

CIMMYT 1989 Annual Report
International Maize and Wheat Improvement Center



Beyond Subsistence: New Options for Asian Farmers

R. Glenn Anderson

1924-1981

Some 25 years ago, Glenn Anderson was instrumental in igniting “the sparks of change” that led to India’s green revolution in wheat and the modernization of agriculture throughout Asia. Glenn was a dedicated and talented scientist, teacher, and research administrator who inspired colleagues and friends alike by his example. His personal and professional quest became nothing less than the alleviation of hunger and poverty in developing countries, and his enduring legacy is a better life for millions of poor people.

It is in that spirit that we dedicate
this *Report* to R. Glenn Anderson.



CIMMYT Files

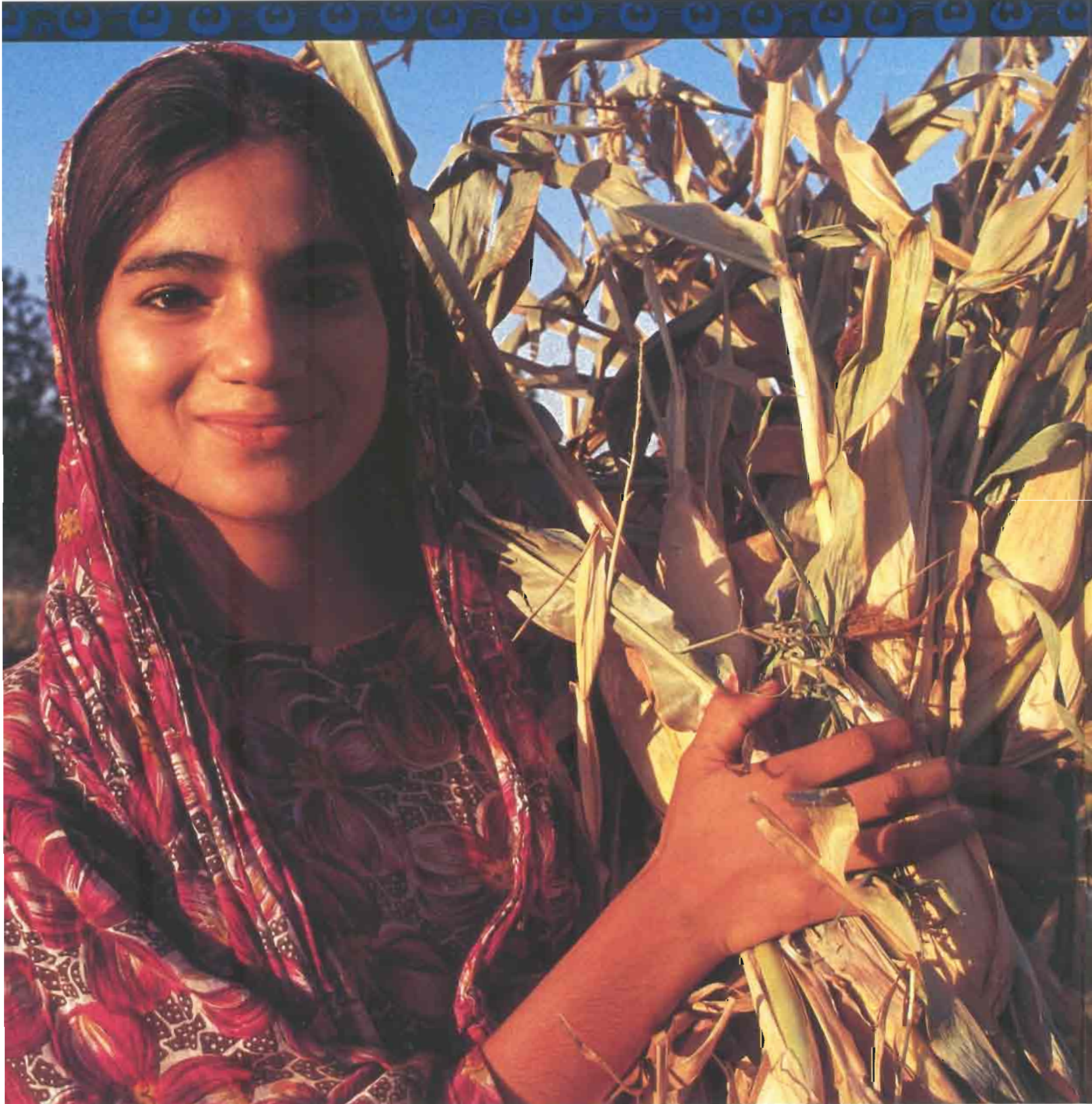
CIMMYT 1989 Annual Report

Beyond Subsistence. New Options for Asian Farmers



The productivity of Asia's agriculture has increased dramatically during the past quarter century, enabling many of the region's poor to move beyond subsistence. For the region to move further along that path, while conserving its heavily used natural resources, agricultural researchers will have to provide a steady flow of new options for Asian farmers.

Comments from Management





Kathryn Elsesser

In this *Annual Report* we concentrate our attention on Asia, the densely populated and extremely diverse geographic expanse stretching from Pakistan to the Philippines and from Indonesia to China. CIMMYT and the Consultative Group for International Agricultural Research (CGIAR) have long been associated with agricultural progress in the region. The CGIAR's efforts in Asia, indeed the efforts of its antecedents, are closely linked with the well-documented success of the “green revolution.” In part due to that success, the region today offers new challenges and new opportunities.

CIMMYT's continuing interest in Asia rests on the importance there of maize and wheat and the number of poor people who stand to gain from improved technologies. That interest is intensified by the critical need to both sustain and build upon productivity gains made through past research while preserving the region's natural resource base. Meeting such challenges will require careful long range planning and the effective allocation of research resources.

million to maize. These figures contrast dramatically with other regions, where much smaller areas are found. Other regions also have far fewer poor people. About half of the world's 5.2 billion people live in Asia and, according to recent estimates by the World Bank, *more* than half of the Earth's 950 million impoverished people reside in the region. Even though population growth rates are slowing in Asia, the population is still expected to double by about 2025.

give rise to new opportunities for progress. Coping with the pressures placed by a growing population on an already intensely used natural resource base will tax our various capacities. Yet in CIMMYT we are convinced that productivity increasing technologies that also protect the environment can be devised. That belief is reflected in the thematic phrase found on the cover of this *Report*--"beyond subsistence: new options for Asian farmers."

Asia, then, was selected as the centerpiece for this *Annual Report* because of its enormous demands for maize and wheat, demands augmented by rising incomes and population; because of the urgent need to cope with the stresses imposed by already intensive agriculture; and because of the opportunities that exist to collaborate with the staff of well developed national programs.

Some of Asia's national programs are among the strongest in the developing world. Their strength and experience, coupled with new orientations in our own work, give rise to new opportunities for progress.

Improving Agricultural Productivity

The management and staff of the Center regularly assess their work, whether for Asia or for other regions of the Third World, in the context of the institution's strategic plan. The plan itself was a major subject of our *1987 Annual Report*. One consequence of such assessments has been a clarification of key issues. An example of the latter was contained in our *1988 Annual Report*, which focused on the conservation and utilization of our genetic resources. We used that forum to describe policies guiding our efforts to conserve such resources and to ensure their distribution.

The 1989 Theme

Our focus on Asia in this *Report* also emerges from issues addressed in the strategic plan, especially those affecting CIMMYT's priorities. The significance of Asia to the Center is undeniable. Asian countries devote some 60 million hectares to wheat and another 37

Few now dispute the value of Asia's agricultural progress during the past quarter century. Improvements in productivity have promoted economic growth and rising incomes. For agriculture to continue making its contributions, however, the sector's output must continue to rise, and the resources used to produce maize and wheat must become ever more productive. We at CIMMYT are concerned by recent evidence suggesting that yield increases for wheat appear to be slowing; there are even disturbing indications of declining productivity in some areas. And while the productive potential of maize has grown steadily over the years, the maize "revolution" in Asia (with the exception of temperate China) is still to come.

We believe that agricultural science has much to offer under these circumstances. Fortunately, some of the region's national programs are among the strongest in the developing world. Their strength and experience, coupled with new orientations in our own work,

In his guest editorial (Point of View, pages 10-17), Dr. Vernon Ruttan concerns himself with the primary constraints affecting agricultural productivity in Asia and elsewhere in the developing world. He notes that, while conventional technology will remain the primary source of growth until well into the next century, for the longer term we must find other sources for improving productivity. He is particularly concerned with organizational issues and with creating more effective institutional mechanisms for bringing science to bear on the challenges facing agriculture.

CIMMYT shares many of his concerns, particularly as they relate to increasing the leverage, and hence the impact, of our work. We are convinced, for example, that national programs will be better served by the Center concentrating more of its resources on research relative to direct forms of support, and by a refocusing of its research to include more "upstream" activities.

National programs are themselves requesting that we implement such changes. Accordingly, our breeders are now giving greater attention to such activities as the development of special trait and source materials. Our pathologists are focusing more on identifying genetic mechanisms for better disease resistance and evaluating their heritability. Our agronomists are concentrating more of their energies on strategic crop management issues affecting entire crop production systems (e.g., Asia's rice/wheat rotation). And our economists are

giving more attention to commodity sector issues and to investigating research resource allocations and impacts.

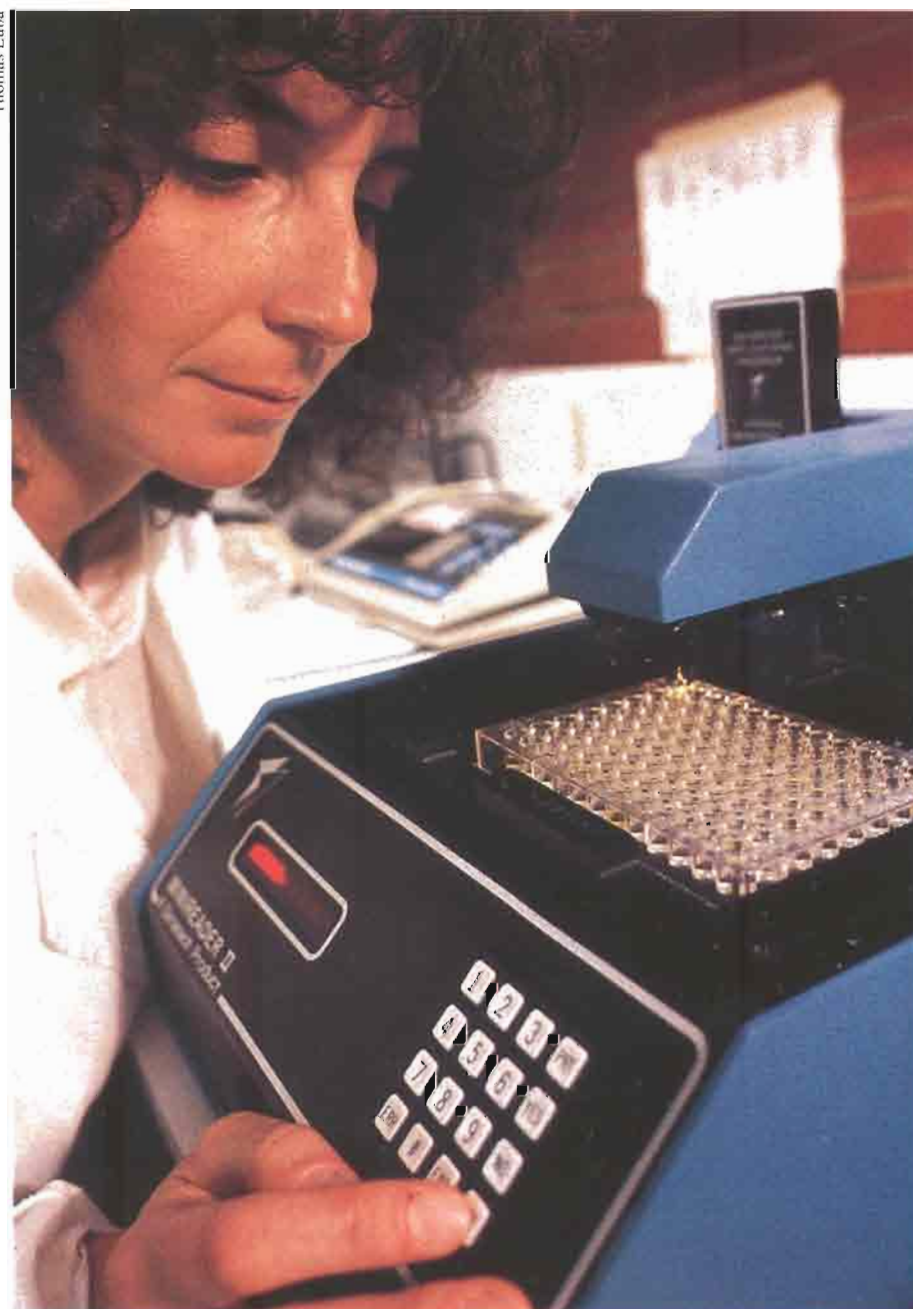
To facilitate such shifts and to help ensure their utility to clients, we are expanding our relationships with developed country centers of excellence through various kinds of collaborative research. We are also expanding our collaborative work with national program clients, in some cases formalizing such relationships and dramatically

altering relative responsibilities. Certain of our support operations are being bolstered as well. We have, for example, established a biotechnology laboratory at our headquarters in Mexico. Its staff engage in a range of activities designed to capitalize on the efficiencies being offered by new techniques developed elsewhere, especially the use of genetic probes to expedite germplasm improvement for specific traits. They are adapting those techniques to CIMMYT's circumstances and, where relevant, for transfer to advanced national programs. We are also giving greater attention to communicating with peers, for example through refereed journals, and we are reorienting some of our training to appeal more to the advanced needs of mid-career scientists.

Among the reasons for making these and other changes is an abiding concern for the efficient use of our resources. Collaborative work in which participants each contribute according to their relative strengths enhances both efficiency and effectiveness. Decentralization to national programs of introductory crop management training is another example of our quest for efficiency. This frees CIMMYT resources for other applications more in line with our comparative advantage and the needs of our clients. The new biotechnology techniques referred to earlier will significantly reduce the cost of our germplasm improvement work and, eventually, that of advanced national programs. Thus, efficiency considerations help guide our hand as

The Enzyme Linked Immunosorbant Assay (ELISA) is an effective technique for identifying isolates of barley yellow dwarf virus (BYDV), a ubiquitous disease of wheat. Resistance to BYDV is generally isolate specific, and epidemiological surveys are necessary to determine the specific resistance required in improved germplasm. For a survey of the isolates prevalent in Mexico, Monica Mezzalama (an associate scientist in the Wheat Program) uses an ELISA reader to identify BYDV isolates in sap extracted from wheat leaves.

Thomas Lutha



CIMMYT responds to the changing needs of clients. And in all of this, doing the right thing contributes most to our pursuit of efficiency. Our strategic plan supports that pursuit well.

Highlights from 1989

In addition to the research and support activities described later in this *Report* (pages 34-55), a number of other noteworthy events took place during the year. We completed the administrative restructuring of the Center, increasing the authority of the Deputy Director General of Research and adding decision points within the Maize, Wheat, and Economics Programs themselves. The structure of the Board of Trustees was also changed with the

addition of an Audit Committee having three members, all drawn from the Executive and Finance Committee.

After being endorsed by the CGIAR in May, we published our strategic plan (*Toward the 21st Century: CIMMYT's Strategy*) and used the strategic directions presented there as the basis for developing our five year budget, itself approved by the CGIAR during International Centers' Week in October 1989. In addition to approval by TAC and the CGIAR of our planned activities and expenditures, our planning and budgeting methodologies were themselves well received.

While implementing the ideas contained in our plan and budget we want to ensure the continued relevancy of our

efforts. To help with that, we established several committees charged with the responsibility of monitoring the major elements of CIMMYT's environment. The function of these committees is to keep our strategic plan "ever green" and to enable the Center to effectively adapt to changing circumstances.

Two important collaborative research efforts were initiated during the year and initial planning for a third was completed. One project, being done in conjunction with Cornell University (USA) and funded by the government of The Netherlands and the Australian Council for International Agricultural Research (ACIAR), involves the development of RFLP maps of the wheat genome. A second project, also

Thomas Luba



The 1980s have been characterized by volatile world grain markets and widespread policy reforms, trends that have heightened the need for timely information on maize and wheat economies. Such information is increasingly necessary for effective research resource allocation both at CIMMYT and in national programs. For that reason, CIMMYT economists now give greater attention to commodity sector studies at the global, regional, and national levels.

funded by the Dutch, involves the University of Missouri (USA) and centers on the use of maize RFLPs in the pursuit of multiple borer resistance (see page 37). As CIMMYT's biotechnology lab comes up to speed, we will shift most aspects of this research to Mexico. A third project, this one involving us in collaboration with the International Rice Research Institute and a number of national programs in Asia, will address factors affecting productivity in the vast area devoted to rice/wheat rotations (see page 26). We are currently negotiating financial support for this effort.

Responding to the demands for higher level training, we initiated specialized training in 1989 aimed at mid-career scientists from developing country national programs. Our first such course ran seven weeks and focused on research program design for maize agronomists. The course drew 20 participants representing 11 countries, and concentrated on data analysis, statistical techniques, and computer applications, all in the context of on-farm research. Planning and registration for a similar course in wheat during early 1990 was completed as well.

Changes in Senior Management

Two important changes occurred among senior management. In mid-year Dr. Roger Rowe, who joined CIMMYT at the beginning of 1989 as Deputy Director General of Administration and Finance, was appointed as DDG/Research. The move gives Dr. Rowe the opportunity to return to direct participation in the research arena and gives CIMMYT the benefit of his substantial experience in this recently expanded

position. His replacement as DDG/Administration and Finance is Dr. Claudio Cafati, who earned his PhD in plant pathology, breeding, and genetics in 1979 from Michigan State University (USA). Dr. Cafati served some 17 years on the agriculture faculty of the University of Chile (as professor of plant pathology and breeding), 6 years as director of a major experiment station for the Chilean National Agricultural Research Institute (INIA) and, from 1986 until joining CIMMYT in early 1990, as General Manager of INIA itself. While Dr. Cafati is well known for his research, his work will draw more heavily on his considerable experience in research administration.

Financial Circumstances

During 1989 the increasing value of the dollar against other currencies was the single most important factor affecting the Center's financial performance, reducing the dollar value of pledges from several key donors. This influence was complicated by the reduced but still significant effect of high inflation combined with a relatively stable peso/dollar exchange rate, increasing our costs in Mexico. Other noteworthy factors include major expenditures on the recently completed biotechnology laboratory and large accounts receivable balances for several donors. Together these factors reduced our year-end cash balances to levels considerably lower

than last year. These and other points are discussed more fully in the financial highlights section of this Report (pages 56-59).

Conclusion

Returning to the Asian theme, CIMMYT's activities are influenced by our perceptions of the complex challenges we and our national program colleagues face, by the opportunities that abound, and by the availability of funding. Indeed, we perceive many more research opportunities than we do sources of funding to pursue them. Population and income projections for the region indicate a rapidly growing demand for maize and wheat during the coming decades. While a fuller exploitation of current technologies appears adequate to meet anticipated demand to the turn of the century, beginning about then farmers in the region will have to start implementing new, sustainable, productivity enhancing technologies. Otherwise, the projected growth in demand will result in disconcerting increases in food and feed grain imports. The views of our guest essayist, Dr. Ruttan, reinforce the notion that new sources of agricultural productivity are needed. CIMMYT's activities reflect our own conviction that we must seek new approaches to technology generation to help meet Asia's complex requirements.



Donald L. Winkelmann
Director General

CIMMYT and the CGIAR



The year 1966 was a propitious one for founding an international agricultural research center. The eyes of the world had turned to the populous countries of South Asia and beheld agricultural production hovering at subsistence levels. The survival of millions depended on the annual success of the cereal crops. That same year CIMMYT came into being.

Recognizing the imminent danger to their citizens, the governments of India and Pakistan independently established emergency programs designed to sharply increase domestic food production. In doing so they sought advice and guidance from the scientific and development communities. Some of the individuals they consulted were then working for the newly formed CIMMYT. Thanks largely to two decades of collaborative research between Mexico's Ministry of Agriculture and CIMMYT's predecessor organization, the Rockefeller Foundation's Office of Special Studies, help from Mexico was available. The semidwarf wheat varieties generated by that joint research had been tested for several years in both India and Pakistan, but they had not yet been widely adopted by farmers. Part of the problem was that improved seed was not available in sufficient quantities. Mexico, asked to provide seed, was able to ship 18,000 t to India and 42,000 t to Pakistan. These modern varieties, in combination with appropriate management practices recommended by the national research and extension systems, made it possible to avert impending food shortages. More than that, they boosted yields far beyond anyone's expectations and were largely responsible for the bumper crops produced in subsequent years.

This early experience galvanized the young Center, helping to establish not only its institutional culture but the tone and direction of international agricultural research done by others. CIMMYT is one of 13 autonomous, international, nonprofit agricultural research and training centers sponsored by the

Consultative Group for International Agricultural Research (CGIAR). Our mission is to help the poor of developing countries by increasing the productivity of resources committed to maize and wheat, whether in research or on the farm. We do this primarily through worldwide programs aimed at improving germplasm and delivering it to Third World national programs; they, in turn, either incorporate these materials into their own breeding programs or release them directly to farmers. Our work reaches beyond germplasm as well. We produce new scientific knowledge and information, generate and adapt research procedures, conduct training in Mexico and abroad, and consult with national programs about their work.

All this is in keeping with the primary concerns of the CGIAR. This system, which was formed in 1971, is a consortium of donors and research organizations cosponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). Funds come from some 40 different donors, including developed

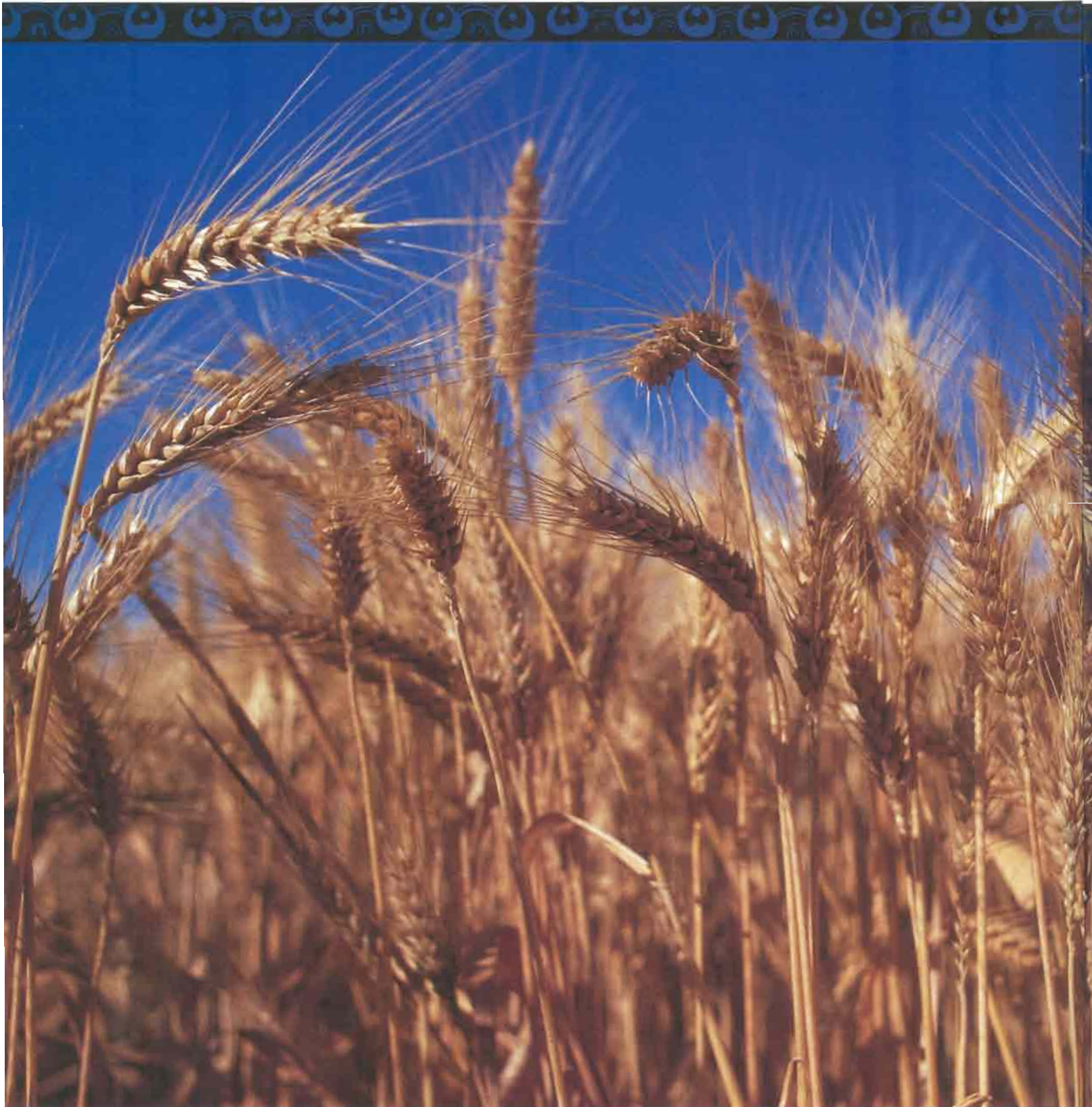
and developing country government aid agencies, international and regional organizations, and private foundations.

The CGIAR is committed to agricultural research and related activities that are international in scope, of enduring importance, and in which its centers have a distinct cost advantage. The system's Technical Advisory Committee, which consists of prominent scientists from around the world, identifies and articulates these activities. Since its inception, the system has emphasized work oriented toward improving the well-being of the poor in developing countries. Recently, concern about the ability of these countries to sustain agricultural development in ways consonant with the preservation of their natural resources has come to the fore. Centers are seeking technological innovations designed to improve the productivity of marginal environments, and the CG is encouraging them to shift their efforts toward strategic research and away from the adaptive work that has characterized many past endeavors. The system has also given special emphasis to research directed toward helping sub-Saharan Africa improve its agricultural productivity.



Location of the 13 international agricultural research centers supported by the Consultative Group for International Agricultural Research (CGIAR)

Point of View





Gene Hettel

Constraints on Agricultural Production in Asia: Into the 21st Century

In the closing years of the 20th century, we are completing one of the most remarkable transitions in the history of agriculture. Prior to this century, nearly all increases in food production resulted from the cultivation of new land. By the first decade of the next century, nearly all increases in food production must come from higher yields. This transition from a resource-based to a science-based system of agriculture has occurred rapidly. Most developing countries have been caught up in this transformation since mid-century, and those of East, Southeast, and South Asia have proceeded further along this path than many other

Third World countries.



*Vernon W. Ruttan, Regents Professor
University of Minnesota, USA*

By the mid-1960s, it had become obvious that increases in cultivated area could no longer provide the primary source of growth in food production in Asia. It was also obvious that growth would have to come from increased use of a new set of highly productive inputs--new crop varieties, fertilizer, and irrigation water.

Since then, much has been accomplished. Agricultural development throughout most of Asia is a major success story: during the 1970s and 1980s, real growth in agricultural gross domestic product in Asia's developing countries has averaged upwards of 3% per year (Vyas and James 1988). Strong national agricultural research programs were established in a number of countries and reinforced by a network of international agricultural institutes. This system has successfully generated a stream of increasingly more productive varieties of wheat, rice, and maize, as well as sorghum and millet and a number of other minor crops (Ruttan 1986).

The gap between yields in Asia and those obtained in the most advanced countries of the developed world has narrowed substantially. In more favored areas, farm-level yields approximate those achieved on experiment stations (Byerlee 1989; Pingali 1989). Rice, wheat, and maize yields in favored areas, particularly in east Asia, approach or exceed levels achieved in some developed countries. In the advanced districts of the Punjab of India, for example, farmers' wheat and rice yields surpass 4 t/ha. The rapid adoption of the new crop production technology confounded the pessimistic projections of those who viewed Asian farmers as excessively bound by custom and tradition. Between the early 1960s and the early 1980s, the percentage of wheat area under irrigation rose from 50% to 72% in India and from 66% to 83% in Pakistan. During this same period, fertilizer use per hectare of cultivated land expanded by over 10% per year, reaching about 80 kg/ha (Byerlee 1989).

As the new technology was introduced, it provoked concern that the resulting gains would become a source of inequity in income distribution and contribute to polarization in rural communities. Critics of the Green Revolution argued that large farmers and landlords would monopolize the new technology, with the consequence that employment opportunities would be reduced and wage rates would decline.

Experience has confounded these concerns. Neither farm size nor tenure has represented a serious constraint on the adoption of modern varieties and the efficient use of available inputs. High yielding varieties did not stimulate the introduction of labor displacing machinery. In fact, *substantial increases* in demand for labor occurred in areas that rapidly adopted the new crop technology (Hayami and Ruttan 1985).

Where distribution of income has widened, it has usually been in less well-endowed areas to which the new technology was not well adapted, rather than in more favored areas where adoption was rapid. Among the countries of Asia, the share of cultivated area devoted to rainfed agriculture ranges from less than one-fourth in Pakistan to over three-fourths in Thailand and several other Southeast Asian countries. With relatively few exceptions, these areas have been bypassed by the advances in agricultural technology that contributed to productivity growth in more favored areas.

The Asian adoption pattern is consistent with worldwide trends: semidwarf wheat and rice varieties have been adopted much more slowly in areas where rainfall remains a serious constraint on the response to other technical inputs (Table 1). In fact, I believe it is unlikely that in the next several decades productivity growth in the rainfed upland areas of Asia will expand at a rate that will generate satisfactory rates of growth of either agricultural production or employment. The most likely prospect is that disparities in income between these and the more favored areas will continue to widen (Byerlee 1989).

New Sources of Growth Needed

Historical trends in production and consumption of the major food grains could easily be taken as evidence that one should not be excessively concerned about the capacity of the world's farmers to meet future food demands. World wheat prices, for example, corrected for inflation, have declined since the middle of the last century (Figure 1). Rice prices have also declined, suggesting that productivity growth in cereal crops has more than compensated for the rapid growth in demand, particularly since World War II.

As we look toward the future, however, the sources of productivity growth are not as apparent as they were a quarter of

Table 1. Percentage adoption of semidwarf wheat, by moisture regime, developing and developed countries and the world, 1980s

	Irrigated	>500	300-500	<300	All areas
Developing	91	60	45	21	62
Developed	96	37	50	na	40
World	92	42	47	21	49

Source: CIMMYT files.
na = not applicable.

a century ago. The demands that Asian societies will place on their agricultural producers from population growth and growth in per capita consumption arising out of higher income will be exceedingly high. Population growth rates are expected to decline substantially during the first quarter of the next century (Table 2). But per capita incomes are expected to increase by upwards of 3% per year. The effect of growth in per

capita income will be more rapid growth in demand for maize and other feed crops than for wheat and rice. During the next several decades, growth in food and feed demand arising from growth in population and income will run in the 3-4% per year range. Most Asian countries will experience a doubling of food demand before the end of the second decade of the next century.

Table 2. Population and growth rates in Asia, 1987-2025

	South Asia	Southeast Asia	East Asia	All Asia
Population 1987 (millions)	1,024	412	1,111	2,546
Population 2000 (millions)	1,328	525	1,317	3,170
Population growth rate, 1987-2000 (%/yr)	2.0	1.9	1.3	1.7
Population 2025 (millions)	1,892	707	1,584	4,183
Population growth rate, 2000-2025 (%/yr)	1.4	1.2	0.7	1.1

Source: CIMMYT files.

Even the most optimistic projections suggest an unfavorable trade-off between self-sufficiency and the prices at which food and feed grains will become available to consumers and producers of animal products. If food and feed grain prices are to remain near present levels it is likely that imports will need to rise substantially for several important countries in the region. If food and feed grain imports are to be held at recent levels, prices paid to domestic producers and, by implication, prices to consumers will have to rise substantially in most countries (Barker and Herdt 1985; Byerlee 1989).

It seems apparent that the gains in agricultural production required over the next quarter century will be achieved with much greater difficulty than in the immediate past. Increasing the yield potential of cereal crops that experienced rapid yield gains in the past is already proving difficult. The incremental response to additional fertilizer use has declined. Expanding irrigated area has become more costly. Maintenance research, the research required to prevent yields from declining, is rising as a share of the research effort (Plucknett and Smith 1986). The institutional capacity to respond to these concerns is limited, even in countries with the most effective national research systems. Indeed, during the 1980s many developing countries have struggled to maintain the agricultural research capacity established during the 1960s and 1970s.

It is possible that within another decade advances in basic knowledge will create new opportunities for improving agricultural technology that will reverse the urgency of some of these concerns. Institutionalization of private sector agricultural research capacity in some countries of the region, particularly India, Thailand, and the Philippines, is beginning to complement public sector capacity (Pray 1983). Advances in molecular biology and genetic engineering are occurring rapidly. But the date when these promising advances will be translated into productive technologies seems to be receding.

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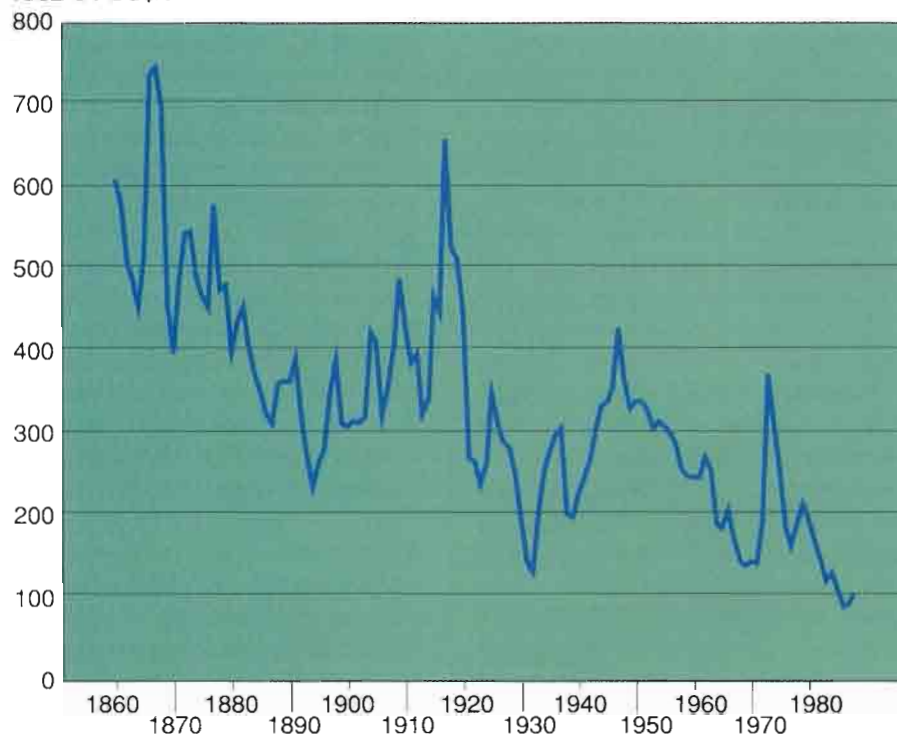


Figure 1. Real wheat prices since the mid-1800s.

Source: US Bureau of Census. 1975. *Historical Statistics of the United States: Colonial Times to 1970*. Washington, DC: US Department of Commerce (for data 1860-1960). US Department of Agriculture. n.d. *Agricultural Outlook*. Washington, DC: USDA (for data 1961-88).

The following general conclusions, from a consultation among agricultural scientists and economists in June 1989,¹ are particularly relevant to the future of agriculture in the developing countries of Asia.

Advances in conventional technology will remain the primary source of growth in crop and animal production over the next quarter century. Almost all increases in agricultural production over the next several decades must continue to come from further intensification of agricultural production; improvements from conventional plant and animal breeding; and more intensive and efficient use of technical inputs, including chemical fertilizers and pest control chemicals.

Productivity gains from conventional sources are likely to come in smaller increments than in the past. If they are to be realized, higher plant populations per unit area, new tillage practices, improved pest and disease control, more precise application of plant nutrients, and advances in soil and water management will be needed. Gains from these sources will require closer articulation between the suppliers and users of new knowledge and new technology. These sources of yield gains are extremely knowledge and information intensive. Consequently, extending the results of research will become an increasingly important source of growth in crop and animal productivity.

Advances in conventional technology will be inadequate to sustain the demands that will be placed on agriculture as we move into the second decade of the next century and beyond.

Increased crop yields have come about primarily by raising the ratio of grain to straw rather than by increasing total dry matter production. Improvements in animal feed efficiency have come by decreasing the proportion of feed consumed that is devoted to animal

maintenance and increasing the proportion used to produce usable animal products.

Severe physiological constraints limit continued improvement along these conventional paths. These constraints are most severe in areas that have already achieved the highest levels of productivity--as in Western Europe, North America, and parts of East Asia. The impact of these constraints can be measured in terms of declining incremental yield increases from higher levels of fertilizer application, and a reduction in the incremental savings in labor inputs from the use of larger and more powerful mechanical equipment. Should the incremental returns to agricultural research also decline, that will impose a higher priority on efficiency in the organization of research and on the allocation of research resources.

A reorientation of the way we organize agricultural research will be necessary to realize the opportunities for technical change opened up by advances in microbiology and biochemistry.

Advances in basic science, particularly in molecular biology and biochemistry, continue to open up new possibilities for supplementing traditional sources of growth in plant and animal productivity, ranging from the transfer of growth hormones into fish to the conversion of lignocellulose into edible plant and animal products.

Realizing these possibilities will require a reorganization of agricultural research systems. An increasing share of the new knowledge generated by research will reach producers in the form of proprietary products or services. This means that incentives must be created to draw substantially more private sector resources into agricultural research. Public sector research will have to increasingly move from a "little science" to a "big science" mode of organization. In the absence of more focused basic research by both the public and private sectors, it seems likely that the promised gains in agricultural productivity from biotechnology will continue to recede.

Efforts to institutionalize agricultural research capacity in developing countries must be intensified. Crop and animal productivity in most developing countries remain well below potentially feasible levels. Access to the conventional sources of productivity growth from advances in plant breeding, agronomy, and soil and water management will require the institutionalization of substantial agricultural research capacity for each crop or animal species of economic significance in each country. In a large number of developing countries this capacity is just beginning to be put in place. Furthermore, a number of countries whose research capabilities grew substantially in the 1960s and 1970s have seen that capacity wane in the 1980s. Countries that do not acquire adequate agricultural research capacity will be unable to meet the demands placed on their farmers as a result of growth in population and income.

There are substantial possibilities for developing sustainable agricultural production systems in a number of fragile resource areas.

Research underway in the tropical rain forests of Latin America and the semiarid tropics of Africa and Asia suggests the possibility of developing sustainable agricultural systems with substantially enhanced productivity even in unfavorable environments. It is unlikely, and perhaps undesirable, that all of these areas become important components of the global food supply system. But enhanced productivity is important to those who reside in these areas now and in the future. Hence research on soil and water management and farming systems for these areas should be intensified.

Substantial basic biological research and training capacity needs to be established in the tropical developing countries.

A series of basic biological research agendas important for applied research and technology development for tropical agriculture presently receive, and are likely to continue to receive, inadequate attention in the developed temperate regions. There is also a need for closer articulation between training in applied science and technol-

1 *Biological and Technical Constraints on Crop and Animal Productivity*, a meeting sponsored by the Rockefeller Foundation and the University of Minnesota (Ruttan, 1989).

ogy and training in basic biology. When such institutes are established they will need to be more closely linked with existing academic centers of research and training than the agricultural research institutes established by the Rockefeller and Ford Foundations and the CGIAR.

Constraints on Sustainable Growth

As we look even further into the next century, there is a growing concern about the impact of a series of resource and environmental constraints that may seriously impinge on the capacity to sustain the growth in agricultural production that will be required in most developing countries. A second consultation on issues of resource and environmental constraints on agricultural production that included scientists involved in studies of climatic change, agricultural scientists, and economists was held in late November 1989.

One set of concerns focused on the impact of agricultural practices in areas making the most progress toward highly intensive systems of agricultural production. These impacts include loss of soil resources due to erosion, waterlogging, and salinization; groundwater contamination from plant nutrients and pesticides; and growing resistance of insects, weeds, and pathogens to present methods of control. If agriculture is forced to continue to expand into more fragile environments, soil erosion and desertification can be expected. Additional deforestation will intensify problems of soil loss, further degrade water quality, and contribute to the forcing of climatic change.

A second set of concerns stems from the impact of industrialization on global climatic and other environmental changes (Reilly and Bucklin 1989). There can no longer be any question that the accumulation of carbon dioxide (CO₂) and other greenhouse gasses--principally methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFCs)--has set in motion a process that will raise global

average surface temperatures over the next 30-60 years. And there continues to be great uncertainty about the climatic changes that can be expected to occur at any particular date or location in the future. It is almost certain, however, that the climatic changes will be accompanied by rises in the sea level, which will impinge particularly heavily on Southeast Asia's islands and greater river deltas. Drier and more erratic climatic regimes can be expected in the interiors of South Asia and North America. As a partial offset some analysts have suggested that higher CO₂ levels may have a positive effect on yield (Rosenberg 1986).

Most carbon dioxide emissions come from fossil fuel consumption. Carbon dioxide accounts for roughly half of radiative forcing. Biomass burning, cultivated soils, natural soils, and fertilizers account for close to half of nitrous oxide emissions. Most of the known sources of methane are a product of agricultural activities--principally enteric fermentation in ruminant animals, release of methane from rice production

and other cultivated wetlands, and biomass burning. Estimates of nitrous oxide and methane sources have a very fragile empirical base. Nevertheless, it appears that agriculture and related land use could account for somewhere in the neighborhood of 25% of radiative forcing (Figure 2).

Alternative policy approaches to the threat of global warming can be characterized as *preventionist* or *adaptionist*. A preventionist approach could involve five policy options: (a) reduction in fossil fuel use or capture of CO₂ emissions at the point of fossil fuel combustion; (b) reduction in the intensity of agricultural production; (c) reduction of biomass burning; (d) expansion of biomass production; and (e) conservation of energy. Of these, only energy efficiency and conservation are likely to make any significant contribution over the next generation. The institutional infrastructure and resources required to make the other options work do not yet exist and will not be in place rapidly enough. We will not be able to rely on a technological fix to the global warming problem. The fixes, whether

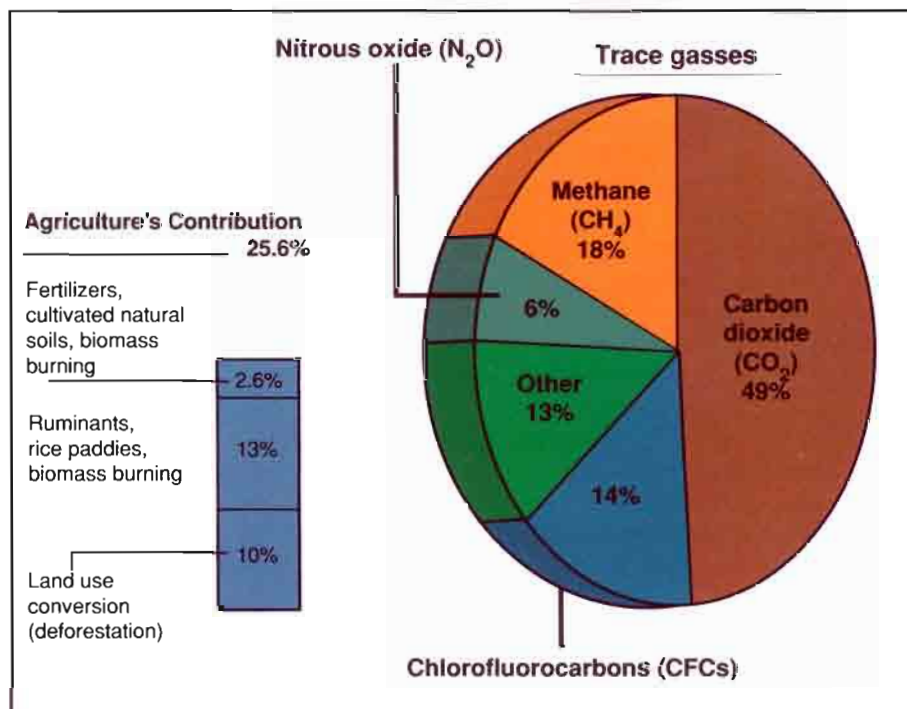


Figure 2. Contributions to increases in radiative forcing in the 1990s.

Source: J. Reilly and R. Bucklin. 1989. Climate change and agriculture. *World Agriculture Situation and Outlook Report*. Washington, DC: USDA/ERS, WAS-55.

driven by preventionist or adaptationist strategies, must be both technological and institutional.

This forces me, although reluctantly, into an *adaptationist* approach for assessing the implications of global climatic change for future agricultural research agendas. In this context, an adaptationist strategy implies the need to move as rapidly as possible to design and put in place the institutions needed to remove the constraints that intensification of agricultural production currently impose on sustainable increases in agricultural production. If we are successful, we will be in a better position to respond effectively as the world's climate changes. The implications for research of the adaptationist approach are summarized below.

Develop alternative land use, farming systems, and food systems scenarios for the 21st century. We must have a clearer picture of the demands that are likely to be placed on agriculture over the next century and of the ways in which agricultural systems might be able to meet such demand. World population could rise from the present 5 billion level to the 10-20 billion range. Income growth rate projections are similarly vague. The resources and technology we use to increase agricultural production will depend on the likely constraints to resource availability and on the rate at which knowledge grows. Advances in knowledge can permit us to obtain more from increasingly scarce resources, thus reducing the resource constraints on commodity production.

absorbing CO₂. The demand for land to protect watersheds and produce biomass energy will also increase.

Strengthen the capacity to monitor the agricultural sources and impacts of environmental change. Even rudimentary data on soil loss are almost completely unavailable in most developing countries. The same point holds, with even greater force, for groundwater pollution, salinization, species loss, and other problems. It is time to design the elements of a comprehensive, agriculturally related resource monitoring system and to establish priorities for implementation. Data on the effects of environmental change on the health of individuals and communities are even less adequate.

Monitoring will require much closer collaboration between production-oriented agricultural scientists, biological scientists trained in ecology, and the physical scientists traditionally concerned with global climatic change.

Design technologies and institutions to achieve more efficient management of surface and groundwater resources. Global climatic change will have a major differential impact on water availability, water demand, erosion, salinization, and flooding. The development and introduction of technologies and management systems that enhance water use efficiency represents a high priority both because of near-term constraints on water supplies and the more distant possibility of seasonal and geographical shifts in water availability. The identification, breeding, and introduction of water-efficient crops for dryland and saline environments is important to achieving greater water use efficiency.

Intensify research on environmentally compatible farming systems. In agriculture, as in the energy field, a number of technical and institutional innovations could have both economic and environmental benefits. Among the technical possibilities is the design of new "third" or "fourth" generation chemical, biorational, and biological pest management technologies. Another

The most favorable economic environment for achieving sustainable adaptation to resource and environmental constraints is characterized by rapid growth of income and employment in the nonagricultural sector.

Initiate a major research program on incentive-compatible institutional design. A major source of the global warming and environmental pollution problem is the lack of incentives for individuals and public agencies to behave in ways compatible with societal development--some might say survival. The first research priority therefore is to initiate a large-scale program of research on the design of institutions capable of implementing incentive-compatible resource management policies and programs. By incentive-compatible institutions I mean those capable of achieving compatibility between individual, organizational, and social objectives in resource management.

Past application of advances in biological and chemical technology, which substitute knowledge for land, and advances in mechanical and engineering technology, which substitute knowledge for labor, have been driven by declining energy prices. There will be strong incentives, by the early decades of the next century, to improve energy efficiency in agricultural production and utilization. Particular attention should be given to alternative and competing uses of land. Land use transformation, from forest to agriculture, is presently contributing to radiative forcing through release of CO₂ and methane into the atmosphere. Conversion of low intensity agricultural systems to forest has been proposed as a method of

is the design of land use technologies and institutions that will reduce erosion, salinization, and groundwater pollution.

Reform agricultural commodity and income support policies. In both developed and developing countries, producers' decisions related to land management, farming systems, and use of technical inputs are influenced by government price supports and subsidies, programs to promote or limit production, and tax incentives and penalties. It is increasingly important that such interventions anticipate the environmental consequences of resulting decisions by land owners and producers.

Design alternative food systems. The agricultural science community should be prepared, by the second quarter of the next century, to contribute to the design of alternative food systems. Many of these alternatives will include plants other than the grain crops that now comprise a major share of the world's feed and food. Some will involve radical changes in food resources (Rogoff and Rawlins 1987).

Perspective

My own perspective on the future of Asian agriculture is cautiously optimistic. The challenges posed by the constraints on crop and animal productivity and by the resource and environmental constraints on sustainability should not be interpreted as a pessimistic assessment. Asian agricultural research institutions, the technology supply industry, and farmers in the region are much better equipped to confront the challenges of the future than the food crises of the past.

It cannot be emphasized too strongly, however, that the challenges are both technical and institutional. The great institutional innovation of the 19th century was "the invention of the method of invention." The modern industrial research laboratory, the agricultural experiment station, and the research university were products of that institutional innovation. But it was not

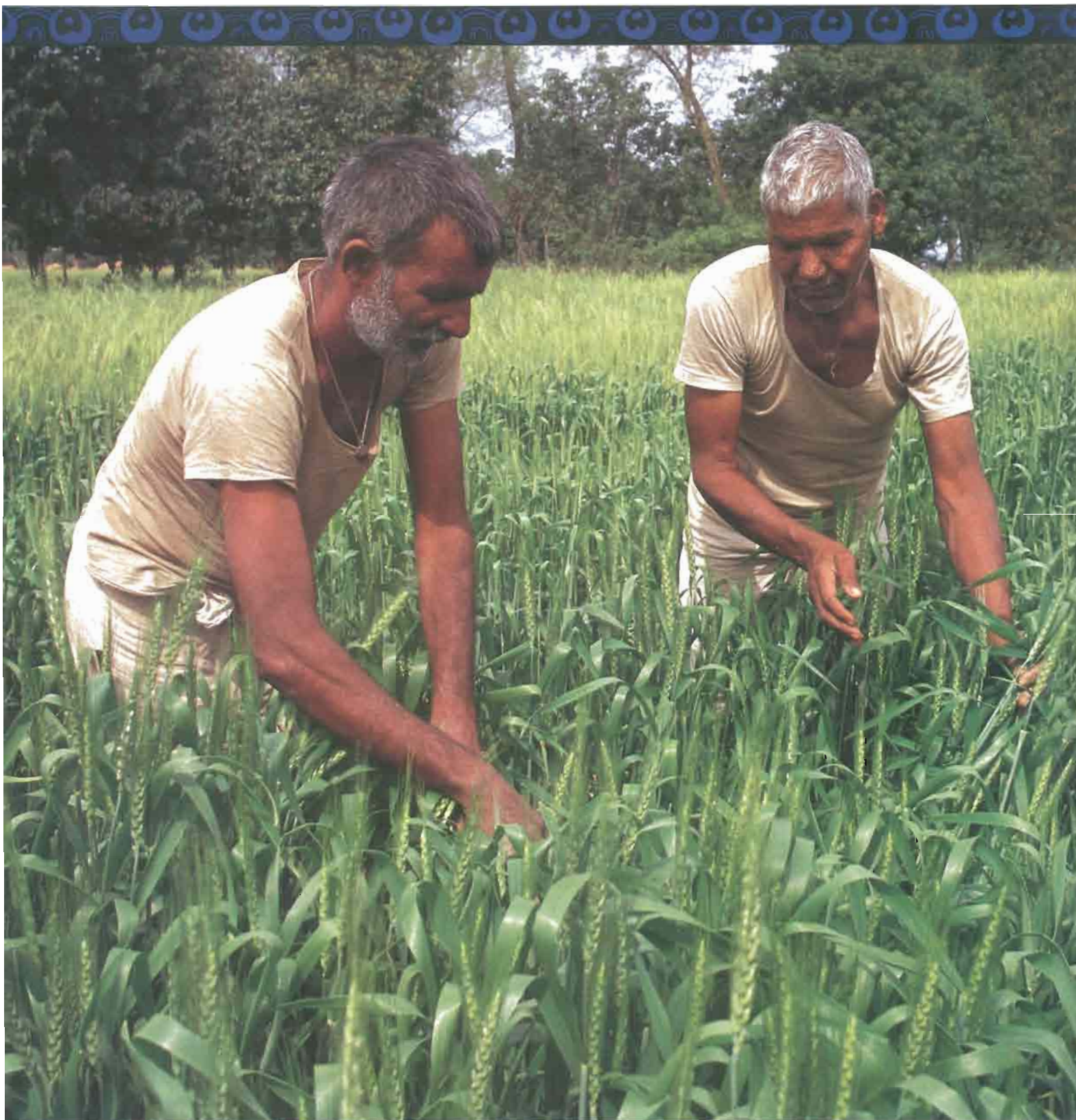
until well after mid-century that national and international agricultural research institutions became firmly established in most Asian countries. The challenge in the next century will be to design institutions that can ameliorate the negative environmental effects of agricultural and industrial intensification.

The capacity to achieve sustainable growth in agricultural production and income will also depend on changes in the economic environment in which Asian farmers find themselves. The most favorable economic environment for improving crop and animal productivity and for achieving sustainable adaptation to resource and environmental constraints is one characterized by rapid growth of income and employment in the nonagricultural sector. Rapid increases in demand, arising from higher incomes rather than explosive population growth, can generate patterns of demand that permit farmers to move out of continuous staple cereal production and into diversified production systems combining higher value crop and animal products. This option would enable more fragile lands to be released from crop production and put to less intensive uses; it may also generate the resources needed to invest in the research and technologies critical for sustained agricultural growth.

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Review of CIMMYT Programs





Beyond Subsistence: New Options for Asian Farmers

Imagine for a moment the circumstances faced by Ram Asere Dube and Gabbu Baniya, subsistence farmers living near Semari village in the *terai* of southern Nepal. Together they farm 1.7 hectares, producing five different crops: wheat, mustard, linseed, and lentil during the winter and rice during the summer. Even at that, these farmers produce no marketable surplus; they are just able to meet the needs of their families. Now jump some 30 years into the future. The Dube and Baniya families have grown considerably yet their land holdings have not. How are they to meet their needs?

This brief profile illustrates the challenges facing farmers throughout Asia¹ in the coming decades. It also drives home the idea that science must contribute to opening productive options for farmers in the region. Many in Asia and elsewhere will participate in the complex process of agricultural development. Millions of farmers will implement solutions to increasingly difficult production problems, and thousands of extension specialists will be involved in reaching these farmers with new technologies. This report, however, focuses on the work of CIMMYT. It shows, by example, how our work for Asia relates to the region's problems and leads to new options for farmers.

improve, and that usually means increased consumption of animal products. That results in higher demand for maize and other feed grains. In Asia population and income growth will combine in the coming decades to boost the demand for food and feed by some 3-4% per year. At that rate, demand will double by 2020 (Point of View, page 13).

These projections mean that Asia's agricultural researchers and extension specialists will have to make a tremendous effort in the coming years if farmers are to stay abreast of growing domestic demand for food. Even if all goes well, grain imports are likely to

India were evaluating the performance of the new high yielding semidwarf wheats from Mexico.

The revolution in wheat--The impact of our work and that of our colleagues in Asia is perhaps best exemplified in this recollection by Dr. Norman Borlaug of the arrival of the "green revolution" in India in March of 1968:

Even with our enthusiasm, we had greatly underestimated the magnitude of the wheat harvest in the Punjab, Haryana, and western Uttar Pradesh, where much of the new technology was concentrated. Back then there were shortages of everything but wheat...labor for harvesting, processing, and moving the grain; jute bags; trucks; railroad cars; and storage space...all were in short supply. When the dust had settled and the final tally of the harvest had been made, it became clear that an unexpected five million tons had suddenly been added to India's wheat supply.

In Asia, changes in population and income will combine to boost the demand for food and feed by some 3-4% per year.

At that rate, demand will double by 2020.

To better comprehend the importance of these efforts, consider the following: Some 2.6 billion people now live in Asia, and according to the World Bank, about 20% of them live in abject poverty. Despite a promising downward turn in population growth rates, when the year 2000 arrives there will still be over 500 million *more* people to feed in the region. By 2025 the Asian population will rise to about 4.2 billion (Table 2, page 13), a level equal to the total number of people that were on the entire planet little more than a decade ago. Per capita incomes in the region are also projected to increase dramatically, on the order of 3% annually. When incomes go up appreciably, diets tend to

rise. In the face of other pressing needs, governments will have to invest additional resources in their agricultural systems and implement a range of policies conducive to agricultural development. The task is daunting, but if past success is a reliable indication of what can be accomplished in the future, then much can be done to increase the long term productivity of Asia's agriculture.

The Impact of CIMMYT's Past Work in Asia

The Center's support of Asian agricultural development actually predates CIMMYT's founding in 1966, going back to 1961 when the first national program scientists from the region--all from Pakistan--came to Mexico for practical training in wheat breeding and pathology. By 1963 both Pakistan and

The results of efforts in Asia by Dr. Borlaug and others--prominent among them Dr. Glenn Anderson, to whom this *Annual Report* is dedicated--graphically illustrate the important contributions made by germplasm improvement research to past gains in cereal productivity and agricultural development (see Point of View, page 12, and the box, Revisiting the Green Revolution in Wheat, page 22). Over 70% of Asia's wheatland is now devoted to semidwarf varieties (Table 3). Nearly all irrigated wheat production environments in the region are sown to semidwarfs, and during the 1980s they spread to all but the most marginal rainfed areas. Even in the more marginal areas, however, improved tall varieties are widely grown. The widespread use of improved wheat varieties, accompanied by significant increases in the use of fertilizer and, where possible, irrigation water, account for over 75% of the total increase in wheat yields in Asia during the past two decades.

¹ Unless otherwise specified, "Asia" refers to the countries of South, Southeast, and East Asia and excludes those west of Pakistan.

The promise of maize--New maize germplasm has so far been less widely accepted in Asia than improved wheats (Table 3), although there are exceptions. Several countries, such as Vietnam and Thailand (see box, The Public and Private Sectors in Maize Germplasm Development, page 24), have successfully promoted improved varieties, and high yielding hybrids have been adopted throughout China. Where such materials are grown in favorable environments--under irrigation during

the winter in India, for example--they have a substantial impact on production. Yet maize is often grown under less favorable conditions, even where it is the primary crop, and much of the higher yield potential of improved varieties thus goes unrealized. A second circumstance that complicates germplasm improvement is the wide variety of environments in which farmers grow the crop. Indian scientists, for example, must cater to five distinct maize zones that range from the

temperate Himalaya region to the flood prone lowland tropical areas of Uttar Pradesh and Bihar.

In spite of these obstacles, maize production has increased vigorously over the past two decades (Table 3). A large share of the output in some countries, such as Nepal and the Philippines, has contributed to food supplies, and to some extent the crop has provided materials for various industrial uses, including the production of starch and convenience foods. But a far more important source of demand for maize grain has been the steady expansion of livestock production, a trend that is creating many new opportunities for maize to contribute to the welfare of farm families and urban consumers.

The importance of people--Agricultural development is sometimes discussed as if it were a mechanistic process, devoid of human character or influence. We see it as quite the reverse: agriculture is, after all, a human invention. Certainly, improved germplasm made a vital contribution to transforming Asia's agriculture. But agricultural progress in the region is largely due to some 30 years of practical, creative, and unstinting work by thousands of national program scientists and extension specialists, as well as millions of farmers. CIMMYT has provided various kinds of training to nearly 2000 Asian scientists, and hundreds more have spent time with us in Mexico conducting research of interest to them and to the Center. The experience gained through such associations has helped create a dedicated cadre of maize and wheat scientists in the region who are versed in the need for farm level impact and in the importance of unhindered exchange of experimental germplasm.

While Asia's agricultural progress has been impressive, the job is far from complete; the work of national programs and CIMMYT continues. Our attention is shifting from initiating technological change to increasing its

Table 3. Maize and wheat statistics for the developing countries of Asia

	South Asia	Southeast Asia and Pacific	East Asia	All Asia
Maize				
Area, 1986-88 (000 ha)	7,553	8,917	20,233	36,702
Yield, 1986-88 (t/ha)	1.3	1.7	3.9	2.8
Production, 1986-88 (000 t)	9,524	15,054	78,009	102,785
Growth in area, 1961-65 to 1986-88 (%)	1.2	1.9	1.2	1.4
Growth in yield, 1961-65 to 1986-88 (%)	0.7	2.4	4.2	3.4
Growth in production, 1961-65 to 1986-88 (%)	1.9	4.3	5.5	4.8
Percent area sown to hybrids, 1988	11	6	74	44
Percent area sown to improved OPVs, 1988	42	32	0	17
Total, improved materials, 1988	53	38	74	61
Wheat				
Area, 1986-88 (000 ha)	31,623	0	29,827	61,450
Yield, 1986-88 (t/ha)	1.9	0	3.0	2.4
Production, 1986-88 (000 t)	60,134	0	89,894	150,029
Growth in area, 1965-67 to 1986-88 (%)	2.2	0	0.7	1.4
Growth in yield, 1965-67 to 1986-88 (%)	3.5	0	5.8	4.7
Growth in production, 1965-67 to 1986-88 (%)	5.8	0	6.5	6.2
Percent area sown to semidwarf wheats, mid-1980s	85	na	60	73

Source: Maize data are from CIMMYT *World Maize Facts and Trends* (forthcoming); wheat data are calculated using FAO data; percent area sown to semidwarf wheats from CIMMYT *World Wheat Facts and Trends* (1989). na = not applicable.

The Green Revolution in Wheat: 25 Years Later

Recently Dr. Norman Borlaug travelled to India and Pakistan to review progress and potential in wheat research and development. While there he met on several occasions with many of the agricultural scientists, administrators, educators, and policy-makers--some 50 individuals in all--who initiated and sustained Asia's "green revolution" in wheat production over the past 25 years. Far from just reminiscing, these colleagues and long-time friends analyzed events that ultimately transformed the agricultural landscape of Asia, took stock of the current situation in wheat research and development, and assessed the prospects for progress during the next two decades. Highlights of their discussions follow:



Chris Dowsell

- Mexican semidwarf wheat varieties and higher yield production technologies--introduced and strongly promoted during the mid-1960s--did much more than stave off widespread famine in India and Pakistan. They transformed South Asia's traditional, resource-based agriculture to a modern, science-based food production system.
- The green revolution in wheat demonstrates the enormous economic and social benefits that can accrue when appropriate government policies are backed by well-focused research. It gave credibility to agricultural research and motivated major new investments to develop national and international agricultural research systems.
- Borlaug and his CIMMYT colleagues (R. Glenn Anderson in India; Ignacio Narvaez in Pakistan) brought more than improved wheat germplasm and crop management practices to South Asia. Their philosophy of interdisciplinary teamwork, their orientation to dynamic field research programs, and their emphasis on the practical needs of small-scale farmers became models for national research organizations throughout the region.
- To maintain current levels of self-sufficiency in wheat production, South Asian farmers must increase output to 95 million tons (MT) by 2000 and 130 MT by 2010. Since little additional land is likely to be available for wheat production, virtually all additional output must come from higher yields.
- Production needs for 2000 can be met using existing technology. Reaching the production target for 2010 will be much more difficult, underscoring the urgent need to slow population growth and to improve the effectiveness of technology delivery systems.
- National wheat research systems are facing increasing institutional difficulties. Research budgets are declining in real terms, political expediency is subverting rational policy decisions, and serious underinvestment in rural education is reducing the ability of farmers to adopt more complex but sustainable high-yield production systems. These trends must be reversed and the entire technology generation and transfer system made more dynamic and effective if the momentum of the past 25 years is to be maintained.

momentum, and from developing the region's agricultural resources to preserving their productivity. In the context of these changing perspectives, some have begun to question the extent to which research should concentrate on improving germplasm relative to other potential investments (Point of View, page 14). Although we are cognizant of such concerns, our strategy emphasizes new approaches to research that complement and extend the impact of our germplasm improvement work.

New Approaches to Research

CIMMYT's primary activity is clearly plant breeding, and our main products are obviously improved maize and wheat germplasm. Our continuing emphasis on this research and these products reflects an enduring belief that better varieties are an effective means of raising the productivity of agricultural resources in developing countries. The emphasis on productivity influences decisions about priorities and how we and our national program colleagues can most effectively allocate research resources. In general terms, CIMMYT is shifting its emphasis toward basic and strategic forms of research and away from direct participation in the applied and adaptive work needed to promote farm-level adoption of new technologies (see Comments from Management, page 5). This fundamental change is occurring for several reasons. The objective of becoming ever more efficient is central to our rationale, as is the observation made by Dr. Vernon Ruttan (Point of View, page 12) that new sources of productivity growth must be developed.

CIMMYT's regional programs, in Asia and elsewhere, figure prominently in our effort to become more efficient and to search for new sources of growth. When we first implemented the concept of regional programs back in the early 1970s, our primary goals were to help strengthen national research programs, improve communication between the Center's headquarters in Mexico and its

national program clients, and to do a better job of assessing the germplasm products developed in Mexico. Since then, the means to those ends and, in some cases, the ends themselves have changed. For example, over the years we have moved some of our research away from headquarters to locations where breeding for specific biotic and abiotic stresses not prevalent in Mexico can be accomplished more efficiently. Our research on downy mildew resistance in maize, being done by CIMMYT regional staff in Thailand in conjunction with the Thai national program, illustrates this strategy.

Our growing emphasis on strategic research offers numerous opportunities for further strengthening national programs through collaborative research while multiplying the impact of CIMMYT's work in Asia. Examples include our regional wheat pathologist's epidemiological studies of the rusts of wheat in Asia and the planned CIMMYT/IRRI/national program crop management research on factors affecting the productivity of the region's vast rice/wheat rotation. Not only do such approaches add to the efficiency of research, they are vital to the development of new sources of growth, enabling us to more effectively identify and resolve major constraints to improved productivity.

Due to the importance of regional programs in meeting the Center's objectives in Asia, CIMMYT maintains four offices there, staffed by nine senior scientists: four crop improvement specialists, three agronomists, and two economists. Financial support for much of their work comes from special project donations, though a significant portion of the Center's core funds are invested as well (see Financial High-

A good example of decentralized germplasm improvement research is the work being done by CIMMYT's maize regional staff in conjunction with the Thai national program. Four adapted maize populations, all with resistance to downy mildew, are being developed to provide new sources of resistance for national programs in the region.

lights, page 59). Bilateral project offices are located in Dhaka, Bangladesh (with funding from CIDA--the Canadian International Development Agency) and in Islamabad, Pakistan (with funding from USAID--the US Agency for International Development). The United Nations Development Programme (UNDP) supports the work of a wheat crop improvement specialist for the warmer marginal environments of Southeast Asia, and our core funded regional staff work out of offices in Nepal (Kathmandu) and Thailand (Bangkok).

Challenges to Asia's Agriculture

Asian agriculture faces several compelling challenges. Ways must be found to both sustain the gains in productivity that Asian farmers have already made and to realize more of the potential that current technologies have to offer. Another challenge is to devise technologies that permit even more intensive use of available land while maintaining overall productivity. And a third is to be successful in meeting these first two challenges while preserving, and



Nathan Russell

The Public and Private Sectors in Maize Germplasm Improvement

Though still problematic in many developing countries, relationships between the public and private sectors in maize germplasm improvement can be cooperative and productive, as is the case in Thailand. There the two have managed to achieve a mutual understanding of their distinct but overlapping roles and of the advantages to be gained from cooperation.

The benefits derived by the private sector from public maize research in Thailand are considerable. By developing and releasing improved varieties, such as Suwan-1 and Nakhon Sawan-1, public sector maize scientists have provided highly marketable products for local agribusiness firms, whose sales complement the seed distribution efforts of public institutions. Moreover, widespread adoption of these improved varieties by farmers has helped create a favorable environment for various multinational seed companies, and area planted to their hybrid maize is gradually expanding. In seeking to develop better adapted, more competitive products, some companies are drawing heavily on the national program and CIMMYT's stocks of improved germplasm. Several are also employing the methodology by which Thai and CIMMYT scientists improve the resistance of their materials to downy mildew, an important disease of maize.

Some argue that national programs should be remunerated for their services to the private sector. Sujin Jinahyon, vice rector of Thailand's Kasetsart University, suggests that, since the private sector will capture 25% or more of the seed market within 10 years, it makes sense for the university to gear some of its maize research to the development of gene pools and inbred lines for sale to private companies. Public institutions might also produce final product hybrids for smaller seed companies that cannot afford to invest heavily in research and development. The public sector, says Taweesak Palam, manager of Pioneer Overseas Corporation in Thailand, could thereby help "provide farmers with additional options and maintain prices at a fair level."

The Thai example shows that cooperation between public and private sector institutions must be based on strength and mutual respect. In general, national programs must have an independent agenda determined by, among other things, the needs of poor farmers. If sufficiently strong, such programs can cooperate with the private sector and still provide an objective source of information about seed company products. In Thailand, cooperative maize yield trials are conducted each year to determine the relative performance of germplasm available from the public and private sectors, and staff from the Department of Agriculture monitor seed production fields to ensure that quality standards are being met. These and other services are what establishes the credibility of government maize researchers as public servants. They also demonstrate how such complementary relationships benefit all concerned.

improving if possible, the longer term productivity of the region's natural resources.

That task is further complicated by the question of how limited research resources should be targeted. To what extent, for example, should CIMMYT concentrate on further improving the productivity of favored areas relative to marginal production environments? There are differences of opinion. Many feel that substantial investments must be made in research oriented toward marginal environments, either because growing demand for cereals will force more production into such areas or because of a perception that relatively more poor people live in them. Others see a larger role for research oriented toward the productivity of favorable environments. And, of course, some believe that we must do more of both.

For the next 10 to 15 years, favored environments will receive much of CIMMYT's attention, primarily because the bulk of Asia's additional agricultural output, especially of food and feed grains, must come from these areas. We feel that the productivity problems presented by marginal environments are especially difficult and the probability of near term success in research is low. We also believe that technological progress in favored areas brings benefits to those living elsewhere through lower food prices for poor consumers, "spillovers," and labor migration. A better understanding these complex relationships and the effects of change on the poor is needed before research resources are shifted in any dramatic fashion to riskier and potentially less rewarding undertakings.

Increasing the Momentum of Productivity Gains

The significance of the challenges to Asia's agriculture varies by crop. Relative to wheat, for example, the most immediate problem appears to be the slowing of productivity growth in those countries that were early beneficiaries

of modern varieties. Maize researchers, on the other hand, are aware they must overcome the key constraints to adoption of improved varieties if they are to build upon recent gains in productivity.

A slowing of gains in wheat yields--In India and Pakistan the rate at which wheat yields have been increasing slowed significantly during the past decade (Table 4). At least two key elements appear to be at work here. First, farmers in the major wheat producing areas have already adopted most of the newer technologies and their management skills are such that they capture much of the potential these technologies have to offer; indeed, much of what remains may not be economically recoverable. There are, of course, notable exceptions to this circumstance. In some large favored areas, such as Pakistan's irrigated Punjab and eastern India, wheat yields remain low (about 2 t/ha) relative to potential even though farmers use improved wheat varieties and modest to high levels of fertilizer. Higher yields are possible from existing varieties through improved crop and resource management. Second, such factors as soil salinity, micronutrient problems, soil structure and health, poor stand establishment, and worsening weed problems appear to be adversely affecting productivity in some key production systems.

Table 4. Changes in growth rates of yields in the major wheat producing countries of Asia

Country	Annual growth rate in wheat yields (%)		
	1951-66	1967-77	1978-88
India	2.09	4.42	2.84
Pakistan	0.85	4.95	1.39
China	1.37	5.94	5.87

Source: Calculated using FAO data.

Because improved wheat varieties are now widely used in Asia, some people have the mistaken impression that the wheat breeders' job is essentially done. Fortunately, the breeders in CIMMYT and in the region's national programs do not agree. Since the advent of semi-dwarf wheats, and the attendant large jumps in productivity, breeders have steadily added about 1% per year to yield potential in favored environments (gains under less favorable circum-

stances are roughly half that). They have also improved yield stability by greatly increasing disease resistance and by adding tolerance to certain abiotic stresses, such as drought (see Wheat Research, page 43).

crop loss and the need to use expensive and potentially hazardous forms of chemical control. Not to diminish the importance of other diseases, by far the most threatening to wheat production in Asia are the three rusts. The causal organisms--obligate parasites--are highly mutable, and resistant varieties generally become susceptible to attack not long after widespread cultivation. CIMMYT's Wheat Program consequently invests considerable resources

The enhanced disease resistance of CIMMYT wheat germplasm lends stability to production, reducing both the risk of crop loss and the need to use expensive and potentially hazardous forms of chemical control.

stances are roughly half that). They have also improved yield stability by greatly increasing disease resistance and by adding tolerance to certain abiotic stresses, such as drought (see Wheat Research, page 43).

Although higher yield potential propelled the semidwarf wheats across Asia, their enhanced resistance to disease is arguably an even more important trait, lending stability to production and reducing both the risk of

in breeding research directed at staying ahead of these mutating pathogens. Even more important, the Program is aggressively engaged in the search for durable resistance to them.

With respect to stem rust (*Puccinia graminis*), this search has already proven successful. Durable resistance, conferred largely by the *Sr2* gene, has protected CIMMYT-derived bread wheats from stem rust epidemics for some 20 years. We now have encouraging evidence (see Wheat Research, page 41) that similarly durable resistance may be possible against leaf rust (*P. recondita*). As for stripe rust (*P. striiformis*), recent indications are that sources of durable partial resistance exist. The search will continue, especially for durable resistance to leaf rust. Throughout Asia large areas are sown to susceptible varieties and, should the right conditions prevail at the right time, serious epidemics of leaf rust could occur. Farmers need new options to guard against this eventuality.

Regional wheat staff are engaged in a number of activities that address Asia's vulnerability, not only to the rusts of

wheat, but also to other sources of yield instability. They are urging government decision makers to give a higher priority to the multiplication and release of newer rust-resistant varieties and to extension strategies aimed at preventing epidemics. Regional staff are working with Indian wheat pathologists to enhance the national program's capacity for analyzing rust races. Such work requires special skills and facilities, as well as a network of trained people for collecting samples. In a related effort, regional wheat pathologists are helping to broaden the array of germplasm being screened by supporting a regional disease trap nursery. Compiled in India, this nursery is now sent annually to all wheat producing countries in the region. Its purpose is to identify the emergence of new races of rust.

Other research aimed at improving the stability of wheat yields points to the use of varietal mixtures as an effective option for farmers. A three-year study of varietal mixtures, cosponsored by the United Kingdom's Overseas Development Administration and CIMMYT, was concluded in 1989. Preliminary assessments of experimental results indicates that this may be a cost-effective strategy for enhancing stability across environments and over time. Trials were grown in a number of locations in India, Pakistan, and Nepal. Over all environments, the mean yield of the three-variety mixture (widely grown commercial cultivars were used) was about the same as the mean yield of each of the component varieties grown separately, which is to say that there appears to be no yield penalty for

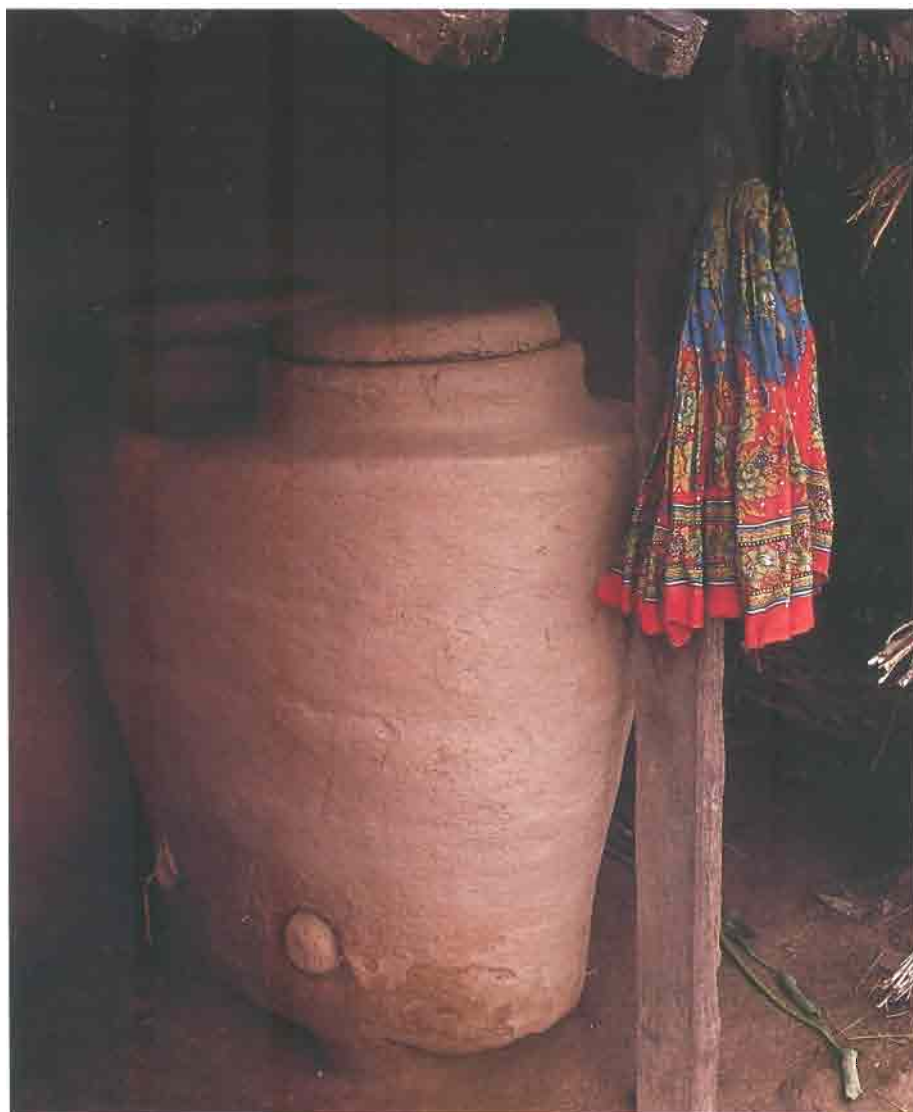
growing the mixture. Moreover, the mixture appears to provide greater yield stability across environments. Future trials will go beyond testing the efficacy of the mixtures strategy to examine alternative varietal mixtures themselves.

Still another way to reduce wheat production risks is to ensure the availability of new varieties to replace those that have become susceptible to mutating pathogens. In Pakistan recent diagnostic surveys involving economists and biological scientists focused, for the first time, on identifying sources of wheat seed used by farmers and on how they manage their seed once they have it. Subsequent surveys identified those varieties that are actually planted and explored farmers' motives for changing varieties. Researchers identified the need for policies that would enable Pakistan's research and seed systems to improve farmer access to new varieties and made specific recommendations toward that end. Such work illustrates how social scientists can help identify important problems and highlights the need for effective policies that enhance farm level adoption of newer technologies.

Productivity of the rice/wheat

rotation--Some 30% of South Asia's 32 million ha of wheat are sown in rotation with rice. It has long been believed that this rotation could be made more productive: only recently has concern emerged about declining productivity in some areas. Diagnostic surveys have been done at various times during the past decade. The three most recent surveys, focused on rice and wheat in the *terai* of Nepal and on wheat in the *terai* of Uttar Pradesh in India, were conducted jointly by CIMMYT, IRRI, and national program staff. Like others before them, these surveys were

Recent surveys have provided insights into farmers' sources of wheat seed and how they manage it between cycles. Clay urns, such as this one on a farm in the *terai* of Nepal, are commonly used for storing grain throughout the region.



Thomas Lubba

designed to identify constraints to improved productivity; they differed from previous efforts, however, in that they were conducted by rice and wheat specialists representing a broad range of disciplines (agronomy, anthropology, economics, entomology, extension, pathology, and plant breeding). Initial findings indicate that the productivity of the rice-wheat system may indeed be declining, at least in certain areas. Some farmers say that yields of one or both crops are decreasing, and long term fertilizer trials on experiment stations would seem to corroborate their belief.

CIMMYT and IRRI have proposed a five-year collaborative research project--involving a number of researchers from national programs in addition to CIMMYT and IRRI staff--that will seek to address near term productivity constraints and longer term sustainability issues related to the rotation. According to the plan developed in late 1989, within three years of project initiation (scheduled for September 1990) the major constraints to farm level productivity should be identified and research designed to overcome them well along. As indicated by the composition of the survey teams, research will be interdisciplinary and, although appropriate germplasm will no doubt play a part in raising productivity, strategic and applied crop management research will provide the key to opening options for farmers (see box, Crop Management Research in Asia, page 28).

On-farm testing and evaluation of new technologies will be an integral part of the project, and the analysis of costs and benefits will be indispensable for

Diagnostic surveys focused on identifying constraints to improving the productivity of South Asia's rice/wheat rotation are conducted jointly by CIMMYT, the International Rice Research Institute, and national programs. Jesse Dubin (left), CIMMYT's regional wheat pathologist, and H.P. Bimb (center), a wheat pathologist for Nepal's National Wheat Development Program, here examine a sample from a farmer's rice field.

assessing the likelihood of adoption by farmers. Social scientists will play an important role in assessing alternative technologies, whether for the rice/wheat rotation project or other such ventures (see Economics Research, page 47). Since long term research will be required to develop such technologies, research managers will need reliable information to justify on-going financial support. Finally, resource preserving technologies will often be more complex than existing modes of production, implying a fairly steep learning curve for farmers. Social scientists can help by factoring ways to reduce farmers' "learning costs" into research and extension strategies.

Increasing the momentum in maize--

During the next 10 years, demand for maize in Asia is projected to grow at about 3.8% annually, largely because of the rising demand for feed. To keep pace, national programs are attempting to reach beyond existing varieties to establish a new generation of improved materials. CIMMYT's regional maize staff and researchers at headquarters are supporting these efforts in various ways, mainly by shaping a wide selection of germplasm to the major environmental circumstances in Asia. One of our main contributions so far has been to engage

in cooperative research for developing varieties resistant to the downy mildew disease; these have been released to farmers in some Asian countries and used by researchers as sources of resistance in others. In an effort to guard against a breakdown of resistance in previous materials and to provide germplasm with even more desirable agronomic traits, regional staff are developing four new maize populations with stable resistance to downy mildew.

They have also begun to concentrate on abiotic stresses occurring in the less favored environments where maize is often grown. Working with researchers in Indonesia, for example, Center staff are screening germplasm for tolerance to high soil aluminum concentrations, and in China and Thailand they have established research partnerships for developing drought tolerant germplasm. Regional staff are exploring similar opportunities for cooperative research on stalk rot, turcicum leaf blight, and stem borers. In addition to their own breeding projects, they will help target germplasm emerging from research at headquarters, including new materials adapted to the highlands and subtropics (see Maize Research, page 35).

Thomas Luba



Crop Management Research in Asia

Asia's diverse farming systems offer numerous opportunities for the more productive use of soil, water, and other natural resources. Crop management research provides an effective means of identifying and dealing with farmers' production problems, thereby increasing agricultural productivity. To be most effective, crop management research requires a farming systems perspective, as well as an integrated, multidisciplinary, problem-solving approach to the research. Biological scientists, economists, extension specialists, and farmers all need to be involved.

Crop management research is normally quite site-specific, and hence falls under the purview of national programs. Still, CIMMYT agronomists and economists have often assisted national programs as they developed practical solutions to specific maize and wheat production problems. At the same time, Center staff have provided training in effective research methodologies, such as on-farm research, and have encouraged a multidisciplinary approach to this work. As national program efforts have become more effective in this area, CIMMYT's work has acquired a broader, more strategic character, addressing issues of regional importance. Yet this strategic research requires a strong sense of what is happening in farmers' fields; hence the continuing importance of farm-level research.

The efforts of CIMMYT and others to strengthen national program capacity in crop management research, and in on-farm research specifically, are now paying handsome dividends. Maize researchers at the University of Southern Mindanao in the Philippines, for example, have conducted collaborative on-farm research with CIMMYT on the management of "aguingay" (*Rotboellia cochichinensis*), a weed that can cause severe losses. In India, the National Coordinated Maize Program will soon begin training of maize agronomists in on-farm research and will include these procedures as an integral part of the overall crop management research strategy. And in Thailand and Pakistan, crop management research on planting wheat after rice with zero tillage has yielded results that may prove useful in other parts of Asia.

While the importance of crop management research is generally acknowledged by national programs in Asia, a farming systems perspective to the work is sometimes difficult to maintain. To provide a more effective framework for such research, CIMMYT's Bangkok-based regional maize agronomist and regional economist developed a model that outlines the functional steps of an integrated research program. Careful distinction is made between the research needed to define a problem and the research required to solve it. Although the same or similar sources of information may be used, such as farmer surveys and on-farm trials, the objectives and analytical

techniques differ for the two research endeavors. To demonstrate how this framework can be applied, our regional maize agronomist is collaborating with Thailand's Department of Agriculture and Department of Agricultural Extension to investigate zinc deficiencies on the Ta Kli soil series in Nakhon Sawan and Petchabun provinces.

On-farm research is one way among many to increase the effectiveness and efficiency of crop management research. A more fundamental means is to improve priority setting, so as to ensure that the right research is being undertaken. To guide such decision making, both CIMMYT and national programs need better information. Toward that end two important activities are now underway. The Center's regional maize agronomist recently initiated a long term strategic research project in cooperation with selected Asian programs aimed at gathering reliable production statistics, detailed information characterizing production environments, and profiles of current production technologies. A second effort, more fully described on pages 26-27, involves the multidisciplinary rice/wheat diagnostic surveys recently conducted in Pakistan, Nepal, and India. The purpose of these surveys is to determine the extent to which the productivity of this system may be declining, and to provide basic information for the proposed research project on the rice/wheat cropping system of South Asia involving CIMMYT, IRRI, and national programs. These strategic efforts, backed by solid, site-specific agronomic research by national programs, illustrate the type of crop management research we believe is needed to achieve more intensive, sustainable agricultural production in Asia.



Boron deficiency in intensively cropped soils has been linked to floret sterility in wheat. CIMMYT's regional wheat agronomist, Peter Hobbs (left), occasionally consults with Thai researchers who are seeking better methods of identifying boron deficiency.

Better germplasm products are essential to sustaining the momentum of maize, but other constraints must be surmounted as well. In Pakistan, for example, maize is a staple food in the north and an important fodder and grain crop in Central Punjab, but average yields in the country remain low, at 1.2 t/ha. Pakistani scientists have long believed that several factors, in addition to a lack of varieties adapted to cooler environments, slow the adoption of improved varieties and management practices. Seed production problems, dual uses of maize for grain and fodder, and limited access by farmers to markets and inputs all appear important. A detailed formal survey of maize in the country's major growing environments, initiated in 1989 by maize researchers from the National Agricultural Research Centre (NARC) and CIMMYT's economics staff in the region, appears to support the national program view. When the final results are synthesized, researchers and policy makers will have a complete picture of maize in Pakistan: production zones and systems; yields; detailed marketing and price information; farmers' maize growing practices, including the levels of inputs they use; how and when farmers obtain new seed; which varieties farmers prefer, and why; and how maize grain and by-products are used.

The research in Pakistan is a good example of the work done throughout Asia. Over the years, we have collaborated with the farming systems research programs of several countries, especially Thailand, Indonesia, and the Philippines. This work, incorporating the expertise of specialists in different commodities and disciplines, has included efforts to understand farmers' reluctance to use fertilizer on maize in Thailand; difficulties associated with weed control in the Philippines; and the

Farmers use maize for fodder as well as for grain in Pakistan and other Asian countries, a fact that may be slowing the adoption of varieties that have been selected more for their high yield potential than for total biomass production.

complex interactions between insect attack early in the maize growing season, plant stand management, and lodging in Indonesia. In the course of these joint efforts, CIMMYT staff gain insights into factors constraining productivity, and their national program colleagues gain experience and facility with a range of research methodologies.

Such multidisciplinary research has generated a base of information that can be used by government decision makers, researchers, and extension specialists to fashion policies, new technologies, and delivery strategies consonant with the realities faced by farmers. The utility of that information is increasingly recognized throughout

To keep pace with rapidly growing demand for maize, national programs are attempting to establish a new generation of improved materials. CIMMYT staff support these efforts by shaping a wide selection of germplasm to the major environments of Asia.

Thomas Lubba



national research systems (see box, An Interview with Amir Muhammed, page 33).

Intensifying Crop Production in Asia

Clearly, many of CIMMYT's activities in Asia focus on sustaining the momentum of productivity gains already achieved and on realizing more of the potential offered by modern varieties and farming methods. As important as this may be, resources are also committed to the difficult task of intensifying crop production where possible. We do this basically in two ways: by developing new genotypes for national programs to use as they create varieties that precisely fit the tight spaces available for them in complex cropping systems and by complementing that effort with strategic crop management research aimed at understanding the variables at work in those systems.

Germplasm to fit complex systems--

Using the improved germplasm currently available, some national maize programs are showing extraordinary ingenuity in finding ways to intensify the production of complex cropping systems. In Vietnam, for example, scientists have successfully promoted transplanting of maize seedlings for production in the winter season after rice harvest, where previously fields were left fallow until the next rice planting. In 1988 winter maize was sown to some 140,000 ha in the Hanoi area, with an average yield of 3.2 t/ha. Transplanting maize is a labor intensive operation, but farmers will readily make this investment if the net gain is attractive; they are naturally less inclined to do so if it is not. Researchers hope to provide a new option, one that will make the system more flexible, by introducing improved early maturing maize germplasm. Farmers will then have the choice of growing high yielding varieties that can be sown directly and still mature before the next rice planting, or they may opt for transplanting an improved, later

maturing variety, which will generally produce more than the early maturing one.

The case of winter maize in Vietnam argues compellingly for better meeting one germplasm need that is evident throughout the region. High yielding, early maturing maize germplasm would offer advantages in many of Asia's complex cropping systems. In addition to enabling farmers to intensify production, it can contribute to maize yield stability through drought escape. To help national programs begin realizing these possibilities, regional maize staff are developing two new early maturing populations (two of the four downy mildew resistant materials mentioned previously), and increased emphasis has been given to this category of germplasm in the breeding work at headquarters.

Expanding into new areas--Just as maize is moving into areas where it has not been grown before, so too is wheat. The genetic diversity of maize, coupled with farmer ingenuity, facilitates such movement. Despite the evident ingenuity of wheat farmers in the region, however, moving this crop into new areas is proving more difficult. Even so, wheat is now being grown in some unlikely places, at least on an experimental basis.



Gene Hetzel

Southeast Asia, for example, is a new and somewhat controversial region for wheat research and production. Our research there, currently supported by UNDP, focuses on wheat for the warmer, more marginal areas. CIMMYT regional wheat staff and their national program colleagues believe the prospects are good for developing appropriate genotypes and management practices.

With the exception of Myanmar (Burma), little area in the region is currently devoted to commercial wheat production. However, there appears to be potential for growth, particularly in the rainfed uplands. Thailand and the Philippines, even though they do not grow much wheat at present, are enthusiastically conducting research. Some of their work focuses on such problems as boron deficiency and spot blotch (*Helminthosporium sativum*), a potentially devastating disease of wheat in warmer, humid climates. Solutions to these problems may be applicable in some traditional wheat areas as well. Other potential benefits include resistance to sclerotium wilt (*Sclerotium rolfsii*) and heat tolerance.

While it appears technically feasible to grow wheat in parts of Southeast Asia, it may not be profitable to do so--at least not now. With high irrigation costs, low yields, and/or competing uses of land, the argument in favor of domestic wheat production is currently difficult to make. But varietal improvement and crop management research could alter the profitability of growing wheat in these environments. Thai economists are analyzing the economics of producing wheat locally, now and in the future. The objective of the study is to provide guidance to researchers and policy makers as they establish priorities for research and development.

Bangladesh has greatly expanded its irrigation in recent years, bringing water to an additional 300,000 ha of previously unirrigated land. Although essential to the country's food production program, there is growing concern about the environmental effects of this expansion.

Sustaining Long Term Resource Productivity

Increasing the momentum of productivity improvements, realizing more from currently available technologies, and intensifying cropping patterns are key to meeting Asia's projected agricultural demand to 2020 (Point of View, page 14). But meeting the region's needs for food and feed after that will depend on sustaining the long term productivity of already heavily used natural resources, especially soil and water. Multiple

cropping, erosion, and irrigation are even now exacting a toll on these resources.

The Technical Advisory Committee (TAC) of the CGIAR observes that "sustainable agriculture should involve the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources." While the phrase "changing human needs" is open to interpretation,

certainly one aspect of change that must be accommodated is the inevitable growth in demand for food and feed.

CIMMYT's general strategies and our specific activities and products, all of which are aimed at meeting that growing demand, reflect consideration of sustainability issues. To begin with, the Center's emphasis on increasing resource productivity helps ensure a sustainability orientation to our work. Because of that emphasis, we avoid practices that will mine the natural resource base upon which the future productivity of agriculture rests. We also believe that our strategic focus on increasing productivity in favored environments will help ease the pressure on areas less suitable to agriculture.

As for more specific activities and products, the following illustrate how our work relates to sustaining natural resources, whether in Asia or elsewhere. Research on diseases and insects, for example, some of which was described earlier, is yielding resistant germplasm that reduces the need for costly and environmentally risky forms of chemical control. Similarly, some of our improved materials appear to be more efficient in the uptake and utilization of inputs, especially water and nitrogen. We are working with others to understand the mechanisms involved and to further enhance those efficiencies. Our efforts to conserve genetic resources (see *CIMMYT 1988 Annual Report Delivering Diversity*) rest on the important role these resources play in germplasm improvement research: we are conserving today that which may be needed to improve agricultural productivity tomorrow. Finally, agronomists, economists, and breeders are jointly developing minimum tillage practices (combined with crop residue retention) designed to reduce the risk of soil erosion. Such tillage systems engender

Soil salinization due to inadequate drainage of irrigation water is adversely affecting agricultural productivity in parts of Pakistan and in some other Asian countries

The ability to meet Asia's needs for food and feed after 2020 will depend on sustaining the long term productivity of already heavily used natural resources, especially soil and water.



Jim Longmire

a range of biotic and abiotic stresses, and new resistant genotypes will likely be needed for them. As the range of these examples illustrates, nearly all of CIMMYT's work can be connected in meaningful ways to sustaining natural resources for future generations. At the heart of our thinking about this challenge is the notion, well formulated by others, that we do not inherit our natural resources from our ancestors so much as we borrow them from our children.

The Importance of Institution Building

The effectiveness with which the national programs of Asia fulfill their responsibilities in large measure will determine how well the region's farmers are able to satisfy the agricultural demands of consumers. In his Point of

View (pages 10-17), Dr. Ruttan makes much of the need to reorient the organization of agricultural research and intensify the institutionalization of research capacity in developing countries. Moreover, he calls for the creation of new institutions having closer linkages to developed country centers of excellence than do, in his opinion, the CGIAR-sponsored international centers.

Clearly, some of what Dr. Ruttan envisions is for others to ponder and perhaps implement. As noted earlier, CIMMYT has contributed to the process of institution building in Asia mainly by investing in people, and the payoff associated with those investments is evident in the region's agricultural progress to date. We recognize, however, that needs have changed and that we must refocus our efforts. Some

of our current activities will continue, including our Mexico-based training in breeding, pathology, and experiment station management, as well as in-country courses on specific topics like seed production and data analysis. Increasingly, certain advanced national programs will assume responsibility for basic training in crop management research. Various advanced courses are now being offered in Mexico aimed at midcareer scientists from developing countries, giving them an opportunity to refurbish skills and conduct specialized research relevant both to CIMMYT and their national programs.

Also noted earlier, we are seeking new forms of cooperation with national programs. In some instances, that cooperation is taking the shape of "research partnerships," in which specific roles and responsibilities are

Thomas Luba



CIMMYT elite maize germplasm is sometimes used for agronomic trials, such as here at the Lumule Agricultural Centre in Nepal. B.R. Sthapit, Chief Agronomist for the Lumule Centre, notes that even though EVT 17 is not well adapted to the local environment, useful agronomic data can be obtained from such trials.

established according to the capabilities of those involved. Participants learn from one another in the course of these associations, adding to their respective stores of knowledge and to their potential research capacity. Examples of this approach include the recent agreements between CIMMYT and the Thai Department of Agriculture (downy mildew resistance in maize), the Chinese Academy of Agricultural Sciences (fusarium head scab resistance in wheat), China's Yunnan Academy of Agricultural Sciences (drought tolerance in maize), and Punjab Agricultural University (Karnal bunt resistance in wheat). Several other research partnerships with developing country national programs have been established outside Asia as well.

Finally, other forms of cooperation emphasize broader participation within the international community of agricultural scientists. Such cooperation often involves one or more developing country programs and universities, as well as colleagues from sister institutes and from developed country centers of excellence. We have used this kind of collaborative research to good effect in the past, and we will increasingly rely upon it in the future. An example from Asia is the planned CIMMYT/IRRI/national program rice/wheat project described earlier, which embodies key elements of this approach.

In efforts like these, the skills and knowledge of the participants combine in synergistic and mutually advantageous ways. This quality characterizes many of CIMMYT's undertakings. We strive to mobilize and combine the experience, energies, and talents of agricultural scientists around the world such that the end result of the total effort surpasses the simple sum of individual contributions. And in all of our work, for Asia and for other regions, one common goal prevails, that of opening new options for farmers in developing countries.

An Interview with Dr. Amir Muhammed

— Pakistan —

Dr. Amir Muhammed has long been involved with agricultural development, notably as Minister of Agriculture for Pakistan, then Chairman of the Pakistan Agricultural Research Council (PARC) for 12 years, and presently as a member of the Technical Advisory Committee of the CGIAR. We recently sought his views on several key issues.



Thomas Lubat

What is the greatest challenge to Pakistani agricultural research in the next decade?

In my view, the biggest problem is the gap between potential yields and those obtained by farmers. We have shown through research that we can get yields three times as high as the national average. So we have to do a careful analysis of the whole production enterprise, including economic factors, to determine how we can realize that potential. Improving agricultural production in Pakistan is now much more complex than planting improved seed and using more fertilizer. We don't have any more land, population has increased tremendously, and we are basically an arid country where water is ultimately the limiting resource.

What kinds of research will be needed to address these more complex problems?

Farming systems research has come up as an important means of understanding how the small farmer really survives. In developed countries, farming has become a specialized profession undertaken by people who are often qualified to do other things. But in the developing countries, farmers have little opportunity to move out of agriculture. Furthermore, in Pakistan over 60% of all farmers have small holdings and the approaches followed in developed countries can be seriously misleading, unless our scientists are sensitized to look at problems differently. Farmers have wheat, fodder, vegetables, maybe buffaloes, cows, chickens: what matters is that, at the end of the day, with family labor and limited land and water resources, how much money has one hectare produced?.

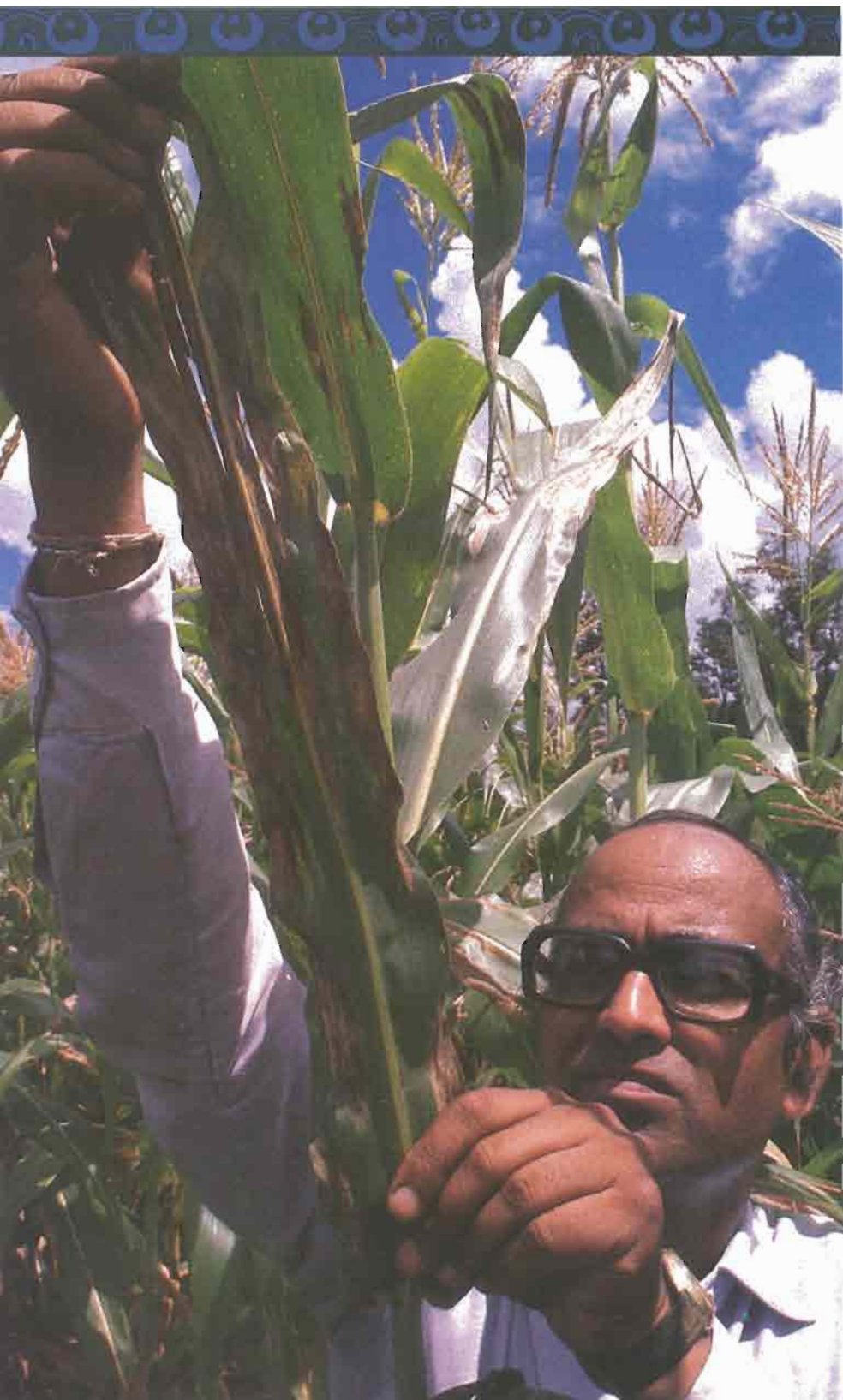
And the role of commodity experts in that situation?

The trouble with the commodity experts is that they only ask the farmer: What has been your wheat yield? What is your maize yield? They tend to evaluate the whole system on that basis only. But if a farmer grew miracle wheat and put nothing else in the field the rest of the year, he would probably be a miserable man compared to the one who harvested two or three crops per year in a rotation. When it comes to actually practicing agriculture, the situation here is much more complex. And our scientists have to be sensitized to that.

Has social science research improved the understanding of farmers' situation in Pakistan?

I would say so. For example, a few years ago the Agricultural Economics Research Unit (AERU) in Punjab interviewed farmers and made the startling revelation that 40% of farmers were still using varieties susceptible to disease. No biological scientist had actually taken the trouble of conducting a survey to see what farmers were doing. The social scientists did it and everybody's eyes sort of popped open. Since then the AERUs--there is one on the campus of each provincial agricultural research institute and one in Islamabad--have done more farming systems studies and other kinds of research, and I think we are entering a phase where the role of social science in agricultural research is really becoming appreciated.

Maize Research



Nathan Russell

A common concern of scientists in national maize programs is that, although their academic training has taught them how to conduct research, it has provided them with little help in resolving the issue of what research to conduct. Difficult enough in a single country, this question is especially complicated for CIMMYT's global maize program.

For researchers in national programs and at CIMMYT, the task of assigning research priorities has been made easier by the work of our regional maize specialists. Their main contribution to priority setting in developing countries has been to offer training in on-farm research, which is critical for accurately identifying farmers' problems, and to provide assistance in research planning. Through their contacts with national programs, regional staff have obtained valuable insights and data about the circumstances of maize production in developing countries, which in turn have helped CIMMYT researchers to determine what categories of germplasm require additional emphasis, which traits are still lacking in this germplasm, and what types of training and other assistance national programs need to conduct their germplasm development and crop management research more effectively. Some of the needs identified are being met by the regional staff themselves through cooperative research projects in developing countries. The following sections discuss work that illustrates particularly well how we adjust research and related activities according to information received through the regional programs and other contacts with our clients, and some sections highlight the role of outreach staff in making those changes.

Highland Germplasm Development

In few areas have the adjustments been as dramatic as in our program for improving highland maize. From 1978 to 1985, the program was geared almost entirely to developing germplasm with the soft flourey and morocho grain types. This allocation of resources was dictated primarily by a scarcity of improved germplasm for the Andean zone, to which these types are unique. Transfer of the work to national programs in the region enabled us to reorient the breeding program at headquarters toward hard endosperm germplasm, which is the preferred type over 93% of the world's highland area.

Deep planting to tap residual moisture--The first task of the program at headquarters was to generate new hard endosperm populations with improved plant type, agronomic traits, disease resistance, and tolerance to various abiotic stresses. Now that a number of good general purpose populations have been developed for all of the major highland mega-environments, the program has also initiated various projects for "fine tuning" the germplasm, so that it more closely meets farmers' requirements. One such project was inspired by a practice that Mexican farmers employ to permit earlier planting of maize. In some areas of the country's highlands, they sow immediately after the danger of frost has passed, some 45-60 days before the rainy season arrives, placing the seed 10-25 cm deep in the soil's reserves of residual moisture with a shovel type instrument (called *tepoztoctoc* in the indigenous Nahuatl language). The aim of our breeding program was to retain the capacity of Mexican highland germplasm to emerge from deep planting while improving its agronomic traits, particularly lodging resistance. What complicated the task is that the sources of these improvements are nonhighland materials that will not emerge if planted deeper than 13 cm. Nonetheless, after three cycles of

selection in four populations (Tepoztoctoc 1-4), the materials emerge reliably from 20 cm and have improved agronomic traits. From these populations national programs can develop varieties or employ the inbred lines we are deriving from them in hybrid development or as sources of the ability to emerge from deep planting.

Highland materials for Africa and Asia--In addition to drawing upon experience in Mexico, where highland maize has been grown for thousands of years, we are developing new populations to meet the demands of farmers in Africa and Asia. These materials require much greater lodging resistance than the weak rooted highland types of Mexico, because hilling up and planting maize in the furrow, a measure Mexican farmers take to prevent root lodging, is not a common practice of growers in Africa and Asia. In the higher latitudes in Asia, farmers also need highland materials that are photoperiod insensitive. For these areas we have developed two populations (Himalaya Blanco and Himalaya Amarillo) and are selecting them for earliness, so that they can be grown in multiple cropping systems involving wheat in the winter season.

Midaltitude Germplasm Development

Responding to the changing germplasm needs of developing countries sometimes requires the combination of a new initiative at headquarters and a new breeding program outside Mexico. Depending on the resources available to us, these efforts may be carried out sequentially, as was the case with highland maize, or simultaneously, as is happening in our work on subtropical germplasm, much of which we also classify as midaltitude maize. By the



Sergio Pastén

Mexican farmers' practice of deep planting into residual moisture a month before the start of the rainy season led CIMMYT's highland maize breeders to develop four new populations that emerge from deep planting and show improved agronomic traits.

early to mid-1980s, it was apparent that, while CIMMYT's lowland tropical materials were performing well throughout the developing world, the subtropical materials were not proving as useful to our cooperators in national programs. The Maize Program was eventually able to shift more resources into subtropical maize improvement at headquarters and in 1985 established a midaltitude maize research station at Harare in cooperation with the University of Zimbabwe.

Building on past experience in southern Africa--Location of this facility in sub-Saharan Africa offered a number of advantages. The continent has some 6 million ha of midaltitude area (out of a developing world total of about 17 million ha of subtropical maize), and the site of the station is well suited to selection for resistance to various of the most prevalent midaltitude diseases as well as to maize streak virus, which is endemic in Africa. One attraction of the southern Africa region in particular is that it has witnessed the development of efficient seed production industries and some of the developing world's most significant achievements in maize germplasm development. In Zimbabwe, Zambia, and Malawi, effective use has been made of a fairly narrow genetic base to generate excellent hybrids mainly for the more

productive environments. Our expectation is that, with a wider array of improved germplasm, national programs will be able to build on these successes and hopefully repeat them in the less favored areas.

A dynamic breeding methodology--

In establishing a research program to supply new germplasm for the midaltitude ecologies, our staff introduced certain methodological innovations. Departing from CIMMYT's traditional approach of improving a more or less fixed set of populations over long periods, they have developed a system in which many new populations are continually created from a large collection of elite germplasm. The populations then undergo recurrent selection in a multistage program, where some are discarded and those showing promise are put to various uses, a process involving a huge volume of materials. The results of evaluations conducted over several seasons show that some new populations are competitive with the excellent hybrids already available in Zimbabwe (see Table 5). As a start toward familiarizing colleagues in national programs with the products of this research, we have secured their assistance in evaluating germplasm and arranged for many of them to visit the midaltitude station.

Table 5. Performance of new streak resistant populations developed at CIMMYT's midaltitude research station in Zimbabwe, compared with hybrids already available in the country

Pedigree	Yield (t/ha)	Days to silk	Common rust*	Ear rot (%)
Hybrids:				
ZS225	8.8	70	2.3	12
SR52	8.6	77	3.0	5
R201	7.9	70	4.0	11
Populations:				
Pop62/Gwebi{1}TZMSR-W	8.6	77	2.2	6
EV7992/EVPOP43-SR	8.1	78	2.8	5
EV7992/R201//EVSr	8.0	75	2.3	8

Note: Data from three locations in Zimbabwe.

* Rated on a 1-9 scale, in which 1 = resistant and 9 = susceptible.

Corn Stunt Resistant Germplasm for Latin America

In only two cases (midaltitude and highland floury and morocho maize) has the Maize Program set up breeding projects outside Mexico to deal with whole classes of germplasm. More commonly, the aim of breeding research in outreach has been to enhance the adaptation and yield stability of elite germplasm for a given region by improving its resistance to a disease that poses serious problems in several countries.

The effectiveness of this approach is well illustrated by our cooperative work in the Central America and Caribbean region to develop germplasm with resistance to corn stunt (caused by *Spiroplasma* sp.), which occurs throughout Mesoamerica, the Caribbean, and in Venezuela. During 1987 in Nicaragua, this disease was responsible for losses of up to 60% over a 12,000-ha area planted to susceptible hybrids, whereas a tolerant variety, grown on some 2,000 ha, yielded twice as much as susceptible genotypes. This variety, Santa Rosa 8073, is the product of cooperation between CIMMYT and national programs during the 1970s and was released in Nicaragua during 1985. In 1986 further work on this disease was initiated, in which S₁ recurrent selection and evaluation are being practiced in four populations, two in the Dominican Republic and two in El Salvador and Nicaragua. The results of evaluations conducted after three cycles of selection indicate that, although two populations apparently have little genetic variation for corn stunt resistance, the others have shown marked progress in both resistance and yield. Synthetic varieties and hybrids generated through this project have been released by national programs and seed companies in eight countries of the region and are yearly planted to about 100,000 ha.

Applications of New Biotechnology

Some traits, such as insect resistance and tolerance to abiotic stresses, tend to be more difficult to develop through conventional plant breeding than disease resistance. In the hopes of acquiring better tools for overcoming particularly recalcitrant problems, the Maize Program is experimenting with two of various approaches encompassed by the term "biotechnology": restriction fragment length polymorphism (RFLP) technology and to a lesser degree tissue culture (see Research Support Services, page 53).

Cooperation with other research institutions--Achieving these advances, however, will be a long term endeavor and initially a very expensive one. To make the task somewhat more manageable, the Maize Program is working on SWCB resistance as part of a CIMMYT-European network that is studying the use of RFLPs in selecting for quantitative traits. Currently, we are evaluating 80 inbred lines representing CIMMYT's elite maize germplasm to determine their molecular allele type for each of about 160 RFLP probes. About half of this work was completed in 1989. We are also increasing F_1 lines (derived from populations formed by

some in *Tripsacum*, establish their homology with those in maize, and eventually employ the probes in selecting for transfer of DNA from the wild relative to maize.

The Changing Role of Agronomy Research

Less numerous than staff engaged in germplasm development, maize agronomists at CIMMYT have tended to be less visible to groups outside the Center and its network of cooperators. Concentrated almost exclusively in regional and bilateral programs, they have supported research in developing countries mainly by immersing themselves in the adaptive crop management work of national programs and by sharing their experience through training and consultation. But since many national programs now have well developed programs of adaptive research, both the appearance and substance of our agronomists' work are starting to change. A meeting in 1989 of all CIMMYT maize agronomists marked the beginning of a new phase in which these staff will have a much clearer identity as a disciplinary group, reinforced through periodic meetings, information exchange, and coordination of agronomy and physiology research from headquarters.

One of the principal tasks of agronomists in this first gathering was to study implications of the Center's strategic plan, which calls for a major shift in emphasis from adaptive research, leading directly to recommendations at the national level, to strategic research, which addresses issues common to various countries in a region. It was apparent from the discussions that every region has agronomic problems of international scope and that our staff are already addressing some of these. In eastern Africa, for example, agronomists have embarked on a project for controlling the parasitic weed *Striga*, and staff in Central America began a series of regional agronomy trials during 1989 to develop technologies for

A meeting of all CIMMYT maize agronomists marked the beginning of a new phase in which these staff will have a clearer identity as a disciplinary group.

Focusing on insect resistance and drought tolerance--We could have chosen to study any of various quantitative or polygenic traits, since a large number of new molecular genetic markers are now available that can be used as tags for major genes determining these traits. But we decided to focus on resistance to southwestern corn borer (SWCB) and anthesis-silking interval or ASI (which appears to be important in developing drought tolerant maize), because of the difficulty of selecting for these traits using conventional techniques and because, though quantitatively inherited, they are controlled by relatively few genes. In developing SWCB resistance, for example, which appears to involve six to eight genes (current research in the Maize Program is expected to confirm this), we should be able to increase progress and reduce costs by prescreening the germplasm for resistance before conducting field evaluations and selecting for other traits.

crossing resistant and susceptible lines) for RFLP analysis and field evaluation of each line's SWCB resistance. Linkage analysis of the results will be conducted to determine relationships between the RFLP markers and genomic segments responsible for SWCB resistance. The Maize Program is involved in a similar project on the genetic control of ASI in cooperation with Mexico's Center for Research and Advanced Studies (CINVESTAV).

In connection with the SWCB resistance work, we are investigating the use of maize RFLPs as genetic markers for *Tripsacum*, a wild relative of the crop that may serve as a source of this and other important traits. Working with the University of Minnesota, USA, we have used RFLP probes to detect in *Tripsacum* molecular alleles not present in subtropical maize that has been hybridized with the wild species. With these probes we will identify chromo-

better management of volcanic and sloping soils. These and other projects covered during the meeting fall within a special category of strategic research, that which contributes to more sustainable and less environmentally destructive agricultural production. In the future this type of work is expected to occupy a sizeable share of the approximately 25% of each agronomist's time devoted to strategic research, and it is probable that all crop management investigations conducted by CIMMYT staff will be guided by a sustainability perspective, with particular emphasis on soil and water conservation, fertility maintenance, and pest management.

Advanced Training for Experienced Scientists

The diversity of maize production environments in developing countries makes the creation of successful breeding and agronomy research programs a huge and difficult undertaking. In a new effort to help scientists in

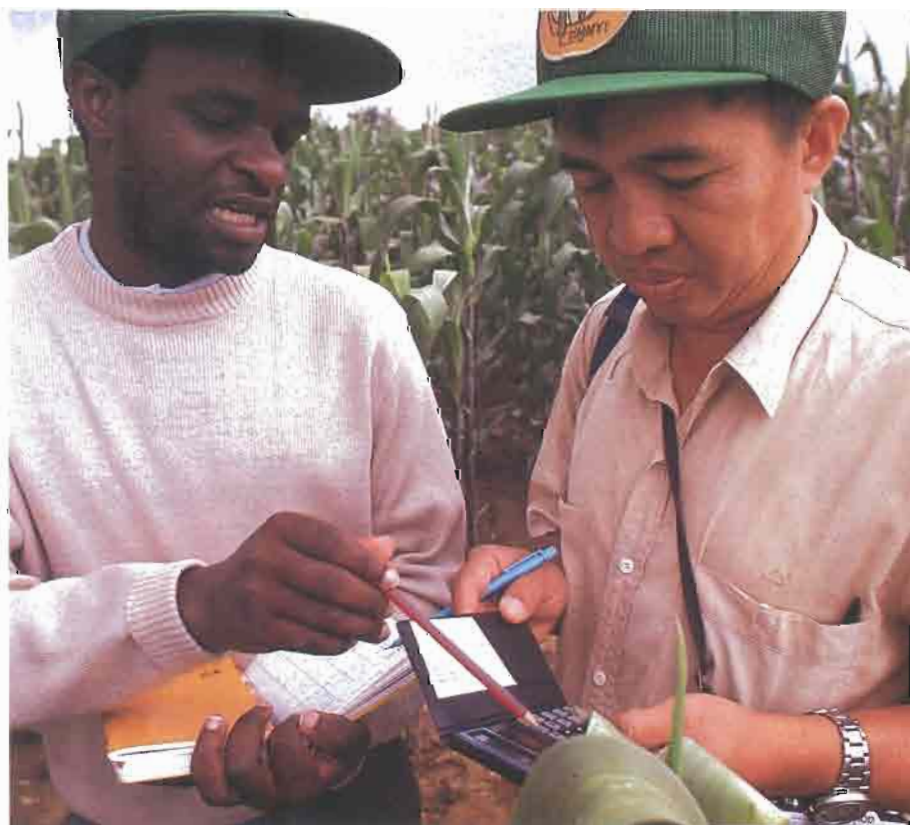
developing countries accomplish this task more effectively, the Maize Program introduced in 1989 a specialized seven-week course entitled "Research Program Design for Maize Agronomists," intended mainly for senior researchers with decision making responsibilities in national programs, and a six-week short course on maize improvement for heads of national breeding programs.

In the course for agronomists, 20 participants from 11 countries worked on diagnosis of field problems in three distinct maize growing environments in Mexico, where they spoke with farmers about agronomic and socioeconomic constraints of maize production. Based on the results of field surveys, the agronomists developed research plans for two of the areas, giving special attention to the priorities of problems identified and to alternative solutions. For each area the group developed field trials to test these solutions at experiment stations or on farm. Using data from previous trials, they addressed both statistical and economic analysis of

results. They spent considerable time practicing microcomputer analysis of agronomic trial data, and 13 stayed on for an extra week to further improve their computer skills. In addition to these activities, participants scrutinized case studies from Ghana and Pakistan, and each developed and presented a research project for his or her home country.

As one would expect from a group of experienced researchers like this one, the exchange of information and experience in their discussions was especially lively and valuable. And in general participants were enthusiastic about the course. Half would have liked to extend it. One participant has already conducted a similar course in his own program to disseminate the skills and knowledge he acquired during his stay at CIMMYT.

The course on maize improvement was designed to provide the 16 participants (from as many countries) with an update on recent advances in plant breeding and to familiarize them with the current strategies of CIMMYT's maize breeding program. For that purpose we invited three scientists from US universities to give a series of lectures on applied quantitative genetics and developments in biotechnology, and our own staff gave overviews of their breeding approaches and of the new germplasm they are developing.



Thomas Luba

Fred Kanampin of Kenya and Rachain Thiraporn of Thailand determine plant density in a farmer's field as part of an exercise in diagnosing field problems. As a result of their experience in CIMMYT's new specialized course for maize agronomists, participants said they would give much more emphasis to field diagnosis in the future.

An Overview of the Maize Program

Nathan Russell



Germplasm improvement (headquarters)

The Program develops and improves a wide array of germplasm within the following categories:

- Lowland tropical
- Subtropical
- Highland
- Quality protein maize (QPM)

Germplasm products are distributed through an **international testing system**.

Germplasm improvement (regional)

These programs develop categories of germplasm or improve particular traits that cannot be handled as effectively at headquarters.

- Corn stunt resistance, Central America and the Caribbean
- Tolerance to aluminum, South America
- Downy mildew resistance, Southeast Asia
- CIMMYT/IITA cooperation, West Africa
- Midaltitude maize station, Zimbabwe

Sergio Pastén



Support of germplasm improvement

These units contribute to germplasm improvement work at headquarters and to national breeding programs by providing germplasm, techniques, and information.

- Pathology
- Entomology
- Physiology
- Germplasm bank
- Wide crosses
- Hybrid program

Nathan Russell



Support of national programs

Training at headquarters--Courses on breeding and crop management research, visiting scientist fellowships, and pre- and postdoctoral fellowships.

Regional programs--Identify the needs of national programs and strengthen their breeding and crop management research capacity through consultation, training, and workshops.

- Asia
- Central America and the Caribbean
- Eastern Africa
- Middle East and North Africa
- Southern Africa
- South America

Bilateral programs--Strengthen research capacity in selected national programs through close collaboration over an extended period. Currently one such program in Ghana.



While the record harvests of India and Pakistan in 1988-89 bring pleasure to CIMMYT's Wheat Program staff, the urge to celebrate is tempered by our knowledge of present and future constraints to improved productivity.

The problems we face are analogous to the pathogens that attack wheat; they mutate into new and complex forms even as we fight them, and eliminating one can open the field to others. That fact has not altered certain basic priorities of the Program: our central activity remains the development of superior germplasm. But the ways in which we obtain it and assure its utility to clients have steadily grown more sophisticated in response to the complexity of the challenges we face.

This is seen partly in a shift toward more strategic research and partly in a re-evaluation of relationships with clients, international centers, and other scientific institutes. Examples of new research directions include tracing cytoplasm origin in pedigrees, studying mechanisms of grain sprouting, and implementing new and powerful designs and analytical techniques for international trials, to name a few. Likewise, we seek more and more collaborative arrangements where outside expertise and our own skills blend to benefit all concerned. Several such Program undertakings exist, including a new agreement with the International Center for Agricultural Research in the Dry Areas (ICARDA) to develop spring and facultative wheats for the West Asia/North Africa Region, talks with representatives from the International Rice Research Institute and the national programs of South Asia on a collaborative project to study the sustainability of rice-wheat cropping systems in the region, or research with Cornell University (New York, USA) to examine RFLP techniques for wheat and barley breeding (see Research Support Services, p. 53).

These enterprises illustrate in part a trend toward greater efficiency that is congruent with guidelines in CIMMYT's strategic plan and the changing needs of clients. Research to solve specific problems and generate new understanding of our germplasm products has an important role in meeting those needs, as the following reports show.

Durable Resistance to Leaf Rust

For a small scale wheat grower in the Third World, stable yields are probably as critical as high yields. To understand why, simply consider the economic and social consequences of plant disease epidemics there. With no access to the chemical controls, rapid variety substitution, government support, and other aids that farmers in developed countries enjoy, a single disease outbreak can spell disaster.

Leaf rust, caused by *Puccinia recondita*, is probably the most threatening wheat disease in the developing world at present. Improved varieties, whose disease resistance is often based on major, pathotype specific genes, generally succumb to mutant virulent strains within five to seven years after widespread adoption, sometimes sooner. Thus, the identification of a gene complex able to provide durable resistance against diverse leaf rust races would constitute a major breakthrough.

In 1985 we began work with support from the German Agency for Technical Cooperation (GTZ) to monitor prevalent races of the three rust diseases (stem, leaf, and stripe) and to study the genetics of leaf rust resistance. Even though known major genes for leaf rust resistance were characterized in over 100 cultivars, the research largely focused on the identification and genetic analysis of adult-plant partial resistance in high yielding, broadly adapted CIMMYT bread wheat germplasm. We now have encouraging evidence that a number of our materials possess a complex, derived from the Brazilian cultivar Frontana, which confers durable leaf rust resistance.

Slow rusting--The resistance of certain cultivars derived from CIMMYT germplasm has held up since the late 1960s. Our findings suggest that the basis of this durability is the *Lr34* gene in combination with other minor resistance genes, a complex we have traced to Frontana. In Mexico the presence of *Lr34* alone in a cultivar will

cause slow rusting; i.e., though the variety displays a susceptible response, disease progress is slower than in a susceptible check variety. In several CIMMYT genotypes, *Lr34* in combination with two or three additive genes retards disease progress to the extent that pathogen development by harvest is negligible.

Similar to stem rust resistance--Our keen interest in this resistance source is due in part to close analogies with the case of the *Sr2* complex for stem rust: alone the *Sr2* gene appears to confer the slow rusting characteristic; in conjunction with other genes it provides durable resistance and has protected CIMMYT derived cultivars from stem rust epidemics for more than 20 years.

Additional sources of resistance--We have identified varieties with partial, adult plant resistance bases that are distinct from those of Frontana. Pavon-76 and its derivatives, for example, have since 1976 been released in Mexico, Algeria, Peru, Bolivia, Chile, and Australia without succumbing to a leaf rust epidemic. Genes from such sources could be used to create genetic diversity around the *Lr34* complex without altering desirable phenotypic traits.

We hope to impart a durable resistance base to more of our emerging germplasm products. We are cataloguing undesigned genes for partial resistance and seeking RFLP markers to aid in selecting new combinations.

Investigating the 1B/1R Translocation

An outstanding achievement of the Wheat Program was successfully combining the diversity of two important genetic pools of wheat: winter and spring habit types. Certain lines derived from that blend--the Veerys--showed yield potentials that averaged 10% higher than those of the green revolution semidwarfs. This and other superior

traits prompted the wide acceptance of Veery wheats among developing world farmers. The source of their special attributes, though, has received limited attention in our Program, where by tradition breeders strive first and foremost to deliver useful germplasm swiftly to national programs. A rye-wheat chromosome translocation, known as 1B/1R, is widely credited with conferring many of the Veerys'

This methodology will be applied as well to other materials. In addition, the 1R rye chromosome has been introduced into the elite durum, Altar-84, for testing in the same way. Past studies at CIMMYT have compared the yield effect of the 1B/1R in different genetic backgrounds, but work with isolines can hopefully provide conclusive evidence regarding the attributes associated with this translocation.

almost exclusively by humans, who have very particular ideas about what is acceptable. The use intended for a given product thus cannot be ignored in germplasm improvement work.

A case in point is that of improved varieties possessing the 1B/1R translocation. Under high speed mechanical mixing, doughs from cultivars with the translocation apparently become sticky, a property that impairs handling. As this bears directly on the utility of many of our products, program staff analyzed the quality characteristics of a number of 1B/1R wheats and compared sister lines with and without the translocation.

A few lines with the translocation showed good breadmaking quality, and some of them did not exhibit the sticky dough trait. These findings suggest that the 1B/1R translocation may not be categorically associated with poor dough handling characteristics and that additional factors, such as growing environment or genetic modifiers, play a large role. In future work, Program scientists will elucidate those factors and how they interact to produce sticky dough. For the time being, our results suggest that breeders can develop 1B/1R materials that satisfy most quality criteria for breadmaking.

Recent concern with maintaining yields and ensuring acceptable grain quality has led our researchers to take a closer look at the presumed connection between the 1B/1R translocation and yield and quality.

properties, but recent concern with maintaining yields and ensuring acceptable grain quality has led our researchers to take a closer look at that presumed connection.

Testing yield with "twins"--One line of research seeks to confirm the role of the 1B/1R translocation in Veery yields. Our scientists are developing two Veery lines identical in every respect except that one will not possess the translocation.

First, researchers crossed the Veery line, Seri-82 (released in Pakistan as Pak-81), with Pavon-76, which does not have the translocation. By backcrossing to Seri-82 several generations of progeny possessing a 1B, 1B/1R complement and then selfing the products of this combination, our scientists are obtaining Seri derivatives without the translocated rye chromosome. Chemical methodology and cytology are being used to verify the genetic makeup of the supposed isolines. The lines will be grown in trials and the yields compared with that Seri-82.

1B/1R and sticky dough--Although increased grain yields are often seen as the key to feeding the world's hungry, abundant harvests serve no purpose unless consumers will use them. Wheat, unlike some other basic grains, is eaten



Thomas Lubta

Synthetics as a Source of Variation

Since the time that farmers began to select seed from superior genotypes for use in future cycles, a breeder's job has been to "prod" mother nature to combine her raw materials in novel ways. But while plant scientists have, at the service of humanity, become ever more bold in manipulating genetic material, nature is often still their best

Capitalizing on genetic diversity often carries a price tag. Years of conventional breeding may be needed to "weed out" the undesirable traits transferred along with useful ones in crosses of wheat with wild relatives such as *Triticum tauschii*.

teacher. In the following project, our researchers drew on her lessons to expand the variety of genetic resources available to breeders.

Since fall of 1987, Program staff have worked to develop synthetic bread wheats for use 1) as sources of resistance or tolerance to a variety of stresses and 2) in identifying molecular gene markers. These lines are called synthetics because they are produced by a process that imitates the natural cross--durum with a primitive grass species (*Triticum tauschii*; formerly *Aegilops squarrosa*)--which in theory led to the first bread wheat. It is believed that, in the natural event, few types of *T. tauschii* were involved, giving the resulting bread wheats a relatively narrow genetic base from that parent. CIMMYT researchers, however, have produced about 150 synthetics by using as many different *T. tauschii* parents, thus tapping into the genetic variability of that species.

From within this collection, our scientists have identified materials with 1) good resistance to the pathogens responsible for a variety of diseases, including Karnal bunt, *Helminthosporium sativum*, and scab; 2) improved tolerance to abiotic stresses (e.g., saline soils); and 3) high levels of polymorphism (identified in the collaborative biotechnology project at Cornell University). This last characteristic should make them especially useful for RFLP mapping. Finally, by enhancing basic variability in wheat, the synthetics should prove a valuable source of materials for national program breeders.

In line source irrigation, water distribution decreases gradually as distance from the source increases. With modifications, this watering system can be used to simulate experimentally the drought stress patterns of a given production environment, thus allowing selection for specific traits associated with drought tolerance there. The approach necessitates multilocation testing, so that drought-related environmental factors not manageable on experiment station plots (such as soil type) are accounted for in selection.

Breeding for Tolerance to Drought Stress

Global wheat productivity is directly linked to moisture availability, and developing country yields in irrigated zones are more than four times those of the driest rainfed lands, where they average only 0.6 t/ha. This fact acquires great import when one realizes that 37% of the developing world's wheat area is semiarid, where moisture is the chief production constraint. Dryland area in developing countries is not likely to decrease, either, since desertification affects millions of arable hectares each year, and uncertain water supplies, high costs, and undesirable side effects have recently curtailed the spread of irrigation or led to reducing its use. The above facts, together with a trend in certain countries toward wheat farming in nontraditional areas, point up the importance of developing germplasm with tolerance to drought stress.

Doing so is not an easy task. Numerous and varied factors may contribute to drought--water input and distribution, relative humidity, soil structure and status, temperature, agronomic practices, etc. It is therefore difficult even to define satisfactorily a drought stress environment. In addition, stress patterns vary greatly from site to site and across years at individual sites. Still, the bottom line for a breeder is to develop genotypes that are more productive with a fixed amount of water.

A drought screening methodology-- An enhanced version of that goal has long been a part of our germplasm improvement work, though we pursued it initially more through screening than through actual breeding. In the International Spring Wheat Yield Nursery (ISWYN) and the International Bread Wheat Screening Nursery (IBWSN), both established in 1964 and continued today, germplasm developed under optimum conditions was exposed to a range of screening environments,

Gene Hettel



including drought conditions. In the early 1970s, we began worldwide distribution of F₂ materials with dryland parentage. The eventual adoption of semidwarf cultivars in many dryland areas prompted the creation in 1976 of the Drought Screening Nursery (DSN).

From testing to breeding--The above methodology--breeding under optimum conditions and simply testing for drought tolerance--generated a number of cultivars well suited for semiarid zones (Marcos Juarez INTA in Argentina, Kalyansona in India, Galvez-87 in Mexico, Pavon-76 and Barani-83 in Pakistan, and Sham-2 in Syria, to name a few). But the possibility of making

even greater progress led our scientists in the early 1980s to begin exposing segregating generations to drought stress. We started targeting materials to a drought "mega-environment" and utilizing both optimum and stressed environments in combination for selection, screening, and testing. Shuttle breeding, where alternate cycles of selection occur at environmentally distinct sites, was employed to improve specific adaptation, thus broadening the overall adaptation of the materials.

As it stands today, our methodology is based on the assumption that yield under drought stress and favorable water levels is associated with two

independently functioning gene systems and that breeders can select for each separately in its respective environment. Thus, it is possible to obtain germplasm that is efficient under stress yet responsive at favorable moisture levels. To further refine our methods, we recently compared the efficiency of breeding under stress with that of breeding under optimum conditions.

Comparing irrigation and stress methodologies--Our scientists chose genotypes for the study according to general selection criteria and then separated the F₃ seed of F₂ individual plants into two identical groups. Selection in successive generations within each group ensued under contrasting moisture environments (see Figure 3). Grain yield of the F₆-derived advanced lines from the two groups was evaluated in 1988 and 1989 under both full irrigation and terminal drought stress. In addition, subsamples of each group were tested both years under uniform water gradients generated by line source sprinklers.

The results verify the suitability of breeding under optimum moisture conditions as was done in the past. However, additional gains in efficiency appear possible through combining that approach with selection for specific traits that enhance tolerance to this stress. Line source sprinkler irrigation would be useful here, since it can simulate the stress patterns of major target zones. Before starting work on traits, though, we need descriptions of target environments based on parameters, such as stress patterns and probability ranges, that predict drought incidence with more precision than do mere rainfall data.

Data show that other components of improved agricultural technology--fertilizer, chemical pest and disease controls, etc.--are crucial to increasing productivity in dryland areas. However, until those inputs become readily available to resource poor farmers, improved germplasm is probably still their best option.

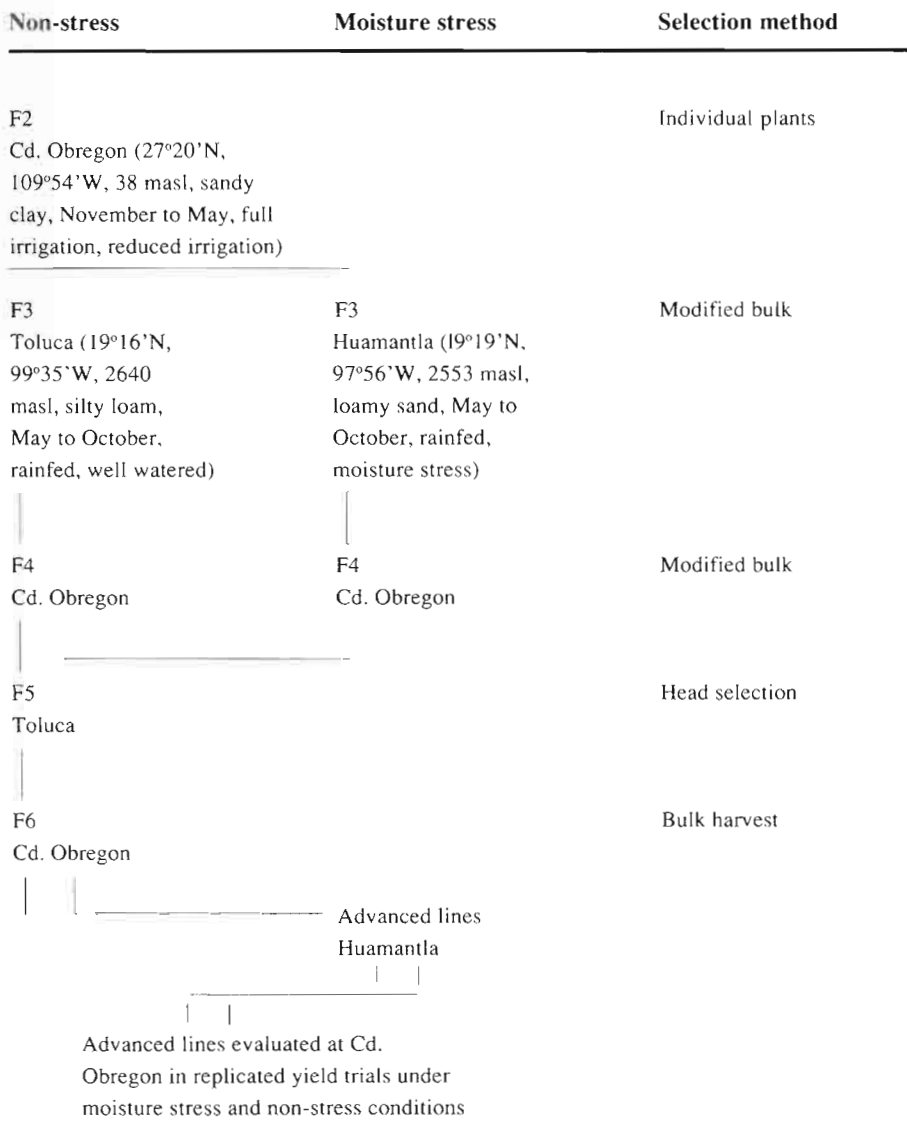


Figure 3. Methodology for selecting wheat under non-stress and moisture stress conditions.

An Overview of the Wheat Program

Thomas Luba



Germplasm improvement (headquarters)

- Spring bread wheat
- Durum wheat
- Triticale
- Barley (ICARDA/CIMMYT)

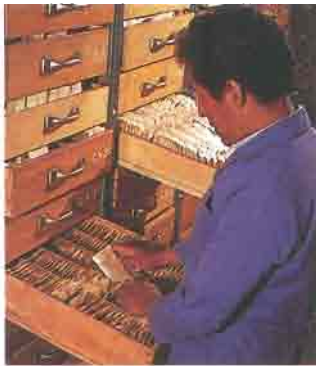
Industrial quality laboratory screens material for quality characteristics.

International nursery system tests and distributes germplasm, along with analyses and interpretation of the tests, to cooperators.

Germplasm improvement (regional)

- Winter wheat (Turkey)
- Warmer marginal environments (Paraguay, Southeast Asia)
- Facultative wheat for West Asia/North Africa (CIMMYT/ICARDA)
- Spring bread wheat for the drier areas of West Asia/North Africa (CIMMYT/ICARDA)
- Spring durum wheat for the drier areas of West Asia/North Africa (CIMMYT/ICARDA)

Sergio Pastén



Genetic resources

Germplasm bank maintains base and working collections of cultivars, breeding materials, and wild relatives.

Wide crosses conducts interspecific and intergeneric hybridization to improve stress tolerance and resistance.

Germplasm enhancement incorporates useful traits into materials used in conventional wheat and triticale improvement.

Sergio Pastén



Crop protection (headquarters)

Pathology supports improvement work and performs research on the epidemiology, host-parasite interaction, pathogen variation, and genetics of resistance for the rusts, septoria and helminthosporium diseases, and barley yellow dwarf.

Crop protection (regional)

- Stripe rust (Andean region)
- Leaf and head blights (Paraguay)
- Disease surveillance (South Asia)

Sergio Pastén



Crop management (headquarters)

Supports nursery and station management, determines conditions for selection and screening, performs on-farm trials, and conducts research on stress physiology, agronomic management and pathology, and the agronomy of new materials from germplasm improvement.

Crop management (regional)

- Bilateral program (Bangladesh)
- Wheat agronomy (Paraguay)
- Wheat agronomy (E. Africa)
- Rice-wheat rotation (South Asia)

Gene Hertel



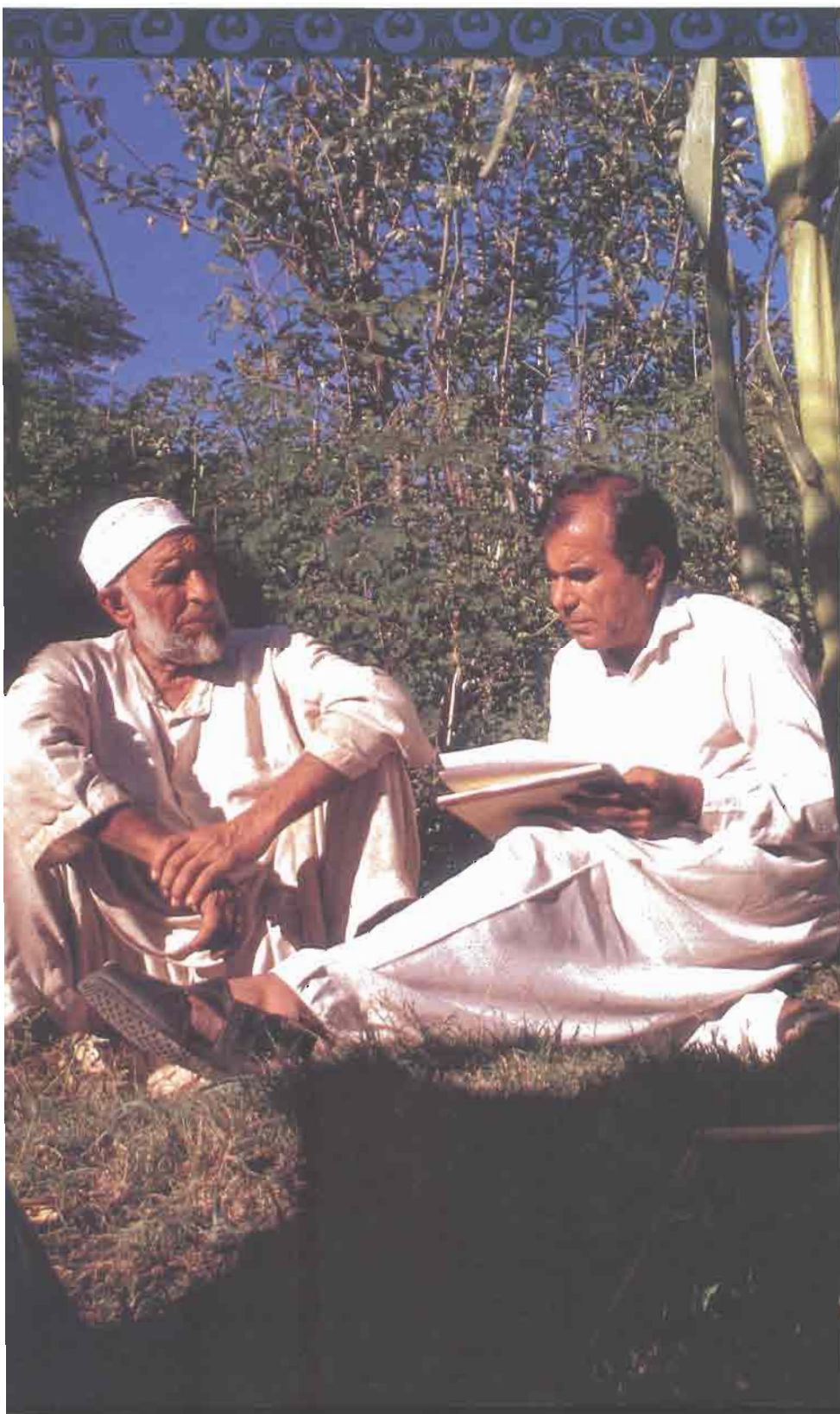
Training (headquarters)

Includes in-service courses on improvement, crop management, pathology, and experiment station management, as well as visiting scientist, post-, and predoctoral fellowships.

Training (regional)

Comprises seminars, courses, and direct consultation.

Economics Research



When CIMMYT's first regional economists were posted to Asia, Africa, and Latin America at the end of the 1970s, they rarely encountered other social scientists in national agricultural research programs. They specialized in on-farm research -- collaborating in research, developing methods, and offering training, mostly to agronomists.

At the end of the 1980s, circumstances in the regions have changed with the establishment of on-farm or farming systems research capacity in many national research programs. The Economics Program's emphasis on training and consulting in on-farm research (OFR) can now shift to the refinement of OFR methods and the exploration of other research issues, often in collaboration with social scientists--who are now present in greater numbers in national programs.

To move forward with a fresh perspective on the tasks at hand, during 1989 the Program began to synthesize its work to date in several areas, including OFR. That process and some of our major research projects are discussed in the sections that follow.

Synthesizing Experiences in OFR

This year several studies of OFR gathered together and assessed research results, indicated possibilities for improving the OFR approach, and noted the advantages to be gained from strengthening OFR capacity in national research programs. For example, several years of OFR by Pakistani researchers, in collaboration with CIMMYT staff, formed the basis for a book describing the principal farming systems of Pakistan and diagnosing major research priorities in those systems. In Ethiopia OFR has been a rich source of farm level data that, when compiled and analyzed, have given a clearer picture of the socioeconomic constraints to maize and wheat production throughout the country. Two especially detailed retrospective studies of OFR in Mexico and eastern and southern Africa are highlighted below.

Toward more effective OFR in Mexico--Mexico's National Institute of Forestry, Agriculture, and Livestock Research (INIFAP), with the collaboration of CIMMYT and France's Center for International Cooperation in

Agronomic Research for Development (CIRAD), has conducted OFR on rainfed maize at five locations in the lowland tropics since 1983. Results from all five study areas were reviewed in 1989 to determine whether the OFR approach had been successful and could benefit more farmers if it were applied on a wider scale by agricultural researchers in Mexico (OFR is one of several approaches for raising agricultural production under evaluation by INIFAP).

In the OFR study areas, fertilizer and improved maize varieties, along with herbicides, insecticides, and the use of tractors, had been adopted at a level higher than the national average, but maize yields were still almost stagnant. As OFR proceeded researchers uncovered problems, mostly agronomic, that had previously gone unnoticed but were reducing the efficiency of the inputs farmers used to grow maize. For example, at La Fraylesca in the state of Chiapas, farmers' maize yields were limited by acid soils, low organic matter content in the soil, soil compaction, and weeds.

Between 1984 and 1988, researchers tested various technological solutions to the most important problems that were diagnosed. After comparing the difference between the observed yield increase from each technology and the yield increase necessary to recover farmers' investment in the technology, it appears that the most promising options for farmers in La Fraylesca are to lime the soil and use a new herbicide; farmers in the other areas would benefit from adopting drought tolerant and earlier maturing maize varieties, as well as seed treatment against soil pests (see Table 6).

The experience of researchers in La Fraylesca and the other study areas demonstrates that the challenge of increasing maize production is institutional as well as technical. The research system would benefit from developing stronger, more effective mechanisms for diagnosing farmers' problems in specific locations in major maize growing regions, setting priorities for

research to solve those problems, and designing appropriate technological solutions. Mexican maize production will have to rise by 25-33% to meet the projected increase in demand from 1987 to 2000. Since very little new land is available on which maize can be grown profitably, most of that increase can only be obtained by improving maize yields.

The projects described here are a strong endorsement of OFR's capacity to solve farmers' production problems and, if this success can be repeated at the national level, to stave off declines in maize self-sufficiency. However, to address problems that are increasingly limiting farmers' maize yields, such as declining soil fertility and inefficient use of moisture, OFR will have to go beyond purely adaptive research toward applied agronomic research. Success also depends on training more researchers in the practice--not merely the theory--of the OFR approach.

Toward more effective OFR in southern Africa--On an even wider scale, a review of OFR throughout southern Africa addressed three major producer groups, each with its characteristic set of production practices: large scale commercial farmers; medium scale cultivators who rely on animal draft power for major farming operations; and small scale, hand hoe cultivators. The review examined the progress of OFR in ameliorating a number of constraints faced by each group of producers and assessed the type and extent of the production gains that have been achieved.

For example, maize production practices and input levels traditionally have been developed under the assumption that farmers will plant early, but recently OFR has shown that many farmers in southern Africa are constrained to plant late and suffer reduced grain yields. Results of this research suggest that much work remains to be done in developing maize germplasm and practices specifically for later planting.

The study of OFR in southern Africa concludes that, although OFR has improved the understanding of farmers' circumstances, the impact on maize production in southern Africa is still limited. Like the review of the Mexican OFR projects, this study recommends that the problem solving approach pioneered by OFR will have much wider potential if it is fully integrated with applied experiment station research and extension and if the quality of the diagnostic work and priority setting can be improved.

Future work in OFR--Together, these overviews of OFR have given the Economics Program a better perspective on where to focus its energies in the development and evaluation of maize and wheat technologies. In the near future, we will continue to synthesize what has been accomplished in OFR, promote greater precision in the execution of research, encourage thorough studies of adoption and diffusion, and engage in on-farm research to capture farmers' perspectives in the design, evaluation, and use

of technology. We will also become more involved in long term, on-farm studies to analyze technologies that help preserve the resource base and in studies of situations in which farmers seem already to have adopted such technologies. Studies have been proposed in Haiti and El Salvador, with the objective of gaining experience that will enable us to decide how we can best contribute to research on the productivity and sustainability of smallholder farming systems over the longer term.

Table 6. Observed yield increases from technological components for rainfed maize and increases necessary to recover farmers' investments, on-farm research sites, Mexico, 1984-87

Site and component	Relevant maize area (%)	Minimum yield increase needed to pay costs ^a (t/ha)	Observed yield increase (t/ha)
Favorable areas			
La Fraylesca, Chiapas			
Liming (2 t/ha lime)	40	1.2	+3.3 ^b
Herbicide (glyphosate 3 L/ha)	32	0.5	+0.9 ^c
Subsoiling, zero tillage	Not yet determined	0.0	-0.9
La Huerta, Jalisco			
Seed treatment (Furadan 300 ml)	87	0.1	+0.3
Drought tolerant variety (OBS 8349x8332)	50	0.1	+0.8
Marginal areas			
Tierra Caliente, Guerrero			
Variety V-455	78	0.1	+0.6
Seed treatment (Furadan 300 ml)	50	0.1	+0.7
Hopelchen, Campeche			
Drought tolerant variety (OBS 8349x8332)	80	0.1	+0.7

Source: Hibon, A. 1990. Las fuentes de crecimiento de la producción de maíz de temporal en México: ¿Hacia una investigación agronómica más estratégica? Mexico: CIMMYT. (Forthcoming).

- a Minimum yield increase necessary for investment in the component to be profitable (cost of capital included).
 b Includes residual effects for three years.
 c Excludes residual effects.

Exploring Issues in Varietal Development

With increasing frequency, the Economics Program is requested to explore many issues in varietal development, including utilization and the economics of disease losses and methods of control. A triticale utilization study conducted from 1988 to 1989 among smallholders in the state of Michoacán, Mexico, has found that triticale is adopted by farmers who are short of land but increasing their livestock ownership. These farmers value triticale primarily as animal feed, not as a food grain that substitutes for wheat. This finding indicates a need for further research on the potential of smallholder cultivation of triticale for feed and forage. During the next five years, the Economics Program hopes to monitor triticale utilization issues and relay that information to the Wheat Program, perhaps supplementing work in Mexico with studies in other areas where smallholders grow triticale.

A study of the economic losses to Karnal bunt (*Tilletia indica*) of wheat in Mexico was undertaken in 1989 with INIFAP and the CIMMYT Wheat Program. Estimating the costs associated with Karnal bunt in northwestern Mexico (the primary area affected) in an average year makes it possible to determine 1) the resources that should be allocated to developing wheat germplasm resistant to Karnal bunt and 2) the appropriate level of investment in measures to prevent the disease from

spreading to other wheat growing areas of Mexico. This work was followed by field surveys in the states of Sonora and Sinaloa, Mexico, to assess whether Karnal bunt is related to specific management practices such as crop rotation or fertilizer use.

Measuring Returns to Research

Assembling information on particular problems such as Karnal bunt is one way to guide difficult resource allocation decisions. Another way to give administrators a better sense of which endeavors are most likely to meet their objectives efficiently is to provide information on the results of specific kinds of research.

Many studies attest to the impact of successful plant breeding programs, but few attempts have been made to determine the potential payoff to crop management research. In 1989 the Program concluded a study of the returns to crop management research done over the years by scientists of the Northwestern Agricultural Research Center (CIANO) in the Yaqui Valley of Mexico. The highly commercial agriculture of the Yaqui Valley is atypical of much crop production in the Third World, benefiting from strong links to an active research system and extension service. However, those links were important for establishing causal relationships between the development, recommendation, and consequent adoption of crop management practices.

The study found that practically all of the benefits to crop management research conducted by CIANO scientists over 10 years were generated by the diffusion of just two innovations--planting wheat in raised beds, and integrated pest management. Those practices provided large per-hectare increases in net income for the farmers who adopted them. Both new practices were also relatively complex technical changes in crop management. From those results one might conclude that the gains to such innovative research will be high in areas like the Yaqui Valley, where farmers have already benefited from the adoption of high yielding varieties, the use of fertilizer, and access to irrigation. The estimated real return on the investment in crop management research was over 20%, comparable to estimates of returns to plant breeding programs. In the future the Economics Program will collaborate in studies of returns to crop management research in other situations if national programs express strong interest in this issue. Such studies may offer the opportunity to test the methodology developed in the Yaqui Valley study under more difficult conditions.

Many studies attest to the impact of successful plant breeding programs, but few attempts have been made to determine the potential payoff to crop management research.

Commodity Sector and Policy Analyses

Along with studies of the efficiency and impact of certain kinds of research, studies of the maize and wheat economies, on a global or national level, are becoming essential to making research decisions at CIMMYT and in national programs. Because of policy reforms instituted as part of the structural adjustment programs of the 1980s, many countries are experiencing substantial shifts in relative wheat and maize prices, supply, and demand. These changes will have important

CIMMYT economists collect and analyze data on the production, utilization, and trade of maize and wheat to understand trends (such as a region's changing self-sufficiency in wheat production) that may affect future research priorities.



Thomas Loba

implications for agricultural research systems into the 1990s.

In 1989 CIMMYT Economics and Maize Program staff contributed to the upcoming issue of *World Maize Facts and Trends*, which presents a special report on maize in sub-Saharan Africa, written in collaboration with the International Institute of Tropical Agriculture. The report is a comprehensive account of maize production and utilization trends, technologies, consumption patterns, and key production constraints. After assessing prospects for raising production and noting research priorities, we conclude

that, of all crops in sub-Saharan Africa, maize appears to have the greatest potential for revitalizing food production. Admittedly, realizing that potential will not be easy; it will require better research at the farm level to identify key production constraints and develop technologies and policies capable of resolving them and additional macro-economic research to help design policies to manage production, consumption, and trade.

Another study, focusing on maize production, consumption, and marketing in Paraguay, was conducted by staff of the Paraguayan national program and a

CIMMYT economist to establish a basis for developing a national maize research strategy. One finding of the study is that the maize marketing system in Paraguay is better developed than is generally believed. A field survey of maize markets disclosed a complex system involving a number of intermediaries and distinct marketing channels (see Figure 4).

Training

As our work in OFR shifts to address more methodological issues, and as others become equipped to offer the kind of training that we have conducted in the past, the Economics Program expects to develop its training activities to reflect the wider scope of its research and to better meet the needs of social scientists in national programs. For the present, Program staff, in collaboration with colleagues from other international centers, national programs, and universities, continue to offer courses on a range of subjects, from the basics of OFR to special topics for social scientists. We also hosted three more visiting economists in 1989--Kofi Marfo, A.A. Dankyi, and Henry Dakurah of the Ghana Grains Development Project, who came to headquarters to analyze the results of adoption studies. They returned to Ghana to plan a more comprehensive study of maize technology diffusion.

The Program continues to document its experience in training others in the OFR approach. In many regions of the world over the past 10 years, we have sponsored call courses on OFR, in which participants convene periodically in a location over one or more agricultural cycles to carry out the successive steps of on-farm research. This year three of our staff assessed call system training in a paper to be published in 1990. A synthesis of our work in this area should be useful to others engaged in training national research and extension personnel in the methods of OFR.

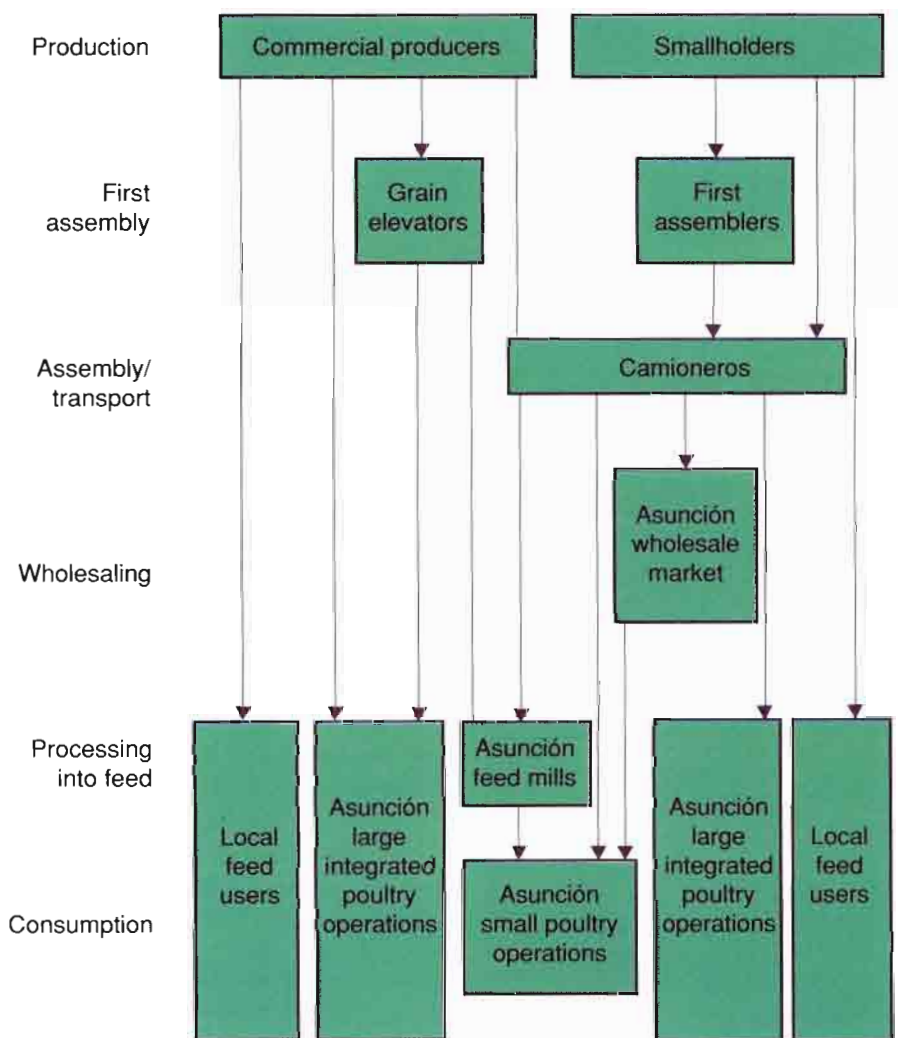


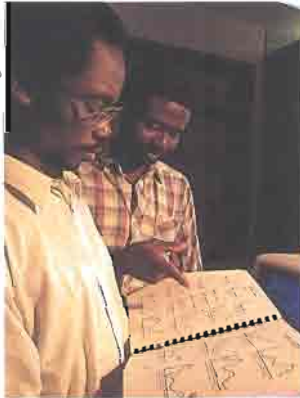
Figure 4. Principal marketing channels in Paraguay for yellow maize destined for animal feed, which constitutes most of the maize that is marketed.

An Overview of the Economics Program

Headquarters and regional/bilateral program staff may allocate their time differently among the Program's three chief areas of work, but all staff contribute to each area. Regional economists working in Central America and the Caribbean, eastern and southern Africa, and Southeast Asia have a special mandate to focus on particular

regional research and training needs. Staff posted to bilateral programs with Haiti, Mexico, and Pakistan collaborate closely with social and biological scientists in those countries to strengthen the social science capacity in the national research system.

Sergio Pastén



Technology design and evaluation

This research includes: 1) designing new technologies, evaluating whether they are appropriate for farmers' circumstances and help sustain the resource base, and assessing adoption by farmers and 2) conducting studies of policies affecting the efficient utilization of technology at the farm level. A chief product of this work is methods and analyses that national programs can use in designing and evaluating technologies.

Thomas Luba



Research resource allocation and impacts

The need for accountability and discernment in the allocation of resources in national programs and at CIMMYT has placed greater emphasis on developing information and methods for setting research priorities and documenting the impact of research expenditures on productivity and income distribution.

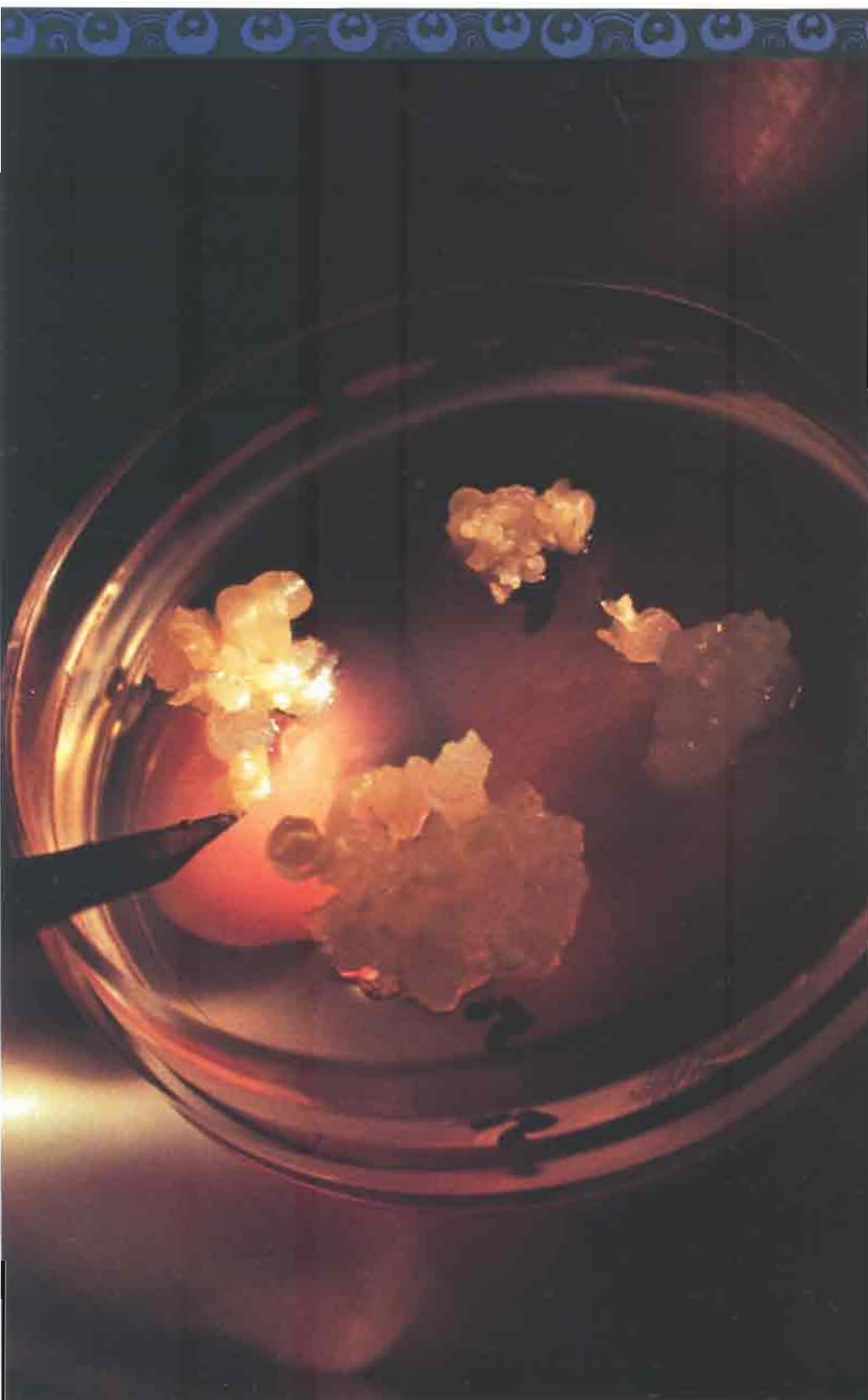
Thomas Luba



Commodity sector and policy analysis

Commodity sector analyses cover all aspects of long term trends in maize and wheat prices, supply, and demand, including policy influences, that have a bearing on decision making for agricultural research, whether at CIMMYT or in national programs.

Research Support Services



Ranging from evaluations of biotechnology tools for breeding to preparation of experiment station fields for planting, the activities of CIMMYT's research support services are highly varied.

Yet, a number of common threads run through the fabric of this seeming patchwork quilt.

Perhaps one of the more interesting is the constant, conscious evolution of the support units to keep pace with the Center's changing vision of its role and priorities. They do this by identifying and promoting within their respective areas of competence useful new ways for the research programs to generate our products and services. And, as this is a two-way street, their counterparts in the programs on occasion return the favor, identifying and promoting improved strategies and methods for support efforts. The following highlights illustrate both types of collaboration, as well as the gradual and deliberate transformation of the support services in response to the larger issues that shape CIMMYT's outlook.

Collaborative Research in Biotechnology

To provide its crop breeders with tools that improve the efficiency and effectiveness of their work, CIMMYT signed on as a participant in two collaborative ventures involving restriction fragment length polymorphism (RFLP) technology.

A three-year special project to develop a set of probes for the wheat and barley genomes was begun at Cornell University, New York (USA), with funding from the Australian Centre for International Agricultural Research (ACIAR) and the government of the Netherlands. The resulting linkage map and probes will help the Wheat Program to identify and combine useful genes from different varieties and to select against undesirable genes and gene interactions. Researchers will also screen a number of important CIMMYT wheat and triticale varieties in hopes of locating important resistance factors in the wheat genome.

The Maize Program is involved in work at the University of Missouri (USA) using RFLPs to identify areas of the genome associated with resistance in CIMMYT materials to several species

of corn borer, the major insect pest of maize in tropical regions. The project, which is funded by the government of the Netherlands, includes the screening of 80 CIMMYT lines and is, in part, CIMMYT's contribution to the European RFLP network. A second project funded by the Rockefeller Foundation includes a collaborative effort with the Center for Research and Advanced Studies (CINVESTAV) of the Mexican National Polytechnic Institute (IPN) to identify RFLP markers associated with drought tolerance.

CIMMYT's own biotechnology laboratory will be operating in 1990, and initial work will focus on the use of molecular markers to analyze the genomes of maize, wheat, *Tripsacum* spp. (wild relatives of maize), rye, and related species. Our scientists will develop technology to enhance the use of such markers in detecting specific segments. Potential activities include developing nonradioactive detection methods, improving the efficiency of handling samples, and designing computer software to help breeders evaluate data from molecular genetics research.

In support of future biotechnology work and to address several immediate concerns of the crop programs, the maize and wheat wide crosses sections are investigating techniques for generating viable plants from normally nonreproductive plant tissues and nonviable embryos. Known as tissue culture, the technique is being applied to research in wheat on callus induced alien transfers, genomic translocations, polyhaploid production, somaclonal variation, and selection for tolerance to saline and aluminum toxic soils. One project involves studies of suitable culture media for triticale and should prove useful in the production of both primary and recombinant triticales. In maize, research has focused on determining the efficiency of callus culture and plant regeneration in several of the Program's inbred lines.

Conservation Tillage on Breeding Plots

Recent concern with sustainability in agriculture has prompted a widespread re-evaluation of soil preparation technology, and conservation tillage has emerged as a suitable alternative for many production circumstances. The use of this tillage method in breeding plots, however, has received somewhat less attention. CIMMYT Experiment Stations is currently studying the feasibility of that application, and while further research is necessary, the results obtained to date are encouraging.

Personnel at the El Batán station recently completed four years of trials on a single plot using two maize varieties (a hybrid and an open pollinated variety), to compare conventional and conservation tillage practices under different fertilizer treatments. As nitrogen levels increased, yields under conservation tillage were superior to those under conventional land preparation, and lodging under conservation tillage was consistently less. In similar trials during two cycles at the Poza Rica station this year, maize grain yields under the two tillage systems were roughly the same.

Acting on preliminary results from these studies, two CIMMYT scientists working with several maize populations based on highland adapted materials planted some of their 1989 El Batán trials under conservation tillage.

The possible advantages of employing this method for on-station experiments are several:

- The reduced number of field operations increases the timeliness and efficiency of experiments.
- There are considerable savings in machinery, installations, inputs, water use, and labor.
- Erosion is reduced and soil quality improved, increasing the operational life of the station.

Extensive interdisciplinary research is needed to clarify such issues as the long term effects of conservation tillage on pest, disease, and weed incidence, as well as its appropriateness for breeding plots where wheat is grown or where wheat and maize are rotated. Nonetheless, interest in this tillage method for breeding work is evinced by the Center's development or purchase of related equipment: Experiment Stations personnel have designed and built a small scale, direct-drill row crop planter that can be used for zero-tillage on the experiment field or by farmers in developing countries, and the Maize Program has purchased a four-row planter for use, among other things, in a conservation tillage system on breeders' plots.

The use of conservation tillage on experiment station fields would be a valuable innovation for an international center such as CIMMYT. But resource poor breeding programs in developing countries may have even more reason to examine the suitability of this technology for their particular circumstances.

A Simple Treatment for Karnal Bunt

The free exchange of germplasm to the benefit of farmers worldwide is an important function of institutions such as CIMMYT. It depends largely on cooperators' confidence in the quality and health of seed they receive. As part of our efforts to conserve that trust, the Seed Health Unit is developing a simple

and inexpensive treatment to assure that seed distributed by the Center is free from Karnal bunt (*Tilletia indica*), a disease for which quarantine regulations can seriously affect global movement of wheat seed.

The treatment involves prewashing the seed, bathing it in a solution whose active ingredient is sodium hypochlorite, and drying it. While research continues to refine the procedure, experiments indicate that the treatment could remove or destroy all *T. indica* teliospores on the surface of noninfected seed. Experiment Stations personnel are now working with Seed Health to construct and test system prototypes for treating seed in the quantities required by the Wheat Program.

Tiff Harris



A new seed treatment developed by Center staff that uses a sodium hypochlorite/detergent bath and air drying to remove or destroy *Tilletia indica* teliospores will enable seed shipped by CIMMYT to meet strict phytosanitary guidelines for Karnal bunt.

An Overview of Research Support Services

Tiff Harris



Experiment stations

Oversees field operations on some 800 ha of land at various research stations and other experiment sites in Mexico.

Sergio Pastén



Biometrics

Provides mathematical and statistical support to crop program researchers in experimental design and the analysis of results.

Systems and computing services

Develops software, installs and oversees the operation of hardware and networks, and is responsible for overall computing infrastructure.

Information services

Assists staff in communicating results of research, provides access to results of outside research, develops training materials, and supports administration in its information function.

Sergio Pastén



Biotechnology

Evaluates and adapts biotechnology techniques for analyzing and improving maize and wheat germplasm.

General laboratories

Analyzes soil and plant tissue samples submitted by the research programs and Experiment Stations.

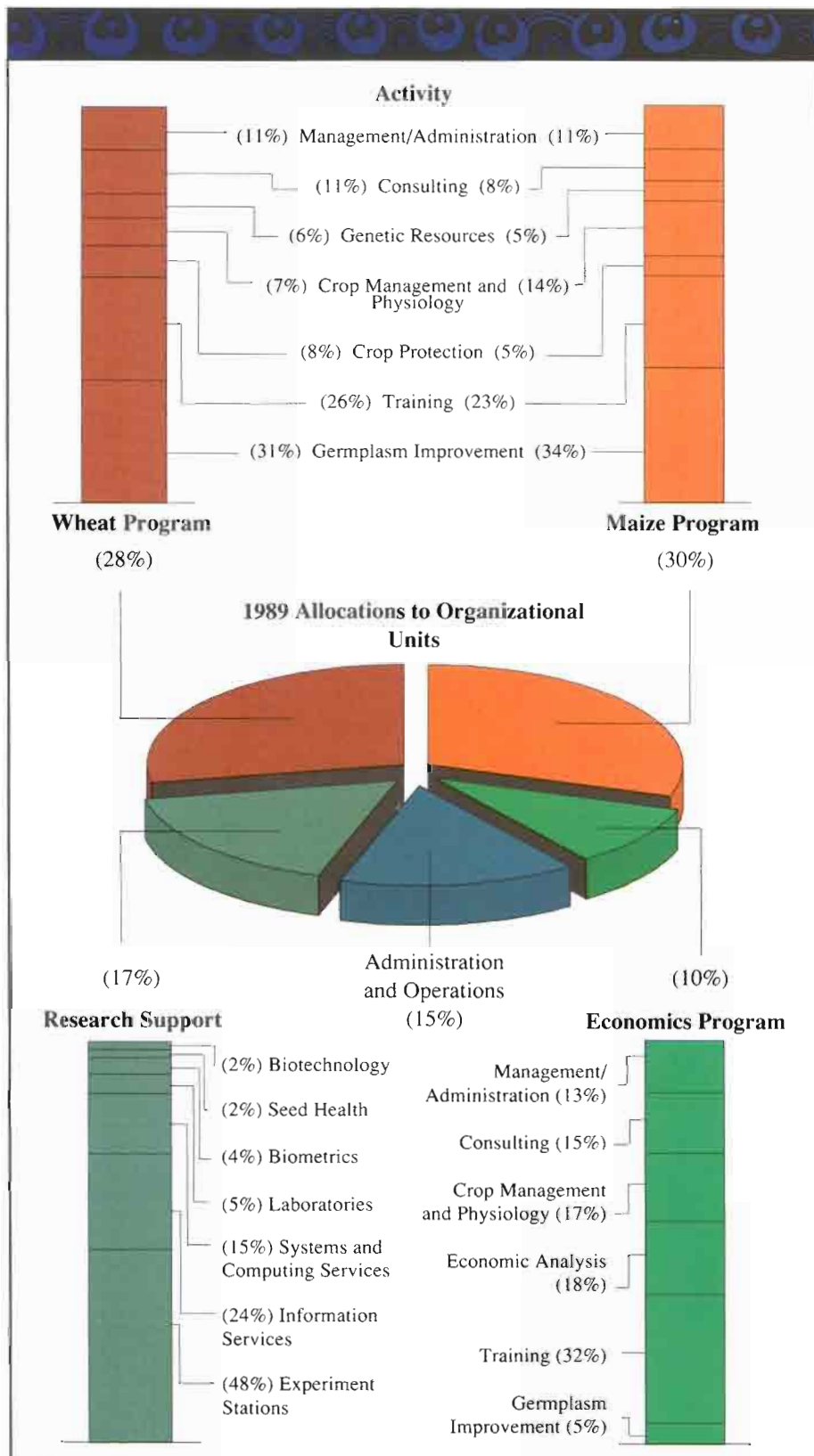
CIMMYT Files



Seed health

Monitors and treats the seed imported or exported by CIMMYT to minimize the risk from seed-borne pathogens.

Financial Highlights 1989



CIMMYT partitions its financial resources among five major organizational units, which in turn allocate resources to various activities. As one would expect, the bulk of our resources are allocated to research on maize and wheat and on economics issues related to those crops.

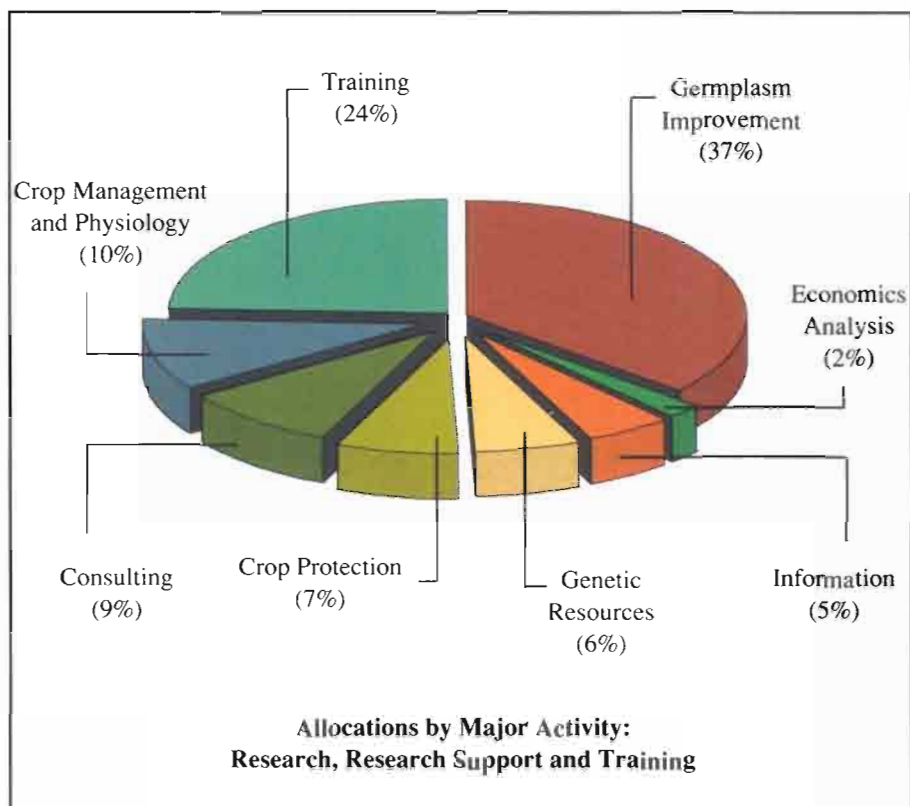
The activities to which each program allocates resources are defined by the Technical Advisory Committee of the CGIAR. Germplasm improvement is predominant among them, consuming some 37% of the Center's research resources at this time (see diagram at right). Training is also a major undertaking, currently accounting for about 24% of the budget. Crop management and physiology research, crop protection, genetic resources, and economics research together account for another 25%, while consulting and information consume the rest.

The relative allocations shown in the diagrams on these pages will change somewhat in the coming years, following guidelines established in our strategic plan--*Toward the 21st Century: CIMMYT's Strategy*--and elaborated in our *Five Year Budget, 1990-1994*. These two documents, both of which were published in 1989, are central to future financial planning. The *Budget* proposes a moderate growth in financial resources for the Center over the next five years.

CIMMYT's ability to fulfill its research and training obligations to the developing world depends on donor funding of core and special project activities. Since 1980, 15 new donors have committed to such support. In 1989, a new contribution of extra-core funds for maize and triticale training activities was made by the Government of the Islamic Republic of Iran. As well, the Fund for Private Assistance in International Development donated extra-core funds supporting additional maize research activities in Zimbabwe.

Our financial statement for this year shows an increase in total assets. This increase is reflected in the enhancement of property, plant and equipment assets, as well as donor receivables. A significant portion of the physical plant enhancements resulted from the construction and equipping of the biotechnology laboratory that will

(continued, page 59)



Balance Sheet

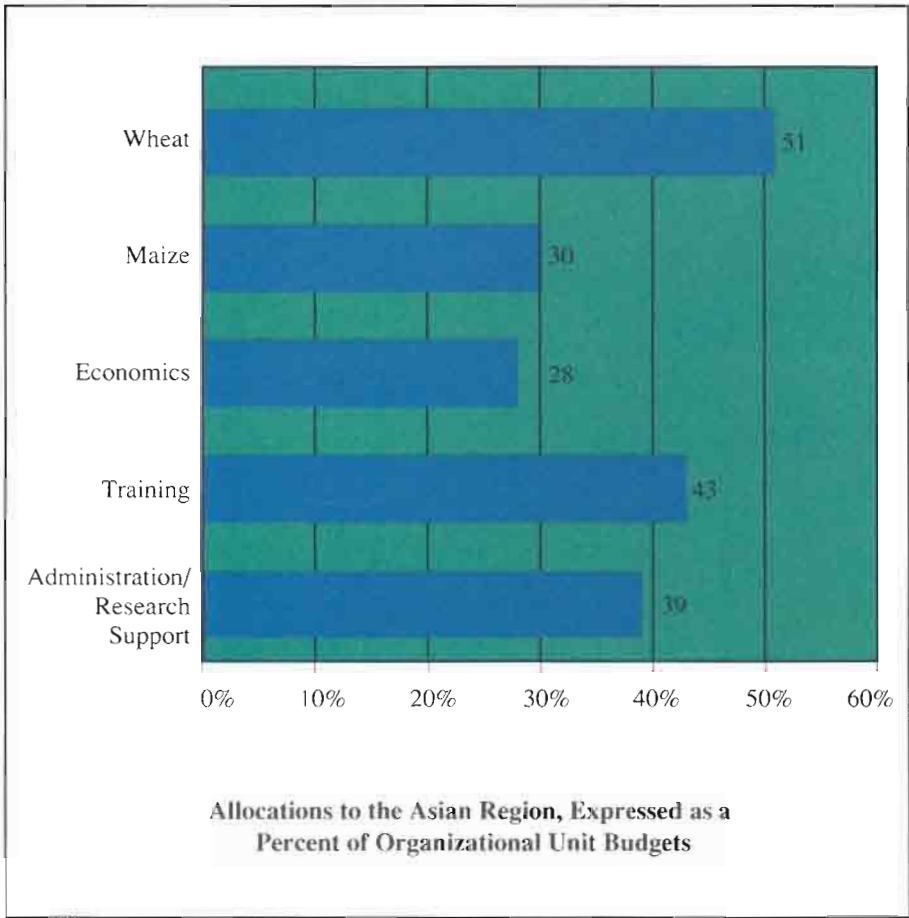
US dollars (000s)

	Year ended December 31	
	1989	1988
Assets	33,905	28,917
Cash and short-term investments	2,487	5,863
Accounts receivable	8,790	1,984
Inventories	118	132
Property, plant, and equipment	22,510	20,938
Liabilities	8,762	6,117
Accounts payable and other liabilities	2,960	718
Accrued staff obligations	889	598
Payments in advance from donors	4,913	4,801
Fund balances	25,143	22,800
Property, plant, and equipment	22,510	20,938
Capital	1,980	1,100
Operating	2,765	2,765
Auxiliary services	361	485
Cumulative translation effect	(2,473)	(2,488)
Total liabilities and fund balances	33,905	28,917

Donor Contributions

US dollars (000s)

	Unrestricted	Extra Core and Restricted	Cooperative	Total
Australia, Government of	652		59	711
Austria, Government of	240			240
Belgium, Government of			166	166
Canadian International Development Agency	1,427		1,664	3,091
China, People's Republic of	50			50
Danish International Development Agency	569		92	661
European Economic Community	1,752	1,230		2,982
Finland, Government of	947		72	1,019
France, Government of		426	89	515
Fund for Private Assistance in International Development			53	53
Germany, Government of The Federal Republic	435		267	702
India, Government of	55			55
Inter-American Development Bank	4,610			4,610
International Crops Research Institute for the Semi-Arid Tropics			378	378
International Development Research Centre			13	13
Islamic Republic of Iran, Government of			27	27
International Board for Plant Genetic Resources			24	24
Italy, Government of		238	131	369
Japan, Government of		1,800	253	2,053
Norwegian Agency for International Development	221		19	240
OPEC Fund for International Development		60		60
Spain, Government of	115			115
Switzerland, Government of		628	478	1,106
The Ford Foundation	100			100
The Netherlands, Government of		227	124	351
The Philippines, Government of	17			17
The Rockefeller Foundation			83	83
The United Kingdom, Government of	1,232			1,232
The World Bank	2,850			2,850
United Nations Development Programme		1,889	8	1,897
United States Agency for International Development	5,250		1,474	6,724
Miscellaneous training and research grants			1,076	1,076
Total	20,522	6,498	6,550	33,570



become fully operational in 1990. In contrast, the accounts receivable balance from donors was unusually high at the close of the year with several major core donations left outstanding. One result of this was an overall reduction in our cash balance as compared to 1988.

Donor pledges in currencies other than US dollars are recorded at their dollar equivalent on the date of deposit. This year the dollar strengthened against major currencies resulting in lower than expected dollar revenues from donations denominated in other currencies. In terms of the Mexican peso, the combined effect of exchange rates and inflation in Mexico continues to influence our financial management, although in 1989 the overall effect was considerably less than that of 1988. The lower dollar revenues combined with local inflation necessitated a draw on the CGIAR stabilization fund.

A complete accounting of CIMMYT's financial position for 1989 has been published as a separate document and is available from the Center upon request. These financial highlights summarize how funds were allocated by the Center. As shown in the chart on this page, our commitment to research and training efforts in Asia are significant. Future planned allocations reflect the many challenges facing the region and their continued importance to CIMMYT and to our donors.

Selected CIMMYT Publications

The following are selected publications released by CIMMYT during 1989. A more complete listing is available from Information Services.

- CIMMYT. 1989. *1988 Annual Report: International Maize and Wheat Improvement Center*. Mexico, D.F. (Also available in Spanish.)
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Lowland Tropical Germplasm

Magni Bjarnason, Iceland, Breeder,
Subtropical Germplasm and
Quality Protein Maize

James Deutsch, USA, Breeder,
Lowland Tropical Germplasm

Dana Eaton, USA, Breeder,
Population Improvement

Gregory Edmeades, New Zealand,
Physiologist

David Jewell, Australia, Breeder,
Wide Crosses

Renée Lafitte, USA, Training Officer
and Physiologist

James Lothrop, USA, Breeder,
Highland Maize

John Mihm, USA, Entomologist

Bobby Renfro, USA, Pathologist

Suketoshi Taba, Japan, Breeder,
Germplasm Bank

Ching-Yan Tang, Hong Kong, Breeder,
International Testing**

Surinder Vasal, India, Breeder,
Hybrid Maize

Willy Villena O., Bolivia,
Training Officer

Jonathan Woolley, UK,
Training Officer

* Appointed in 1989

** Left CIMMYT in 1989

Andean Region
(staff based in Colombia)

Hernán Ceballos, Argentina, Breeder

Wayne Haag, USA, Breeder**

Edwin Knapp, USA, Agronomist

Shivaji Pandey, India, Breeder

Asia Region
(staff based in Thailand)

Carlos De León G., Mexico, Pathologist

Gonzalo Granados R., Mexico,
Entomologist

Michael Read, USA, Agronomist

Eastern Africa Region
(staff based in Kenya)

Brhane Gebrekidan, Ethiopia, Breeder

A.F.E. Palmer, UK, Agronomist

Joel Ransom, USA, Agronomist

**Central America
and Caribbean Region**
(staff based in Guatemala)

Hugo Córdova, El Salvador, Breeder

William Raun, USA, Agronomist

North Africa/Middle East Region
(staff based in Turkey)

Sutat Sriwatanapongse, Thailand,
Breeder

Southern Africa Region
(staff based in Zimbabwe)

Bantayehu Gelaw, Ethiopia, Breeder

Stephen Waddington, UK, Agronomist

**Cooperative Program with
IITA in West Africa**
(staff based in Cote d'Ivoire)

Alpha Diallo, Guinea, Breeder

**Midaltitude Maize Station
in Zimbabwe**

Hiep Ngoc Pham, USA, Breeder

Kent Short, USA, Breeder

Richard Wedderburn, Barbados,
Entomologist

Ghana

Francisco R. Arias M., El Salvador,
Agronomist

Associate Scientists

Héctor Barreto, Colombia, Training

Julien Berthaud, France, Geneticist*

Jorge Bolaños, Nicaragua, Physiologist

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Elias Elias, USA, Breeder

Antonella Furini, Italy, Tissue Culture

Diego González de León, Mexico,
Geneticist (stationed at University
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Gengchen Han, China, Breeder

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Bernard Triomphe, France, Agronomist

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Pathologist**

Keith Ess, USA, Breeder*

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Pathologist**

Daniel Jeffers, USA, Pathologist*

Karimbhai Meredia, India,
Entomologist**

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Crop Management and Physiology)

George Varughese, India, Associate
Director (also Acting Leader,
Genetic Resources)

Osman S. Abdalla, Sudan, Head,
Durum Wheat

Maximino Alcalá S., Mexico, Head,
International Nurseries

Arnoldo Amaya C., Mexico, Head,
Wheat Quality Laboratory

Mark Bell, Australia, Training Officer

Pedro Brajcich, Mexico, Head,
Durum Wheat**

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Virologist/Entomologist

Paul Fox, Australia, Breeder/Statisti-
cian, International Nurseries

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Trainer

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Head, Triticale
Sanjaya Rajaram, India, Leader,
Germplasm Improvement, and
Head, Bread Wheat
Ricardo Rodríguez R., Mexico, Head,
Germplasm Enhancement
Kenneth D. Sayre, USA, Agronomist
Ravi P. Singh, India, Geneticist/
Pathologist
Bent Skovmand, Denmark, Head,
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Enrique Torres, Colombia,
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Hugo Vivar, Ecuador, Head,
ICARDA/CIMMYT Barley

Andean Region

(staff based in Ecuador)

Santiago Fuentes S., Mexico,
Pathologist

East Africa Region

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Douglas G. Tanner, Canada,
Agronomist

South Asia Region

(staff based in Nepal)

H. Jesse Dubin, USA, Pathologist/
Breeder
Peter R. Hobbs, UK, Agronomist

Southeast Asia Region

(staff based in Thailand)

Christoph E. Mann, West Germany,
Breeder

Southern Cone of South America

(staff based in Paraguay)

Girma Bekele, Ethiopia, Pathologist
Man Mohan Kohli, India, Breeder
Patrick C. Wall, Ireland, Agronomist

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Cooperative Program

(staff based in Syria)

Byrd C. Curtis, USA, Breeder
M. Miloudi Nachit, West Germany,
Breeder
Guillermo Ortiz Ferrara, Mexico,
Breeder

Bangladesh

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Sirkka Immonen, Finland, Triticale*
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Small Grains Biotechnology
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Pathologist**
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D. Steven Calhoun, USA, Breeder
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Dennis Lawn, USA, Pathologist
María Teresa Nieto-Taladriz, Spain,
Breeder**
Iván Ortiz Monasterio, Mexico,
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Thomas S. Payne, USA, Breeder
Robert Raab, USA, Training**
Matthew Reynolds, Great Britain,
Physiologist*
Nitschka ter Kuile, USA, Tissue Culture
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Breeder

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Robert Tripp, USA, Assistant Director
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* Appointed in 1989

** Left CIMMYT in 1989

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