CIAT scientists are using land surveys to specify productive land-use options.

agroecological datasets conceivable. Among the notable developments are the unified description and mapping of soils such as has been done in the FAO/UNESCO Soil Map of the World, and the U.S. Department of Agriculture's Soil Taxonomy; standardized recording and communication of weather information as promoted by the World Meteorological Organization; quantitative assessment of the potential output and population-supporting capacity of natural resources in FAO's Agro-Ecological Zones project and more recent developments stemming from it in several countries; remote sensing; and recent advances in assessing natural resource endowment with computers.

At a CGIAR inter-center workshop on agricultural characterization, classification, and mapping, held at FAO in Rome in April 1986, participants called for the cooperative study of agricultural environments by the centers, international institutions and developing country researchers. The participants recognized the need to:

- Describe agricultural production environments in standard terms, based on common standards of observation and measurement;
- Compile accessible datasets on aerial, edaphic, biological, and human factors (although the centers are not yet prepared to attempt to incorporate human factors into the data sets) for each environment; and
- Involve the CGIAR centers primarily, because of their special advantage, in the collection of data on food crops and livestock and their adaptation across environments.

Box 2.2. Retrieval of agroecological data by CGIAR centers.

In a survey to determine the extent of computerized databases on agroecology held by CGIAR centers, CIAT, CIMMYT, CIP, ICARDA, ICRISAT, ILCA, and IRRI reported 19 datasets on daily rainfall and meteorological data covering 46 countries. ICRISAT, ILCA, and IRRI, together, have useful compilations on monthly or weekly rainfall or climatic summaries for Africa and Asia. CIAT has developed an extensive climatic data-retrieval system with 5,200 stations for Latin America and 4,300 stations for Africa. Climatic data are usually simple, sequential numeric files. They are more readily computerized than data on soil profiles and crop geography, which have complex structures and hence are difficult to manage in machine-readable datasets.

Soil-related datasets based on the FAO/UNESCO Soil Map of the World are held by ILCA and IRRI. ICARDA has a dataset on soils related to fertilizer use on barley. CIAT, in a 10-year-long effort, has compiled a massive description of soils and land forms over approximately 820 million hectares of lowland tropical America (see Box 2.3 "The CIAT land-systems study" and Cochrane *et al.*, *Land in Tropical America*, CIAT, 1985).

With the survey confined to machine-readable datasets, four types of information on crop distribution and adaptation are available within the CGIAR system. CIP maintains an international potato cultivation reference file, compiled from various sources. Similarly, IRRI has assembled a map-based description (Huke, 1982) of rice cultivation throughout Asia. In the germplasm databases of CIAT and ILCA, environmental data attached to passport datasets are a useful research tool. And from networks of yield trials on performance of test varieties, CIAT and ICARDA have put together datasets with agroecological import.

Number of stations in CIAT's climatic database and data reported by them, February 1986.

	Latin America	Africa
Rainfall	5,214	4,293
Raindays	1,649	693
Temperature mean	2,106	1,664
Temperature maximum and minimum	1,106	865
Potential evapotranspiration	1,318	464
Sun hours	1,383	544
Global radiation	1,276	319
Relative humidity	1,415	302
Dew point	458	661
Wind speed	322	343

They underlined, based on recognition that there is no single universal set of agroecological zones, that the overriding aim is to characterize agricultural environments, rather than to impose a classification system on them.

Varied approaches to classifying environments

The CGIAR centers' approaches to agroecological zoning are as different as their mandates. Centers whose research pivots on crops or livestock seek more detailed understanding of the regions that produce those commodities, as well as adjacent areas that might be affected by new technology for the commodity. Some centers, however, in addition to working on certain commodities, are responsible for areas that have special resource problems or potentials, e.g. the semi-arid tropics (ICRISAT), dry areas of West Asia and North Africa (ICARDA), the humid and subhumid tropics (IITA), certain zones of livestock production in Africa (ILCA), and the acid soils of Latin America (CIAT). These centers must deal with resource-base zoning problems, as well as zoning needs for their mandated commodities. Examples of the application of zoning by CIAT (see Box 2.3), IRRI, IITA and CIMMYT demonstrate how centers fit the approach to their goals.

At CIAT, the highly variable tropical ecosystems in Latin America led researchers to gather extensive climatic, edaphic, and cropping systems data (on beans, cassava, pasture species, and rice) for Latin America in order to define land systems and microregions. Land systems are areas with recurring patterns of climate, landscape, and soils. CIAT's analysis relied on satellite and radar imagery and occasionally aerial photography to provide a geographical base. Microregions are defined from data describing the growth and development of a particular crop—sowing dates, harvest dates, varieties used, incidence of disease, pests, and weeds, areas sown, associated crops and cropping sequences, and yields. Microregions for different crops, or even the same crop in a different cropping system, can be superimposed on the land system map.

As an example, CIAT scientists have defined environments for upland rice which is seeded under dry conditions and dependent on rainfall for moisture. One finding that arises from this example of agroecological zoning is that soil fertility is not necessarily a strong indicator of a favored upland ecosystem. Rather, climatic stresses, such as the probability of mid-season drought, are often more important in sorting out preferred environments.

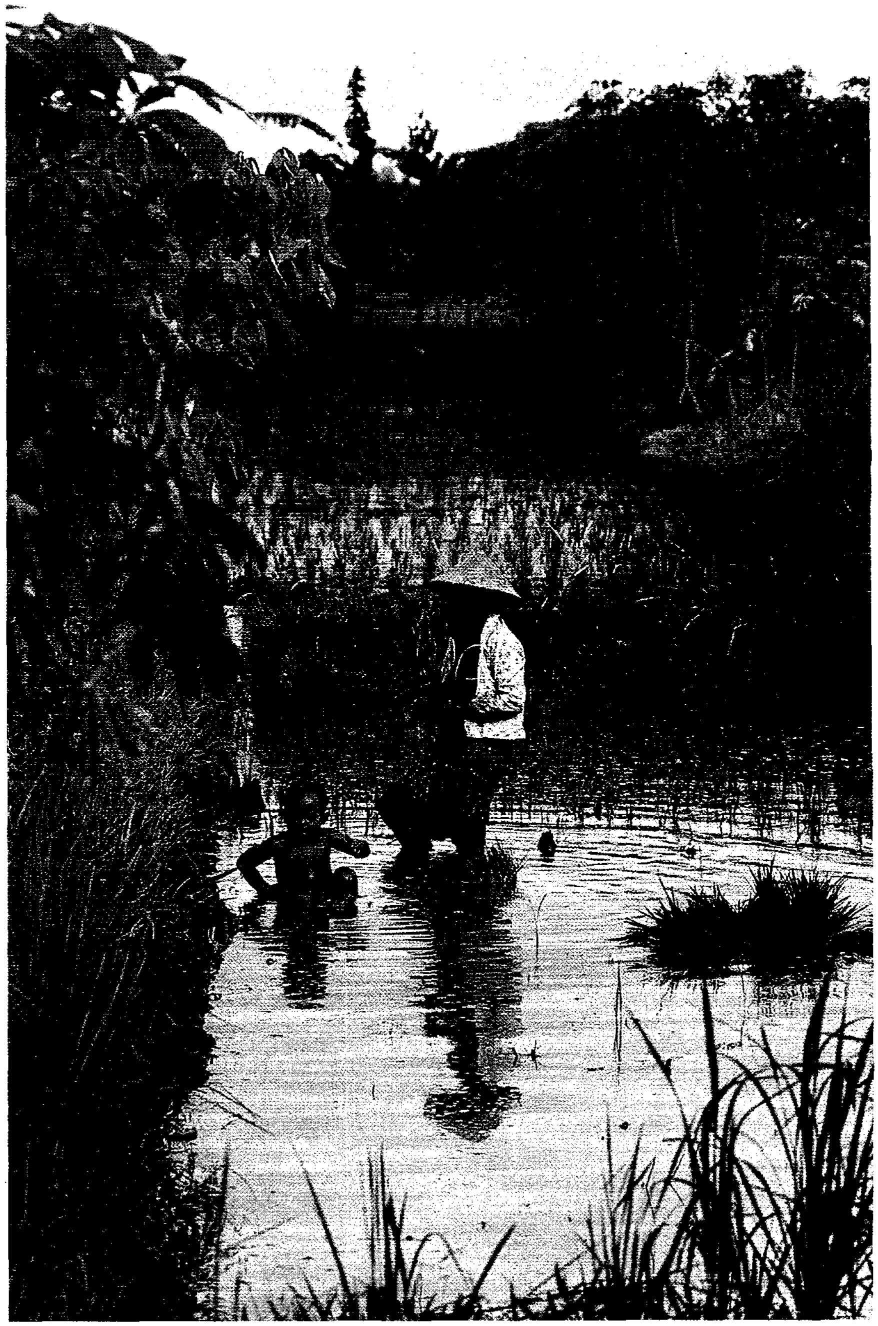
Classifications can be a useful tool to clarify thought in complex situations, but there can be limitations, as indicated by an example from CIAT's cassava program. In cassava, growth slows markedly below 20°–21°C. While it would be informative to trace that isotherm using the standard climate mapping classification developed by Köppen, for example, the demarcation of temperature regimes in that system is at 18°C and 24°C, making it unsatisfactory for cassava studies.

IRRI—with a global mandate for rice—has organized its breeding program in relation to five rice-growing environments throughout the world. For favorable rice environments, the center's major aims are to raise and stabilize yields, raise the yields of irrigated rice, and develop earlier-maturing varieties so that cropping can be intensified. In less-favored environments, IRRI hopes to increase productivity and stabilize yields (Table 2.1).

Table 2.1. Estimated worldwide harvested rice area by five major rice environments.

Rice environment	Harvested area (million ha)		Proportion (%) Harvested area	Proportion (%) Global rice output
Irrigated	78		53	73
Wet season		69		
Dry season		9		
Rainfed lowland	33		23	17
Drought-prone		13		
Submergence-prone		4		
Drought- and submergence-prone		3		
No single severe constraint		6		
Medium deep water (0.25-0.50 m)		7		
Tidal wetlands	5		3	1*
Deep water	11		8	5
Deep (0.5-1.0 m)		6		
Very deep (> 1.0 m)		5		
Upland	19		13	5
Long growing season, fertile soils		2		
Long growing season, infertile soils		7		
Short growing season, fertile soils		5		
Short growing season, infertile soils		5		
Total	146		100	100*

Source: IRRI
*Due to rounding.



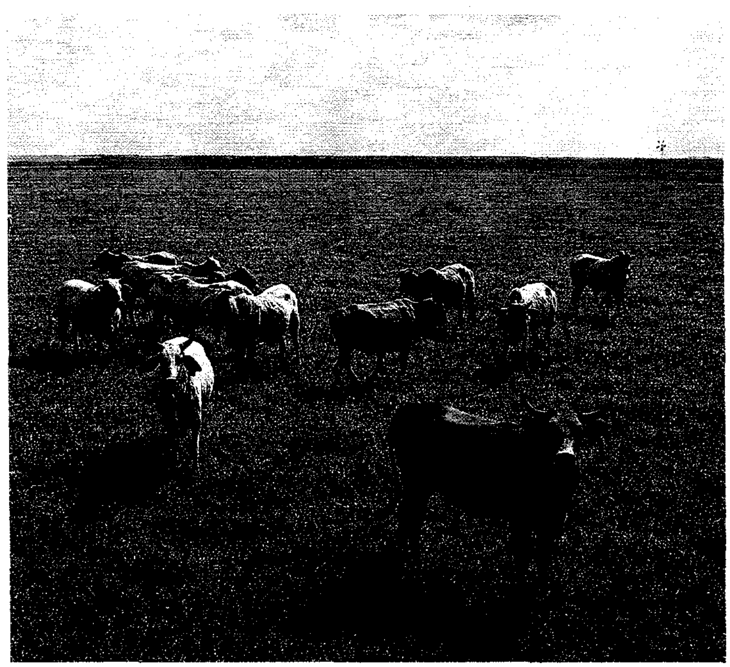
IRRI is refining priorities of its rice breeding program, based on assessment of potential productivity by rice environment. In Indonesia, a farmer in a government transmigration scheme is growing swamp rice in a challenging environment.

For several Asian countries, IRRI has developed a specific classification based on the growing period for paddy rice and upland crops. In Indonesia, paddy rice is the main food crop and agroclimatic zones were determined by the amount of monthly rainfall and the number of consecutive wet months (at least 200 millimeters of rainfall) and length of dry period (number of consecutive months with less than 100 millimeters a month). So far, 12 agroclimatic zones have been delineated on Java, Sulawesi, and Sumatra.

In Africa, IITA is concerned with diverse crop production environments of the western and central regions. For IITA scientists, it is important to understand the range of environmental variation in a region and the effect of such variation on the needs for a specific technology in different areas. There have been numerous approaches to classifying the region agroecologically. The most suitable system depends on the questions being posed and the nature of the specific area being considered. In most classification schemes of the region, the general pattern is similar even when different variables are used, but there are numerous variations in the details of boundary locations and terminology. Generally, agroecological regions are classified either on the basis of vegetational or climatic variables, including various possible expressions of moisture balance. For West and Central Africa, a vegetational classification is often used because of the marked distinctions between the forest and savanna zones, though there are also numerous subzones within them and transitional areas between them.

At CIMMYT, scientists have characterized the major production environments for wheat, triticale, and maize, starting with a general definition of macroenvironments for each crop. A more refined demarcation of environments is evolving from country-by-country estimates of such variables as moisture stress and soil toxicities. Six sub-environments for wheat and 20 sub-environments for maize have been described so far. CIMMYT's most detailed compilation of environmental

CIAT is introducing improved pasture species (left) for the improved diet and productivity of Latin American livestock (right).

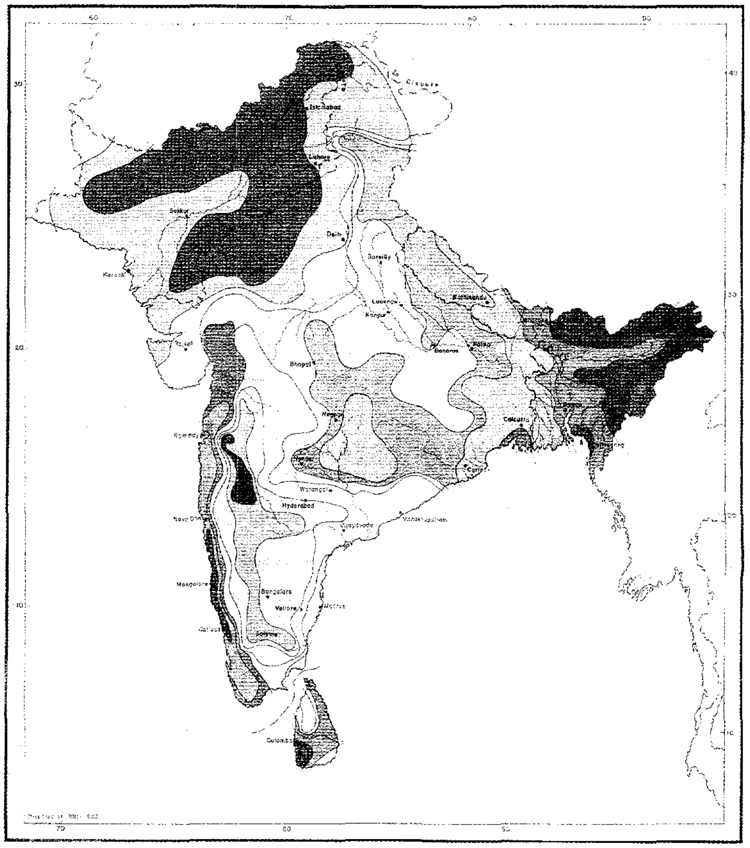


South Asia: agroclimate

Number of Dry months	Number of Wet months
11-12	0
9-10	0
7-8	0
6-10	1
8-9	2
5-7	2
7	3
7-8	3
6-8	4
5-6	5
4-6	6 or more

Dry month = < 100 mm. precipitation
Wet month = > 200 mm. precipitation

Peak precipitation
at least one month > 500 mm.



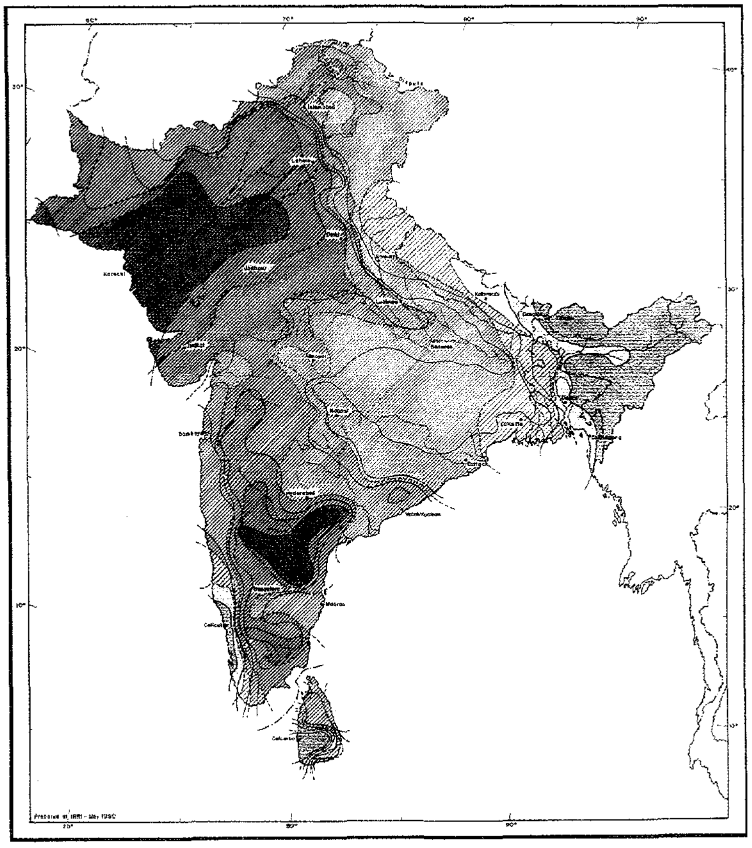
South Asia: the dry season

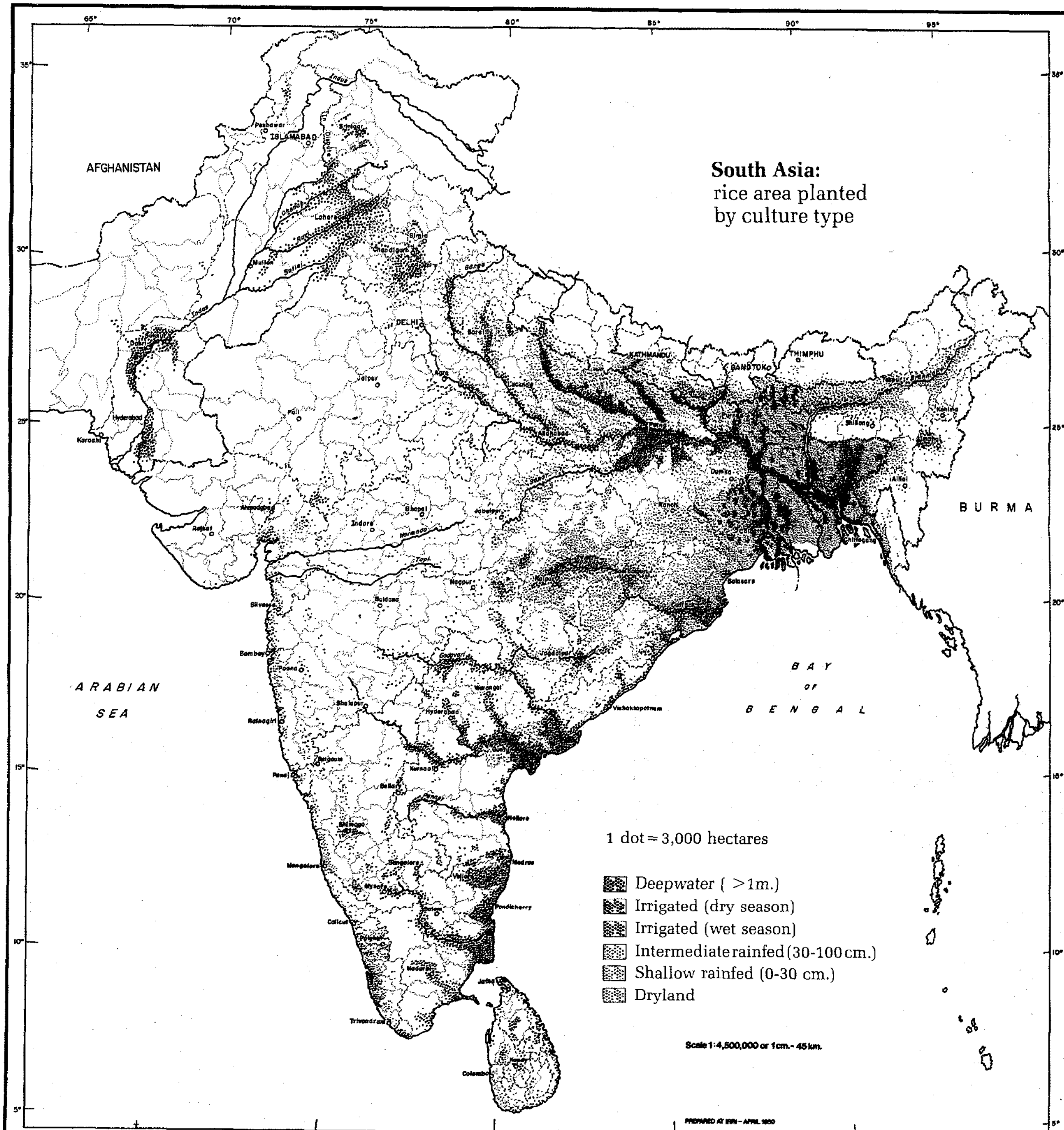
Length of dry season
(Month counted as dry when Thornthwaite's PE > P)

- 12 dry months
- 10 or 11 dry months
- 9 dry months
- 8 dry months
- 7 dry months
- 6 dry months
- <6 dry months

Total water deficit
(Σ of 12 monthly figures of Thornthwaite's PE – AE)

- >1000 mm
- 750-1000 mm
- 501- 750 mm
- 251- 500 mm
- 101- 250 mm
- <101 mm





IRRI maps for South Asia capture complexities of agroecological data for evaluation: Rainfall pattern (at left, top), compared to definition of dry season (left, bottom) using evapotranspiration index and current area under rice production (above). The current areas under rice production indicate how the zoning picture is complicated by the presence of ground water (rivers) and the use of irrigation in otherwise low-potential environments.
Editor's note: Maps do not reflect positions by IRRI, the CGIAR or its cosponsors regarding political boundaries.

At WARDA's experimental station in Mali, deep-water rices are being evaluated for traits leading to higher productivity.

data is for sub-Saharan Africa where three major agroecological zones and nine sub-environments have been described. The relative uniformity and broad distribution of sub-environments globally suggests that germplasm is likely to perform well across comparable locations. For example, high-performing maize germplasm at test sites in Central America is likely to do well in corresponding sub-environments in West Africa, provided that resistance to maize streak virus is added, or in Southeast Asia, provided that downy mildew resistance is incorporated.

Matching cropping patterns with climate

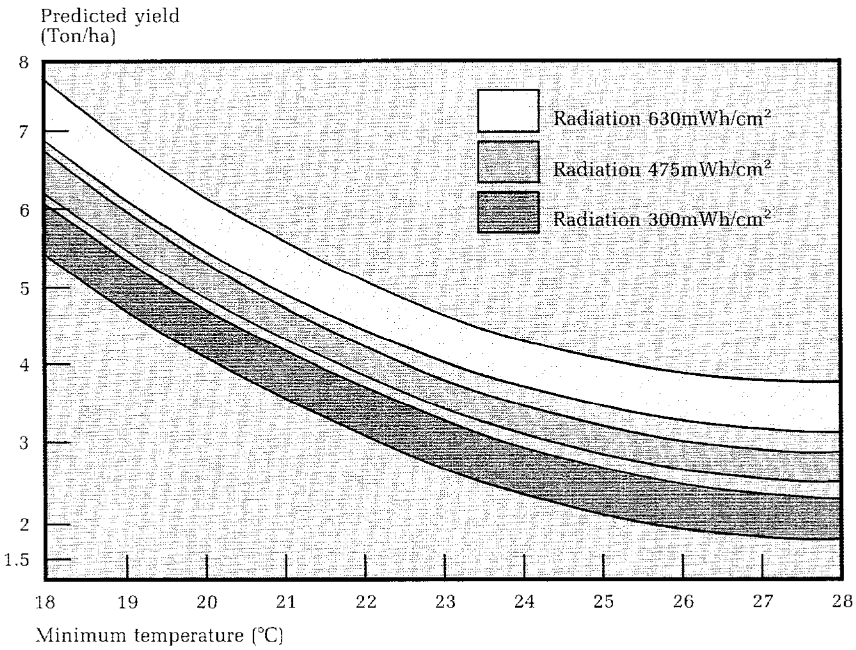
The design of biologically feasible cropping patterns is a process that matches the crop's physical characteristics (over their growth duration) to the area's physical conditions (over the year).

Climatic information can be efficiently used for predicting land suitability for specific crops, different cropping patterns, and performance of alternative patterns over time. Improved climatic analysis increases the likelihood of success for cropping patterns chosen for a given agroecological base. It also helps simplify the description of experimental sites, so researchers can concentrate on the physical parameters that really matter.

The International Rice Testing Program, which includes IRRI, CIAT, IITA, and WARDA, has conducted a rice-weather nursery where a broad range of weather data are carefully recorded. This collaborative activity includes the World Meteorological Organization, the United Nations Development Programme, and the Netherlands. By allowing scientists to compare the performance of a standard set of varieties under carefully measured weather conditions in many locations, these nurseries have illuminated the effect of weather variables on yield. This information has also been used to construct a model from which the performance of an adequately fertilized irrigated rice crop in different conditions can be developed. Included in the rice-weather studies were efforts to predict rice yield on the basis of solar radiation and minimum temperatures (Fig.2.1).

In association with several countries of the Sahel, ICRISAT uses rainfall information for marking off semi-arid areas, for delineating zones for the transfer of improved groundnut technology, and for defining problems requiring interdisciplinary collaborative research. Based

Fig. 2.1. Predicted yield for irrigated rice based on minimum temperatures and solar radiation during ripening.[a]



Source: IRRI/IRTP nurseries.

[a]The shaded area for each radiation value is the 90-percent confidence interval.

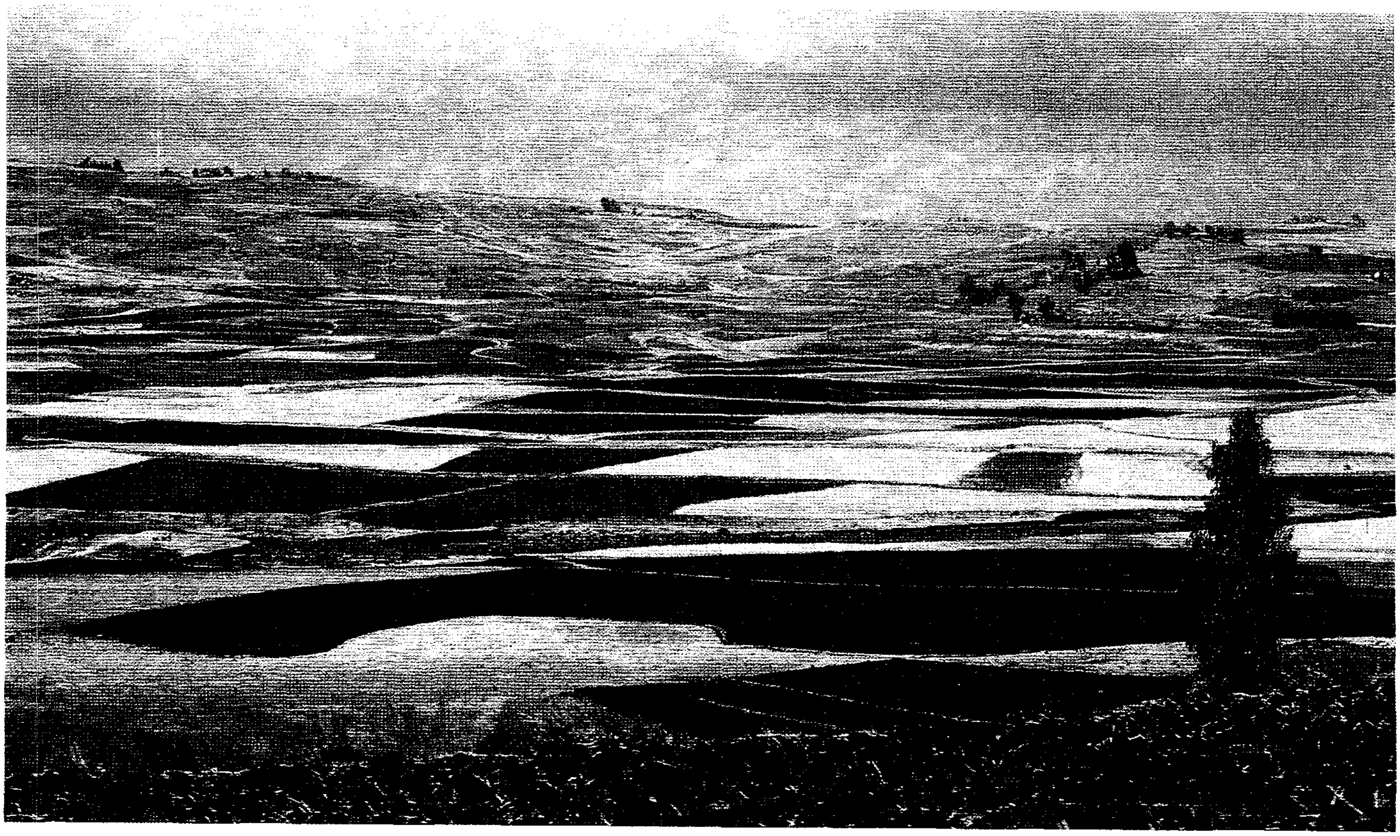
on an analysis of weather and production in the region, ICRISAT scientists have confirmed the link between falling groundnut production and declining rainfall over the past two decades. How to stabilize and restore yields in the face of a shorter growing season has been a specific problem for Sahelian farmers. ICRISAT's response is the development of earlier-maturing and drought-resistant groundnut varieties.

ILCA scientists have been employing remote sensing over the past three years to predict drought and to determine the length of plant growing seasons and the production of plant biomass over large, often inaccessible, areas of Africa. Two ILCA teams have been involved—one in West Africa focusing on annual grasslands and the other in East Africa studying the more diverse perennial grasses. In Niger, ILCA is collaborating with the government, the U.S. Agency for International Development, and Tufts University (United States) to develop an early warning system for drought. The field work involves measurements of canopy reflectance and biomass, and is combined on the ground with low-level aerial photography (and reflectance characteristics). Development of precise estimates of grass production during seasons and over several years is hampered by the complexities of calibrating satellite information. But estimation of the length of growing periods from satellite data seems feasible, using techniques developed by ILCA in Ethiopia. The results could be useful for environmental monitoring of crop and biomass production. In Kenya, initial results of collaborative work involving ILCA and the United Nations Environment Programme suggest that satellite information can be directly used for predicting climatic disasters, but further research on calibration and correction for atmospheric interference is required. Such techniques have considerable promise as cost-effective and reliable tools for predicting and monitoring rangeland production.

ICRISAT's computation of the length of the growing season for 160 locations in West Africa, using the world soils map and a review of existing criteria for climatic zonation in West Africa led, in 1986, to the significant research finding that two rainfed crops could be grown in sandy soils in parts of the Sahelian region. The date of the onset of rains is strongly correlated with the length of the growing season, according to recent findings, and tactical use of crop choices could enable farmers to be more productive under certain rainfall regimes.

Efficiency of international trials

Once agroecological zones are delineated, the placement of research trials pertaining to specific environments can be planned more rationally. Results obtained in one environment can be used to predict the results in another that is similar or differs from it in known aspects. The vast network of multilocational testing trials used by the CGIAR centers and national programs would benefit from this efficiency.



ILCA's use of satellite imagery to estimate biomass and vegetation in Africa is supplemented by on-ground surveys to confirm observations.

The well-established international nurseries and yield trials conducted by the CGIAR centers in conjunction with collaborators in national programs test the performance of varieties in different environments. The centers' current approach to international testing is to distribute trials widely at the request of cooperators. Repeated field trials over several years are costly. Also the data returned often vary greatly from location to location, and because the locations often change from year to year, it is not easy to draw firm conclusions about performance and stability. If, however, locations for testing were more carefully grouped in well-defined environments, data on genotype-environment interactions would be more valuable to researchers. For national programs, reliable maps of sub-environments would also help in identifying relevant field trials in other countries and in applying the findings in analogous environments within their own borders.

IFPRI and the Australian Centre for International Agricultural Research have found in a recent study that there are substantial spillover effects from regions where research is conducted to other regions with similar agroecologies and infrastructure. Research networks can enhance the mutual benefits to be gained from such spillover effects.

Box 2.3. The CIAT land-systems study.

CIAT began land-resource survey work in 1977 to gain better understanding of the varied landscapes for farming in tropical America. It targeted the lowlands of South America east of the Andes—covering 820 million hectares and extending from Panama to southern Brazil—for agroecological zoning. A major objective was to narrow the gap between the actual and expected performances of improved varieties of tropical crops (beans, cassava, rice, pasture species).

CIAT collected information on climate (radiant energy received, temperature, potential evapotranspiration, water balance, other climatic factors), landscape features (landform, hydrology, vegetation), and soil (soil chemical and physical characteristics). Data were then used to create a mosaic of zones that incorporated nuances in moisture and soil regimes as well as vegetation. After climatic analysis, the landscape was subdivided into land systems, which were delineated on 1:1,000,000 satellite imagery and, for some areas, on side-looking radar imagery. The land surface was mapped to illustrate areas sharing similar ecological characteristics.

Field work studied variations within land systems and helped standardize descriptive criteria. These variations, although not mapped because of scale limitations, were described as "land facets" and helped bridge the gap between land systems and soil units.

Whenever information was available, physical and chemical properties of topsoils (top 20 centimeters) and subsoils (21-50 centimeters depth) of the individual land facets were recorded, tabulated, and coded.

Based on computer printouts of land-system groupings that integrate the broad climatic, topographic, and natural vegetation classes, five agroecological zones were selected to define the humid lowlands of central tropical South America. Three of the zones are savanna (poorly drained, hot, and warm) and two comprise forest (semi-evergreen and tropical rain).

The five zones represent a first approximation to put gross climate and landscape differences into perspective. In order to turn this broad view into a framework for establishing research priorities and to define conditions for selecting, testing and transferring new pasture plant varieties, CIAT had to look much more closely at a number of factors, including for example:

- rainfall patterns, which are erratic in some areas;
- soil chemical conditions, specifically deficiencies in phosphorus, potassium and calcium;
- soil physical conditions affecting moisture-holding capacity;
- relative levels of soil fertility.

The picture that emerges from the land-system evaluation, and by inference, priorities in research on genetic traits in pasture species, is considerably different from the one previously inferred from generalized small-scale maps. Phosphorus fixation is not a potential problem over much of the region, nor is aluminum toxicity as widespread as thought (though both are significant in warm savannas). Thus, phosphate rock and minimal lime applications may be low-cost solutions for a deficiency in phosphorus or for toxicity problems, respectively. Pasture plants tolerant to high aluminum saturation are still desirable, but not all pasture germplasm need be screened for tolerance to high-level saturation, as has been the practice in the past. However, potassium, calcium and magnesium levels are low on a large proportion of the soils, suggesting that pasture plant germplasm that copes with such low levels would be desirable.

The study found substantial fertility reserves in forest vegetation. In the tropical rainforest ecosystems, particularly, it suggests that the search for pasture germplasm adapted to low soil fertility need not be a top priority.

Careful site analysis also plays an important role in farming systems research. Choice of research site, targeting of areas to be studied, and understanding of the farmers' environment all can be enhanced by improved environmental characterization. A real need in farming systems research is better methods for using secondary data on climate, soils, and land capability.

Priorities and strategies of individual centers

Agroecological zoning efforts have helped the CGIAR centers refine their priorities. In West Africa, IITA, in ordering priorities for rice research over the next 20 years, defined the major ecologies and determined their respective relative importance to future rice production. An important conclusion from this analysis is that the inland valley swamps, hydromorphic (poorly drained) environments and favorable upland areas account for almost two-thirds of the projected increase in production (Table 2.2).

Table 2.2. Estimated potential gains in rice production by ecology in West Africa over the next 20 years.

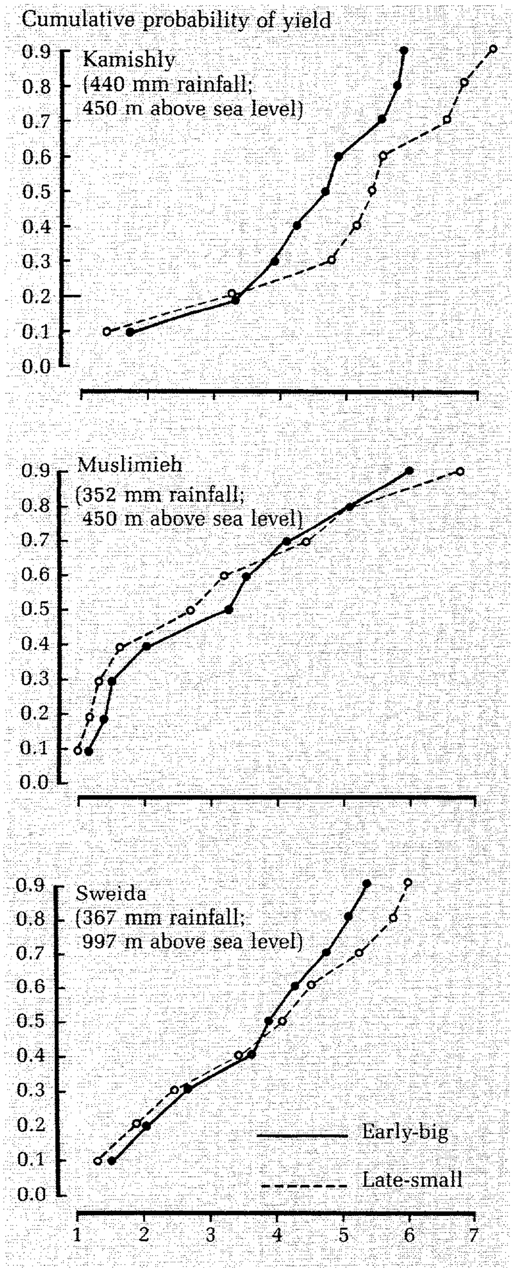
Ecology	Proportion of total area (%)	Yield (t/ha) Current	Target	Projected gain	Contribution of ecology to increased production (%)
Upland					
Unfavorable	10	0.5	0.5	0	2
Favorable	24	1.0	1.5	0.5	18
Hydromorphic	24	1.5	2.0	0.5	23
Lowland					
Inland valley	19	1.5	2.3	0.8	22
Mangrove swamp	8	2.0	2.8	0.8	11
Riverine	9	1.5	2.3	0.8	10
Irrigated	6	3.0	4.0	1.0	14
Average		1.4	2.0	0.6	

Source: IITA

Simulating crop performance

The application of modern methods of systems analysis, in combination with recently developed techniques for simulating crop growth and yield, offers alternative and complementary approaches for evaluating and predicting the effects of environmental variation on opportunities for increased crop and livestock production. Descriptions of an environment's aerial and edaphic factors, while necessary, are not

Fig. 2.2. **Simulation of grain yield by two hypothetical wheat varieties at three locations in Syria.**[a]



Source: ICARDA

[a]The lines reflect the relative ability of the variety to cope with climatic risk. The curve predominantly on right represents the "best-bet"—if minimum risk in variable climate is first priority. The "late-small" variety (late maturing, small kernels) is less risky at Kamishly and Sweida, and "early-big" is preferable at Muslimieh.

sufficient for researchers seeking to simulate crop growth. Center scientists need to be able to associate—conceptually, and preferably quantitatively—variations in these factors with crop variations in structure, growth cycle, and yield. Until modelers can develop coefficients to predict variations in different environments, they have to rely mainly on such measurements as weather and soils data, phenological observations, and plant dry weight and harvest index (in cereals, ratio of grain weight to total plant weight).

Genetic coefficients are factors that affect the accumulation of biomass over time and the time patterns of radiation received, temperature, and water balance. Coefficients are used in models that can predict performance in environments in which they have been validated and hence lessen the need for formal experiments. Modeling is particularly useful for marginal and unpredictable environments where many field experiments are wasted because the variance in experimental conditions is small relative to the variance across locations.

IRRI, in collaboration with the Centre for Agro-Biological Research (the Netherlands), has organized training in crop modeling and systems analysis for eight teams from seven Southeast Asian countries. It is also working with other countries in the region to set up small groups (soil scientist, agro-meteorologist, agronomist, often from different national agencies) to work on specific questions in agroecological characterization.

In Syria, ICARDA scientists have developed a simulation model, SIMTAG (simulation of *Triticum aestivum* genotypes), to predict how climatic variability affects wheat yields. With climatic data supplied by the national meteorological service for three sites, the model compared the ability of two hypothetical varieties to provide high and stable yields. The hypothetical varieties were "early-big" (maturing early, with few but big kernels and a high kernel-filling rate) and "late-small" (late-maturing with many small kernels and a lower filling rate). Both were "grown" in a "good" (Luvisol) soil. The simulation addressed the problem of high seasonal variability in rainfall and yields. The ratio of rainfall between the driest and wettest season is 1:3, while the ratio in wheat yields for the respective rainfall conditions is 1:15. SIMTAG also provides day-to-day accounts of water balance and crop development as part of the analysis. Over 25 seasons, late-small was superior to early-big at two sites—at one because of higher rainfall and at the other, which has a higher elevation, because of lower evaporative demand (Fig. 2.2). At the third site, which had low rainfall and high evaporative demand, the early-big variety was superior. The probability of grain yield under environmental risk can help determine the most desirable germplasm traits for field testing. ICARDA scientists found, based on the simulations, that six seasons of field results were not sufficient to ensure correct interpretation of varietal characteristics most desirable for a specific location over the long run.

Looking ahead

At the CGIAR centers, environmental priorities are shifting. This stocktaking and redefining of priorities has become possible because the gains achieved for major crops in favorable environments have enabled scientists to address a wider circle of agricultural environments. But as a wider research net has been cast, new challenges — physical, biological and socioeconomic — have been encountered. Characterizing the environment in detail becomes vital as the centers confront two continuing challenges: safeguarding and stabilizing food production in line with the needs of an ever-increasing global population and contributing to improved productivity of cropping systems in less-favored environments. The job requires the collaboration of national and international agencies, some of which are not a part of the agricultural research system and yet whose work is essential to this endeavor.

Based on agroecological characterization of production environments, the sources and magnitude of increased food production can begin to be identified (Table 2.3). The result is an important tool for research scientists and policy-makers, as they grapple with priorities for deploying resources and strategies for food security.

Table 2.3. IRRI research efforts on major rice-growing environments, compared with anticipated economic returns from productivity increases in each area.

Rice environment	Staff efforts Current (%)	Staff efforts Projected (%)	Projected economic benefits (%)
Irrigated	51	42	58
Rainfed shallow	22	26	27
Upland	14	16	4
Deepwater and tidal/adverse	12	15	10
Total	100*	100*	100*

Source: IRRI
*Due to rounding.

3. Policy: Influences in developing technology

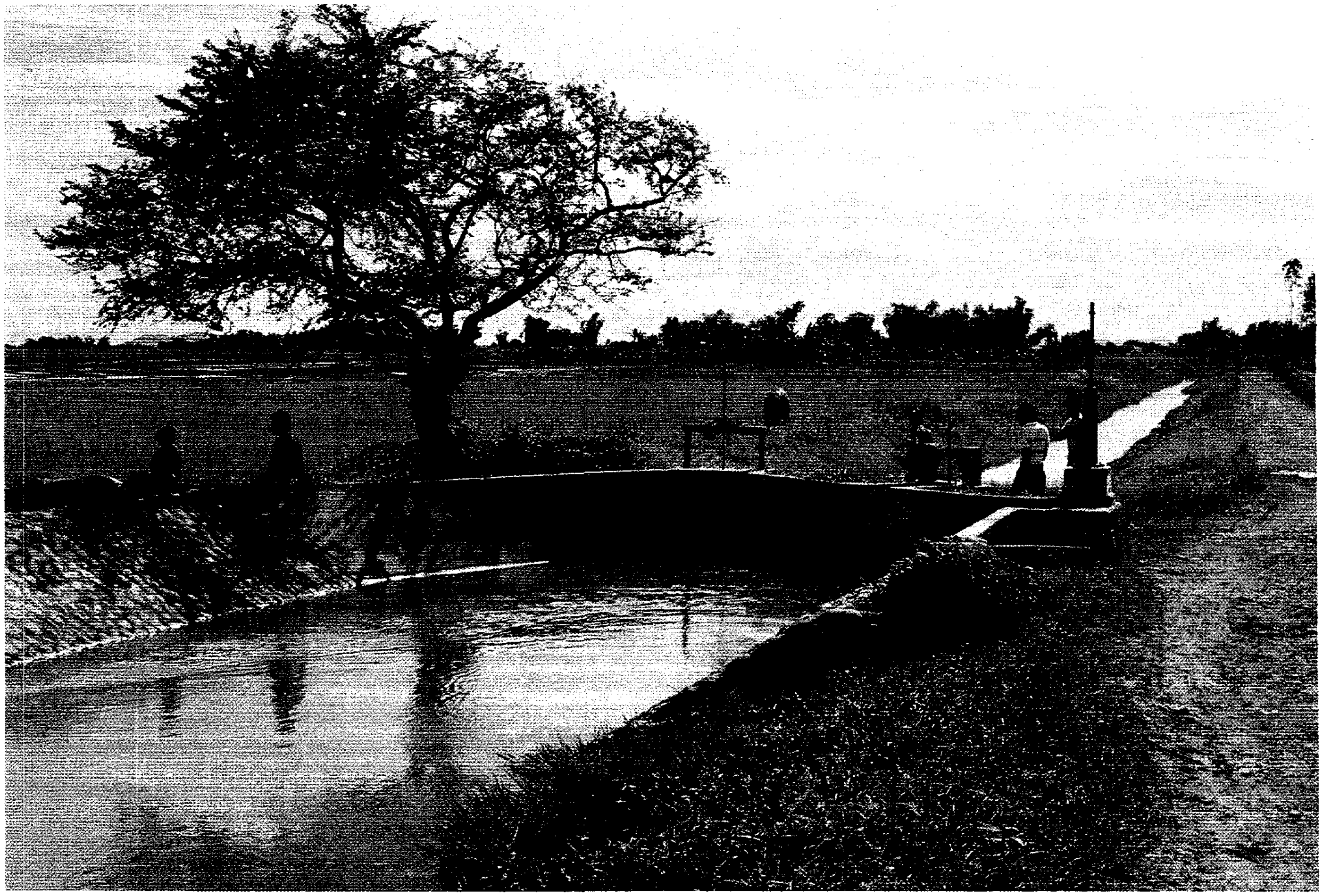
Physical resources are the foundation of agriculture. Climate and soils set the range of crop and animal production opportunities available to farmers in specific localities. However, tying technology into an environment demands a broader perspective, because farmers' choices of what to grow and what techniques to use are guided by overlying economic, institutional and policy factors.

More detailed agroecological characterization improves the ability of CGIAR centers to set priorities and target their research efforts towards high-potential payoffs. At the national level, the clear identification of research goals and the mobilization of emerging technologies require positive policies (avoiding distortions of comparative advantage) and effective institutions including research organization, input and credit channels, transport and marketing services. The importance of these factors to the global agricultural research system's ability to move advances in agricultural technology to poor farmers is illustrated here by examples of the CGIAR centers' research on policy and institutions.

Comparative advantage

One of the main methods used in policy research by IFPRI and other centers is domestic resource cost analysis, a technique which values production inputs and outputs, even those imported or exported, in terms of domestic resources. It looks across the physical, economic, policy, and institutional environments in which farmers operate to identify the comparative advantage of a country, or a region of a country, in producing a particular product rather than another. The method highlights policies necessary to reconcile farmers' interests with the national interest. It often identifies existing policies on taxes, subsidies, or exchange rates that keep farmers from exploiting the comparative advantage of their physical resources and basic economic circumstances.

IFPRI, in collaboration with IRRI, recently completed a study of the price and investment policies needed to accelerate the expansion of food-crop production in the Philippines. The study found that the Philippines' basic agricultural comparative advantage is to meet domestic demand for rice and maize (as food and animal feed) and to use these two crops as major determinants of economic growth through agriculture. According to the study, while maintaining stable rice and maize prices at somewhat above world-market price trends, the government should greatly expand investments in productivity-enhancing programs, such as irrigation and technological development, to maintain long-term growth rates in rice yields and to accelerate the growth of maize yields. As productivity rises, price levels can be eased at a rate that balances increased consumer benefits with improving agricultural incomes.



IFPRI policy study suggests investment in irrigation schemes in the Philippines in which the community takes responsibility for organizing use of water.

Investments in irrigation should emphasize construction of new systems to bring irrigation to farmers dependent on rainfall, rather than reinforcing the advantages of farmers who already have irrigation. Also, since the study found no significant regional differences in the comparative advantage of growing rice, investments in irrigation should stress the lower-productivity regions. Both actions would help make new irrigation systems instruments for reducing income disparities between rich and poor farmers.

As part of the study, IFPRI examined competition between two key inputs, fertilizer and irrigation, for government budgetary resources. The study notes that "the massive subsidies that government would have to provide to lower the fertilizer price by 50 percent would be better spent on irrigation and other productivity-enhancing investments." The study also evaluated the irrigation options for government investments. It recommended organizing new irrigation systems communally. Despite the fact that crop yields in communal schemes are lower than in other types, initial investment and operating costs are very much lower, giving them better and more consistent economic performance.

Although the study identified new irrigation systems as the most efficient and equitable investment for government funds, it also examined options for rehabilitating existing systems, to which significant budget resources are already committed. The major problem in existing systems is distribution of water. Diversion irrigation schemes with no storage serve two-thirds of the irrigated area in the Philippines and usually operate by continuous and simultaneous water supply to the whole area under command. There are few difficulties when water is ample; but in years when rainfall is low, inequities occur in the sharing of water. On the whole, these absolute shortages cannot be remedied in a cost-effective way through rehabilitation or by the rotational management of water. In new irrigation systems, however, the analysis suggests that rotational management should be instituted to help avoid the income disparities that have arisen from uneven access to water where distribution is continuous.

Domestic resource cost analysis has not, so far, been widely applied to the allocation of resources for agricultural research. Based on a series of case studies, done in collaboration with national agricultural research systems, CIMMYT's economics program is developing a manual on domestic resource cost analysis for use in assessing the national comparative advantage of alternative research programs. The manual will help research managers identify discrepancies between farmers' interests under current policy and under local comparative advantage which may be distorted by that policy.

For example, a recent study, conducted in collaboration with INIA, the national agricultural research agency of Mexico, investigates the comparative advantage of irrigated and rainfed wheat in two areas of Mexico. Mexico faces increasing consumer demand for wheat products and the trade and financial situation favors expanding domestic wheat production rather than imports. Greater output in irrigated areas will have to come from yield increases unless wheat replaces other crops. This raises the question of whether policy-makers should give more attention to rainfed wheat production.

The study analyzes the comparative advantage of wheat produced in the irrigated Yaqui Valley of the state of Sonora, the most important wheat-growing area in Mexico, and the rainfed highland area in the states of Tlaxcala and Hidalgo. It shows the substantial influence of government in setting both input and output prices for Mexican wheat. In general, producers have been receiving below world-market prices for wheat. This is particularly the case in Tlaxcala which is adjacent to major consuming centers and, hence, has markedly lower transportation costs than alternative sources of supply. Policy has also intervened to change price relationships with other crops. In most cases, farmers receive higher-than-world prices for competing crops, especially maize and oilseeds.

To some extent, government policy has compensated producers through subsidies on inputs. Subsidies on fertilizer, diesel fuel, credit, seed (in rainfed areas) and water (in irrigated areas) combined, exceeded

50 percent of production costs in 1979-82, for example. Since then, direct government subsidies have been reduced in relative terms, and credit and water remain the major sources of assistance. The high-level subsidies have encouraged the intensive use of inputs and incurred high costs in terms of national resources.

The production of oilseeds and maize seems to have no comparative advantage over wheat in Sonora. For irrigated wheat, the major research opportunity is to find ways to reduce production costs. With government's commitment to reduce subsidies, there is a need to look for ways to use credit, water, fuel, and fertilizers more efficiently. In Tlaxcala, the study indicated that wheat production also has a comparative advantage relative to other crops, especially maize. This potential for wheat has not yet been realized, partly because pricing policies have generally not encouraged its production and partly because more productive wheat varieties have yet to be extended to local farmers.

The analysis of the comparative advantage of wheat production in these two regions in Mexico suggests that rainfed wheat in the central highlands may be as competitive as irrigated wheat in the northwest. So far, very little research and extension have been devoted to wheat grown under rainfed conditions in Mexico. The case for allocating resources to the rainfed crop is strengthened by the CIMMYT/INIA study.

Fertilizer policies: Bangladesh and China

Bangladesh. In association with the Bangladesh Institute of Development Studies, IFPRI recently completed a study on fertilizer pricing policy and food-grain production strategy. In Bangladesh in the mid-1970s, the fertilizer subsidy absorbed up to 27 percent of the government's development budget for agriculture. Since then, the government has gradually raised the price of fertilizers to farmers. Even so, fertilizer use expanded so rapidly that the absolute amount of the subsidy was not much reduced, though the proportion of the agricultural budget absorbed fell to 13.6 percent by 1984. At that time, the government asked IFPRI to identify the price increases required to completely remove the fertilizer subsidy by 1988.

IFPRI found the subsidies to vary considerably, depending on type of fertilizer and source of supply. The average economic subsidy was 17.7 percent for urea, 29.3 percent for triple superphosphate, and 24.4 percent for muriate of potash. The study projected that across-the-board price increases of 16 percent for two years would compensate for anticipated cost inflation and also eliminate subsidies.

Further analysis by IFPRI indicated that these price increases would reduce fertilizer use by about 22 percent, causing a 2.2 percent drop in foodgrain output, which would be equivalent to 350,000 tons of rice. Recovery of the subsidy would also represent a 2 percent tax on

Box 3.1. Labor and organic fertilizers in China.

The process of collecting, mixing, storing, transporting and applying organic fertilizers, according to one Chinese study, requires 35-45 days of human labor and 20-25 days of animal labor per 100 kilograms of nitrogen. On this basis, China's target—doubling the current use of organic fertilizers—would require the labor of 170 million-220 million people for one month each year at extremely low wages, and this labor would have to be found in high-yield, high-opportunity-cost areas of the country.

farm household incomes. In 1986, the Bangladesh government completely eliminated the subsidy on urea, though phosphate and potash are still partially subsidized.

China. Completed in 1986, IFPRI's work on fertilizer in China analyzed the historical development of the fertilizer industry in order to identify factors that would help shape policies for meeting national needs in the 1990s. The study identified several distortions in past fertilizer policy and distribution that will have significant implications for the future.

First, the study found that fertilizer use is concentrated in the rich agricultural areas, often close to urban markets. To a large extent, these better agricultural areas have captured the distribution system. To a significant degree, fertilizer has been obtained only in exchange of marketable crop surpluses, which provide food for the cities and raw materials for industry. Because marginal areas tend to produce close to the subsistence level, they cannot generate the surpluses necessary to barter for fertilizer. Estimates for one province suggest that only 3 kilograms of nutrients per hectare were being applied in the less fertile areas, while application rates in the richer lands were up to 46 times as great. Other nationwide estimates indicate that by the late 1970s, the value of the paddy rice produced from a marginal application of fertilizer had fallen to a ratio of 2.5-5 to 1 on fertile lands, compared with a ratio of 15-25 to 1 in areas of more depleted soils.

A second observation is the imbalance in the proportions of nitrogen, phosphorus and potassium (NPK) applied. The 1984 figures for domestic manufacture show a ratio 100N:21P:0.3K. The actual consumption ratios for 1983 have been estimated at 100:30:5, the balance improved by imports. However, in 1983 Chinese planners were indicating a suitable ratio to be 10:50:20 or even 10:60:30. (The world consumption ratio is 10:52:40). The shortfalls in phosphates and potash indicate that on good agricultural land receiving high levels of nitrogen, response rates may have been held down by the poor balance in the types applied, the nitrogen being unable to express itself in the absence of adequate phosphate and potash.

The IFPRI research further indicates that the future of China's traditional use of organic fertilizer is in doubt. The use of organic fertilizer is highly labor-intensive with low rewards. Aspirations for higher incomes in the future are likely to encourage a shift from organic supplies to chemical fertilizers. The implications are far-reaching in terms of possible pollution and, more important, the development of soil structural problems known to follow the reduction of the organic matter content of the soil.

In China, efficiency in the use of fertilizer will be at a premium in the 1990s. Near Beijing, a farmer hand-meters fertilizer into irrigation water.

The research concludes that without large public investments in new fertilizer plants or a firm commitment to import fertilizer, much of the growth in agricultural production for the 1990s will have to come from more efficient fertilizer use. IFPRI's analysis of the fertilizer industry suggests several routes to higher efficiency:

- Improve the balance of nutrients used on high-yielding agricultural land.
- Reallocate fertilizers from good to less-good agricultural areas to improve the average response of crops to fertilizer use at existing levels of supply.
- Conduct localized research to determine more precisely the quantities and times of application appropriate for particular soil and water conditions.
- Develop better placement methods and fertilizer formulations to ensure that crops recover more of the nitrogen applied. Plant uptake of nitrogen by plants varies with soil type; estimates of uptake in some areas are as low as 22 percent, which could probably be doubled.
- Improve packaging, storage, and distribution. Losses due to volatilization before application may be 20 percent nationally and up to 40 percent in some areas.

Responding to concern over slow rates of fertilizer uptake in countries south of the Sahara, which are experiencing major food supply problems, IFPRI has shifted its focus increasingly to Africa. Its research emphasis is to seek policies that will increase fertilizer use by smallholders. Work began in Rwanda in 1986.

Box 3.2. On-farm client-oriented research.

An ISNAR study identifies several inter-related functions which on-farm client-oriented research should perform when fully integrated into a national agricultural research system:

- Incorporate a problem-solving approach.
- Contribute to an inter-disciplinary perspective.
- Characterize major farming systems and client groups.
- Adapt existing technologies or contribute to the development of alternative technologies for targeted groups of farmers.
- Promote farmer participation in research as collaborators, experimenters, testers, and evaluators of alternative technologies.
- Provide information for setting research priorities, planning, and programming.
- Promote collaboration with extension and development agencies to make the generation and diffusion of technology more efficient.

The institutional environment

ISNAR addresses both the policy and the institutional environments through its advisory service to national agricultural programs, which aims at improving their capacity to respond to farmers' needs and to develop useful technologies; its new research program which is developing concepts, tools and analytical methods in research policy, organization, and management appropriate to developing countries; and its training program.

In 1986, it launched a study of the integration of on-farm research into national agricultural research systems—the first in a series of in-depth studies on critical management issues. Its purpose is to elucidate the critical organizational and managerial factors that allow for effective integration of on-farm research into the broader research endeavor so that it enhances research capacity and the generation and dissemination of technology.

Studies were begun in Africa, Asia, and Latin America of eight national agricultural research systems that have had sufficient time to experiment with, and develop, diverse organizational arrangements and management systems for implementing and integrating on-farm client-oriented research. The case studies are expected to be completed by mid-1987.

These examples of CGIAR research emphasize the importance of policy and institutional environments in making good use of the underlying physical environment of climate and soils. They demonstrate that appropriate policies and effective institutions are a prerequisite to the mobilization of CGIAR-related technologies by partners in national programs.

4. Impact: From farmers' fields to national policies

Individual CGIAR centers continue to gather and analyze information about the impacts of technical change as one important aid in charting the course of future research. The examples of impact presented here are chosen to illustrate two important facets of the evolving role of the centers in the global agricultural research system.

- The impact of CGIAR activities and products will be apparent more at intermediate levels of the global agricultural research system rather than directly in farmers' fields where national institutions play a central role.
- The assessment of potential impact will be increasingly vital to the CGIAR centers in choosing research priorities.

The closeness of national agricultural research systems to resource-poor farmers makes national systems the foundations of the global system. Improving national capacity includes increasing their ability to signal the real needs of their client farmers to the CGIAR. Both these components of the global system need strong competence in assessing the potential impact of technologies as an aid to more efficient priority-setting. It is widely acknowledged that "miracle" technologies are few and far between. The mainstay of agricultural research is the purposeful anticipation, targeting and solution of high-priority problems that affect large numbers of poor farmers. In this regard, CGIAR efforts on agroecological characterization are an important step towards better estimation of the potential impact of research activities. For example at ILRAD, which focuses on developing methods of immunization for trypanosomiasis and East Coast Fever in African cattle, the centers' new social science unit will try to anticipate the ramifications of successful development of such methods on the economy and ecosystem, already struggling with dramatic population increase. Prior assessment of the impact of immunization can help to ensure that innovations in animal health are of real benefit and do not add to the socioeconomic or ecological strains on Africa.

Several of the following examples demonstrate the essential partnership between national research systems and the CGIAR centers in improving agricultural productivity. The national systems increasingly take responsibility for the use, adaptation and refinement of products coming from the CGIAR centers to meet the specific needs of their farmers and institutions. Other examples demonstrate the research investment in time and resources required before fruition.

Managing Vertisol soils

Burgeoning populations have heightened the interest of the development community in the management and sustainability of resources. Not only will land currently under cultivation need to be used more intensively—the traditional focus for agricultural research, but marginal lands will increasingly be brought into cultivation as rural people are compelled to move to find a means of support.

ICRISAT is one of two CGIAR centers specifically mandated to focus on the problems of agricultural production in low rainfall and poorer soil areas; ICARDA is the other. A third, IITA, is specifically mandated to identify an alternative to shifting cultivation. This traditional land-use management system for the fragile soils of the humid tropics is being rapidly overwhelmed by high rates of population increase.

Vertisols are marginal soils, common in valley bottoms. These fertile soils are easily waterlogged and their high clay content makes them difficult to plough. ICRISAT's long-term experiments with Vertisol soils in India have established that improved drainage to reduce waterlogging is a crucial principle for managing these soils. The broadbed-and-furrow technology developed by ICRISAT reduces waterlogging and facilitates faster, earlier planting of crops. The broadbeds support the plant above the water table. The furrows provide drainage to prevent the water table from intruding into the root zone and causing waterlogging. ICRISAT's techniques are now being applied in Ethiopia in a collaborative project with ILCA and four national institutions.

The project includes the development of a modified Ethiopian plow to prepare broadbeds and furrows. In 1986, field trials resulted in grain yield increases of 25-63 percent for breadwheat, 144 percent for durum wheat, 297 percent for horse beans, and 84 percent for finger millet. In trials with 34 farmers around Debre Zeit, the technology also reduced labor inputs by 40 percent for teff (a local cereal) and maize, thus substantially increasing labor productivity on these test farms.

There is huge potential impact on the Vertisols—deep black cotton soils —widespread in sub-Saharan Africa. They account for about 70 percent of all highland African soils with slopes between 0 and 8 percent and cover 100 million hectares of the continent, including 7.6 million hectares in the Ethiopian highlands alone. The indications in Ethiopia are strongly favorable. Nevertheless, even if farmer acceptance is immediate, the CGIAR system will have well over ten years of work invested in the technology.

Box 4.1. Millets, a crop for marginal areas.

ICRISAT has had recent success in its germplasm development to enhance farming in marginal areas. Its pearl millet variety WC-C75 has been in increasing demand in India since its release in 1982. The variety has stable grain yield, good disease resistance, and a high fodder yield, which has made it popular with Indian farmers. The Indian Council of Agricultural Research reports seed production targeted for the 1987 rainy season will allow the planting of 1.5 million hectares.

Broadbed-and-furrow technology is improving drainage on deep black cotton soils (Vertisols) in Ethiopia.

Triticale

Other centers also devote significant effort to the problems of toxicities, drought, and low fertility that characterize marginal lands. For example, CIMMYT's 20 years of work on triticale has heightened awareness of the crop's potential in marginal environments.

As more favorable pricing policies are introduced, the area devoted to triticale in developing countries is likely to expand further. The potential is very significant. Over 3 million hectares currently in wheat, barley, or rye could be sown to triticale because of its superior productivity, including significant semi-arid areas of Asia, the Middle East, and North Africa. Other important potential production areas are the Brazilian *cerrados*, northern Zambia, and tropical highlands in many Southeast Asian countries. Triticale clearly outperforms wheat in these environments and some 15 million additional hectares could come under the crop (Table 4.1).

This man-made cereal crop recently celebrated its 100th birthday, having first appeared in the 1870s, although it was treated more as a biological oddity than a crop for most of its history. A product of a cross between wheat, a member of the genus *Triticum*, and rye, a member of the genus *Secale*, it takes half its name from each parental genus. By 1986, however, triticale plantings worldwide passed the million-hectare mark, a tenfold increase in a decade. Much of this expansion is the

Box 4.2. Breeding triticale for marginal environments.

The breeding strategy for developing triticale materials suited to drier tropical highlands and acid soils begins with the selection of parents having adaptation to acid soils and sprouting resistance. (Sprouting of the grain before planting or in storage is undesirable.) CIMMYT scientists have taken two approaches to breeding for sprouting resistance and for a good (unshrivelled) seed type. First, triticale strains and segregating populations are planted during January so that ripening coincides with maximum rainfall during June and July. This procedure facilitates screening for sprouting resistance and the capacity to produce plump seed. In the second approach, laboratory tests are used to eliminate those lines with unacceptably low sprouting resistance.

A primary concern in developing germplasm for low rainfall regions is ensuring that materials maintain acceptable test weights (a measure of grain quality) and yields under drought conditions. Varieties and lines with proven tolerance to drought stress are intercrossed to enhance the tolerance. The resultant segregating populations undergo selection under low moisture conditions for at least three generations. At every stage, non-adapted populations are eliminated, based on their yield and test weight. Surviving populations are then planted under optimal conditions to identify plants that have more genetic yield potential.

Table 4.1. Potential triticale area in developing countries (thousand ha).

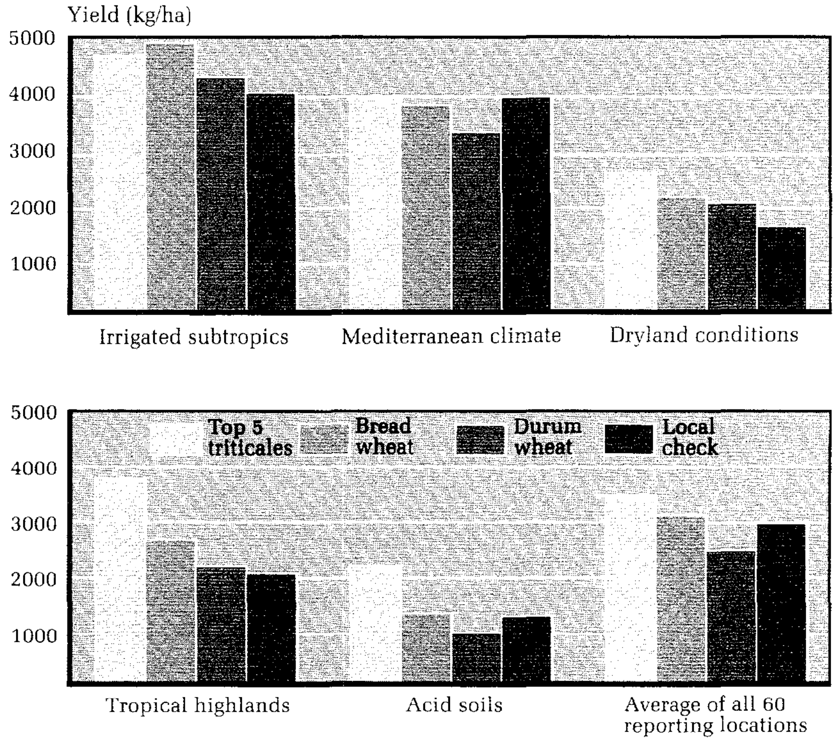
Location	Highland/acid soil conditions			Semi-arid
	Crop substitution	New cultivation	Total	Crop substitution
East Africa	60	1,720	1,780	—
North Africa	—	—	—	600
Asia	500	—	500	1,610
Southeast Asia	—	540	540	—
South and Central America	510	12,500	13,010	30
Total	1,070	14,760	15,830	2,240

Source: CIMMYT

result of commercial varieties that have been developed by national programs from CIMMYT materials and released to farmers since 1968. Of the 32 nations that have released triticale varieties, 11 are developing countries, and it is in their more marginal areas that the new crop is beginning to find a valuable niche.

In its early years, the CIMMYT work on triticale, done in collaboration with the University of Manitoba in Canada, used sites in both Mexico and Canada to advance two breeding generations each year and benefitted from the spontaneous outcross of a triticale with an unknown Mexican semi-dwarf breadwheat, which came to be called Armadillo. Its good agronomic traits proved to be highly heritable, and by 1970, most CIMMYT triticales had Armadillo in their pedigrees and Armadillo materials were distributed to breeders around the world. (Armadillo was later found to be a substitution of the 2D chromosome from breadwheat for the 2R chromosome of rye. Triticales having D chromosomes are called substituted types and triticales having all seven R chromosomes are termed complete types.) Theoretically, the genetic constitution of triticale provides a built-in potential for adaptation to a wider range of soil and water conditions than other small grain crops. The International Triticale Yield Nurseries have been distributed continuously since 1969 and currently are grown in 71 countries at 115 locations. An analysis of the international nursery results in 1982 and 1983 across agroclimatic and edaphic conditions shows that triticales are comparable to breadwheats in favorable environments—the irrigated subtropics and the Mediterranean region—and superior in dryland conditions, in the tropical highlands, and on acid soils (Fig. 4.1). Since

Fig. 4.1. Relative yield performance of triticales under differing agroclimatic conditions.[a]



Source: CIMMYT/14th ITYN data 1982-83.

[a]Compared to the average of all 60 reporting locations and the long-term check varieties (1982-83).

rye has high tolerance of acid soils, it is probably the source of triticale's generally superior performance in such soils. In one experiment, 10 of CIMMYT's best triticales were compared to 10 CIMMYT breadwheats most tolerant of acid soils, and the least productive triticale yielded more than the best-performing breadwheat.

Although CIMMYT's triticale program commits some resources to breeding for optimal crop production environments where an alternative to breadwheat or durum wheat might be needed, the outstanding performance of triticale in difficult environments has prompted the program to place emphasis on geographical areas where wheat is not a real competitor.

Bean varieties take hold in Latin America and Africa

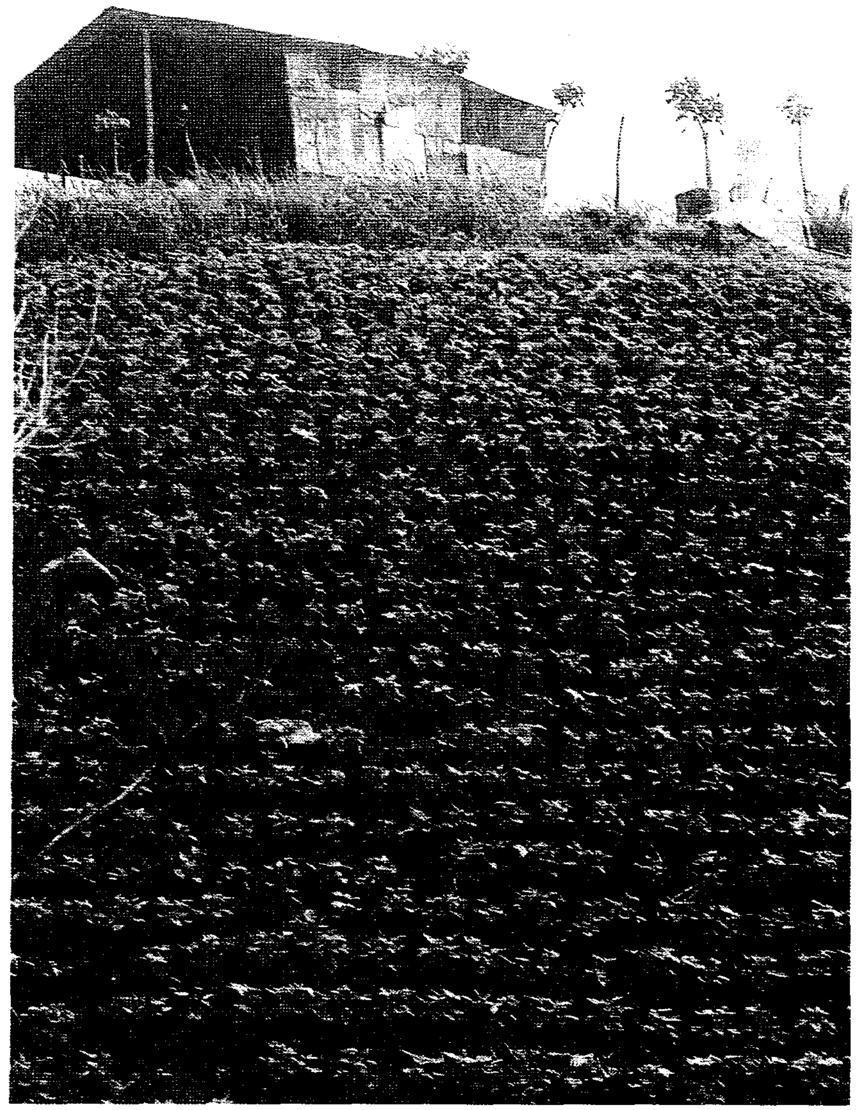
Growing beans is the major means of support for an estimated 5 million people in Latin America and Africa. For many more families, beans are an important part of their cropping system and diet. In parts of central Africa, for example, bean consumption reaches 50 kilograms per person yearly, and contributes as much as a third of total proteins in the diet. At CIAT, the adoption of improved bean varieties is monitored through farm surveys that also allow scientists to identify persisting production constraints that may warrant further research or a modification of selection procedures. By 1986, national programs in Latin America had released over 100 new bean varieties derived from CIAT germplasm. Studies have been undertaken in five Latin American countries reporting widespread adoption. Table 4.2 includes an estimate of the additional production due to the new varieties.

From 1975 to 1983, bean production in Costa Rica was stagnant, ranging between 11,000 and 16,000 tons a year. Then, starting in 1984, Costa Rica enjoyed three successive record bean harvests, and from 1985 it has had no bean imports, although it had been importing about half its bean requirements for more than a decade.

In southern Costa Rica, the availability of new varieties and viable, more intensive, management practices has provided incentives for farmers to move away from the traditional shifting cultivation in which beans are broadcast and no inputs are purchased. The new technology is significantly more labor-intensive than the old one and therefore

Table 4.2. Documented impact of improved bean varieties from CIAT germplasm network, 1986.

Country	Area in improved varieties (ha)	Percent area in improved varieties	Production increase due to new varieties (tons)
Argentina	90,000	40	26,300
Costa Rica	21,700	62	5,300
Cuba	16,900	80	7,100
Guatemala	12,300	13	4,100
Nicaragua	14,000	17	3,500
Total	154,900	43	46,300



In Costa Rica, improved varieties and management techniques for the common bean *(Phaseolus vulgaris)* have bolstered production, particularly for small farmers.

suited to farmers with plentiful labor, but limited land. Small farmers, those with fewer than 10 hectares, were found most likely to couple the new varieties with more intensive management, weed control, and application of farm chemicals. The new planting system spread rapidly throughout Costa Rica. The potential benefits from better varieties and more intensive management have encouraged land-use methods to evolve in response to the increasing population pressures placed upon the traditional system.

CIAT's bean program in central Africa is much newer than the Latin American one. Its studies on Africa are therefore still concentrating on identifying farmer and consumer preferences in beans. Table 4.3 shows varieties grown in on-farm trials in Rwanda as ranked by yield and by farmers' evaluation. The differences are striking and emphasize the importance of the identification of varietal types attractive to farmers and consumers alike. Farmers downgraded the highest-yielding variety, Ikinimba, because of its sprawling plant type, which makes weeding difficult. Farmers also felt that its tendency to lie on the ground would affect grain quality by increasing the danger of rotting, and they noted that the variety was difficult to thresh.

In Rwanda, preferences by farmers and consumers for bean varieties differ from yields realized.

Table 4.3. Comparison of bean yield data and farmers' varietal preferences in Rwanda.

Variety	Yield (t/ha)	Yield rank	Farmers' preference ranking
Ikinimba	1.65	1	7
A 197	1.22	2	4
ISAR mixture	1.22	3	6
Kirundo	1.07	4	3
Kilyumukwe	1.05	5	1
Local mixture	1.05	6	3
Rubona 5	1.04	7	5
Umutikili	1.02	8	2

Source: CIAT

Fig. 4.2. ISNAR's involvement with research systems in 32 countries, 1981-86.

Type of study by country / Year	Overall system review (performance potential, structure and organization and sometimes policy environment).	Institutional review (internal management and linkages with operating environment).	Human resources study (personnel management including recruiting, compensation, performance, and sometimes training).	Research strategy and plan development: giving a new sense of direction.
1981	• Costa Rica • Kenya	• Indonesia		
1982	• Burkina Faso • Fiji • Guyana • Ivory Coast • Malawi • Papua New Guinea	• Rwanda		• Pakistan • Solomon Islands
1983	• Dominican Republic • Somalia • Sri Lanka	• Madagascar	• Cameroon • Sudan • Thailand • Zimbabwe	• Western Somoa
1984	• Zaire	• Morocco	• Bangladesh • Jordan	• Kenya
1985	• The Gambia • Panama • Tunisia		• Argentina • Colombia	• Fiji • Sri Lanka
1986	• Niger	• Costa Rica • Ethiopia • Zimbabwe		

Changing institutions

ISNAR's role in the development of the national agricultural research systems shares an important characteristic with the development of improved germplasm—the pay-off is not immediate. Changing policies, processes, and attitudes requires a no less patient and painstaking approach than plant breeding. Fig. 4.2 outlines the nature of ISNAR's involvement in diagnostic reviews with 32 countries since its founding in 1980 and indicates countries in which reviews have been followed up by direct ISNAR assistance in the development of research strategy and planning. The impact of the earlier collaborations between ISNAR and national agricultural research systems is only now becoming evident.

Coincidentally with CIAT's work on the introduction of new bean varieties, in Costa Rica, ISNAR was involved in helping to develop a more efficient national research organization in the country. ISNAR had undertaken a review in Costa Rica in 1981, but there was little apparent reaction to its review report for several years. In 1986, Costa Rica invited ISNAR to conduct a second review, and in planning for the review, the Ministry of Agriculture and Livestock documented actions, begun in 1985, that stemmed from the 1981 report (Box 4.3).

Box 4.3. ISNAR: Recommendation and response in Costa Rica to a diagnostic review.

In 1981, an ISNAR review team made the following recommendations to the government of Costa Rica to improve its agricultural research system:

- Decentralize administrative procedures.
- Improve the integration of research and extension activities.
- Strengthen regional research efforts through the formation of multidisciplinary research teams at that level.
- Improve the process of priority-setting, planning, and programming.
- Strengthen the national agricultural research system by providing additional funds for operating expenses, increases in the quantity and quality of professional staff, establishment of a new, if modest, center for laboratory work.

The planning document prepared for a second review in 1986, which was undertaken at that time. Costa Rica, in turn, listed the steps taken (often through Executive Decree) in response to ISNAR's recommendations.

- Administrative decentralization of ministry activities, including the shifting of research staff from central headquarters to the regions, to decrease bureaucratic delays and bring the management of ministry services closer to the community.
- Integration of research and extension staff into multidisciplinary research and extension teams at the regional level to improve research problem identification, programming, technology verification, and validation on farmers' fields.
- Creation of a planning and programming unit in the Ministry of Agriculture and Livestock with a director reporting to the minister and vice minister. Staff members of the unit are assigned to all regions.
- Strengthening of the resources available for research and extension by enlarging the research staff (by 45 persons) and the extension staff (by 49 persons) and raising staff quality by offering 13 master's degree and 3 Ph.D. scholarship grants; building a new central laboratory; establishing computer terminals and a database at regional centers; and increasing the availability of vehicles and technology for regional and off-station research and extension activities.

Developing regional cooperation

Among CGIAR centers, ISNAR is solely concerned with assisting national agricultural research systems to build managerial capacity, although most other centers contribute to the improvement of research organization at the national and regional levels. Through its potato program in Burundi, for example, CIP is gradually developing regional cooperation in potato research in eastern Africa.

In 1979, the government of Burundi organized a national program for potato improvement with financial aid from Belgium, under the auspices of the Institut des Sciences Agronomiques du Burundi (ISABU). After the necessary infrastructure was established, the program was reinforced in 1983 by the addition of a CIP scientist, also funded by Belgium.

The program's principal objectives are to identify better-adapted cultivars and to ensure their multiplication and diffusion in adequate quantities. At the same time, the necessary agronomic and storage techniques are to be developed to exploit the varietal potential. The varietal improvement program is based on the evaluation in Burundi of improved tubers produced at CIP headquarters in Peru. Clones showing moderate late-blight resistance and other suitable agronomic characteristics, such as earliness, are put through a series of on-station trials, followed by multilocational trials throughout the country, ranging in altitude from 1,260 to 2,250 meters. Trials are conducted, as much as possible, under conditions found in farmers' fields.

The program also evaluates some varieties or clones at an advanced stage of selection from CIP, as well as from sources in other developing countries, including Kenya, the Philippines, and Rwanda. Such material, particularly from neighboring countries like Rwanda that have similar agroecological conditions, has helped the program to move immediately into the later stages of evaluation and to begin multiplication. Reciprocally, adapted material identified by the program is now being freely exchanged with neighboring countries.

The final stage of the varietal evaluation program consists of a series of on-farm trials, which follow procedures developed by CIP. In these trials, the program tests the suitability of advanced clones for farmers' conditions and, perhaps equally important, gathers information from farmers on production constraints and characteristics desired.

In 1983, a survey of the potato multiplication centers showed that almost all sites were unsuited to producing clean seed pototoes, primarily because bacterial wilt, root-knot nematodes, and powdery scab were present. Since no ideal site was found, the program decided to enlarge a small center at Mwokora, an isolated area in the north (2,300 meters elevation). This center has become the focal point for multiplying and diffusing quantities of high-quality seed tubers to other agricultural development projects, which in turn further multiply the seed before passing it to other smaller projects or "farmer-multipliers."

The farm at Mwokora has also proved successful for testing and demonstrating cultural techniques with application to many crops and regions throughout the country. Most of the farm is situated on steeply sloping land in an area where rainfall is high (1,800 millimeters a year) and often intense. The soils are acid (pH 3.9-4.1), have over 45 percent silt and clay, and are suitable for cultivation only because the organic matter content is above 20 percent. The need for careful soil management of these delicate soils gave the program an opportunity to demonstrate conservation methods applicable to a high-rainfall area.

A 2-1/2 year rotation has been established in which potatoes are grown only once during the five cropping seasons. In the other seasons, maintaining the level of organic matter in the soil by using green manure crops is emphasized. As an additional way to maintain soil fertility on the farm, beef cattle have been introduced to produce manure. Although animals are traditional in Burundi agriculture, the long dry season results in considerable weight losses if stored feed is not available. The program has demonstrated that it is possible to produce cheap fodder throughout the dry season by introducing various fodder crops, particularly swedes and kales, new to the Central African region. Trials to study the effect of farmyard manure on potato yields indicate that responses of up to 10 tons per hectare may be expected on the poorer soils—a significant boost to the seed potato multiplication scheme.

Box 4.4. Strengthening regional cooperation: the Central African potato network.

In the early stages of its development, the Burundi national potato program received considerable assistance from a similar project operating in neighboring Rwanda. This help came particularly in the form of advanced germplasm that had already undergone initial evaluation under similar conditions in Rwanda. As the Burundi program developed, it focused on bacterial-wilt control and storage problems. In these two areas, the program now has more experience and technologies than the national programs in neighboring countries. Consequently, the flow of ideas and material is now undergoing a reverse process, with new concepts in storage technology and advanced germplasm from Burundi being tested in Rwanda. To strengthen this cooperation, CIP and the national potato programs of Burundi, Rwanda, and Zaire in 1982 established a country network, PRAPAC. Within PRAPAC, which the U.S. Agency for International Development supported for its initial five years, each country concentrates its limited resources in those spheres for which it has a comparative advantage. Through regular meetings, the country representatives exchange ideas and genetic material with the other participating countries.

Masai pastoralists in Kenya are benefitting from deregulation of beef prices.

The generation of new ideas and the production of seed alone do not ensure the future of a crop; thus the program regards training of its own staff and the extension and research staff from other national agricultural development projects as an important task. Regular training courses in both French and Kirundi are given by the program staff with support from ISABU staff, agricultural workers from neighboring countries, and CIP staff from Peru or its regional headquarters in Nairobi.

Price controls

A recent example of the impact of policy-related research is ILCA's work on meat pricing, in collaboration with the Ministry of Livestock Development in Kenya. The program also helped institutionalize the collection of market information to allow for more informed pricing decisions. Prices of basic commodities in Kenya have long been controlled by the government. Meat prices have been among the lowest in the world (retail prices were less than US$1.50 per kilogram in 1986). In 1982, ILCA economists reported that the low meat prices were discouraging livestock production, and they suggested that the government could not effectively set meat prices in the absence of systematic information on market prices, supply and demand, and production and marketing costs. They recommended a low-cost method of collecting such market information. In 1986, for the first time, the government set prices for beef above those for mutton and goat meat.

ILCA's analysis of production and marketing information revealed a decade-long deterioration in the prices of animals sold by pastoral producers relative to the costs of resources needed to produce them.

The important policy and institutional constraints were found to be low producer prices for cattle, an underdeveloped market for sheep and goats, and the ineffectiveness of group ranch management. The ILCA research emphasized that the pastoralists suffered from a declining resource base in the face of rapid population growth, which was exacerbated by the government policy of keeping beef prices low for urban consumers. The study estimated that beef prices would have to rise 25 percent to maintain parity for the pastoralists.

Consequently, the ministry reassessed the price-fixing process and decided to eliminate it, leaving prices to be determined by supply and demand. ILCA is evaluating the impact of the deregulation by monitoring livestock prices received by Masai pastoralists at Emali, a major regional livestock market. So far, producers' prices have risen 30 percent due to deregulation.

The commodity centers working with national programs have a comparative advantage in this type of policy research, which depends on an intimate knowledge of their product in a particular local environment. The contribution to the policy-making process, in this case, the

Box 4.5. Incomes to Masai pastoralists from livestock production.

For Masai pastoralists, livestock provide the main means of subsistence by supplying milk and meat for consumption and sales throughout the year. The proceeds of sales are used to purchase both food and non-food items. The average annual gross output of the Masai livestock production system from 1981 to 1983 was estimated to be 3,800 kilograms of milk and 7,100 kilograms of meat per household. Net output was worth about US$2,715 per household and US$270 per person. This corresponds to US$7.40 per hectare or US$19.90 per tropical livestock unit (250 kilograms liveweight). The net output of large producers was worth US$5,370 per household or US$370 per person, while that of small producers was valued at US$1,290 per household or US$160 per person. These levels of output, however, are attainable only during good years (such as those of the study period) when the livestock population is high. Net output of the system becomes negative during drought periods, when large numbers of livestock perish.

low-cost approach to the collection of livestock market information, is a permanent contribution to national decision-making. The immediate and observed impact is an increase in meat prices to producers. Over the medium term, producers would be stimulated by the higher prices to sell more animals. In the pastoralist system of the Masai, if this happens, it will have a favorable impact on resource conservation by reducing the stocking rates and the pressures on grass and soils. These later steps in the impact chain are much more difficult to monitor, particularly when the effects of the price increase are confounded with many other factors in a constantly changing production environment.

It is impractical for the national systems and the CGIAR centers to continue to monitor in detail the widening impact of all the technologies they produce. It is, however, important that where macroeconomic effects are significant—self-sufficiency in rice in Southeast Asia and the need for diversification into other crop and livestock enterprises may be such a case—that the global agricultural research system is tuned to pick up such a shift and change research priorities.

5. Key CGIAR events

The dominant theme of the CGIAR since mid-1986 has been elaboration of strategy in many fields. At its Ottawa meeting in May 1986, the CGIAR endorsed most elements of the research strategy proposed by TAC. It also approved the concept that setting priorities and deciding on strategies is not a periodic matter that can be done and set aside for a number of years. It is, rather, a continuing process in which new questions are raised as a result of fresh appraisals of experience, changed circumstances in the developing world, or opportunities opened by scientific discovery. As a consequence, the Group gave TAC a number of immediate questions for further strategic investigation.

Shortly after the Ottawa meeting, TAC organized several subcommittees to help deal with its large agenda.

- One subcommittee is exploring the global role of the CGIAR, that is, the relations of the centers among themselves, with other public and private research institutions wherever located, and with the national agricultural research systems of developing countries.
- A second is considering the overarching issues of sustainability of agricultural production systems, an area of urgent concern to the centers, but which still requires a carefully designed research agenda as well as identification of practical institutional steps.
- A third deals with the processes by which TAC monitors the implementation of CGIAR priorities and draws together the diverse product of continuing strategic analyses into a coherent whole.

Box 5.1. Meetings in 1986 through May 1987.

CGIAR: May 19-23, 1986, Ottawa, Canada
November 3-7, 1986, Washington, D.C., United States
May 18-22, 1987, Montpellier, France

TAC: 40th Meeting, June 22-July 2, 1986, Cali, Colombia
41st Meeting, October 29-November 1, 1986, Washington, D.C., United States
42nd Meeting, March 16-24, 1987, Rome, Italy

Board Chairs: March 18-20, 1986, Rome, Italy
October 31-November 1, 1986, Washington, D.C., United States
March 19-20, 1987, Rome, Italy

Center Directors: June 23-27, 1986, Cali, Colombia
October 28-November 1, 1986, Washington, D.C., United States

Other aspects of TAC's work continue outside the subcommittee structure, including a proposal for bringing aquaculture research into the CGIAR and a similar proposal related to vegetables. TAC and the center directors are collaborating in the preparation of an overall policy for CGIAR involvement in the collection, preservation, evaluation, and utilization of plant genetic resources.

The CGIAR secretariat is TAC's partner in the development of a new approach to the review process within the CGIAR. This work benefitted from Vernon Ruttan's study of the existing system, which was discussed at length at the Group's mid-term meeting in 1987. The Group strongly supported the study's contention that future reviews of center performance should give major consideration to the validity and quality of center research strategies.

The issue of strategy is also at the heart of a new resource allocation process approved by the Group at the May meeting. In light of each center's strategy and results of external program and management reviews, TAC will undertake an overall look at the program of each center and then recommend its essential programs/activities for Group approval for a five-year period. Such center programs/activities will not be subject to further review until the end of the five years unless circumstances change significantly. TAC will also recommend other desirable activities for funding, which may be subject to more frequent review.

One purpose of the new resource allocation system, which will be applied for the first time to three centers in 1987, is to ensure that center programs are congruent with system priorities. Others are to reduce both the detailed attention TAC must give to the annual budget exercise and the burden placed on centers in preparing for that exercise and to enable TAC to identify funding requirements for center programs over a five-year period, thus giving donors a sense of overall direction and requirements as a basis for planning. The new procedure does not imply that donors will be asked to make firm funding commitments for five years. A request for such commitments would cause both constitutional and practical difficulties for many donor members of the Group.

External reviews

An external review of ILCA was completed and considered by the Group. Continued attention was given to WARDA and IBPGR, following up on earlier reviews.

ILCA. The external program review of ILCA, which was considered along with the management review at International Centers' Week 1986, found much progress had been made in resolving problems identified in the first such review, five years earlier. The review team also found that the basis had been laid for an effective program dealing with livestock systems in Africa, but that the program should be better focused. Acting on the recommendation of TAC, the Group asked ILCA to prepare such a program strategy for consideration, with TAC recommendations at International Centers' Week 1987.

The management review of ILCA likewise found significant improvement in the support base and management infrastructure, but recommended further improvement in the mechanisms for program delivery, particularly the process for establishing and implementing center strategy. The review closely examined the role of the center board. This emphasis was a change from previous reviews and was commended during the Group's discussion of the report. Although the team praised much of the board's work, it was critical of performance in providing leadership to management, specifically in the area of developing research strategy. The center made a positive response to the suggestions of the review, and the CGIAR secretariat was asked to monitor the implementation of the various suggestions and keep the Group informed.

WARDA. A remarkable transformation in the situation of WARDA occurred during the year covered by this report. In May 1986, the Group concluded that CGIAR support could not continue without major changes in the form of governance of WARDA's research program. At the request of CGIAR chairman S. Shahid Husain, a negotiating mission was undertaken by Moise Mensah, assistant president of the International Fund for Agricultural Development (IFAD), under the auspices of the International Development Research Centre. It laid the groundwork for decisions by WARDA's member governments to transform their organization into a research center controlled by a board with powers comparable to those of boards of other CGIAR centers.

With the diplomatic leadership of Minister I.F. Sagna of Senegal, chair of the WARDA council, the new board was appointed, half from West Africa and half chosen by the CGIAR from the rest of the world. Sufficient funds were received from member states to liquidate WARDA's overhanging debt. Several donors gave strong support by providing funds to meet costs during the transition period; at the same time, staff and other expenses were reduced sharply. Meeting in June 1987, the board chose Eugene Terry, of Sierra Leone, as WARDA's first director general, and he was confirmed by the council of ministers. A strategy for rice research in West Africa is under preparation, and the board is seeking funds for the construction of a main research station at a location to be determined.

IBPGR. For IBPGR, major progress was made in settling longstanding management issues through an agreement signed in December 1986 by the deputy director general of FAO, Declan Walton, and the board

Box 5.2. New publications about the CGIAR and its work.

Gene Banks and the World's Food (Princeton University Press, 1987) by Donald L. Plucknett, Nigel J.H. Smith, J.T. Williams, and N.M. Anishetty —each affiliated with the CGIAR secretariat or IBPGR—examines the worldwide effort to collect, preserve, and use plant genetic resources for improved agricultural production. Covering the history of germplasm preservation from early plant collectors through the era of cytopreservation, the authors emphasize the importance of access by farmers and plant breeders to the widest possible array of germplasm.

Partners Against Hunger (World Bank, 1986) by Warren Baum, former CGIAR chairman, was officially released at International Centers' Week in 1986. Described by reviewers as the first authoritative history of the CGIAR, it explains how the CGIAR has forged a partnership of scientists and aid administrators from industrialized and developing countries, assesses the impact of the CGIAR on agricultural development, and considers the potential for replicating the CGIAR experience in other fields of development.

chairman of IBPGR, W.J. Peacock. The agreement resolves issues identified in the external review of the center, including a system for hiring of scientific personnel at appropriate grades, provision of adequate office space, and the responsibility of IBPGR staff to the board. The agreement provides a framework for IBPGR to operate within FAO, as desired by all parties, through 1988. Before the agreement expires, its implementation will be appraised to determine whether it works and whether it should be extended with or without changes.

Changing relationships with national systems

The centers collaborate with national agricultural research systems that are at various stages of evolution. The pace at which national systems could assume responsibility for types of research and training done by the centers has been debated for a number of years. The discussion gains urgency as the rapid pace of change in biological science puts pressure on the centers to shift part of their limited resources to the application of new scientific tools to developing-country problems.

In January 1987, CIMMYT and IRRI staff participated in a forum arranged by IFAD, in collaboration with several other donor organizations, on the prospect and willingness of several developing-country national agricultural research systems involved in rice and wheat research to assume more prominent roles in global research on those crops. As reported at the Group's meeting in May, the results were positive: while the first concern of national systems obviously is to respond to national priorities, there are opportunities for expanded collaborative research, particularly in ecologies different from those at the centers, and in training.

Recognizing that much more exploratory work needed to be done, the Group urged TAC and the centers to follow up on this initiative and include specific proposals in their programs in the near future. One early step will be getting the views of the national systems whose needs would be potentially served in part through the collaboration of other national systems.

Collaboration among centers

A characteristic of center activities in recent years has been increased collaborative work both among centers and with other scientific institutions. The need for centers to work together in Africa was recognized early in 1986 as being particularly critical and a task force was created, including TAC and donor representatives, as well as leaders of national systems in Africa. The task force has since met several times under its chair, TAC chairman Guy Camus. It works closely with a subcommittee of center directors that has a parallel purpose.

The task force and the centers have identified three initiatives which they are pursuing:

- Mounting a program dealing with maize-based cropping systems in the mid-altitude regions of southern Africa (in collaboration with the Southern African Centre for Cooperation in Agricultural Research (SACCAR);
- Determining how—in a to-be-designated African country—the need for external assistance in agricultural research can best be met from the CGIAR and other sources; and
- Studying the existing research programs on cassava and maize in West African countries and identifying further needs.

Centers are compiling an inventory of their activities throughout Africa (through ISNAR) and are preparing a research strategy for Africa (through IFPRI).

Collaboration among centers was also manifested in numerous other ways, among them:

- A meeting in Kenya at the International Centre for Research on Agroforestry in September 1986 concerned with agroforestry research and involving ICRISAT, IITA and ILCA. Participants identified a number of potential areas for collaboration.
- A series of meetings between center experts in plant genetic resources and TAC to work out an overall appraisal and policy statement for the Group.

- A meeting of representatives of national agricultural research systems from Latin America at CIAT in August 1986 to discuss research priorities and practical lines of collaboration in the region (with representatives of CIMMYT, CIP, ICRISAT, and ISNAR).
- Creation of inter-center committees on public relations and on information and communication, both of which are working on strategies and programs for joint action.

Scientists and institutions in industrialized countries

Collaboration with European scientific institutions was a particularly appropriate topic for special attention at the Group's 1987 mid-term meeting at Montpellier, France, the center of French research on problems of the tropical world. The preliminaries of this meeting offered many opportunities to appreciate the work being done by French institutions involved in tropical agriculture. At the meeting, the results of a two-year study on existing and planned scientific collaboration between CGIAR centers and European institutions were presented. Conducted by Rudolf Binsack, on secondment to the CGIAR secretariat from the Gesellschaft für Technische Zusammenarbeit (GTZ) of the Federal Republic of Germany, the study indicated a high level of present collaboration and future needs that are substantial in both range and volume. Also at the meeting, representatives of countries in other regions called attention to similar types of cooperation with institutions elsewhere and to possibilities of enhancing such relationships to the benefit of CGIAR programs. At the same time, questions were raised about modes of financing, particularly contributions that are restricted to expenditure through host-country institutions. The Group agreed that the principal test of such collaboration should be the value to center research, and that the centers should be the initiators, lest they be overwhelmed with offers of collaboration.

Personnel changes

At the May 1987 meeting, CGIAR chairman Husain announced that because of a reorganization in the World Bank, he would be shifting to regional duties and would no longer be able to serve as chair of the CGIAR. The Group responded to the news with surprise and regret. A resolution of gratitude to Mr. Husain for his contribution over the past three years was signed by all present. The chair of the Group is being assumed by W. David Hopper, newly appointed senior vice president of the World Bank for policy, planning and research. This step will assure continuity of leadership pending consultations about the Group's needs from its chairman and the process of filling the position.

A change in leadership occurred at ILCA in November 1986. Peter Brumby resigned as director general and was replaced by John Walsh.

Box 5.3. Prizes and honors.

IITA was awarded the 1986 CGIAR King Baudouin Award for its work with maize streak, one of the principal cereal diseases in tropical Africa (see CGIAR *Annual Report, 1985*.) The award is presented every other year to one of the CGIAR centers for a particular technology that improves the welfare of farmers in developing countries. Streak-resistant varieties and hybrids are being grown or multiplied in Benin, Ghana, Nigeria, Tanzania, Togo, and Zambia. By 1990, the Nigerian government expects that approximately 2 million hectares of maize will be seeded with streak-resistant varieties—nearly all of the maize grown by Nigerian farmers.

IITA's achievement was based on the development of simple ways to identify resistant plants; the evolution of research methodologies that helped scientists to understand the virus and its vector, the leafhopper *Cicadulina* spp; and the cooperation of national programs and other international centers, principally CIMMYT. Studies show that the resistance in the IITA lines is multigenic and is thus less likely to break down than lines containing only a single source of resistance. The significant reduction in the incidence of the disease is expected to lead to greater stability of maize yields, encouraging farmers to use more inputs, thus increasing total maize production.

Also in 1986, several CGIAR staff and managers received international awards for their work. Among them:

Randolph Barker and **Robert W. Herdt** with **Beth Rose,** received the American Agricultural Economics Association's 1986 Award for "superior achievement as exemplified by quality of communication" for the book, *The Rice Economy of Asia* (Resources for the Future/ IRRI, 1986). Barker and Herdt are former IRRI staff members. Herdt subsequently served as a CGIAR secretariat scientific advisor and is currently with the Rockefeller Foundation.

Henry M. Beachell and **Gurdev S. Khush** were awarded the 1987 Japan Prize, the nation's top scientific award. Beachell, the former head of plant breeding at IRRI, and Khush, the current leader, were cited for their roles in the development of the semi-dwarf rice varieties that launched the Green Revolution in rice farming. They were the first agriculturists to receive the award. The prize was awarded to Beachell and Khush in April 1987 in the presence of Crown Prince Akihito and Princess Michiko.

Former IRRI director **Robert F. Chandler** received the U.S. Presidential End Hunger Award in Washington in October 1986. The award citation notes Chandler's "continued, demonstrated vision, initiative, and leadership in the effort to achieve a world without hunger."

ILRAD senior scientist **H. Hirumi** received the 30th annual Noguchi Prize for Medical Research in Tokyo in November 1986. Hirumi is a member of the team of scientists responsible for one of ILRAD's major research achievements—the development of techniques to grow trypanosomes in the laboratory.

King Carl Gustaf of Sweden presented the International Inventors Award in June 1986 to IRRI's **Amir U. Khan** for the development of the axial flow thresher, a machine that processes high-moisture paddy rice and reduces threshing losses. Versions of the thresher are presently manufactured in eight countries.

John W. Mellor, along with **Bruce F. Johnston,** received the American Agricultural Economics Association's 1986 Award for a "publication of enduring quality" for "The Role of Agriculture in Economic Development" which appeared in *The American Economic Review* in 1961. Mellor, director of IFPRI, also was the first social scientist to be awarded Finland's Wilhuri International Prize. He was cited for having "...furthered and developed the cultural and economic progress of mankind."

IRRI director general **M.S. Swaminathan** received the World Cultural Council's Albert Einstein Award in November 1986 in Guadalajara, Mexico, for his "outstanding contribution to scientific research and the application of science to human welfare." Swaminathan also was one of five people to receive the 1986 Krishni Ratna Awards from the India's Farmers Welfare Trust Society. The awards, which were presented by India's president, Giani Zail Singh, are conferred to people "devoted to the welfare of the Indian farming community."

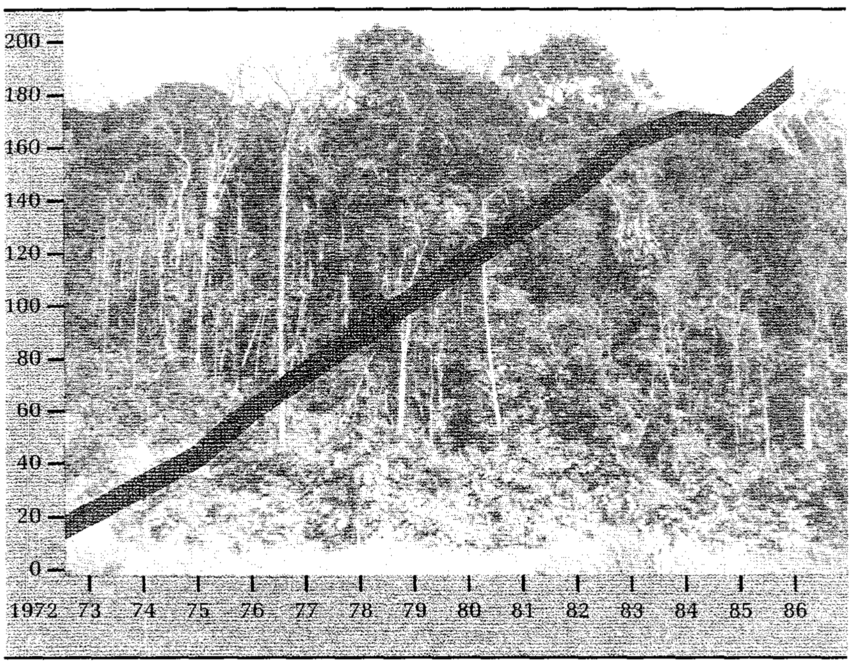
6. The financial situation

Contributions to the CGIAR in 1986 increased by US$26 million, including US$22 million in core contributions and nearly US$4 million for special projects. Total funding amounted to US$235.5 million, or 12 percent more than in 1985. However, only about one-third of the increase was the result of higher donor pledges. About two-thirds of the growth in core contributions resulted from the weakening of the U.S. dollar relative to other currencies, and the system thus realized the effect of increases in non-dollar pledges which had occurred in previous years.

One new donor, Austria, joined the group in 1986 and another donor, the African Development Bank, renewed its contributions, bringing the total number of donor members in 1986 to 39.

Actual core funding in 1986 was US$192.2 million, US$7 million more than estimated at International Centers' Week in late 1985, an increase that was also mainly due to weakening of the U.S. dollar. After a net set-aside of US$3.8 million for the stabilization fund, the amount available from donor contributions to the centers' core programs was US$189.4 million (Table 6.1).

Fig. 6.1. CGIAR core funding, 1972-86 (US$million).



At the start of 1987, based on firm commitments from donors and informal estimates, the CGIAR secretariat projected that core contributions would be US$191 million. This amount would finance about 97 percent of most centers' programs (provided that the World Bank does not set aside its normal contribution of up to US$5 million in the stabilization fund), which were appproved for funding at an aggregate level of US$196 million. The 1987 core funding estimate reflects a significant decline in U.S. dollar contributions, which is fortunately offset by an increase in the dollar value of non-dollar contributions.

Table 6.1. CGIAR funding, 1982-86 (current US$ million).

	1982	1983	1984	1985	1986
Total donor core funding[a] (stabilization mechanism included)	143.8 —	164.7 [2.3]	173.2 [0.9]	170.2 [4.4]	192.2[e] [3.8]
Total core expended[b]	147.0	163.8	177.9	176.4	189.4
Operations	136.0	150.9	157.9	163.3	175.2
Capital	11.0	12.9	20.0	13.1	14.2
Non-core (special project) donor funding[b]	28.0	23.6	29.8	39.6	43.3
Total non-core expended					
Operations	27.0	23.7	28.5	35.7	41.3
Capital	—	0.2	1.0	3.9	1.2
Total donor funding	171.8	188.3	203.0	209.8	235.5
Percent change from previous year					
in core funding	10	14[c]	5	–2	13
in non-core funding	37	–15[d]	26	32	9
in total funding	13	10	8	3	12

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

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

[c] Including a transfer of about US$9 million from special projects to core. Excluding this transfer, the growth rate in 1983 would have been about 8 percent.

[d] Excluding the transfer of special projects to core. Including this transfer, the growth rate in 1983 would have been about 17 percent.

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

With continuing decline of the U.S. dollar, exchange rate gains are likely to raise 1987 core funding to US$199 million. Special project contributions are projected in the US$40 million-$45 million range, bringing total funding for the year to US$239 million-$244 million.

During the 1986 mid-term meeting in Ottawa, Canada, there was general agreement among CGIAR members that active publicity and promotion are required on behalf of the centers' activities and accomplishments. In this context, national support organizations are being established in Australia, Japan, the United Kingdom and the United States.

Expenditure trends

In 1986, the CGIAR's recent decline in operational expenditures in real terms began to reverse (Table 6.2). After taking into account an inflation rate of 6 percent, expenditures grew 1.3 percent over the 1985 level. Capital expenditures were US$14.2 million, slightly more than US$1 million above 1985. In addition, centers' operating funds increased by about US$6 million, and centers are carrying forward about US$3 million for commitments on capital that were funded but not expended in 1986.

Table 6.2. Center operating expenditures in constant terms, 1982-86.

Center	1982	1983	1984	1985	1986
	[In constant 1986 US$ million]				
CIAT	19.7	23.2	23.1	21.4	21.3
CIMMYT	20.6	21.8	22.7	22.2	21.4
CIP	10.7	11.8	12.0	12.0	12.4
IBPGR	3.8	5.5	4.7	4.6	4.8
ICARDA	16.2	17.9	17.6	17.5	18.0
ICRISAT	16.1	19.9	18.1	19.6	20.6
IFPRI	4.1	4.8	5.0	4.4	4.5
IITA	22.6	20.9	20.3	18.9	17.5
ILCA	11.2	13.3	14.3	13.8	13.7
ILRAD	8.5	10.0	9.6	9.3	9.3
IRRI	24.0	23.7	23.1	22.9	23.6
ISNAR	3.0	4.4	4.2	4.4	4.4
WARDA	3.2	2.8	2.3	2.0	3.7[b]
Total	163.6[a]	180.0	176.9[a]	173.0	175.2
Percent change	6.5	10.0	–1.7	–2.2	1.3
Additional expenditures: [current US$ million]					
Capital	11.1	12.9	20.0	13.1	14.2
Non-core expenditures	27.0	23.9	29.5	39.6	42.5

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

Core operating expenditures in constant dollars remained roughly the same or increased at 11 centers in 1986, but declined at CIMMYT

Figure 6.2. Core expenditures, 1986.

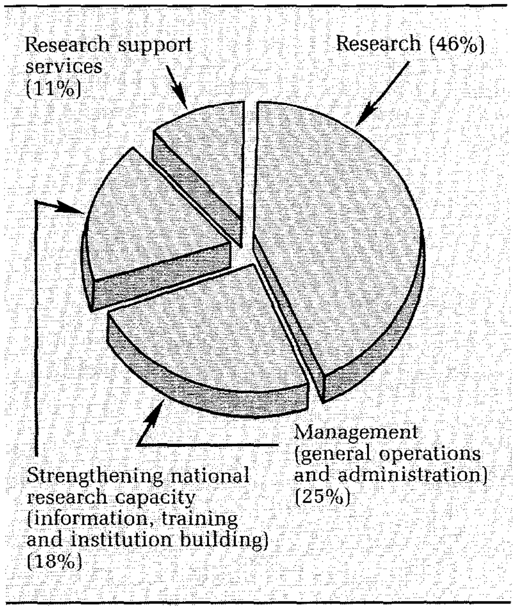
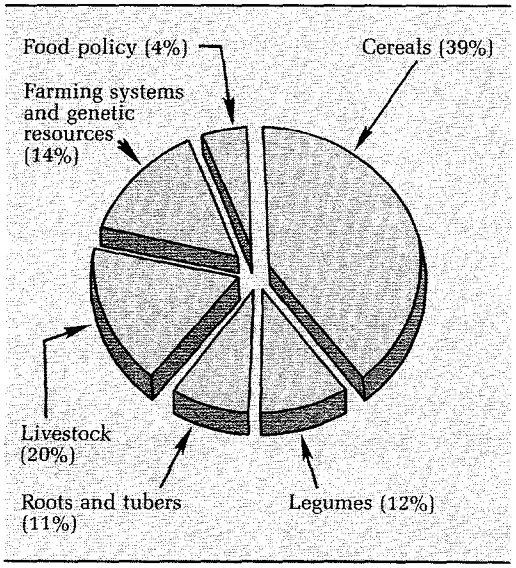


Figure 6.3. Core research expenditures, 1986.



and IITA, due to devaluations of the Mexican peso and Nigerian naira, respectively.

Analysis of the 1986 core operating expenditures by program, commodity/activity, and region indicate consistency in general pattern over the past three years (Tables 6.3–6.5).

Table 6.3. Core expenditures by program (percent), 1984-86.

Program	1984	1985	1986
Research	47	45	46
Research management[a]	26	26	25
Strengthening national research capacity[b]	15	17	18
Research support	12	12	11

[a] Comprises general operations and administration.
[b] Through information, training and institution building.

Table 6.4. Core expenditures by research commodity/activity (percent), 1984-86.

Commodity/activity	1984	1985	1986
Cereals	41	40	39
Legumes	12	10	12
Roots and tubers	10.3	12	11
Livestock	19	20	20
Farming systems and genetic resources	14.3	14	14
Food policy	3.4	4	4
	100	100	100

Table 6.5. Core expenditures by region (percent), 1984-86.

Region	1984	1985	1986[a]
Sub-Saharan Africa	39	39	38
Asia	25	25	25.5
Latin America	23	22	22
North Africa/Middle East	13	14	14.5
	100	100	100

[a] Without an exchange rate gain of US$3.5 million at IITA, due to devaluation of the Nigerian naira, the distribution would have been 40 percent for Africa, 25 percent for Asia, 21 percent for Latin America, and 14 percent for North Africa/Middle East.

Direct research expenditures account for about half of operating expenditures; the balance is divided among research management, strengthening of national research capacity, and research support. The proportion of expenditure on research management and research support declined marginally in 1986, with a matching increase in funds for research and strengthening national research capacities (Fig. 6.2).

Table 6.6. Center core program expenditures, 1982-86.

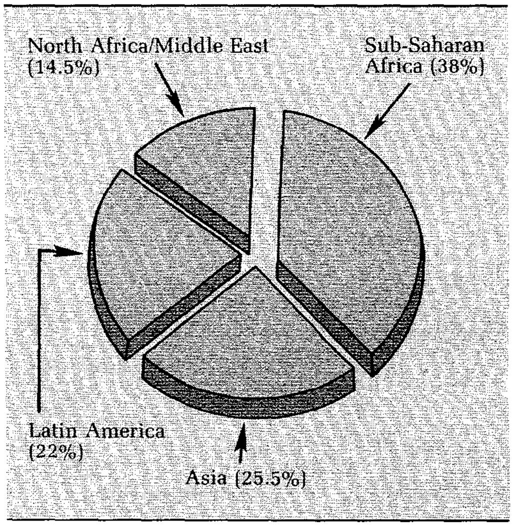
Program/activity	1982	1983	1984	1985	1986	Average annual change (percent) 1982-86
	(In constant 1986 US$ million)					
Research						
Cereals	29.8	33.5	32.2	31.1	31.6	1.5
Legumes	7.9	8.9	9.6	8.7	9.5	4.8
Food policy	2.2	2.9	3.0	3.2	3.0	7.3
Livestock	14.6	15.5	16.1	16.0	15.6	1.7
Farming systems and genetic resources	10.1	11.7	11.6	10.6	11.4	3.1
Roots and tubers	8.6	8.5	8.7	9.1	8.9	1.0
Subtotal	73.1	81.0	81.1	78.7	80.0	2.3
Strengthening national agricultural research	23.3	27.7	28.2	29.4	32.1	8.4
Research support	19.1	21.3	21.6	20.6	19.9	1.1
Research management	48.2	50.0	46.1	44.3	43.2	–2.6
Total operations	163.6[a]	180.0	176.9[a]	173.0	175.3	1.7

[a]Due to rounding.

Table 6.7. Non-core program expenditures, 1984-86.

Program	1984	1985	1986	% of Total
	(In current US$ million)			
Research	15.1	23.0	27.3	66
Strengthening national research capacity	12.9	11.0	12.0	29
Research support	0.4	0.7	0.9	2
Research management	0.1	1.0	1.1	3
Subtotal	28.5	35.7	41.3	100
Capital	1.0	3.9	1.2	
Total	29.5	39.6	42.5	

Figure 6.4. Core expenditures by region, 1986.



Stabilization mechanism

The CGIAR stabilization mechanism was created to guarantee the U.S. dollar exchange rates of donor contributions prevailing on the pledging date at International Centers' Week and to finance extra costs when budgeted assumptions about inflation are exceeded. In 1986, coverage of the mechanism was expanded to include capital costs. The fund was used to compensate for adverse price movements in operating expenditures at CIP, ICARDA and ISNAR and for increased construction costs at ICRISAT's Sahelian center. These increases were due to the weakening of the U.S. dollar relative to the Dutch guilder (ISNAR) and the CFA franc (ICRISAT), and higher-than-budgeted local inflation for CIP and ICARDA.

By contrast, IITA benefitted by US$3.5 million as the result of the Nigerian currency devaluation in October 1986. Normally, a center would pay such a gain into the stabilization fund. In this case, however, the CGIAR secretariat and IITA agreed that the gain should be used to replenish the center's working capital, which had decreased due to extraordinary expenditures in 1985.

The stabilization fund started with a balance of US$6.9 million at end-1985 and rose to US$15.2 million in 1986, following a World Bank contribution of US$7.4 million and interest earned of US$0.8 million. In total, the mechanism paid out US$3.6 million for inflation-related adjustments, resulting in a balance of $11.5 million at end-1986.

The CGIAR secretariat commissioned a study on the optimal size of the stabilization fund by the Financial Policy and Analysis Department of the World Bank. Its report, circulated to members at International Centers' Week 1986, recommended that the fund be maintained at a level of US$10 million-$16 million to cover exchange rate and inflation risks within each calendar year.

Other financial matters

Following discussion of the recommendations of the finance and budget study, an accounting practices manual was prepared and circulated to Group members. An auditing practices manual and financial management handbook have been drafted and are being discussed with centers' managers and boards.

Medium-term resource allocation process

According to the new five-year resource allocation process (see Chapter 5, Key CGIAR events), IFPRI and ISNAR discussed their medium-term proposals at TAC's March 1987 meeting, followed in June by three other centers (CIP, IBPGR, and ILRAD). Medium-term budgets for IFPRI, ILRAD, and ISNAR were recommended for approval to the Group. TAC expects to act on the proposals for the remaining centers in 1987 and 1988.

Annex 1. About the CGIAR.

The Consultative Group on International Agricultural Research (CGIAR) is an informal association of countries, international organizations, and private institutions, cosponsored by the World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP) The three cosponsors brought donors together in 1971 to get the international community to earmark a small proportion of its concessional aid for agriculture in the developing countries to support, on a sustained basis, a well-defined and closely monitored program of research on food commodities CGIAR operates without a formal charter, relying on the consensus deriving from a sense of common purpose

CGIAR started with a nucleus of four existing international agricultural research centers—CIAT, CIMMYT, IITA, and IRRI—established by the Rockefeller and Ford Foundations in Colombia, Mexico, Nigeria, and the Philippines, respectively At the start, there were 15 donors providing about US$20 million. The number of centers has now increased to 13, supported by 39 donor members and other contributors providing about US$235 5 million in funding in 1986

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

The programs of the commodity-oriented centers vary, but common components include genetic resource conservation and classification, biological research to improve yields or incorporate resistance to pests and diseases, farming systems studies to gain an understanding of farm-level constraints, and training and other activities to strengthen national research systems

The CGIAR's objectives may be summarized as follows· "Through international research and related activities, to contribute to increasing sustainable food production in developing countries in such a way that the nutritional level and general economic well-being of the low-income people are improved "

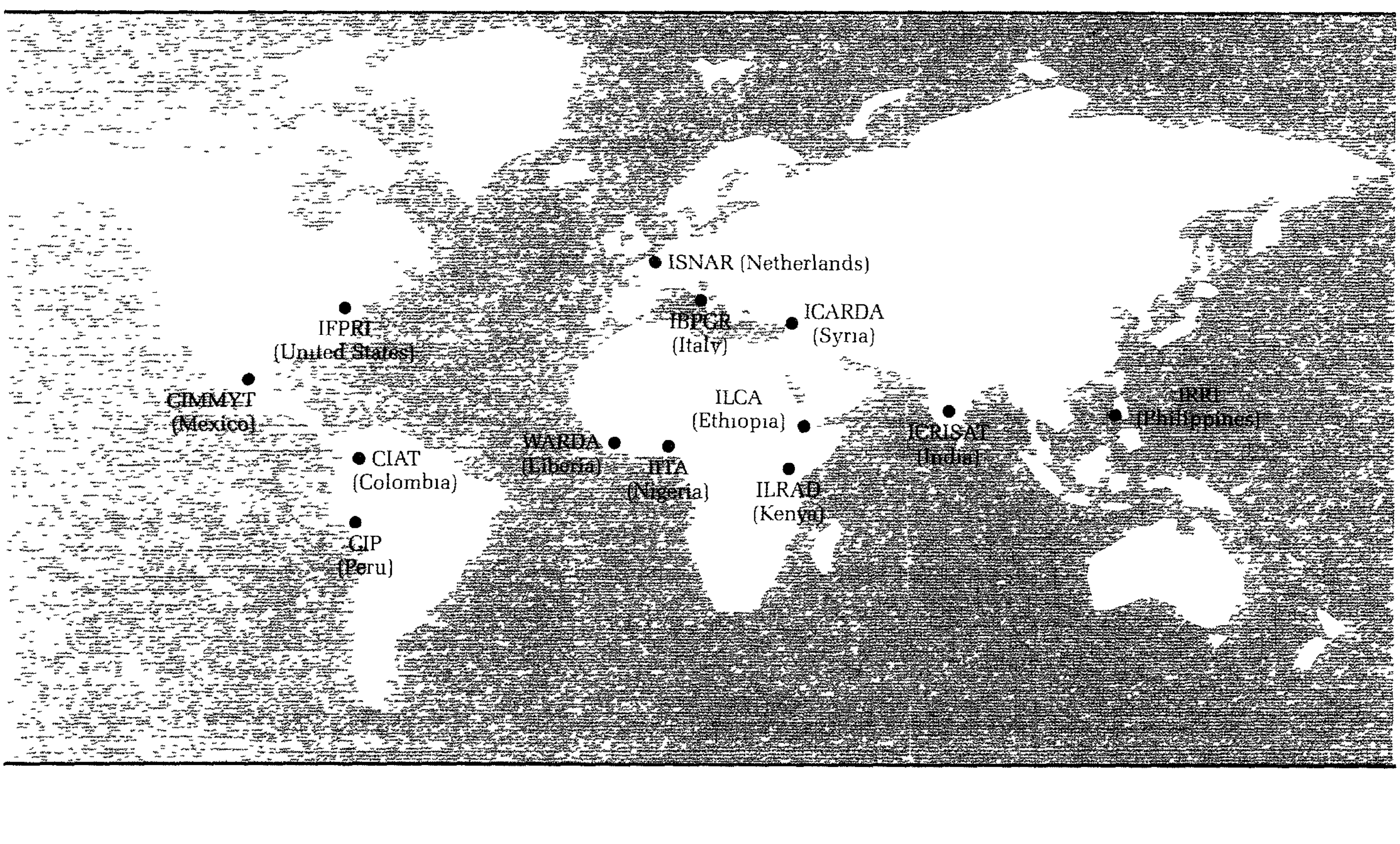
The CGIAR is serviced by an executive secretariat, located in Washington, D C and provided by the World Bank A Technical Advisory Committee (TAC), comprising a chairman and 14 scientists drawn equally from developed and developing countries, makes recommendations on research programs and priorities and monitors performance through annual program and budget reviews and periodic external reviews by independent scientists invited to serve on specially constituted panels TAC is supported by a secretariat, provided by the three cosponsors of CGIAR and located at FAO headquarters in Rome

The CGIAR secretariat coordinates fund raising in support of TAC-recommended work at the centers. In keeping with the concept of accountability to donors, the secretariat assists the centers in maintaining and disseminating scientific and financial information on their work on a comparable basis through reporting systems drawn up in consultation with them The secretariat also provides some common services and overall administrative support

CGIAR meets twice a year, once in Washington, D C in October/November and once elsewhere in May. The meetings receive and discuss recommendations on overall strategy, budgetary needs, and management issues pertaining to the centers as a group Reports from individual centers, as well as independent external evaluations, are presented periodically at these meetings. Present at these twice-yearly meetings are representatives of 10 developing countries, selected by regional conferences of FAO, to represent the developing regions.

The funds provided by donors are not pooled, but go directly to centers according to allocations made for each by individual donors The World Bank uses its contribution to balance the amount each center receives in relation to approved budget levels.

Global location of the 13 CGIAR-supported centers.



Annex 2. CGIAR major crops and activities.

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

Annex 3. CGIAR organization, May 1987.

Continuing members:

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

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

Fixed-term members of developing countries:

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

CGIAR Interim Chairman:

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

CGIAR Executive Secretary:

Curtis Farrar
World Bank
1818 H St , N W
Washington, D C. 20433, United States

Technical Advisory Committee:
TAC Chairman:

Guy Camus
c/o World Bank
66 Avenue d'Iena
75116 Paris, France

TAC Members:

Michael H Arnold
Charan Chantalakhana
C.T de Wit
Ola Heide
Alexander McCalla
Amir Muhammed
Ibrahim Nahal
Thomas R Odhiambo
Ernesto Paterniani
Abdoulaye Sawadogo
Winfried von Urff
E. T York
Tomio Yoshida

TAC Executive Secretary:

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

CGIAR-supported Centers:

CIAT Centro Internacional de Agricultura Tropical
Apartado Aereo 6713
Cali, Colombia

Director General· John L Nickel
Chair: William E. Tossell[1]

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

CIP Centro Internacional de la Papa
Apartado 5969
Lima, Peru
Director General Richard L Sawyer
Chair: John W Meagher

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

ICARDA International Center for Agricultural Research in the Dry Areas
P O Box 5466
Aleppo, Syria
Director General Mohamed A Nour
Acting Director General G. Jan Koopman[3]
Chair. Jose I Cubero

ICRISAT International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O
Andhra Pradesh 502 324, India

ICRISAT Sahelian Center
B P. 12404
Niamey, Niger (via Paris)
Director General. Leslie Swindale
Chair: Fenton V MacHardy

IFPRI International Food Policy Research Institute
1776 Massachusetts Avenue, N W
Washington, D.C , 20036, United States
Director John W Mellor[2]
Chair. Dick de Zeeuw

IITA International Institute of Tropical Agriculture
PMB 5320
Ibadan, Nigeria
Mailing address:
IITA, Ibadan, Nigeria
c/o Ms Maureen Larkin
L W Lambourn & Co.
Carolyn House, 26 Dingwall Road
Croydon CR9 3EE, United Kingdom

Director General Laurence D. Stifel
Chair: Lawrence A. Wilson

ILCA International Livestock Center for Africa
P.O Box 5689
Addis Ababa, Ethiopia

Director General: John Walsh
Chair Ralph Cummings, Sr.

ILRAD International Laboratory for Research on Animal Diseases
P. O. Box 30709
Nairobi, Kenya

Director General: A. R. Gray
Chair: Hans E Jahnke

IRRI International Rice Research Institute
P O. Box 933
Manila, Philippines

Director General. M. S. Swaminathan
Chair: Kenzo Hemmi

ISNAR International Service for National Agricultural Research
P O. Box 93375
2509 AJ The Hague
Netherlands

Director General: Alexander von der Osten
Chair M Henri Carsalade

WARDA West Africa Rice Development Association
P.O. Box 1019
Monrovia, Liberia

Acting Executive Secretary: Alieu Jagne
Director General. Eugene Terry[3]
Chair. Moctar Toure

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[1]Chair, Board Chair Group
[2]Chair, Directors General Group
[3]Assumes position September 1987

Annex 4. Donor contributions to center programs, 1972-86 (in US$ million).

	Core Programs							Total (Core + Non-core)			
Donor	1972-76	1977-81	1982	1983	1984	1985	1986	1983	1984	1985	1986
Australia	4 00	13 28	3 77	4 06	4 00	4.18	4 52	4 11	4 03	4 27	4 85
Austria	—	—	—	—	—	—	1 00	—	—	—	1 01
Belgium	3 48	13.70	1 85	1 88	1 71	2 01	1 77	2 46	2 31	2 66	2 48
Brazil	—	—	—	—	1 00	—	—	—	1 00	—	01
Canada	17 37	36 14	8 29	9 94	10 03	9 70	10 66	10.74	11 58	12 74	14 26
China	—	—	—	—	0 50	0 50	48	—	0.50	0 50	48
Denmark	1 71	4 69	0 96	0 95	1 24	1 12	1 65	0 95	1 24	1 26	1 67
Finland	—	—	—	—	0 50	0 60	99	—	0 50	0 60	99
France	1 05	3 14	0 90	1 01	0 88	1 23	2 07	1 10	0 94	1 39	2 15
Germany, Fed Rep	13 27	39 06	7 84	7 89	6 67	6 15	8 03	8 68	7 39	8 14	8 90
India	—	0 50	0 50	0 50	0 50	0 49	50	0 50	0 50	0 49	50
Iran	1 98	3 00	—	—	—	—	—	—	—	—	—
Ireland	—	0 38	0 21	0 34	0 41	0 40	58	0 34	0 41	0 40	58
Italy	0 10	1 90	1 59	6 10	6 62	6 49	8 33	6 10	6 62	6 78	9 73
Japan	2 49	26.25	8 85	9 13	9 72	11 09	15 89	9 48	10 46	12 05	18 92
Mexico	—	1 45	0 10	0 15	1 22	0 37	20	0 15	1 44	0 47	25
Netherlands	4 11	11 54	3 24	3 58	3 28	3 89	6 65	4 12	3 79	4 53	7 88
New Zealand	0 11	0 14	0 02	0 02	0 02	0 01	.01	0 02	0 02	0 01	01
Nigeria	1.30	5 36	1 13	1 00	1 00	0 85	19	1 40	1 60	1 29	38
Norway	3.33	9 27	1 87	2 19	1 92	2 27	3 12	2 19	1 92	2 27	3 40
Philippines	—	0 65	0 45	0 35	0 32	0 23	27	0.35	0 32	0 23	27
Saudi Arabia	1 00	1 00	—	1 50	1 50	—	—	1 50	1 50	—	—
Spain	—	0 50	0 46	0 52	0 52	0 50	50	0 52	0 52	0 50	50
Sweden	7 19	14 80	3 18	3 05	3 07	3 02	4.20	3 05	3 07	3 02	4 21
Switzerland	1.87	9 47	2 76	4 89	6 70	5 17	7 11	5 91	8 21	7 80	9 08
United Kingdom	9 02	27 51	6 34	5 92	5 66	6 32	8 40	5 98	5 74	6 33	8 55
United States	41 60	128 09	40 79	44 55	45 25	45 16	46 25	55 02	56 85	60 19	60 22
Country Subtotal	114 98	351 82	95.11	109 52	114 23	111.74	133 36	124 67	132 46	137 90	161 30
Ford	16 79	6 20	0 81	1 31	0.99	0 90	90	1 75	1 37	1 68	1 73
Kellogg	1 32	0 63	—	0 63	0 34	—	—	0 69	0 41	—	—
Kresge	0 75	—	—	—	—	—	—	—	—	—	—
Leverhulme	—	1 08	0 65	0 75	0 81	0.60	62	0 75	0 81	0 60	62
Rockefeller	17 10	6 67	0 80	0.50	0 50	0 80	93	0 54	0 55	0 99	1 22
Foundation Subtotal	35 96	14 58	2 26	3 19	2 64	2 30	2 45	3 72	3 14	3 27	3 57
ADB	0 30	1 20	—	—	—	—	—	0 17	0 45	0 64	71
AFDB	—	0.15	0 02	—	—	—	59	—	—	—	59
AFESD	—	1 12	0 24	0 23	0 23	0 34	34	0 23	0 23	0 34	34
EC	—	17 38	4 72	5.16	4 72	6 58	7 14	6 25	6 01	7 95	8 47
IDB	11 15	32 19	8 10	8 16	8 73	8 17	9 39	8 16	8 73	8 17	9 44
IDRC	3 95	5 68	1 20	1 80	1.01	1 30	1 18	2 45	2 78	3 12	3 51
IFAD	—	11 05	5 94	8 37	7 02	3 15	45	10 31	8 67	5 26	1 22
OPEC	—	1 90	3 58	2.25	2 19	1 00	47	2 25	2 19	1 05	87
UNDP	7 42	21 59	6 19	6 86	8 06	7.49	8 42	7 16	9 12	8 85	8 87
UNEP	0 94	0 49	0 18	0 13	0 03	—	—	0 17	0 03	0 02	03
WORLD BANK (IBRD)	16 15	53 33	16 30	19 00	24 30	28 10	28 40	19 50	24 68	28 87	29 61
International Donor Subtotal	39 91	146 08	46 47	51 96	56 29	56 13	56 39	56 65	62 88	64 27	63 66
Other Donors	—	—	—	—	—	—	—	3 29	4 60	4 37	7 01
TOTAL	190 85	512 48	143 84	164 67	173 16	170.17	192 20	188 33	203 08	209 81	235 54

Annex 5. CGIAR-supported center expenditures, 1971-86 (current US$ million).

Center	Core Operating Expenditures						
	1971-76	1977-81	1982	1983	1984	1985	1986
CIAT	24 5	61 6	17 9	20 8	21.4	20 6	21.3
CIMMYT	34 0	71 5	17 8	17 9	20 3	21 0	21.4
CIP	8 7	31 3	8 9	9 3	9 9	9 6	12.5
IBPGR	1.4	12 0	3 1	4 5	4 1	4 3	4 8
ICARDA	1.4	32.8	11 5	13 8	14.8	16.0	18.0
ICRISAT	11.7	43.0	14 0	17 7	16 8	18 8	20.6
IFPRI	—	10 3	3 1	3 8	4 3	4 1	4.5
IITA	31 6	65 4	18 8	19 0	20 0	20 2	17.4
ILCA	4 4	33 7	8 2	10 1	11 8	12 6	13 7
ILRAD	2 5	28 3	7 5	8 4	8 5	8.8	9 3
IRRI	24 2	66 9	20 3	19 9	20 5	21 6	23 6
ISNAR	—	2 4	2 3	3 3	3 3	3 8	4.4
WARDA	1 8	8 6	2 7	2 4	2 1	1 9	3 7
Total	146 2	467 8	136 0	150 9	157.9	163 3	175 2

Center	1971-86 Cumulative			
	Operations	Capital	Special Projects	Total
CIAT	188 1	18 6	18 6	225 3
CIMMYT	203 9	9 6	34 2	247 7
CIP	90.2	9 3	5 5	105 0
IBPGR	34.2	—	0 8	35 0
ICARDA	108 3	37 6	11.1	157 0
ICRISAT	142 6	41 2	24 6	208 4
IFPRI	29 9	0 7	8.2	38.8
IITA	192 4	27.8	69 5	289 7
ILCA	93.7	17 9	8 1	119 7
ILRAD	73 0	20 4	1 4	94 8
IRRI	195 2	16 6	57 0	268 8
ISNAR	19 0	0 7	2 4	22 6
WARDA	23 4	1 6	17 0	42 0
Total	1,393 9	202 0	258 9	1,854 8

Annex 6a. Regional origin of internationally recruited staff and board trustees, 1986.

Region	Staff	%	Trustees	%
Asia	154	18.3	37	19.7
Sub-Saharan Africa	111	13.3	35	18.6
N Africa/M East	34	4.1	10	5.3
Latin America/Caribbean	95	11.4	23	12.2
Europe	212	25.4	44	23.4
North America	196	23.5	30	16.0
Australia/New Zealand	33	4.0	9	4.8
Total	835	100	188	100

Annex 6b. Regional origin of internationally recruited staff by center, 1986.

Center	Asia	Sub-Saharan Africa	N Africa/ M East	L America/ Caribbean	Europe	N America	Australia/ New Zealand	Total
CIAT	5	—	1	20	19	24	5	74
CIMMYT	13	6	3	23	17	35	8	105
CIP	7	4	3	34	27	16	—	91
IBPGR	2	1	1	3	7	2	—	16
ICARDA	9	4	19	3	14	12	3	64
ICRISAT	27	9	3	1	24	19	5	88
IFPRI	13	1	1	2	2	10	—	29
IITA	33	32	1	4	21	28	1	120
ILCA	2	11	—	—	33	7	4	57
ILRAD	2	6	—	—	33	10	1	52
IRRI	34	—	—	3	5	23	5	70
ISNAR	3	2	1	2	10	10	1	29
WARDA	4	35	1	—	—	—	—	40
Total	154	111	34	95	212	196	33	835

Annex 6c. Regional origin of board trustees by center, 1986.

Center	Asia	Sub-Saharan Africa	N Africa/ M East	L America/ Caribbean	Europe	N America	Australia/ New Zealand	Total
CIAT	2	1	—	7	2	4		16
CIMMYT	4	2	1	3	2	3	1	16
CIP	3	—	—	3	1	1	1	9
IBPGR	5	2	—	1	6	2	1	17
ICARDA	1	—	7	1	6	1	1	17
ICRISAT	4	2	—	—	4	4	1	15
IFPRI	4	2	1	2	2	4	1	16
IITA	1	6	—	3	4	2	—	15
ILCA	—	5	—	—	5	2	—	12
ILRAD	—	5	—	—	3	3	1	12
IRRI	9	1	—	1	2	2	1	16
ISNAR	3	2	—	1	4	1	1	12
WARDA[1]	1	7	1	1	3	1	—	14
Total	37	35	10	23	44	30	9	188

[1]WARDA Scientific and Technical Committee

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