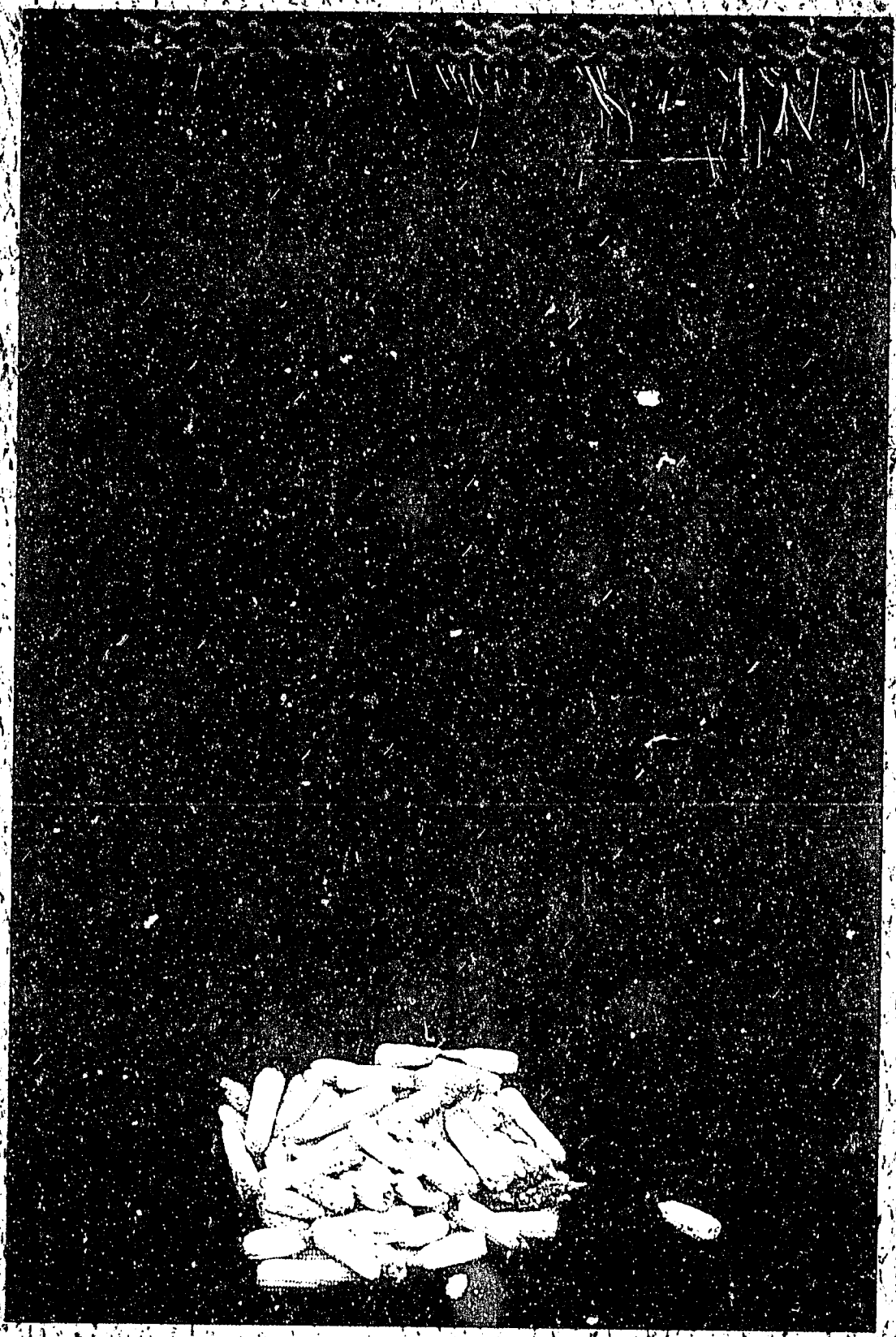
PN-ABT-193 ISN. 91336

CIMMYT 1990 Annual Report

International Maize and Wheat Improvement Center



Sustaining Agricultural Resources in Developing Countries:
Contributions of CIMMYT Research

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Correct Citation: CIMMYT. 1991. *CIMMYT 1990 Annual Report (International Maize and Wheat Improvement Center). Sustaining Agricultural Resources in Developing Countries: Contributions of CIMMYT Research.* Mexico, D.F.: CIMMYT.
ISSN 0257-8735

AGROVOC Descriptors: *Zea mays*; wheats; plant breeding; developing countries; research institutions.
AGRIS category codes: A50; A01. **Dewey decimal classification:** 630.

Writing/Editing: Tiffin D. Harris, Kelly Cassaday, Nathan Russell, Michael Listman, Gene Hettel, Thomas Luba and Alma McNab.
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Cover Photo: Kathrin Elsesser

Printed in Mexico.

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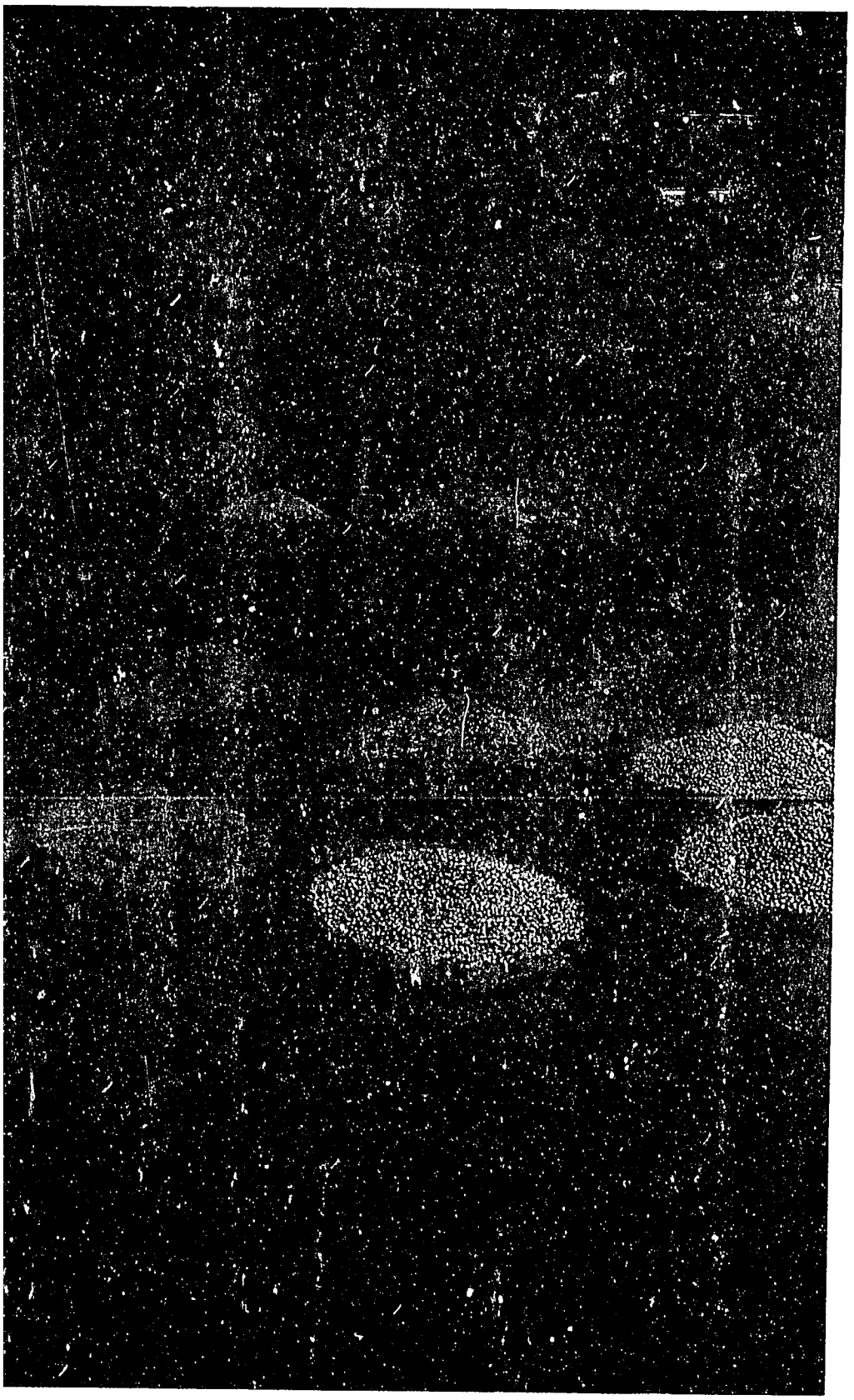
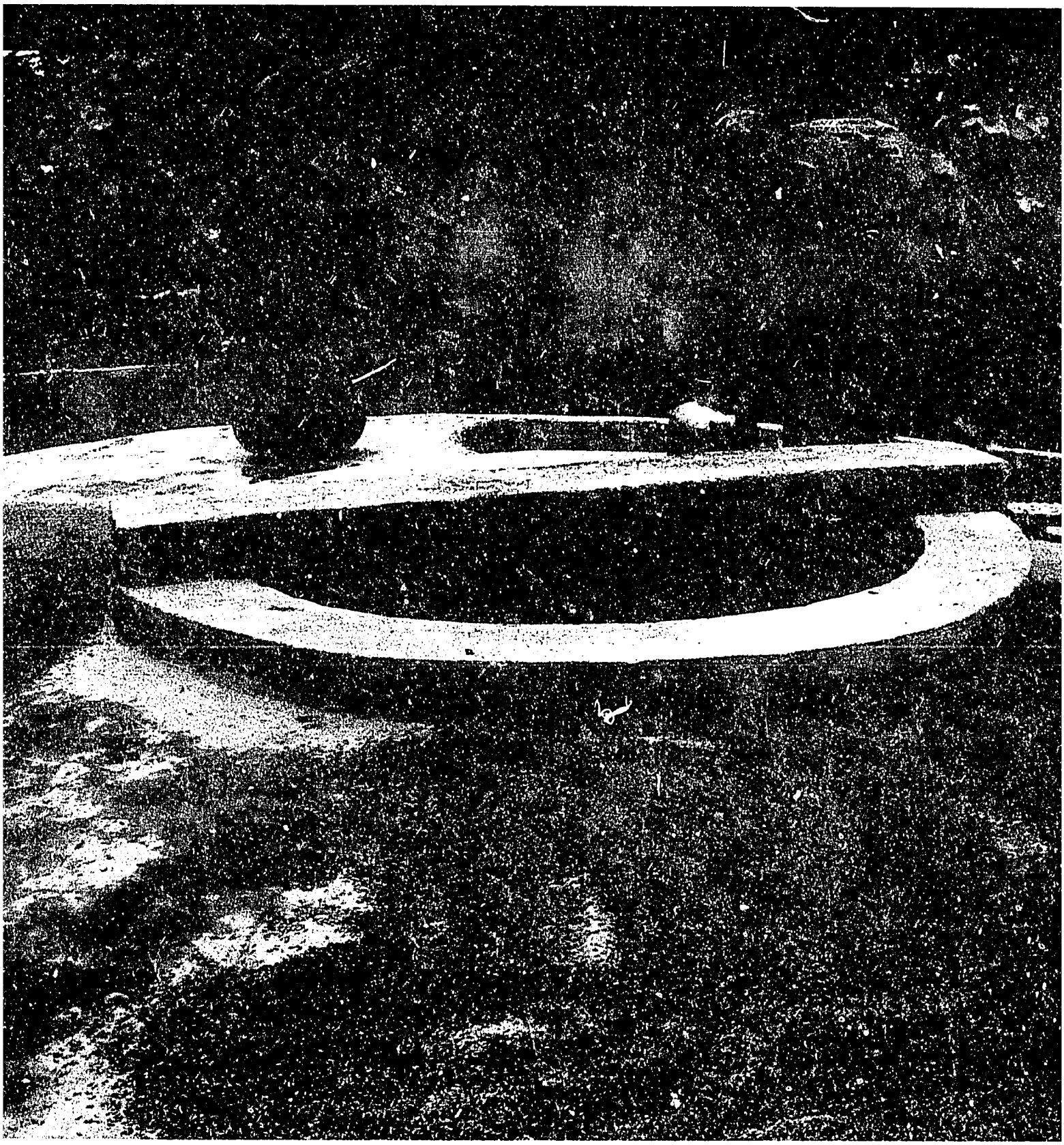


Thomas Luba

In this century, agricultural productivity in many developing countries increased dramatically, spurring economic growth and improving the well-being of hundreds of millions of the world's poor. As the next millennium approaches, one of humankind's greatest challenges is to maintain and improve upon those gains so as to meet growing needs while sustaining Nature's endowment.

Comments from Management



Thomas Luba

CIMMYT concentrates on increasing the productivity of the resources committed to agriculture, with the aim of opening new options for the poor, and on sustaining natural resources, especially those used in agriculture. Innovative research is required to meet both the needs of the poor and those of the environment. Our *1990 Annual Report* reviews the progress being made in some of our work, emphasizing that part of our portfolio most related to sustaining natural resources.

While CIMMYT has always been concerned with good husbandry, our emphasis on long-term environmental issues is more recent. Like others, we are conscious of humankind's burgeoning numbers and we are ever more aware of their impact on the environment. Population growth in poor countries is clearly the global community's most daunting challenge. With the number of people there likely to double in 35 years or less, with old and new residents competing for already inadequate resources, with would-be survivors driven to wrest ever more from their surroundings, any extrapolation to the future must raise anxiety, and if not about tomorrow then about tomorrow's tomorrow.

Population growth is not the only source of increased demand for the products of agriculture. Rising incomes will also have their effect. We now estimate that developing country utilization of maize will double in less than 20 years while that of wheat will double in less than 25 years. The needed increases in production will require an ever more intensive use of agricultural resources, at a time when agriculture is seen by some as a major source of problems that affect the environment. Eroding genetic diversity, soil erosion, reduced fertility, increased salinization, depleted aquifers, and deforestation all relate to agriculture, and each demands attention. Our conviction that CIMMYT has a role in the search for solutions led us to put greater emphasis on the environment.

Some say that current concern for the environment is excessive. We can now measure environmental factors with greater accuracy and sensitivity than ever, yet we know little about how current levels of many factors compare with earlier levels. Furthermore, the consequences of changing levels of some factors are not yet well understood. Perhaps we are perceiving threats where none exist. Yet while there may be less cause for concern in some arenas, in agriculture the threat seems much clearer and more immediate.

However perceived, interest in sustaining natural resources is clearly increasing. We at CIMMYT see it as a lasting concern resting on significant considerations: the evident need to conserve resources for future production (what some call the problem of "intergenerational equity") and the impact that degradation of resources in one arena can have in another (the problem of spillovers). Also, some are concerned that the emerging environment will be less satisfying to the senses than the existing one (an aesthetic effect). These considerations have a place in the discussion about agriculture and must be measured against other concerns, one of which must certainly be near-term productivity and income.

It is clear that issues related to sustaining the productivity of natural resources used in agriculture are complex, and the relative importance given to problems varies considerably. For this reason, CIMMYT sought two "points of view" for this *Annual Report*. Dr. M.S. Swaminathan, Director of the Centre for Research on Sustainable Agricultural and Rural Development in Madras, India, has a lifelong experience in developing countries. Ambassador Robert Blake is Chairman of the Washington D.C.-based Committee on Agricultural Sustainability for Developing Countries, a coalition of environmental and assistance organizations concerned about agricultural development. Both examine the interactions among population growth, poverty, and environmental degradation.

We welcome the chance to present the views of two such informed and committed observers.

There are various frameworks for dealing with "sustaining natural resources." The concept itself, at its broadest, reflects the need to ensure that the future characteristics of natural resources are taken into account in current agricultural research. We follow the framework of the Consultative Group for International Agricultural Research (CGIAR) as expressed by its Technical Advisory Committee (TAC). It argues for "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." As our *Report* makes evident, much of what we do fits comfortably within this framework; some quite obviously, such as the conservation of genetic diversity, and some less obviously, but probably with greater impact.

TAC stresses "maintaining" the environment and "conserving" natural resources. It is axiomatic that conservation requires investment, and that such investment has an associated opportunity cost, at times, for example, in the form of reduced near-term productivity. Tradeoffs, then, must be made. The magnitude of the tradeoffs could be assessed more realistically, we believe, were there explicit recognition

In assessing future productivity, we believe that it is probably the better environments—those destined to provide an ever growing portion of the future's foodstuffs—that will warrant the greatest concern about sustaining natural resources.

of two other potential means for saving natural resources. One is in new, natural resource-saving technologies, such as plant varieties that process natural resources more efficiently (see page 30). The second is in the substitution of one resource for another, such as capital or labor for natural resources. These natural resource-saving options could be especially important in assessing the effects on intergenerational equity of investments in conserving natural resources.

Beyond definitions and concepts we are seeking more clarity about the important themes treated under the rubric of sustaining natural resources, in particular that pertaining to marginal lands (defined on page 28). While larger investments in marginal lands can be made in the service of sustaining natural resources (such lands do appear to be more susceptible to degradation, and hence require more protection), such investments are sometimes argued in terms of equity (as these areas have benefited less than others from improved technologies, a balance must be righted) and in terms of productivity (having received less attention in the past, there are opportunities for large gains). Discussions about such investments are sometimes vague as to expected gains.

With respect to productivity, work by our Economics Program shows that rates of gain in marginal areas compare quite unfavorably with those in better environments. In the rainfed wheat areas of central India, for example, yields have increased over the past two decades by only about 1.4% per year. On the other hand, in the well-watered and irrigated areas of northern India, wheat yields have increased during the same period by about 2.8% per year. Comparable Indian research and management skills have simply done much better in the one area than in the other. I add that there is similar evidence from other regions around the world.

Even so, there is cause for concern that rising populations will inexorably push onto marginal lands, strengthening the argument for larger investments there. We can avoid surprises by being explicit about how much conservation, equity, and productivity we expect to derive from such investments. The important point, however, is that both marginal land *and* better lands must be sustained while productivity in each is enhanced.

We believe that one of the most effective means to protect marginal environments is to further enhance productivity in better environments. Advances in more favored areas can reduce pressure on marginal lands in two ways. Increased output from better land lowers prices, thereby dissuading those who might otherwise have been disposed to cultivate the marginal areas. (If, of course, the improved technologies will also lower production costs in marginal areas, as sometimes occurs, then the effect is reduced.) More important in the longer run and through agriculture's role as an engine of growth, advances in better environments will contribute to an increased demand for labor, which itself will create more attractive options than that

Nathan Russell

More appropriate methods of fertilizer application should help farmers like these in Mindanao, the Philippines, make more efficient use of this input.

of cultivating marginal lands. Both points are exemplified in India, where real prices for wheat have declined notably over the past two decades (see Figure 3, page 24), where much labor has been absorbed in nonagricultural pursuits, and where one must wonder what consequences for marginal lands were averted by the large production increases in better areas (see M.S. Swaminathan, page 12). Increased cropping intensity may exact some environmental costs in favored areas. However, these are clearly offset by the relief of pressure on the more vulnerable marginal areas that would otherwise be cultivated by those too poor to have any viable alternatives.

Moreover, it is important to recognize that it is not only in marginal environments that resources must be sustained. Indeed, in assessing future productivity, we believe that it is probably the better environments–those destined to provide an ever growing portion of the future's foodstuffs–that will warrant the greatest concern about sustaining natural resources.

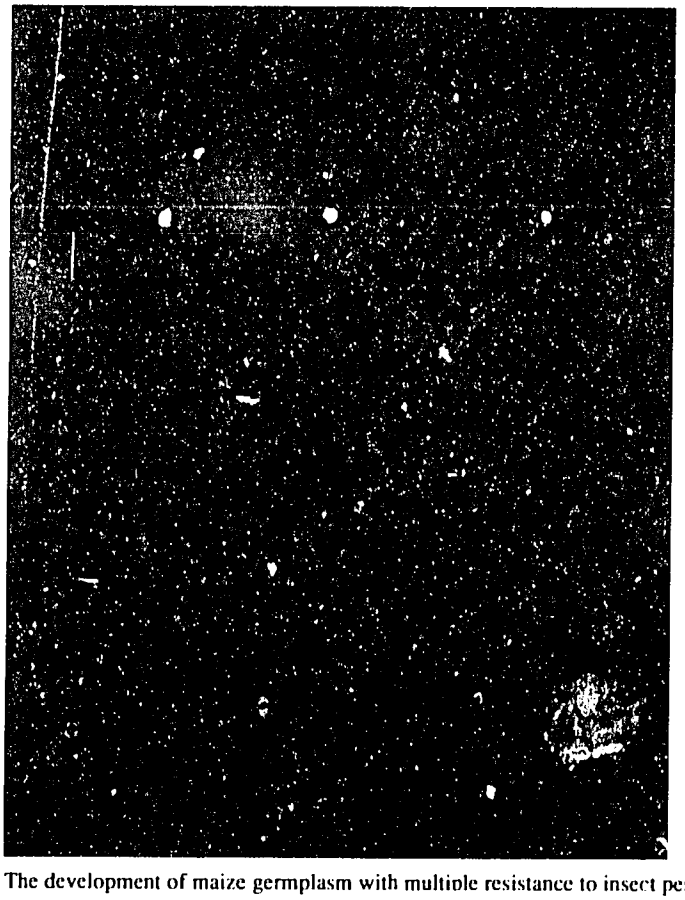
Let me now turn to some of the themes treated in the pages that follow. There are five major areas in which we believe that CIMMYT can best contribute to sustaining the resources used in agriculture.

Much of our energy is focused on developing more efficient germplasm, materials that perform better than their antecedents at all levels of management (see Review of CIMMYT Programs, pages 26-32). While these measures can lead to more intensive cultivation in some environments, and consequently require more concern for the natural resources there, they will result in reduced pressure on the more fragile environments, as discussed earlier.

Another important contribution of the Center is adding pest resistance to improved maize and wheat materials. Host plant resistance, usually at the heart of integrated pest management strategies, has the great advantage of permitting acceptable levels of production with less need to resort to pesticides. That means that costs of production are reduced, that farmers without adequate access to agricultural chemicals are not disadvantaged, and, most important to the point at hand, chemical threats to the environment are reduced (see pages 28-29).

A third contribution is in the acquisition, conservation, regeneration, evaluation, and documentation of the genetic materials in our germplasm banks. Preserving the genetic diversity of maize and wheat ensures future access to the genetic combinations of the past, with their potential advantages in meeting new demands on plants (see pages 25-26).

Thomas Luba



Thomas Luba

The development of maize germplasm with multiple resistance to insect pests is a good example of CIMMYT's efforts to provide sustainable solutions to developing country farmers' problems. Borer leaf damage on resistant germplasm developed at CIMMYT (left) is minimal compared to the susceptible variety on the right.

A growing portion of CIMMYT's resources are being devoted to strategic crop management research, a fourth dimension, where we are exploring our potential contribution to the development of sustainable maize- and wheat-based cropping systems. Two examples of this work are featured in this *Annual Report*. In one, CIMMYT and the International Rice Research Institute (IRRI) are working with several national agricultural research systems in South Asia to investigate the extent and causes of the apparent declining productivity of the region's immensely important rice-wheat rotation (see box, page 31, and Wheat Research, pages 42-43). In another, CIMMYT has been engaged for the past several years in strategic agronomic research on maize-based cropping systems in Central America, especially those encountered on volcanic soils. This work concentrates on erosion control and on maintaining soil fertility (see box, page 33). Both projects rest on collegial cooperation with national systems and both require the skills of several disciplines. Beyond improved technologies, we will learn more about CIMMYT's potential contribution to managing natural resources.

In particular, these programs and other such efforts give us special insights into the influence of biological, economic, and policy considerations on sustaining resources. What shapes much of our thinking is the knowledge that individual farmers make most of the crucial decisions about managing resources and the conviction that their actions can be made more congruent with conservation through imaginative public policies. As we see it, such policies should seek to more directly connect those who favor additional conservation with the farmers who finally decide on resource use. With our considerable experience in on-farm research we should have much to contribute in this area.

Finally, our training programs, which cater to hundreds of developing country researchers each year, aim at sensitizing participants to the importance of taking the long view when shaping more productive technologies. In time, through our own accumulating experience and that of others, we can add to such training layers of substance about maintaining natural resources.

These are five dimensions through which CIMMYT responds to the claims of the environment. We will be alert to new opportunities that might open up in the future.

Changes in Senior Management

Three related changes occurred in CIMMYT's senior management team during 1990. In August, Dr. Ron Cantrell, Director of the Maize Program, resigned to become Head of the Department of Agronomy at Iowa State University. During his tenure from January 1984, Dr. Cantrell presided over such initiatives as the development of special-trait populations, the decentralization of selected research to regional programs, and the establishment of work related to hybrid maize. He is succeeded by Dr. Ripusudan Paliwal, who had served as Associate Director of the Program. Drs. Cantrell and Paliwal comprised a genuine management team, and jointly charted the course of maize research in CIMMYT. Dr. Paliwal chose Dr. Richard Wedderburn as his Associate Director. Dr. Wedderburn joined the Center as a postdoctoral fellow in 1973, and a year later was posted to a bilateral project in Zaire. That posting began a sequence of regional positions, culminating in his assignment in 1988 as team leader in the Southern Africa Regional Program. Dr. Wedderburn thus brings to his new position a wealth of experience with developing country maize researchers and a keen understanding of Maize Program operations. In his new position he will emphasize these dimensions of Program activities.

Financial Circumstances

CIMMYT's 1990 total funding reached US$ 33.2 million, with $25.6 million coming from core sources and $7.6 million from special projects. Of special concern in 1990 was the continuing gap between Mexico's inflation and the devaluation of its currency, resulting in a dollar-denominated cost increase in Mexico of some 18% during the year. Conscious of the likelihood of this development, we curtailed 1990 spending. Because of this financial stringency, and its likely continuation, a program to reduce staff numbers was initiated in late 1990. At year end, accounts receivable from donors were again quite high, but our cash position had improved over the end of 1989 (see Financial Highlights, pages 56-57).

To Conclude

As we move into the last decade of the 20th century, CIMMYT is healthy and leaner. With the changes in Maize Program leadership noted above, our senior management team has been entirely transformed during the past six years, bringing fresh insights as we convert challenge to opportunity. All of us—trustees, staff, and management—are increasingly sensitive to the longer term environmental concerns described in this *Report*, and we all remain committed to opening new options to the poor through productivity-increasing technologies. We think good progress is being made on both fronts, with much compatibility between the two ends. I trust that the reader will see it that way, too.

Donald L. Winkelmann

Donald L. Winkelmann
Director General

CIMMYT and the CGIAR

Kathrin Elsesser

Edward Wolf of the Worldwatch Institute wrote in 1986 that, "After 20 years, the Green Revolution stands as a touchstone in international agricultural development. This agricultural strategy...transformed the lives and prospects of hundreds of millions of people...." Now, however, there are disturbing signs that the revolution may be flagging.

A clear challenge confronting agricultural researchers worldwide is to maintain, indeed to augment, the momentum of the Green Revolution. But that already formidable task is now complicated by growing concern about the environmental impacts of humankind's many activities, including, of course, agriculture. Forward thinking people are not asking simply how we will feed, clothe, and house the world's five billion-plus inhabitants, with special attention to the needs of the poor; they are asking how we will do that *and* respect the rights of future generations. The challenge, then, is to meet growing demands for food and fiber while sustaining the natural resources upon which agriculture depends.

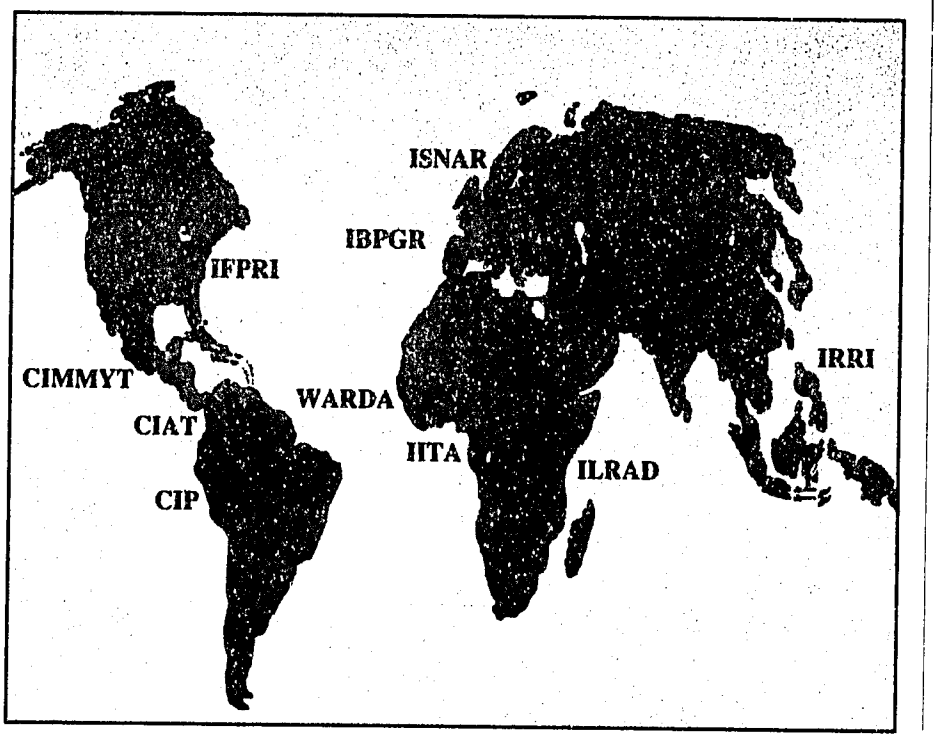
CIMMYT played a critical role in fomenting the Green Revolution of the 1960s and '70s. The products from our work during the 1980s are now generating payoffs for hundreds of millions of poor farmers and consumers worldwide. There is much we can do to augment the productive potential of Third World agriculture in the future. The Center's mission is to help the poor of developing countries by increasing the productivity of resources committed to maize and wheat. We seek to do so in ways consistent with conserving the natural resource base of agriculture.

CIMMYT was one of the four original centers in the Consultative Group for International Agricultural Research (CGIAR or CG), an association formed in 1971 of countries, international and regional organizations, and private foundations dedicated to supporting an international system of agricultural research centers and programs. The purpose of the CG's research effort is to improve the quantity and quality of food production in developing countries. The World Bank, the Food and Agriculture Organization, and the United Nations Development Programme are cosponsors of this effort. In 1990, the CG had 40 members, 35 of whom provided funds in support of the system. The CGIAR is guided by a Technical Advisory Committee (TAC), a group of some 18 prominent agricultural scientists from around the world.

In May 1986, TAC recommended that the CGIAR incorporate the concept of "sustainability" into the goals of the system. The CG immediately saw wisdom in doing so, and made "increasing sustainable food production" an explicit goal. That action initiated a series of important events. Prominent among them was the establishment in 1988 of a Sustainability Committee, appointed by then Chairman of the CGIAR, David Hopper, to assess present and potential future efforts aimed at sustainable agriculture.

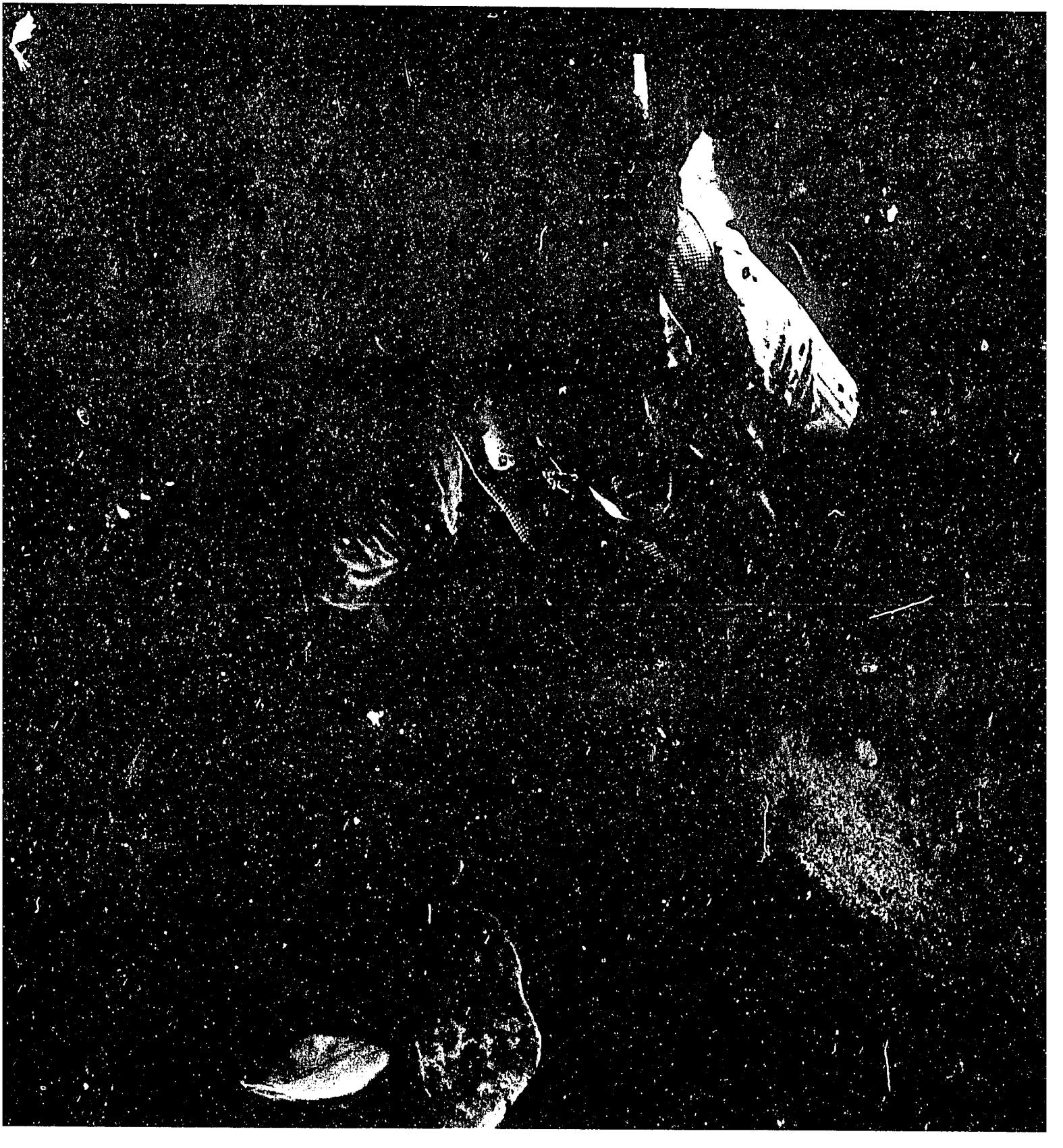
In its final report (May 1990), the Committee saw four major challenges for the CGIAR that cut across a range of sustainability-related issues: 1) protecting the genetic base of agriculture, 2) preserving the natural resource base upon which agricultural productivity depends, 3) conducting effective research for less favorable environments, and 4) identifying opportunities for implementating integrated farming systems that require fewer "external inputs" (those not produced on the farm, such as pesticides and petroleum-based fertilizers). The report notes the critical importance of taking a long-term approach to research, identifying accurate sustainability indicators, increasing the priority accorded sustainability-related research by developing country national programs, and improving the ability of CG centers to anticipate and respond to emerging threats to sustainable agriculture.

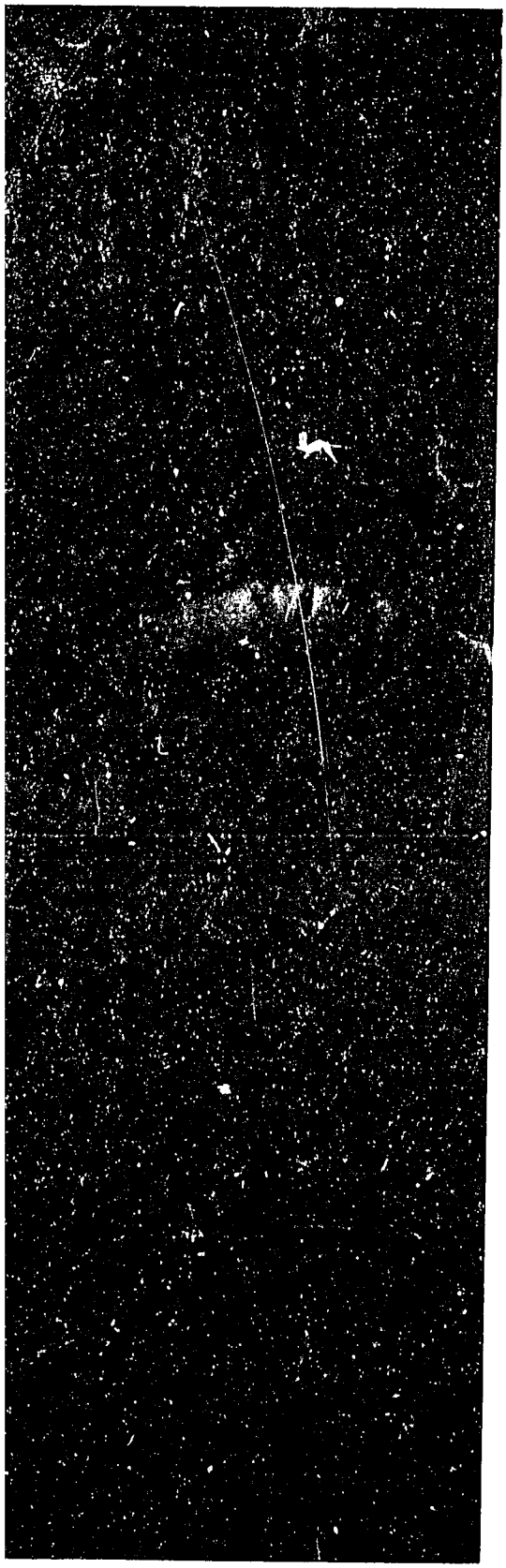
The Committee concluded that CG centers can best contribute to sustainable agriculture, not by making wholesale changes in their research agendas, but rather by sensibly adapting those things they do best (such as germplasm improvement, component management research, socioeconomic investigations, and training) so as to ensure incorporation of sustainability concerns. The system, then, continues its commitment to research directed toward improving the circumstances of the poor in developing countries, be they producers or consumers, with an added emphasis on conserving the resources used in agriculture.



Locations of the international agricultural research centers supported in 1990 by the Consultative Group for International Agricultural Research.

Points of View





Kathrin Elsesser

The complexity of the theme treated in this *Annual Report* led us to seek the perspectives of two distinguished individuals concerned with sustaining agricultural productivity in developing countries. Dr. M.S. Swaminathan, Director of the Centre for Research on Sustainable Agricultural and Rural Development (Madras, India), argues forcefully for the "onward march" of the Green Revolution. Ambassador Robert O. Blake, Chairman of the Committee on Agricultural Sustainability for Developing Countries (Washington, D.C., USA) challenges governments, development agencies, and international agricultural research centers to translate rhetoric about sustaining agricultural productivity in developing countries into concrete action.

The opinions expressed by Point of View authors are not necessarily those of CIMMYT.

The Green Revolution and Small-Farm Agriculture

Dr. M.S. Swaminathan
Director, Centre for Research on Sustainable Agricultural and Rural Development, Madras, India

The onward march of the Green Revolution in wheat, rice, and maize is an ecological and economic imperative in population-rich but land-hungry countries like Bangladesh, China, and India. If the Revolution is allowed to falter, the poverty of small-farm families will persist, since they will have very little marketable surplus and thus will not be able to profit from the remunerative output-pricing policies of governments. Nor will it be possible to prevent further expansion of cultivated area at the expense of forests and soils vulnerable to erosion or other forms of destruction.

Consider the following differences between developed and developing country circumstances: In 1945 the USA had about 5.9 million farms. By 1985 this number had declined to about 2.2 million. In contrast, at the time India became independent in 1947, the country had about 50 million farms. By the early 1980s, this number had risen to about 90 million (Figure 1). Projections indicate there are now some 100 million farms in the country (the decadal agricultural census is just starting). Today, every fourth farmer in the world is Indian, and nearly half of the country's land is being utilized for crop production. Meanwhile, in the USA only about 20% of the land is used for crop production. Affluent countries have gross national products (GNPs) that vary from 12 times the value of agricultural production (as in New Zealand) to 50 times that value (as in Belgium, Germany, the United Kingdom, and the USA). In these countries employment in the tertiary (services) sector exceeds that in the primary and secondary sectors combined (the first of which encompasses farming and other enterprises based on natural resources and the second manufacturing). In India, by contrast, over 30% of the GNP comes from agriculture. Even more significant, about 70% of the country's current population (nearly 850 million people) depends upon the primary sector for a livelihood.

In general, opportunities for traditional rural societies to enhance their standard of living are closely linked to declines in the farm population. As can be seen in Figure 2, however, the trend in developing countries is headed in the wrong direction. About half the population of the world today is working or seeking work in agriculture. Only about 10% of the population in developed countries is now employed in the farm sector, having shrunk from about 38% over the last 40 years. Compare that with the developing world. Forty years ago about 81% of the population was working in agriculture; today some 63% of all developing country residents are still employed in agriculture (Hendry 1988).

The famine of food at the household level largely arises from a famine of jobs and purchasing power. The pace of progress in the movement of men and women from agriculture to other sectors has been slow. Self-employment opportunities in nontraditional and off-farm occupations are limited, especially in slowly growing economies. On the other hand, population growth has resulted in the diminution and fragmentation of farm holdings. Diversification of employment opportunities and income sources, of course, can insulate people from violent fluctuations in their economic fortunes. In India, however, where there is relatively little diversification of incomes compared to developed countries, drought has caused serious disruption in the economy of the people, making it essential for the government to initiate large-scale "food for work" programs. Improved employment opportunities arising from rapid economic development are essential for food security as well as for resource conservation.

These trends in employment, income, and land use provide the context in which the future of the Green Revolution in developing countries must be viewed. In 1965 farmers in India produced 48 million tons of wheat and rice on 54 million hectares of land. In

1990 they produced 127 million tons of wheat and rice on about 68 million hectares. Obviously, land-saving technologies have raised yields and thereby reduced pressures to expand cultivated area to forested and other protected areas. This is true in other developing countries as well. Even so, both the United Nations Environmental Programme and the Food and Agricultural Organization estimate that over 75% of the annual global deforestation of 17 million hectares occurs for expanding food production. Thus, there is no option but to adopt land-saving agricultural practices in countries where land is limited and population pressure is increasing. This is why defending the yield and economic gains achieved through the Green Revolution during the last 20 years and extending them to more regions and farming systems are both ecological and economic imperatives.

Making the Green Revolution "Greener"

In January 1968, when there was evidence that India was on the threshold of making impressive progress in wheat production using the semidwarf wheats introduced from CIMMYT, I made the following observations:

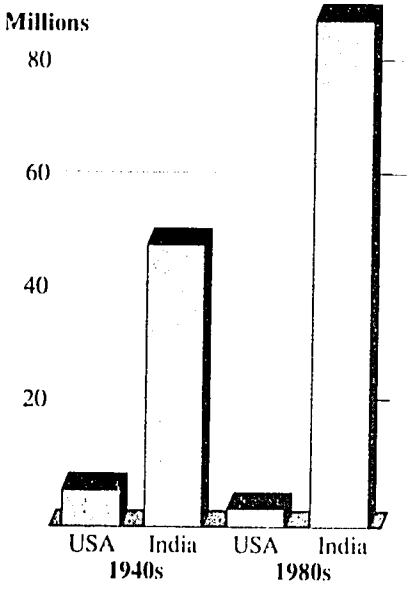


Figure 1. Number of farms in India and the US, 1940s and 1980s.

Intensive cultivation of land without conservation of soil fertility and soil structure would lead ultimately to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in the grains or other edible parts. Unscientific tapping of underground water would lead to the rapid exhaustion of this wonderful capital resource left to us through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high-yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops.... Therefore, the initiation of exploitive agriculture without a proper understanding of the various consequences of every one of the changes introduced into a traditional agriculture and without first building up a proper scientific and training base to sustain it may only lead us into an era of agricultural disaster in the long run, rather than to an era of agricultural prosperity (Swaminathan 1968).

Thus it was clear from the beginning that the indiscriminate use of chemicals and nonadoption of ecologically sound crop management practices might have a number of unfavorable effects. Public health problems could arise, and the sustainability of high yields over the long term could be threatened.

Fortunately it appears possible to reduce input levels with no effect on yields by improving technical efficiency. Byerlee (1987) points out that technical inefficiency—the difference between actual production by farmers and their potential production given current levels of input use—generally ranges from 20% to 50%. He concludes that a new and more complex second generation of inputs and management practices can play an important role in productivity growth, while keeping input use at reasonable levels. Investments in better information and the skills of farmers to improve their technical efficiency are needed to maintain momentum in traditional Green Revolution areas.

At the same time, the Green Revolution needs to be expanded to cover more crops, areas, and farming systems, and our emphasis should be on improving the technical efficiency of small-farm agriculture. This expansion, however, must be made in ways that consider the ecological implications of productivity-enhancing technologies—a further "greening" of the Green Revolution.

Pathways to Improved Agricultural Productivity in Developed Countries

Growing concern over the level of input use is hardly limited to developing countries. Indeed, moves to reduce the use of agricultural chemicals are receiving considerable attention in Europe and the USA. These moves appear to have been at least partially inspired by notable prescriptions to achieve ecological farming, as described by Fukuoka (1978), and by the low-input, sustainable agriculture (LISA) movement in the USA. Both approaches place strong emphasis on

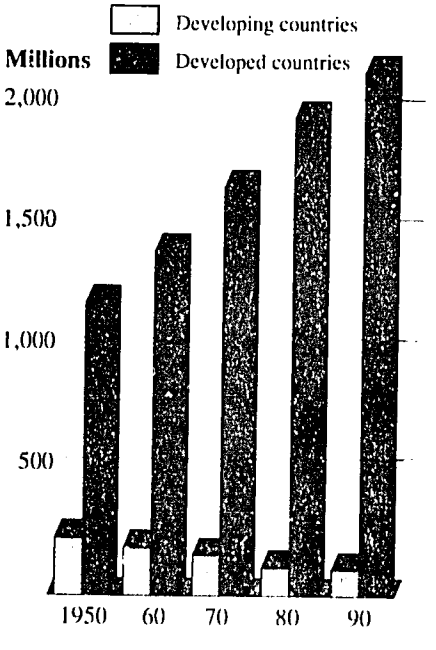


Figure 2. Agricultural work force in developing countries.

the use of organic matter (as opposed to synthetic inputs) in maintaining soil fertility and resource quality.

Scandinavian countries have enacted legislation to reduce pesticide use, with Denmark calling for a reduction of 50% by 1997 and Sweden setting a target in 1988 of a 50% cutback within only five years. Their lead has already been followed by other countries in Europe (Ministry of Agriculture, Nature Management, and Fisheries 1990, Warrell 1990). A report on alternative agriculture (National Research Council 1989) defined such alternative systems as those incorporating natural processes, reducing the use of inputs from off-farm sources, making greater use of the biological and genetic potential of plant and animal species, ensuring the *long-term sustainability of current production levels* (italics mine), and improving farm management and the conservation of soil, water, energy, and biological resources. Significant government support for the development of such systems exists; the US *Food, Agriculture, Conservation, and Trade Act, 1990* (farm bill), for example, authorizes US$ 40 million annually for LISA research (Madden and O'Connell 1990).

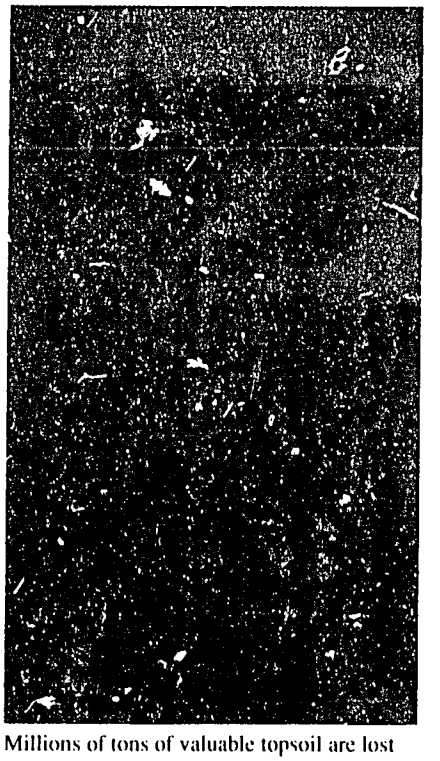
The efforts of industrialized nations to promote the long-term sustainability of current yield levels are indicative of the technology options under consideration. I wish to stress, however, that, while defending the status quo in yield may be the priority task in industrialized nations, raising average yields is the urgent need in developing countries. To what extent, then, is the experience of industrialized countries applicable to the generally small-scale farming circumstances of developing countries?

Pathways for Developing Countries

Sustainable pathways toward "greening" the Green Revolution in developing countries like India and China may differ dramatically from those applicable to developed countries; that is, technological options must be appropriate both to the needs and opportunities of such population-rich but land-hungry countries. There are at least two difficulties in applying the Fukuoka and LISA models to the circumstances of developing countries.

First, in tropical and subtropical environments, the oxidation of humus is high, and soils generally tend to be lower in organic matter content. They will benefit from the incorporation of crop residues, but such residues are invariably needed for other uses, such as animal feed. Many soils are eroded, and their nutrient status tends to be low due to continuous cultivation for centuries. Even so, farmers who are producing barely enough to meet the needs of their families find it extremely difficult to invest in resource-enhancing technologies (such as systematic cereal-legume crop rotations). If unchecked, weeds, insects, and pathogens multiply and spread, causing considerable losses. Plowing or puddling is needed to control weeds, and resource-poor farmers must have improved varieties with genetic resistance to insects and diseases.

Thomas Luba



Millions of tons of valuable topsoil are lost each year to erosion caused by overgrazing and other negligent land management practices.

The second difficulty is that, while these models offer good longer term benefits, they entail few near-term advantages. It is hard for very poor farmers, whose main preoccupation is survival, to base their actions on the requirements of a distant and uncertain future. Yet sustainable agriculture requires that attention be paid concurrently to intra- and intergenerational equity.

*Intra*generational equity, which aims at giving a fair deal to the economically and ecologically disadvantaged, demands resource neutrality in technology development and dissemination. This new dimension complements the scale-neutral research already in process. In working toward intragenerational equity, agricultural researchers can help all farmers, regardless of farm size and capacity, to mobilize inputs and absorb risk. Obviously, research strategies and public policies will have to be suitably integrated to achieve this goal.

Achieving *intergenerational* equity involves conserving the ecological foundations of sustainable advances in biological productivity. This will require greater efforts in conserving resources used in agriculture and in eliminating agriculture's contribution to the accumulation of greenhouse gases in the troposphere. I believe the appropriate measure of productivity is the value of output divided by the value of the inputs required to produce it, plus some factor that indicates changes in environmental capital stocks. If such a formula is to be useful, however, we need internationally accepted measurement and monitoring tools.

The final report of the CGIAR Committee on Sustainable Agriculture noted in some detail the difficulties inherent in monitoring sustainability (Swindale 1990). Certainly, no single indicator is likely to incorporate the many normative—and therefore difficult to quantify—judgments that must be made in gauging progress toward sustainable agriculture. These would include judgments about the

reversibility of degradation, the critical threshold of decline, and the level of diversity necessary to protect the future genetic base of agriculture. The Committee also points out, however, that several quantifiable indicators can, if measured over the long term, provide data that help to determine the sustainability of most agricultural systems. These indicators include soil organic matter, soil acidity, crop yields or biomass yields per hectare, and the net value added to production. I join the Committee in its plea for a considerable investment in developing and testing quantitative models to guide future sustainability research and to extend the utility of findings to new situations.

Where Do We Go from Here?

Given the complexities inherent in achieving sustainable agricultural systems, especially in developing countries, as well as the pressing need to do so, what are the key steps toward success? In my view, at a minimum they include the following:

- We need to develop technologies that can help increase the productivity and profitability of small-farm operations, without forcing undue tradeoffs between current and future production systems.

- We need to further develop and implement techniques like integrated nutrient supply (involving a blend of biofertilizer, organic and green manures, and mineral fertilizers), and integrated pest management (involving genetic, biological, and cultural control methods, as well as the application of chemical pesticides when needed), so as to achieve technical efficiency and ecological sustainability.

- Any research agenda for sustainable agriculture should give priority to securing the livelihood of families that either have no assets or only small holdings. Chambers (1991) has often stressed that, in the case of the Green Revolution technologies in wheat and rice, farmers who took advantage of them adapted the growing conditions to suit the needs of the technology. On the other hand, farmers located in complex, diverse, and risk-prone (CDR) areas will need technologies tailored to their agroecological and socioeconomic circumstances. There is considerable evidence that this can be done. The experience of CIMMYT scientists shows that varieties with good adaptation to diverse growing conditions can be developed. Recombinant DNA techniques are providing additional tools for achieving novel genetic combinations. Given appropriate breeding methods and selection procedures, it should be possible to develop new germplasm for CDR areas, which, when integrated with efficient methods of soil fertility restoration and water saving and sharing, will help to elevate and stabilize yields in such areas.

- In many CDR areas, policies aimed at changing systems of land use will probably be needed. Agroforestry involving sylvipastoral or sylvihorticultural practices may be the ideal land and water management system for such conditions. Yet, unless the people living in such areas are somehow assured of a steady supply of basic staples at reasonable prices, they will continue to grow annual crops in marginal and erodable soils. Land use changes in ecologically desirable directions can be triggered only through public policy measures designed to ensure, among other things, economic and physical access to food for the families cultivating the land.

Conclusion

For most developing countries, and especially for countries like India and China, the only viable path toward sustaining the natural resource base of agriculture is by increasing the productivity of farmers, that is, through the onward march of the Green Revolution, though in ways more sensitive to potential ecological impacts. Creative blending of new and traditional technologies can help to achieve needed improvements in agricultural productivity, employment, and economic growth. However, no amount of effort to implement the appropriate mix of technologies will bring lasting benefits in the absence of enlightened public policies designed to facilitate and reinforce their adoption.

In the end, of course, farmers judge the value of new technologies, and their concerns tend to center on household food security. On an individual level, the future means little if you cannot survive the present. Productivity-enhancing technologies and the policies intended to facilitate them must be developed with that reality in mind.

References

Byerlee, D. 1987. *Maintaining the Momentum in Post-Green Revolution Agriculture: A Micro Level Perspective from Asia.* MSU International Development Paper No. 10. East Lansing: Michigan State University.

Chambers, R. 1991. Presentation at the Dialogue on "New Technologies: Reaching the Unreached." M.S. Swaminathan Research Foundation Monograph 3. Madras: M.S. Swaminathan Research Foundation.

Fukuoka, M. 1978. *The One-Straw Revolution: An Introduction to Natural Farming.* Emmaus: Rodale Press.

Hendry, P. 1988. Food and Population: Beyond Five Billion. *Population Bulletin* 43.

Madden, P.J., and O'Connell, P.F. 1990. LISA: Some early results. *Journal of Soil and Water Conservation* 45:61-64.

National Research Council. 1989. *Alternative Agriculture.* Washington, D.C.: National Academy Press.

Ministry of Agriculture, Nature Management, and Fisheries. 1990. *Nature Policy Plan of the Netherlands.* The Hague: Ministry of Agriculture, the Netherlands.

Swaminathan, M.S. 1968. Presidential Address. In: *Proceedings of the Fifty-fifth Indian Science Congress.* Part II. Varanasi, India.

Swindale, L.D. 1990. *Sustainable Agricultural Production: Final Report of the CGIAR Committee.* CGIAR Document No. MT/90/18. The Hague: CGIAR.

Warrell, E. 1990. Reducing pesticide use: The Danish experience. *Shell Agriculture* 8:18-20.

Promoting Agricultural Sustainability for Developing Countries: An Urgent Agenda

Ambassador Robert O. Blake
Chairman, Committee on Agricultural Sustainability for Developing Countries, Washington D.C., USA

The world may well be faced in the not-too-distant future with a serious crisis in feeding its growing billions. Population in many developing countries is doubling every 20 to 30 years. At the same time international reserves of basic grains are declining, per capita food production is decreasing in large parts of Africa and Latin America, and the economic resources and governmental institutions needed to cope with these problems continue to weaken in many poor nations.

These facts present an especially difficult challenge for those developing countries that already have huge numbers of undernourished people, stagnating agricultural productivity, and rapidly degrading farmlands. Few are the developing countries that are not literally mining their soil in the name of higher agricultural production.

Can they—and if so *how* can they—achieve sustainable farming systems so that not only this generation but also future generations can be fed? The answers to both questions are in real doubt. There are few signs that population growth will level off anytime before the middle of the next century. True, the burden of answering these questions will be on the governments and citizens of the developing countries. But the citizens of the United States and other industrialized nations hold many of the keys to helping solve these problems, particularly by assisting developing countries to apply the tools of science and technology more effectively. Hopefully we can also help them mobilize both the will and the resources to support the heavy expenditures and tough political decisions that will be required if sustainable agricultural systems have any chance of being created.

Yet more than enough is already known to make a real start toward putting agricultural production on a sustainable basis, even in the case of less well-endowed lands. Why then has this not happened? Because governments, development agencies, and research institutions have given little real thought to how to achieve high enough production levels over a longer period, and how to do so without continuing to mine irreplaceable natural resources. Because not enough answers have been provided through research on how the tougher dimensions of the sustainability problem can be solved. Because the outreach systems needed to stimulate farmers to accept new plants and technology simply do not exist in many countries. Because nowhere near enough resources have been dedicated to the achievement of agricultural sustainability by governments or development agencies. Because more attention is still being focused on the short-term political and financial costs of pursuing sustainability than on the heavy long-term costs of not doing so.

There is another serious impediment to the achievement of sustainability: too many governments still believe that they cannot afford to conserve their precious soil, water, and forests. Too often they fail to recognize that the costs of protecting these resources now are infinitely lower than the costs of trying to restore them later.

Two Positive Developments

Yet the picture is not all dark. Two breaks in the clouds signal the growing recognition of the importance of agricultural sustainability. The first was the formation three years ago in the United States of the Committee on Agricultural Sustainability for Developing Countries by a coalition of environmental groups, nongovernmental organizations, and development and policy research groups. The Committee has since expanded, adding new member organizations and a growing

number of university and scientific advisers, all of them actively involved in agricultural development in the dev loping countries. The Committee has also begun to work with like-minded organizations in other countries, particularly in the developing world. The Committee aims above all to make policy makers, opinion leaders, and scientists so conscious of the urgency—and possibility—of creating sustainable agricultural systems that they will give this prospect much higher priority.

The second hopeful development has been the growing interest of the US university leaders in joining actively in the effort to help the developing world achieve agricultural sustainability. The Committee, for its part, has sought to channel and magnify these efforts by working in close alliance with the university-oriented Board for International Food and Agricultural Development and Economic Cooperation (BIFADEC) and with one of the US academic community's most vigorous "trade associations," The National Association of State Universities and Land Grant Colleges (NASULGC), a recent addition to the Committee's membership. Together we have sought to introduce new vigor and new thinking about sustainability into the agricultural programs of US Agency for International Development (USAID). Special attention has been directed at the US government-supported collaborative research support programs (CRSPs) conducted through the universities. The Committee has also agreed with its academic allies on the longer range goals of making sustainability a central focus of all university agricultural teaching and research and of getting the universities to take on a larger role in promoting sustainability through expanding their collaborative efforts with organizations in developing countries.

Committee Priorities

The Committee from its first days has concentrated a major portion of its efforts on analyzing and influencing the work of the world's development agencies, particularly those based in Washington, D.C. It has focused on the development agencies because they alone have the financial and human resources and the leverage with developing country governments necessary to change entrenched policies and to finance expensive programs.

How well are these development organizations doing and what problems do they face? Do they have policies and procedures that ensure the "sustainability" of their own agricultural development programs? Are development agencies producing programs that contribute to sustainable agricultural development? The answers to these questions are complicated and differ with each institutions.

USAID—While still working on much too small a scale, USAID has gone farther than other development agencies in thinking through what agricultural sustainability should mean in practice. In the process, it has given much higher priority to rural natural resource protection. Solid sustainability principles are increasingly reflected in USAID's statements about agricultural development and are incorporated into its training programs. More specifically, USAID is in the process of launching a CRSP aimed directly at promoting sustainable agriculture. It is also supporting the community-based agricultural development programs of American private voluntary organizations in a number of countries.

But the picture in USAID is not all good. Most USAID missions still have difficulty rigorously applying sustainability principles to their own agricultural projects. Even worse, as federal funding for development has become increasingly scarce, USAID has tended to concentrate its funding on easier projects with the "biggest returns" in political terms rather than on those that make the greatest contribution to sustainable agriculture or to the reduction of poverty in general. And, most regrettable of all, USAID's efforts are neither large enough nor focused enough on sustainability to make anywhere near the impact that the present situation urgently requires.

Unfortunately, with the end of the Cold War, interest in development is lagging all over the world. A new rationale for

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Large tracts of virgin forest are being put to the torch to make room for agriculture in many areas of the developing world.

launching more—and more effective—collaborative efforts between industrial and developing countries in agriculture, population, health, education, and the environment is badly needed. But events will not wait for changes in public opinion. USAID and other development agencies must be stimulated to do much more to promote agricultural sustainability *now*.

World Bank—The World Bank is rhetorically committed to agricultural sustainability, but its actions in this regard still do not match its rhetoric. Of all the development agencies, it has the greatest potential to help developing countries make the difficult transition to agricultural sustainability. But there are big problems. The Bank thinks of itself primarily as a bank and not a development agency. As such, it is not yet ready to accept the risks of financing the large volume of small-scale, farm-level agricultural production loans which the transition to a sustainable system requires. Its environmental department, which is the logical center for promoting such changes, still lacks the strength and the clout to persuade the key regional operations departments to dedicate the resources needed to ensure environmental soundness in agricultural (and other) projects. For example, irrigation projects that don't provide financing for necessary but expensive drainage systems, that don't provide for enough continuing supervision, and that don't require enough participation in management by associations of irrigation users are still too often approved. Another point: Despite its strong verbal commitment to reducing poverty in the agricultural sector, the Bank is rapidly losing its capacity to plan and supervise poverty-oriented, farm-level agricultural programs because of its failure to replace retiring technical staff.

All these tendencies must be overcome. Fortunately, the Bank is full of good people who are well aware of the environmental consequences of Bank actions and who support important changes in the way the Bank operates.

IDB—The Committee is increasingly working with the Inter-American Development Bank (IDB). That institution, with strong environmental leadership from its president, is in the process of initiating some ground-breaking programs in agriculture through its newly headed agricultural department and its newly formed environmental department. These are hopeful signs.

Other development agencies—The Committee also follows, but much less closely, the work of other "bilateral" development agencies and regional banks. Almost all of them have, in the wake of the Brundtland Commission's recommendations, come to acknowledge the primordial importance of promoting sustainability. Yet few have established effective programmatic responses. Some, like the Swedish International Development Agency, have programs that promote one aspect or another of agricultural sustainability. However, these programs still tend to be small, both in relation to the agencies' total efforts and to developing country needs. Little has yet been done to eliminate conflicts and duplications of effort among development agencies in the promotion of sustainability.

International Agricultural Research Centers—The Committee is concentrating an increasing amount of its attention on the work of the international agricultural research centers (IARCs). It is the Committee's view that the IARCs have an absolutely central role to play in the promotion of sustainability. The IARCs' output over the last two years in this regard is encouraging overall but still far from large enough or sophisticated enough to respond to developing countries' sustainability problems. Individually and collectively they have been mandated to fully incorporate the principles of sustainability into their research. Some centers are further along this path than others. Most are paying increasing attention to breeding sturdier and more

Thomas Luba

A Nepali scientist participates in an informal field survey in Rupandehi District to hear about farmers' experiences with the rice-wheat rotation. This kind of monitoring alerts researchers to potentially serious problems that might never be perceived in the more controlled conditions of experiment stations.

productive plants and to designing systems for nutrient supply and pest management that meet the needs of the millions of small farmers on less well-endowed lands. But as the centers point out, they are also faced with the crucial task of maintaining the productivity of the world's principal food crops. Dividing their finite resources between research on cropping systems and plant breeding for the most productive lands and research aimed at the less well-endowed lands is a continuing problem, as is ensuring against an overly "top-down approach" to research.

Given the urgency of increasing global agricultural productivity and production, the key role that agricultural research must play in this effort, and the overall inability of the national agricultural research institutions in so many developing countries to meet their own needs, the challenge to the IARCs is enormous and growing. They must find more and better ways to interact with small farmers, to meet farmers' expressed needs, and to get new technology out to farmers. They must concentrate even more on designing cost-effective and labor-effective systems that incorporate the rapidly emerging lessons of sustainable production and resource conservation. If they are to do all this—and in as timely a manner as sound research permits—the centers must be given the progressively greater support that our committee advocates.

Time to Move Forward

If there has been some progress in helping developing countries carry out environmentally sound agricultural development, the advances made so far have just not been good enough or widespread enough to touch more than a small number of farmers in the developing countries. Time is not on our side. We must lose no chance to move forward by finding ways to:

- Utilize, on many more farms in every developing country, the more productive and more resource-conserving technology that has already been developed.
- Develop the plants and the systems capable of doubling or even tripling present amounts of food without destroying natural resources.
- Get governments in both the south and the north to face up to the gravity, difficulty, and urgency of allocating the necessary resources and to make the tough political decisions that the achievement of sustainability will require.

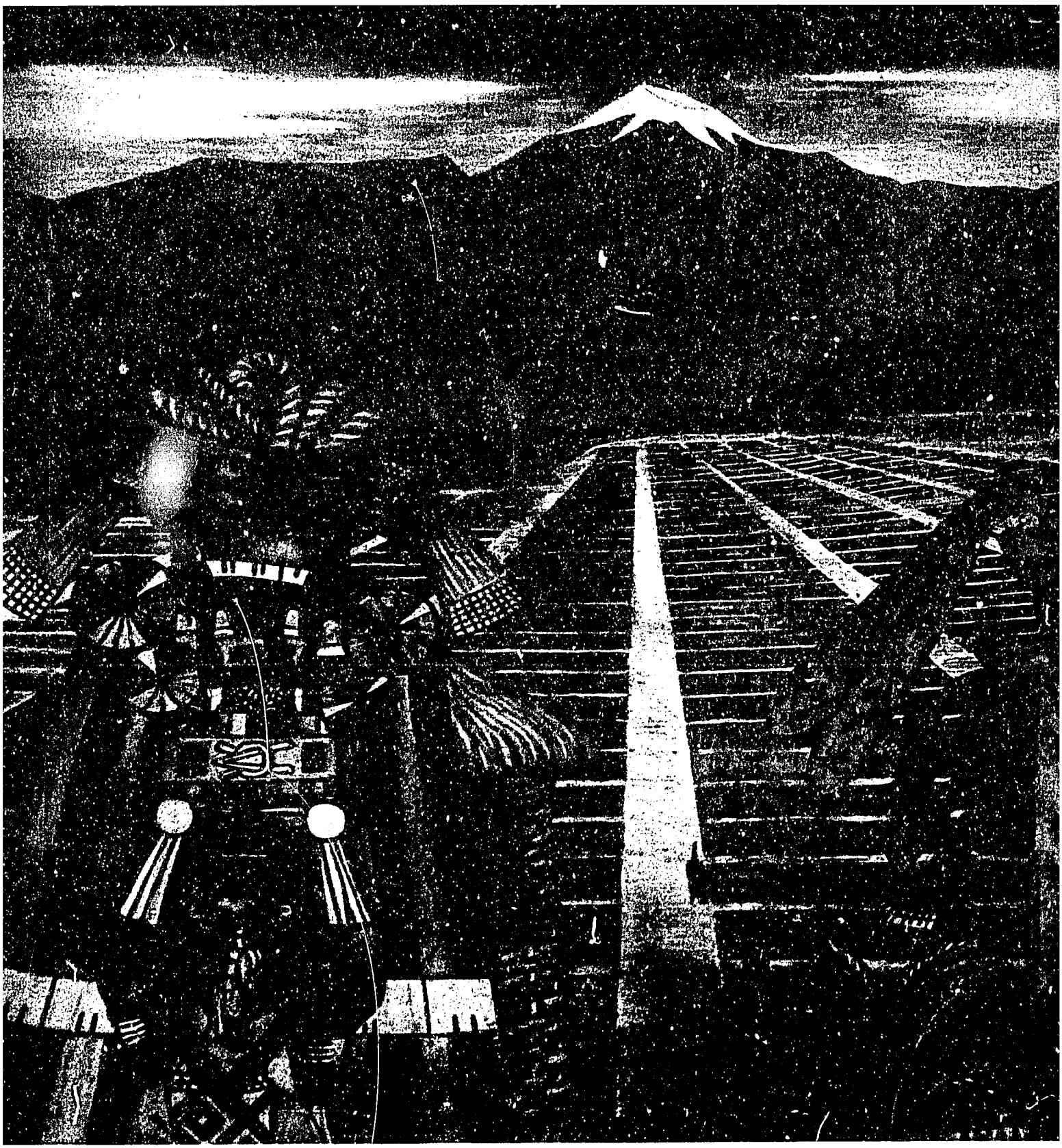
How You Can Personally Contribute

The search for progress cannot just be left to others. We must *all* play our part. I would suggest a short list of priorities and invite readers of CIMMYT's *Annual Report* to reflect on how they can personally contribute. We must all:

- Seek to better understand the obstacles to achieving agricultural sustainability and recognize—and incorporate into our thinking and work—the hard truth that providing global food security will require much higher production levels.
- Try to launch some kind of personal collaborative effort with someone or some organization in a developing country, if possible going beyond what our own organizations may already be doing.
- Recognize—and incorporate as an organizing principle into all that we do—that for rural poverty to be reduced and greater food security to be achieved, there must be much greater and more sympathetic involvement of the small farmers, including those on the less well-endowed but still viable lands.
- Miss no opportunity to bring home to political and opinion leaders the importance and the possibility of making progress toward agricultural sustainability.
- Do more to promote an effective, farmer-based participatory approach to agricultural research and to all aspects of agricultural development.
- Give serious thought and attention to how better to get research results out to farmers. Study the work of at least one effective outreach program by a farm group or nongovernmental organization in a developing country.
- Use our influence with the World Bank, USAID and other development agencies, and with the IARCs to convince them to give high priority to programs that promote agricultural sustainability. Work to help them come to terms with the institutional problems of adapting successful, site-specific village models more broadly.
- Recognize that allocating resources and setting priorities are, above all, political problems and be ready to enter actively into this arena. Take our case to legislators, administrators, editors, reporters—anyone who can impact the political process. No one should hold himself or herself aloof—certainly not the scientist. Each of us has a special niche where he or she can be effective.
- Finally, work with universities, private voluntary organizations, and aid-giving institutions to establish more realistic, multidisciplinary, and culturally sensitive training in sustainable agriculture for students from developing countries.

These are tough challenges. We *must* pursue them with vigor, skill, and urgency. With the passing of the Cold War, much of our attention will have to be directed toward how to bridge the huge and growing gap in resource use and living standards that separates the industrial and the developing countries. This is not just an ethical and humanitarian problem; it is loaded with political dynamite as well. By promoting new and successful models in north-south cooperation in achieving agricultural sustainability, we can contribute not only to the welfare of millions of people but also to lasting peace.

Review of CIMMYT Programs



Ma. Luisa Garcia
Ana Maria Sanchez

Mural by Diego Rivera, National Palace, Mexico City. Courtesy of the Department of the Federal District, Mexico

Sustaining Agricultural Resources in Developing Countries: Contributions of CIMMYT Research

Not far from CIMMYT's headquarters in Mexico lie the remains of the "floating gardens" or *chinampas* of Xochimilco. The conquest of the Aztec empire eventually led to the demise of this remarkable agricultural system, but for centuries it permitted intensive and continuous production of maize and other staple foods for a large number of the people living in the Valley of Mexico. History is rich with similar examples of stable and apparently sustainable agricultural systems falling prey to unexpected change. Our situation today differs in that we know change is coming. We also comprehend the huge dimensions of the challenges we face, and the high cost of failure.

To the year 2000 and beyond, agriculture worldwide must provide sustenance for an additional 80-100 million people each year. Nearly 90% of these new arrivals will be born in developing countries, where land is already under heavy population pressure; some regions, such as sub-Saharan Africa, already face severe food deficits. To maintain food production at an adequate level without degrading our natural resource base will, in the words of the 1987 Brundtland Report to the World Commission on Environment and Development, take an effort "colossal both in its magnitude and complexity, presenting a greater challenge to the world's food systems than they may ever face again."

In recent years, the "sustainability" of agriculture has captured widespread interest, and many descriptions of what the concept means are now available. We in CIMMYT take that offered by the Technical Advisory Committee (TAC) of the Consultative Group for International Agricultural Research (CGIAR) as a good first approximation (see Comments from Management, page 4). The TAC holds 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." In referring to changing human needs, the Committee is recognizing the dynamic aspects of the problem. TAC also obviously calls for protecting the existing endowment of Nature.

As was mentioned earlier (pages 4-5), we favor a more open framework for assessing the sustainability of agriculture, one in which larger harvests for growing populations can be obtained by substituting other resources, whether capital or labor, for those left us by Nature. Our view also emphasizes the potential for technolog-ical change to enable greater efficiency in using resources, as in the case of improved plants that are more efficient in the use of nitrogen (see page 30). Thus, our framework permits the possibility, over the long term, of drawing down on Nature's endowment. That need not imply, however, circumstances prejudicial to future generations.

We do not encourage a cavalier attitude toward Nature's bequest. Indeed, we must be as careful as we can in deciding about investments aimed at conserving natural resources. Still, conserving resources for the future requires sacrifices in the present, and the poor in developing countries can easily be the losers when such sacrifices are made. Our point is that the potential payoffs from resource substitutions and improved technologies should permit us to be somewhat less parsimonious with the earth's natural resources than TAC appears to believe necessary. Of course, the science that leads to the discovery of new sources of productivity and the development of improved technologies that save natural resources is itself costly, and those costs should be factored into the debate about sustainability as well.

Many justifications for sustaining natural resources used in agriculture have been put forth, most of which seem to fall into one of three broad categories: a desire for intergenerational equity, the problem of negative spillovers (such as pesticide residues in food), and concern for environmental aesthetics. Much of the debate about sustainability issues stems from the relative importance accorded these considerations. In the USA, for example, the importance given to the theme rests on perceived environmental and public health costs exacted by extensive use of chemical fertilizers and pesticides. To reduce input costs, preserve the natural resource base, and protect human health, a growing number of US farmers are exploring alternative agricultural systems (National Research Council 1989). In an affluent country where demand for food is growing slowly (if at all) and where food security is less of an issue than public health, a definition of sustainable agriculture that emphasizes reducing negative spillovers while maintaining current levels of production makes perfect sense. Developing countries, however, are not well served by such a static conceptualization.

Population growth and rising incomes in Third World countries require an emphasis by them (and by CIMMYT) on the "changing human needs" mentioned in TAC's definition. Based on current growth rates for population and per capita incomes in developing countries, we estimate that Third World demand for maize and wheat will increase each year at about 3.1% and 4.2%, respectively, until the year 2000. Assuming that the area planted to wheat can be expanded by some 0.8% annually until then, yields will have to increase by about 2.3% per year to meet growing demand. Maize yields will have to increase even more vigorously, at about 3.2% per year, assuming that area planted to the crop expands at an annual rate of 1% in developing countries.

We believe that such "land-saving" productivity growth in maize and wheat can be achieved in the more favorable production areas in the developing world, and that such growth helps protect the environment (see Comments from Management, page 5). The challenge for policy makers, researchers, and farmers is to achieve these productivity increases without destroying the natural resource base upon which sustainable agriculture depends.

Trends in Cereal Production, Yields, and Prices

The current debate about sustainable agriculture comes at the end of a period of extraordinary growth in cereal production worldwide. Since the end of World War II, basic cereal production has increased at a rate of 2.8% per year, keeping well ahead of the 2.3% annual increase in population growth. As a result of the Green Revolution, dramatic increases were achieved during the 1960s and 1970s in the production of four of the major cereals, but

particularly of wheat and maize. From the early 1960s to the late 1980s, production of wheat grew by an average of 3% per year globally and at an even more impressive rate in the developing world, reaching an unprecedented 4.9% per year. Production of maize increased slightly faster than wheat in a global context, and at a pace second only to wheat in the developing world (Table 1).

Increases in the production of all cereals were largely due to yield gains. Wheat yields, for example, rose at a rate of 3.7% annually in the developing world, while area expanded by about 1.2%. Developing country maize yields increased at an annual pace of 2.7%, with area growing at about 1% per year (Table 1).

Such data, however, can be misleading. In 1988, Lester Brown, president of the World-Watch Institute, stated that growth in grain production had slowed in the developing world's most populous countries, including China, India, Indonesia, and Mexico. He also noted that Africa's per capita food production had declined by 15% during the previous two decades, and that during the 1980s Latin America had become the second major region to experience a substantial decline in per capita grain production (Brown 1988).

Since then, several studies involving particular crops and countries have lent credence to Brown's concerns. An examination of wheat yields in the Punjab of Pakistan, for example, showed that while yields increased rapidly during 1967-76, they grew at a significantly lower rate during 1977-86 (Byerlee and Siddiq 1990). This is surprising in view of the rapid growth in the use of inputs in the area, especially irrigation water and fertilizer. By the mid-1980s, for example, Pakistani farmers were applying an average of 120 kg of fertilizer per hectare (application rates have since increased to about 150 kg/ha). Conservative estimates indicate that this level of fertilization should have brought about yield increases of at least 725 kg/ha, but the actual increase was only little more than half that from the early 1970s to the mid-1980s.

Much the same experience with inputs has occurred in other countries that were prominent participants in the Green Revolution. Given the increased use of inputs, it seems reasonable to conclude that, at least in specific countries, the fruitful combination of high-yielding varieties, improved irrigation, and application of fertilizer—which together accounted for more than 75% of the total increase in wheat yields in Asia during the past two decades—has reached the stage of diminishing returns. The total output of wheat is continuing to rise, but to obtain each additional kilogram of yield requires increasing amounts of inputs (Byerlee 1989). Furthermore, in developing countries as a whole, the rate of growth in wheat yields has slowed over the past decade (Table 2).

Other crops are experiencing similar problems. The growth rate of rice yields in Indonesia, Malaysia, Pakistan, and other key wheat-producing countries has declined, even though important advances have been made in the improvement of pest resistance and earliness (Pingali 1988). The global rate of increase in maize yields has dropped from 2.9% per year in the 1970s to 0.2% in the 1980s (Table 2). Among developed countries, where growth in maize production slowed from 2.8% to 0.2% over that period, much of the decline was the result of two severe droughts that occurred in the USA

Table 1. Growth in cereal production, yields, and area, 1961-1989

Average annual rate of increase	Wheat	Maize	Rice (%/yr)	Millet/ sorghum	Barley
In production					
Globally	3.0	3.1	2.9	1.1	2.8
Developing world	4.9	3.7	3.0	1.1	1.0
In yield					
Globally	2.6	2.4	2.1	1.6	1.6
Developing world	3.7	2.7	2.2	1.6	1.5
In area					
Globally	0.4	0.8	0.7	-0.5	1.2
Developing world	1.2	1.0	0.8	-0.5	-0.5

Source: Calculated from FAO data.

Table 2. Trends in growth rates of maize and wheat yields

Region	Wheat yield growth rate (%/yr) 1970-80	Wheat yield growth rate (%/yr) 1981-89	Maize yield growth rate (%/yr) 1970-80	Maize yield growth rate (%/yr) 1981-89
Sub-Saharan Africa	3.5	1.9	0.9	1.2
West Asia and North Africa	3.4	2.3	2.3	4.1
South, East, and Southeast Asia	3.8	3.3	3.5	2.3
Latin America	0.5	2.3	1.9	0.2
Developing Countries	3.5	3.0	2.8	1.4
Developed Countries	1.3	2.3	2.8	0.2
World	2.0	2.5	2.9	0.2

Source: Calculated from FAO data.

during the 1980s. In the developing world, a less precipitous decline in the rate of yield increases occurred, from 2.8% to 1.4%, though differences among regions are significant (Table 2).

Clearly, a continuation of these trends would not bode well for developing countries. The increasing productivity of agriculture has led to declining real prices for a number of commodities, including maize and wheat, an obvious boon to the poor in developing countries. Evidence of this strong downward trend is shown in Figure 3. Note that price trends in selected developing countries long associated with the Green Revolution tend to mirror the international trend (anomalies are usually a function of government support polices).

CIMMYT is committed to helping developing countries address the challenge of maintaining and indeed of extending the gains of the Green Revolution, but in ways consistent with the need to conserve natural resources. We believe that we can be most effective by continuing to focus on those things we do best:

- Conserving and using maize and wheat genetic resources.
- Developing and distributing improved germplasm.
- Developing sound crop management principles and practices in conjunction with national agricultural research programs.
- Analyzing the impacts of technological change and the appropriate allocation of scarce research resources.
- Ensuring that our training programs continue to reflect a strong field orientation, encouraging course participants to "think long term" and integrate principles of natural resource conservation into their research.

There are, of course, many other themes and issues relevant to agricultural sustainability, ranging from the effects of global warming and industrial pollution to deforestation and controlling population growth. For the most part, however, these challenges lie beyond the scope of CIMMYT's research and

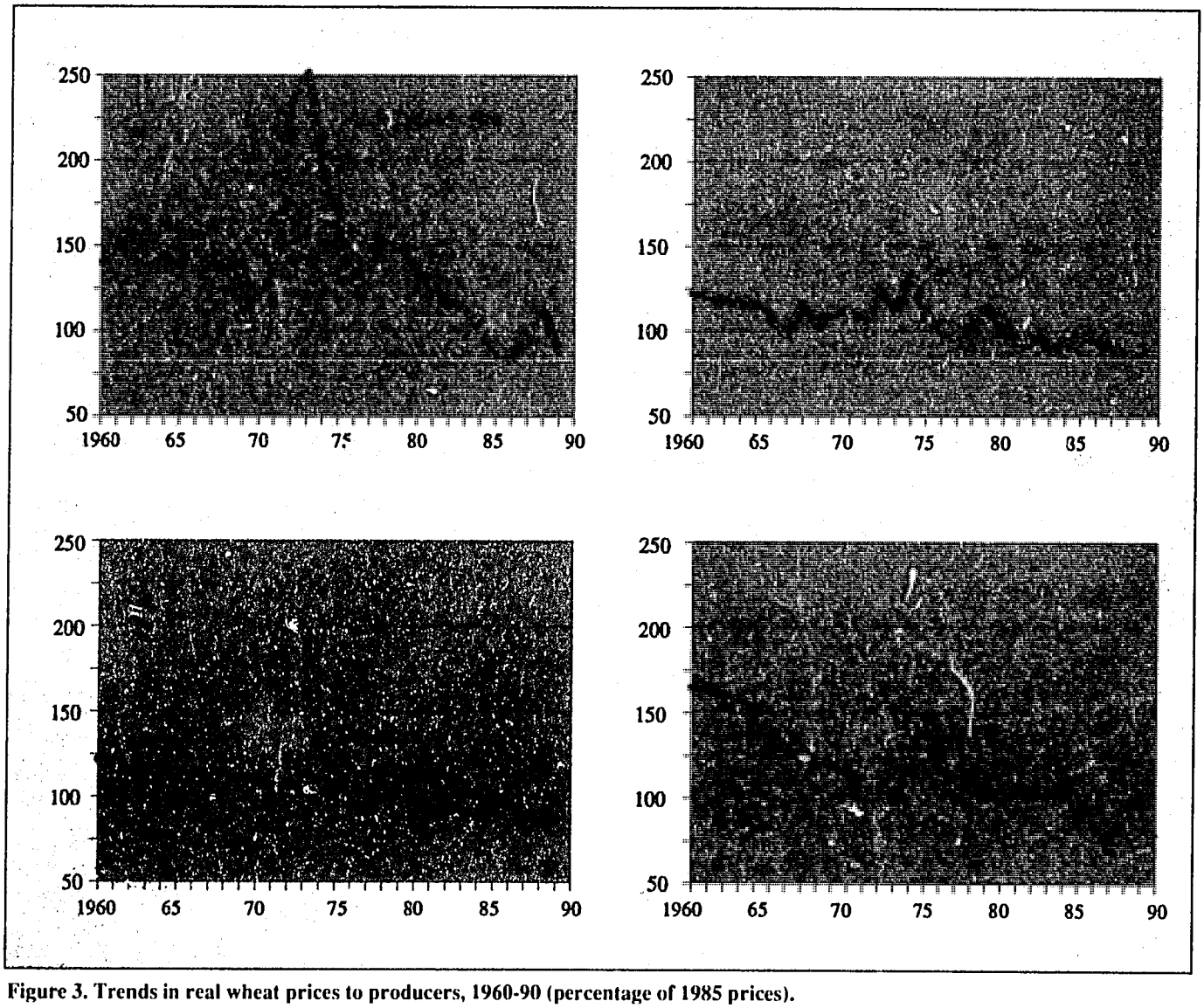


Figure 3. Trends in real wheat prices to producers, 1960-90 (percentage of 1985 prices).

training programs, and must be dealt with by other international organizations and by national governments.

Conserving and Using Genetic Resources

An important contribution to understanding the requirements of sustainable agriculture comes from agroecologists, who point out that, for a system to be sustainable, it must be resilient to stress or external shocks. That resilience rests on the diversity represented in the system, either in terms of genetic variability in a given area or the diversity over time and space of farming operations.

CIMMYT concerns itself with the genetic variability found in maize and wheat. Our interest stems from the dual role of that variability in protecting farmers against potentially devastating disease epidemics, and as the foundation upon which future progress in germplasm improvement rests. Our strategy for conserving and using the genetic diversity contained in our crops is described in detail in the Center's *1988 Annual Report* (CIMMYT 1989). A central feature of our strategy, however, is to acquire and preserve sources of genetic diversity for maize and wheat, including materials whose value may not yet be apparent. We view such work as an essential function for the Center, one directly related to our concern for the future. In preventing the irreversible loss of this diversity we help maintain potentially productive options. But for those options to be exercised, at CIMMYT or elsewhere, we must also ensure efficient access to bank holdings and continually seek effective means for using them.

The Center's maize and wheat germplasm banks engage in a range of management, database development, and research activities. Management work includes seed storage, regeneration of accessions, and distribution of seed samples of bank holdings to scientists working elsewhere. Both banks are making progress toward better management of "passport" data, toward promoting international cooperation in the exchange of information, and toward expanding our databases by incorporating information about the specific traits of individual accessions. Success in the latter is facilitated through research by bank managers, who are now evaluating materials and engaging in various forms of "prebreeding" to increase the utility of bank holdings.

elsewhere as well, with priority given to public sector researchers in developing countries. We have taken pains to ensure access to bank holdings by producing a CD-ROM (compact disk, read-only memory) containing the passport information for each accession in the bank. This disk has been distributed to all interested developing country maize programs. It is being updated and expanded to include evaluation information and passport

Sustainable agricultural systems require a continuous flow of improved varieties to stay ahead of evolving pests and to overcome the limitations imposed by abiotic stresses.

CIMMYT's maize bank maintains "base" and "active" collections of landraces, with an emphasis on those originating in the Western Hemisphere. The base collection, comprising nearly 11,000 accessions, is kept in long-term storage at -15°C, which preserves seed viability for 50-100 years. To help ensure the security of this valuable resource, duplicates of the base collection are placed in other banks. Seed regeneration is a vital aspect of bank management and requires large amounts of land and labor. Each year we regenerate about 300 accessions in Mexico, and we rely on the assistance of several national programs and private organizations to keep our regeneration activities on schedule. The active collection, which, like the base collection, contains the world's largest representation of landraces, is kept in medium-term storage (0°C, good for some 20-25 years). This collection, which also contains seed of selected elite populations developed by CIMMYT and other institutions, is used by our own maize breeders to obtain additional sources of resistance to various biotic and abiotic stresses, and is open to maize scientists working

data for accessions held by a network of national germplasm banks in Latin America.

CIMMYT's wheat bank currently contains over 90,000 accessions, most of which are the product of nearly 50 years of breeding research by the Center and its predecessor organization in Mexico. Most of those materials are spring bread wheats, though collections of durum wheat, triticale, barley, and rye are also maintained, as are representative collections of the wild relatives of wheat and several primitive species. For many years, the main function of the wheat bank was to support active breeding research at CIMMYT and elsewhere. While that remains a prominent activity, in 1988 we agreed with the International Board for Plant Genetic Resources (IBPGR) that we would broaden the Center's responsibilities for both the acquisition and long-term conservation of bread wheat and triticale germplasm. Both functions reflect the importance of maintaining future options for researchers, and for farmers as well. Over the longer term, the wheat bank

will conserve, regenerate, evaluate, and document its holdings. All materials are currently stored under medium-term conditions (-2°C, which will maintain viability for 40-50 years), and we are now constructing longer term storage facilities. The bank provides back-up storage for the International Center for Agricultural Research in the Dry Areas (ICARDA) collections of barley, spring durums, and the wild relatives of wheat. We also back up the collections of several national programs. The bank is computerizing its passport information, and as the bank manager's research progresses, evaluation information will be added to the database. There are also plans for producing a compact disk similar to that developed by the Maize Program for use by national programs and others.

Sustainable agricultural systems require a continuous flow of improved varieties, both to stay ahead of evolving pathogens and other pests and to overcome the limitations on productivity imposed by certain abiotic stresses. The Center's maize and wheat banks are thus seen as complementary to our aggressive plant breeding programs, which are directed at capturing useful genetic diversity and delivering it to national programs and, through them, to farmers.

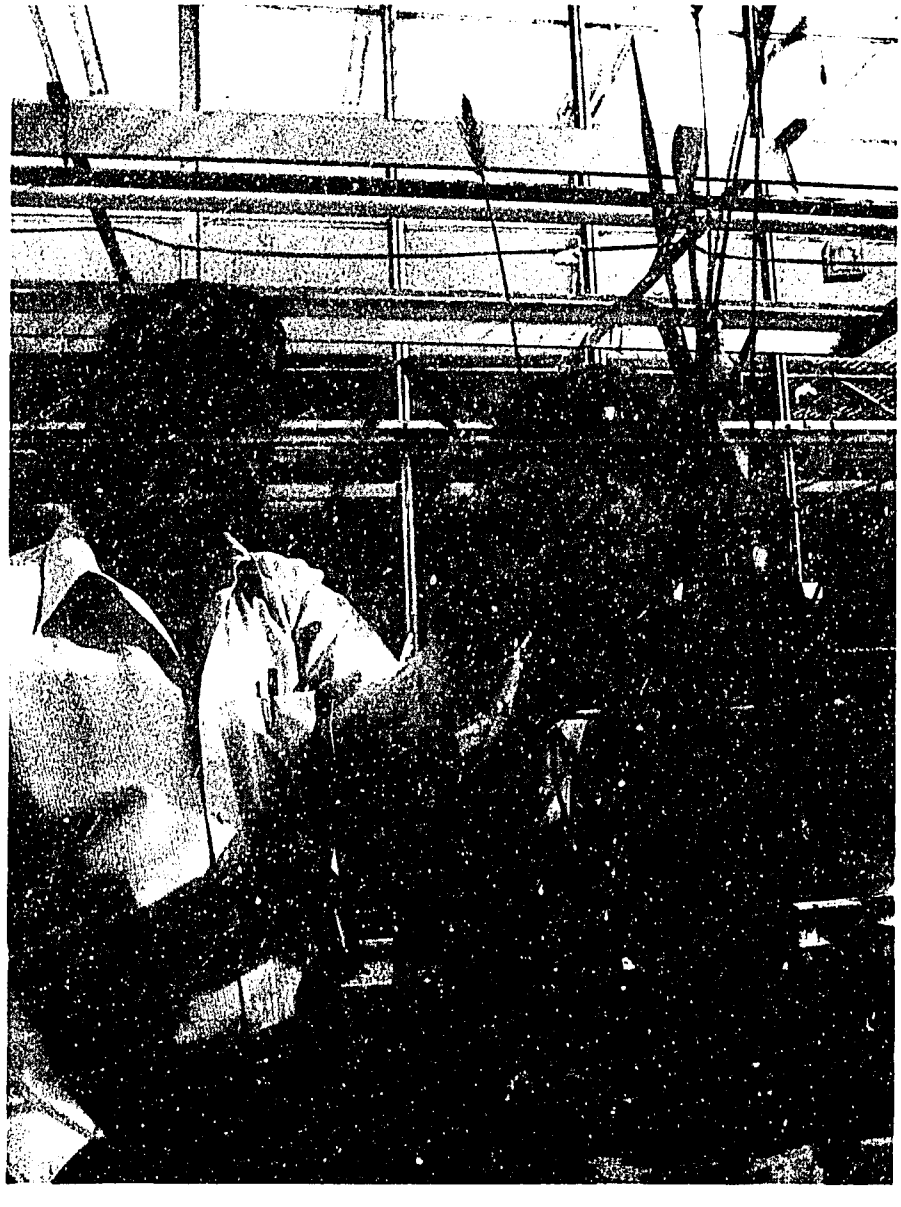
The Contributions of Plant Breeding

The developing world's hard-won advances in food production were brought about in large measure by the development and spread of high-yielding varieties. These varieties were able to take advantage of higher levels of inputs and, not surprisingly, progress was more rapid in favorable production environments than in marginal areas. From the early 1960s to the late 1980s, for example, wheat production grew at an annual rate of 4% where the crop is grown under favorable conditions, compared to only 2% under more marginal circumstances (Morris et al. 1990).

Curiously enough, now that we are faced with the task of maintaining, even increasing, the high rates of gain to which crop research has contributed so heavily, some people have the impression that plant breeding is less relevant than other disciplines. Some even believe that high-yielding varieties are part of the problem. One assertion is that the rapid spread of improved varieties and associated technologies has caused the production of cereals to become less stable. Strong counter-arguments to that idea—based on a considerable body of evidence accumulated over the past two decades—have been made in recent years (see box, page 27).

In addition to concern about yield stability, some critics of modern agriculture point to negative spillovers from erosion and the use of chemical inputs. They are also concerned about the effects on soil fertility of intensified cropping patterns made possible by earlier maturing or less photoperiod-sensitive varieties.

Sergio Pasten



In a genetic study in the greenhouse to confirm the variability of *S. tritici* resistance, Zahir Eyal, visiting scientist from Tel Aviv University, and Lucy Gilchrist, CIMMYT wheat pathologist, score septoria disease symptoms on progeny derived from crosses made with wheat varieties suspected of having unique resistance genes (see Wheat Research, page 43).

As noted earlier, CIMMYT's view is that the widespread adoption of land-saving technologies has tremendously reduced the pressure to farm more fragile lands. Increased productivity in favored areas resulted in additional marketable surplus, which lowered commodity prices over time (Figure 3, page 24) and reduced farmers' incentives to expand onto more fragile and less productive lands. Increased productivity also contributed to agricultural development and economic growth, helping to create employment alternatives for the rural poor who, for the lack of such options, tend to support themselves by farming ever more fragile lands. We see this as a very positive result of the improved yield potential of modern varieties. But our plant breeders (and crop management specialists) are also cognizant that a considerable investment must be made to maintain those gains and to address concerns related to the environment. Some of these efforts are described below.

Our breeding work is organized around relatively homogeneous *mega-environments* of at least one million hectares each (some are much larger). We strive for wide adaptability of improved genotypes within those environments, providing national programs with classes of high-performance materials that they then refine in their own breeding programs to meet the more specific needs of farmers. This approach has proven remarkably effective and we are convinced that it has more to offer. In late 1990, for example, CIMMYT brought on staff a specialist in geographic information systems to help refine our characterizations of maize and wheat mega-environments. By doing so, we can become more sensitive to the environmental circumstances for which we breed. Maize and wheat physiology research is also becoming more prominent in our crop improvement work, as we add to the efficiency of new genotypes in the use of moisture and nutrients.

The Yield Stability Controversy

Some have said about the Green Revolution in wheat, rice, and maize production that the rapid spread of high-yielding varieties (HYVs) and associated technologies has caused the production of these crops to become less stable over time and space. Unstable yields are a major source of risk, which in turn makes farmers less inclined to invest in improvements that would raise production and result in more efficient use of resources.

A considerable amount of evidence now suggests that improved varieties, more often than not, give high and stable yields across environments in which they are adopted. Many contributions to the debate on this subject have come from CIMMYT staff. In studies of data from the Center's international wheat trials, for example, Worrell et al. (1980) and Crossa et al. (1991) indicate that some HYVs developed in high-yielding environments perform better (i.e., produce higher and more stable yields over time) than local varieties and landraces even in marginal areas. CIMMYT staff presented similar arguments at an interdisciplinary workshop held in 1986 by the German Foundation for International Cooperation and the International Food Policy Research Institute (Pfeiffer and Braun 1989; Pham et al. 1989), and have published in various journals on the subject (Crossa et al. 1988a, 1988b, 1989).

This is not to deny the existence of yield variability where HYVs are widely grown. The point is simply that 1) improved germplasm generally possesses yield-stabilizing traits that endure over time and across environments and 2) HYVs do not necessarily yield less than local varieties under unfavorable conditions. What may happen, however, as suggested by Anderson and Hazell (1989), is a sharp decline in the yields of input-responsive, high-yielding varieties during a year when inputs are not available, environmental conditions are not favorable for their use, or grain prices lead to changes in fertilizer levels. Thus, instability is not inherent in the HYV itself but may occur in the circumstances affecting its production.

It appears that the most important of these circumstances are environmental. In a study of wheat yields from 1950 to 1986 in 57 countries, Singh and Byerlee (1990) found that most variability could be accounted for by climatic factors, such as moisture availability, as well as by the size of a country's wheat area. They concluded that HYVs and fertilizer had no significant effect on yield variability and that in most cases (especially that of wheat production in India) yield variability had actually declined with the rapid adoption of HYVs. These and other studies constitute a strong case supporting the notion that HYVs need not be associated with yield instability.

The question of how to work toward greater efficiency in resource utilization is complicated by the question of which environments to emphasize. There is some difference of opinion whether concern about sustainable agriculture should focus on favorable environments or marginal ones. The former are clearly more important in terms of production. But as cropping intensity increases in these areas, it may become ever more difficult to obtain and sustain higher levels of productivity. The potential for negative spillovers from agriculture grows as well. Moreover, large numbers of poor people live in these areas and rely on agriculture for their livelihood. Thus, favorable environments must continue to receive a large share of the resources committed to research aimed at sustaining resource productivity.

Determining the extent to which scarce research resources should be allocated to marginal environments is complicated by lack of data and by uncertainties about payoffs. Help in doing so, however, is now coming from CIMMYT's Economics Program. Their most recent work in this arena relates to allocation and policy options involving the improvement of wheat and barley in low rainfall areas in the West Asia/North Africa region, and on modelling the effects of technological change on the poor in Pakistan's favored and marginal areas (see Economics Research, pages 46-50).

Determining the extent to which scarce research resources should be allocated to marginal environments is complicated by a lack of data and by uncertainties about payoffs.

Even so, a significant share of the poorest of the poor in developing countries live in rural areas classified for a variety of reasons as marginal for producing crops. For our purposes, an environment is considered marginal when the yield of a crop is reduced to less than 40% of that environment's potential, as determined by the amount of radiation received during the growing season. This poor productivity might be caused by a shortage of moisture, by flooding, soil erosion, extreme temperatures, disease and/or insect pressures, soil acidity, soil salinity, and deficiencies or toxicities of nutrients or minerals. In those areas already under cultivation and where only one or a few major constraints limit production, we see good opportunities to increase productivity.

For nearly all environments, however, an important means of raising productivity in the long term is to steadily advance genetic yield potential (see Wheat Research, page 45). Since the release of the first semidwarf varieties in the 1960s, the yield potential of new wheat varieties has risen at an average rate of about 1% per year, and the tremendous contributions to agricultural productivity of these high-yielding wheats are well known (see Points of View, page 12). Less well known perhaps, but certainly no less important, have been the gains in the yield potential of maize germplasm from CIMMYT. For example, open-pollinated maize varieties developed by the Center for lowland tropical zones showed a genetic gain of 1.6% per year from 1974-75 to 1980-81. Even more striking progress has been made by others with temperate maize germplasm. In the USA, even after the tremendous successes already achieved, Duvick (1991) suggests that a yield plateau is not yet in sight. We believe that much the same can be said about maize germplasm for tropical environments. This material is far from reaching the limits of its adaptation and performance. It contains vast untapped genetic diversity, and heterosis is only now beginning to be exploited.

High yield potential by itself, however, is not enough if prevalent diseases and insects constrain production. In various ways these pests reduce the efficiency with which plants use nutrients, water, and sunlight. Some biotic stresses mainly depress yield, others reduce grain quality (and thus the usable portion of yield), and many affect both. But all, if unchecked, result in the squandering of resources.

Considerable progress has been made in developing host plant resistance to the major diseases of maize and wheat in the developing world. In maize this resistance is polygenic and thus less likely to break down (i.e., it is more durable over time) as pathogens undergo genetic change. The major foliar diseases of maize were brought under control in the tropics during the 1960s through genetic resistance after severe epidemics of southern rust occurred in sub-Saharan Africa during the 1950s. Large losses caused by the downy mildew disease in Asia were reduced to a minimum by the late 1970s, with only occasional reports of heavy losses in limited areas. And though it still depresses yields somewhat, late wilt in Egypt has been much reduced through the development and widespread dissemination of resistant germplasm. Some diseases, particularly those caused by viruses, remain uncontrolled, although resistant germplasm is under development or already available. The maize streak virus disease of sub-Saharan Africa, for example, will certainly be reduced in severity as resistant materials now available are taken up by farmers.

Stem rust of wheat (once the most devastating disease affecting the crop) was brought under control through the deployment of *Sr2* and other genes. This combination of resistance genes is

now carried by nearly all CIMMYT bread wheat germplasm and is believed to be stable. During the last 30 years, no epidemics of stem rust in bread wheat have been reported (Roelfs 1988). Our wheat breeders and pathologists believe they are near to a similar success in combating leaf rust, which became a global problem after stem rust was contained. Resistance from the South American variety Frontana, which appears to rest on the *Lr13* and *Lr34* genes, shows strong promise for providing stable resistance. This gene combination is now found in a large proportion of our advanced bread wheat germplasm (Rajaram et al. 1988). Good progress has also been made toward achieving "partial resistance" to stripe rust, meaning that the disease is present but slow to develop, and work on *Septoria tritici* is advancing as well (see Wheat Research, pages 43-44).

With the exception of a small amount research aimed at developing resistance in wheat to stem sawfly, Hessian fly, and Russian wheat aphid, CIMMYT's allocations to insect resistance work are focused on maize. Although progress has been slower than in our work on disease resistance, significant advances have been made recently. We have developed maize germplasm with resistance to several insect pests, including various species of borers and fall armyworm, that severely limit production in the subtropics and tropics (Mihm 1985, 1986; Smith et al. 1989). Work is also in progress to develop maize materials tolerant to pests of stored grain.

For lack of effective controls, chemical or otherwise, developing country farmers lose some 30% or more of their maize production to field and storage pests. In some areas of West Africa, they avoid planting maize altogether in certain seasons, because experience has taught them that the crop will be completely destroyed by insects (Bosque-Perez et al. 1989). Our resistant germplasm is now in the hands of national programs, but until it is widely distributed to farmers in the tropics and subtropics, insect pests will continue to be a major constraint of maize production and a serious threat to sustainable agriculture. Host plant resistance will provide an inexpensive and effective solution to insect problems and greatly reduce the need for pesticides.

In combination with heavy disease and insect pressures, nutrient and moisture deficiencies can dramatically reduce agricultural productivity. Often, however, abiotic stresses are so severe that there is little yield to protect from disease and insect attack. Germplasm that is better suited to environments where such stresses occur frequently may at least provide farmers with respectable and more stable yields through greater efficiency in the use of limiting resources.

In our research on drought tolerance in maize, for example (which we define as the ability of one genotype to be more productive in terms of grain yield than another under similar conditions of low moisture availability), it has been established that selecting under drought for a narrower anthesis-silking interval (ASI) improves the ability of a genotype to develop an ear and hence produce grain even under severe moisture stress (Bolaños and Edmeades 1988). Based on this observation, four elite populations are being improved for ASI through recurrent selection under drought. Gains in grain yield per cycle of selection have exceeded 6% at around 2 t/ha over eight cycles (see Maize Research, page 38). An important bonus of this work is that these gains are expressed in well-watered environments as well (Bolaños and Edmeades, forthcoming 1991).

Poor soil fertility (especially the lack of adequate levels of nitrogen) is a widespread problem, one that is getting worse as cropping intensity increases. We are therefore interested in improving the efficiency of maize and wheat to use available nitrogen in such soils. Though the nitrogen responsiveness of maize is high, developing country farmers frequently cultivate the crop in low-nitrogen soils and often cannot compensate for this deficiency by

Thomas Luba

Subsistence farming families, such as those in the high mountains of Nepal, often suffer significant losses of their stored grain to insects. In addition to improving yield and other desirable traits, CIMMYT is working to enhance the grain storage characteristics of its mandate crops.

applying inorganic fertilizer, either because its use entails excessive economic risk or it is not available when needed. To enhance soil fertility for brief periods, many farmers practice shifting cultivation, leaving fields fallow to at least partially recover from the drain of cultivation. But with ever increasing demands on agriculture, fallow periods in such systems are becoming shorter, leading to a variety of productivity-inhibiting problems. Genotypes that extract and use available soil nitrogen more efficiently would help address both difficulties. Improved uptake efficiency would reduce the loss of the nutrient through leaching or denitrification, and improved nitrogen-use efficiency would allow farmers to get more grain from their scarce nitrogen supplies.

We already know that there is genetic variability in maize both for total nitrogen uptake and the efficiency with which absorbed nitrogen is utilized. The results of early studies suggest that it should be possible to identify materials that show an advantage in these traits under both high and low fertility (Lafitte and Edmeades 1987, 1989). To examine the response to selection, our maize physiologists selected experimental varieties out of the cultivars chosen for study. They found that selections made for yield alone across high and low nitrogen levels show moderate improvement in grain yield under both circumstances. Similar results were obtained under low levels of nitrogen only and using a selection index made up of a number of traits besides yield, including ear leaf chlorophyll content and leaf senescence rate. On the basis of these results, a program of full-sib recurrent selection was initiated. Several cycles of selection have been completed and were evaluated in 1990. Results showed that promising gains were made with this selection methodology, and plans for using it to improve other tropical germplasm for tolerance to low nitrogen and improved recovery of nitrogen are being implemented.

The Wheat Program is also interested in the nitrogen-use efficiency question, but from a different perspective. During a three-year project terminating in 1990, the Program evaluated the efficiency of nitrogen uptake and utilization in its older germplasm relative to its newer materials. The experiment compared the yield of prominent varieties released during the last 25 years at different levels of nitrogen. Results indicated that both nitrogen uptake and the efficiency with which nitrogen is used have improved over time, even though the Program has not specifically selected for such an improvement. In other words, selection for yield and other traits under the favorable conditions of northwest Mexico's Yaqui Valley has, as a byproduct really, also improved the ability of the Program's newer germplasm to make use of available nutrients. Though additional research aimed at identifying the best level of nitrogen under which to select germplasm aimed at low nitrogen and high nitrogen environments is now underway, preliminary findings show that the germplasm coming from CIMMYT is equally benefiting farmers who can apply nitrogen fertilizer and those who cannot (Figure 4), under irrigation and probably under rainfed conditions as well.

While work on tolerance to drought and to low nitrogen in maize and wheat is conducted by CIMMYT staff in Mexico, research on acid soils for both crops is being carried out through cooperative arrangements with national programs in Brazil, where this abiotic stress is a significant problem. In general, acid soils are highly leached, low in available phosphorus, and high in exchangeable aluminum. Excessive amounts of exchangeable aluminum are toxic to maize and wheat.

In 1974 the Wheat Program began a collaborative project with Brazilian colleagues aimed at combining the high yield potential of CIMMYT's semi-dwarf wheats with the aluminum toxicity tolerance of indigenous varieties in Brazil. A shuttle breeding

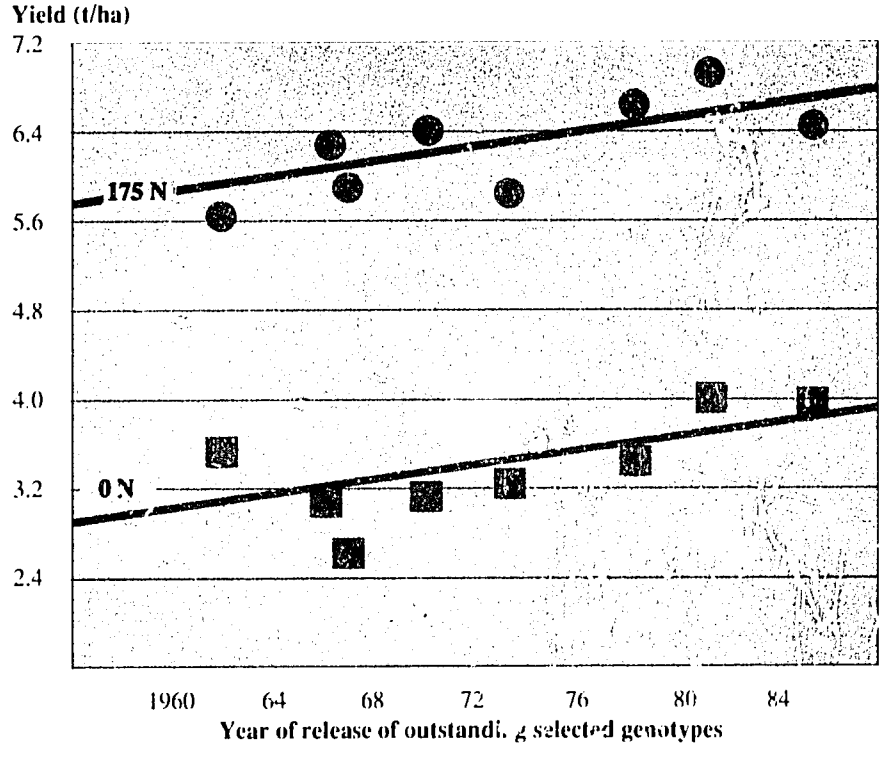


Figure 4. The parallel slopes showing the genetic progress of CIMMYT wheat germplasm under high and low nitrogen regimes indicate a benefit to farmers who can and cannot apply nitrogen. Outstanding genotypes are depicted by their year of release to show improvement over time.
Source: Ortiz-Monasterio et al. (1990).

Sustaining the Rice-Wheat Rotation in South Asia

Nearly 40% of the 33 million hectares of wheat cultivated in South Asia is now grown in rotation with rice—more than 11 million hectares in India, 1 million in Pakistan, nearly 500,000 hectares each in Bangladesh and Nepal, and a small but nationally significant area in Bhutan (see map). In many areas, farmers began growing wheat in the winter season after rice only with the introduction of the new wheat and rice varieties of the Green Revolution—less than 25 years ago. Today, the productivity of both crops seems lower than that which can be reasonably expected. In particular, long-term rice-wheat trials in India and Nepal are showing a significant downward trend in rice yields.

With this in mind, CIMMYT and the International Rice Research Institute (IRRI) have begun implementing a joint special project with the national agricultural research programs of India, Pakistan, Nepal, and Bangladesh. This collaborative research endeavor—funded by the Asian Development Bank (ADB) and the US Agency for International Development (USAID)—involves a number of activities:

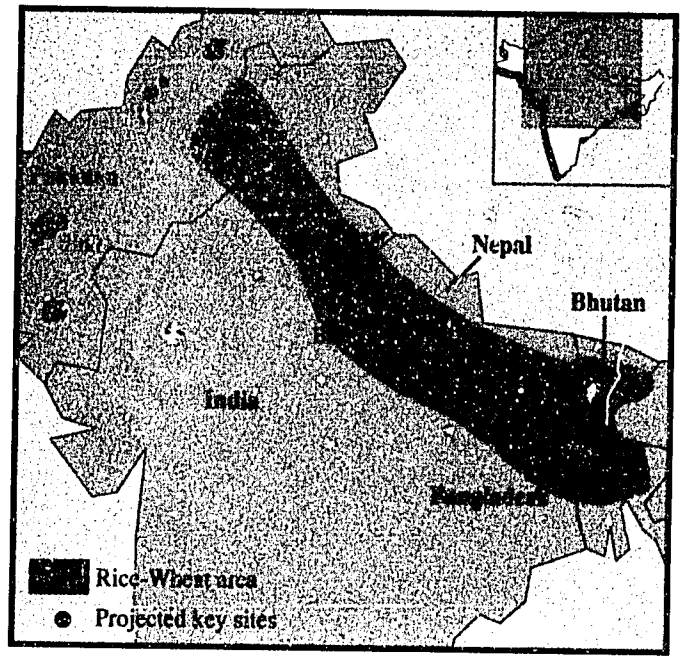
- Project participants are identifying at key locations themes for applied and adaptive research directed toward major problems associated with the rice-wheat cropping system, including issues of near-term productivity and longer term sustainability.
- A program of strategic crop management research is being developed with contributions from specialists in soil physics, microbiology, and other disciplines.
- Over time, comparative analyses of problems affecting the rice-wheat system in South Asia will be conducted, and solutions that may prove effective across a wide range of local circumstances will be sought.
- Participants will also seek to improve the understanding of how best to address sustainability issues through collaborative research, formal and informal training, and the exchange of information and scientific staff.

A number of productivity constraints appear to be relevant across the region. Some, however, are likely to be specific to only a few locales. Due to that probability, along with the obvious need for on-farm research and for long-term experimentation, project implementation involves first identifying key locations in the rice-wheat system. The map shows where some of these key sites may be located.

The first steps in the research process have been exploratory. Two CIMMYT wheat scientists based in Nepal (an agronomist and a pathologist), and a Center economist who is based in Thailand, have conducted, in collaboration with IRRI and national programs, diagnostic surveys of farmers' fields in areas tentatively identified as key sites for long-term research. These diagnostic surveys, the most recent of which was done during 1990 near Pantnagar University in the Indian state of Uttar Pradesh (see Wheat Research, pages 42-43), will help focus the project's research at each location.

In addition to the diagnostic surveys, a program designed to monitor farmer practices and the productivity of their resources has been initiated. Some 160 farmers in the Rupandehi District of Nepal are participating in this work. Background information about their resources has been compiled, and rice and wheat yields, as well as production practices, will be monitored over time. Changes in these factors will be correlated with changes in measures of soil quality (such as phosphorus and zinc levels, pest levels, organic matter, and soil compaction), and with changes in technology (such as water management techniques and the adoption of new varieties).

Together with IRRI, CIMMYT will help bring about the needed research by providing support to collaborating national program scientists at key locations and by ensuring back-up research when necessary. Current project plans call for one IRRI rice scientist to join one CIMMYT wheat scientist in the region to help facilitate the research effort and to participate directly in various aspects of the initiative.



Borders of South Asia's rice-wheat area are constrained by altitude and temperature for rice in the north, irrigation availability and temperature for wheat in the south, by irrigation availability, hills, and temperature for rice in the west, and by hills in the east.

system was employed in which germplasm was grown alternately in Brazil on acid soils and in Mexico for selection of suitable plant types (Hettel 1989). Laboratory screening was also used to select for aluminum tolerance. Wheat materials developed through this work show acceptable levels of aluminum tolerance, give twice the yields of previously available germplasm without heavy applications of lime, and are now among the major cultivars grown in Brazil (Kohli and Rajaram 1988).

Brazilian scientists have also made remarkable progress in developing maize genotypes with high levels of tolerance to aluminum toxicity. The hybrid BR 201, developed recently by the Brazilian Agency for Agricultural Research (EMBRAPA), can be grown in acid soils with little or no applied lime. CIMMYT staff based at the International Center of Tropical Agriculture (CIAT) in Colombia have made good progress in developing tolerance to aluminum toxicity in broadly adapted maize germplasm, and these materials are showing promise in the Andean zone and other parts of the world as well.

Developing better resistance to biotic and abiotic stresses is clearly a major challenge to crop breeding in the service of sustainable agriculture. Another is to develop genotypes that are uniquely suited to the intensive and conservation-oriented cropping systems that will be essential for achieving sustainable production over the long term. CIMMYT approaches this challenge in several ways. On-farm research in Pakistan, for example, revealed the need for varieties that better fit farmers' intensive cropping systems by performing well when planted late, after rice or cotton. Our wheat staff and rice scientists from the International Rice Research Institute (IRRI) are basing some selections on performance of genotypes in a rice-wheat rotation (see box, page 31). The Center's maize scientists are working with CIAT staff to ascertain whether maize and beans possess genetic variability for traits that would permit higher yielding combinations of these crops. Other work involves the evaluation of maize and wheat genotypes under minimum tillage (especially for disease resistance) and the identification of maize varieties that are especially suited for use in Vietnam and a few other countries where farmers are transplanting seedlings into paddy fields following rice. All these efforts will contribute to sustaining productivity, both in marginal and in favorable environments.

Crop Management Research

While CIMMYT is best known for its improved germplasm, we see the crop management research (CMR) done by our agronomists and economists as an essential component of research directed at sustaining the productivity of resources used in agriculture, both in favorable environments and in marginal areas. Indeed, for at least one type of marginal area, where sloping soils are subject to devastating erosion, CMR will almost certainly make the primary contribution to sustainable production, with improved germplasm being secondary (see box, page 33).

Nathan Russell

A major challenge for plant breeders in working toward more sustainable production is to provide varieties that are uniquely suited to complex cropping systems such as this one practiced in southern Ghana.

As we see it, CIMMYT has a comparative advantage in CMR related to sustaining resource productivity because of our capacity to focus on relevant problems for the long periods that such research often requires. Our CMR work is largely strategic, with results having broad applications in a number of countries. The emphasis is on generating diagnostic tools and research methodologies, and on elucidating CMR principles upon which recommendations can be based, rather than on making recommendations for specific areas (though that sometimes happens as a spinoff of our collaborative work with national programs). During the past few years, the Center has been shifting resources into strategic CMR so as to strengthen its hand in dealing with questions relating to sustainable agriculture. We are especially interested in the long-term productivity of major wheat and maize cropping systems in developing countries.

One example of this interest involves our economists and wheat agronomists, who are investigating the extent and underlying causes of an apparent decline in productivity of the rice-wheat rotation that is widely practiced in Asia (see box, page 31, and Wheat Research, pages 42-43). The effects on productivity of minimum tillage is another question being addressed, and our staff have gained considerable experience in seeking to answer it, particularly in Mexico, Central America, and the Caribbean, but also in southern Africa and in the Southern Cone of South America. This practice can not only help conserve energy but also prevent or even reverse the physical degradation of soils (Fischer 1988). Currently, CIMMYT agronomists and economists in Central America are working with their colleagues in national programs to define more precisely the edaphic and

Maize Production on Sloping Soils in Central America

Over 60% of the maize produced in the Central America and Caribbean region is grown on sloping soils that are highly subject to erosion. And the proportion is slowly increasing as maize is displaced from more favorable lands by higher value crops. If measures for controlling soil erosion are not put into practice more widely, this problem will soon pose a major obstacle to long-term growth in maize production. To counter this threat with technologies that are applicable in many parts of the region, CIMMYT staff have embarked on several cooperative research projects with national programs. This work is funded by the Swiss Development Corporation.

One approach we are studying is interseeding of leguminous cover crops with maize. By providing greater soil cover, the legumes appear to reduce soil erosion and runoff, while increasing water infiltration. In addition, if farmers do not remove the legume (e.g., for use as animal feed), the practice can add organic matter to the soil. To explore the possibilities of the system, on-farm trials with three leguminous species have been conducted for two years by maize researchers and social scientists in several countries. One conclusion supported by the results is that, if *Canavalia ensiformis* and *Stizolobium deeringanum* are grown in rotation with maize as green manure crops, in the following season they help maintain maize yield under low fertility. In addition to the on-farm trials, CIMMYT staff have been working with researchers in several Central American countries and more recently in Mexico to delimit areas where a maize-legume (*S. deeringanum*) rotation is already practiced and to study the elements that made this system attractive to farmers.

A comparable effort got underway this year in the Metalío-Guaymango area of El Salvador, where farmers have employed conservation tillage for as long as 15 years in a maize-sorghum system. Rather than use crop residues as animal feed or burn them before planting, as is commonly done in much of Central America, these farmers leave residues as a soil cover, which reduces erosion and runoff, increases water infiltration, and contributes to soil organic matter. It appears that adoption of conservation tillage in this area was heavily influenced by efforts of the extension services, perhaps by agrarian reform in 1980 (which made land owners of the majority of farmers in the area), and possibly by short-term beneficial effects on yield stability. Where cattle graze the stover, the long-term benefits of conservation tillage are much reduced. On-farm trials were conducted in 1990 to examine the impact on maize yields of different levels of soil cover.

Though not yet widely practiced in the tropics, conservation tillage would seem to be an especially promising alternative for crop production on sloping soils, since it requires much less labor than other methods of controlling erosion, such as terracing. We are hopeful that studies initiated by CIMMYT staff and their colleagues in national programs will lead to the development of effective strategies and systems for promoting conservation tillage throughout the Central America and Caribbean region.

socioeconomic conditions conducive to the adoption of minimum tillage by farmers (see box, page 33).

Our staff in Central America are also coordinating a series of regional trials in which legumes are interseeded with maize. The legume serves as a living mulch, protecting the soil against erosion; it fixes atmospheric nitrogen, thus lessening the need for chemical fertilizer in a subsequent maize crop; and it reduces certain weed populations through shading or allelopathic effects. One purpose of the regional trials is to compare the effects of different legumes. Species with particularly high carbon-to-nitrogen ratios may be more effective in maintaining and improving the soil, because more of the legume biomass is incorporated into the soil-humus complex upon decomposition (see box, page 33).

CIMMYT staff working in a bilateral project in Ghana have also extensively researched cereal-legume intercropping, particularly the maize-cowpea system. Other new maize projects that have a bearing on sustainable agriculture are studies in eastern Africa on the management of acidic highland soils and control of the parasitic weed *Striga* through crop management practices, an effort in southern Africa to determine the climatic and management factors responsible for yield reductions in late-planted maize, and research in Central America on sulfur deficiencies as they relate to phosphorus-use efficiency in volcanic soils.

Such research requires careful monitoring of farm-level trials and helps reveal how farmers might be motivated to adopt practices that yield long-term payoffs. Much of this work draws on methods developed by CIMMYT over the years for conducting on-farm research and for monitoring changes in cropping systems, especially the effects of particular crop management practices.

CIMMYT agrees with others who insist that sustainable agricultural systems are essential. We believe that much of what we do contributes to the development of such systems.

Training with a Sustainability Perspective

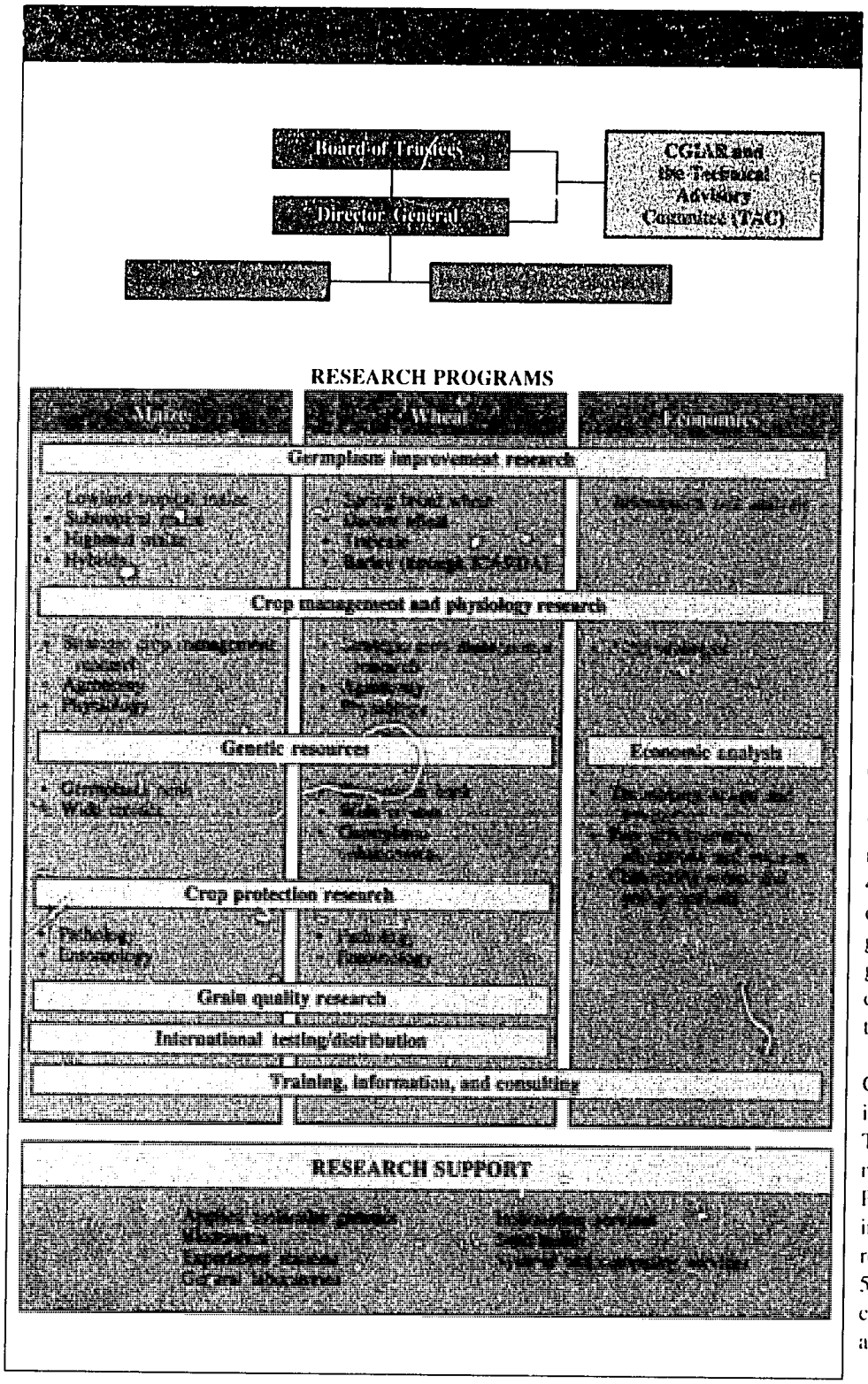
Over 23% of the resources allocated to CIMMYT programs is devoted to training of one kind or another (see Financial Highlights, pages 56-57). Formal instruction ranges from entry-level in-service training in crop improvement, crop management research, and experiment station management, to advanced specialized coursework for midcareer researchers aimed at refurbishing specific skills. Informal training also occurs during the course of various forms of collaborative research between CIMMYT and national programs.

Increasingly, these training efforts are taking on a sustainability perspective, encouraging course participants to consider the importance of sustaining agricultural resources over the long run. Trainees have the opportunity to learn how tools that may be new to them, such as computer-based crop models and certain statistical packages, can enhance their ability to deal with the long-term experimentation required by sustainability research. And we are making specific changes in curricula and in informal interactions to reflect our growing emphasis on this theme. For example, pending the availability of financial resources, we plan to establish several longer term research sites in major ecological zones of the State of Mexico, near the city of Chalco. Trainees would be able to experiment with a number of treatments at these sites (including various tillage practices, different forms of straw management, fertility trials, and a range of weed control measures) so as to gain insights into the effects on productivity of different practices. This is one example of our commitment to ensure that trainees are sensitized to environmental issues and that they learn about the impact of various practices on the quality and productivity of the natural resource base of agriculture.

Conclusion

Winding through all these diverse research and training activities is at least one common thread: a growing interest in how to increase Third World agricultural productivity in the near term, while attending to the quality of the natural resource base upon which long-term productivity depends. CIMMYT agrees with others who insist that sustainable agricultural systems are essential. We believe that much of what we do contributes to the development of such systems. We also agree with our Point of View authors that there is more that CIMMYT staff and their national program colleagues can do, and we are seeking to identify those opportunities and implement appropriate activities. Persistence, imagination, and close integration across disciplines will be required to successfully meet the challenge of sustaining agricultural productivity. Fortunately, those same traits have come to characterize most of our endeavors during the past 25 years and will no doubt continue to do so.

Highlights of 1990 Activities



The preceding pages describe work that contributes directly or indirectly to sustaining agricultural resources in developing countries. CIMMYT staff are involved in many additional undertakings as well, some of which are highlighted in the pages that follow.

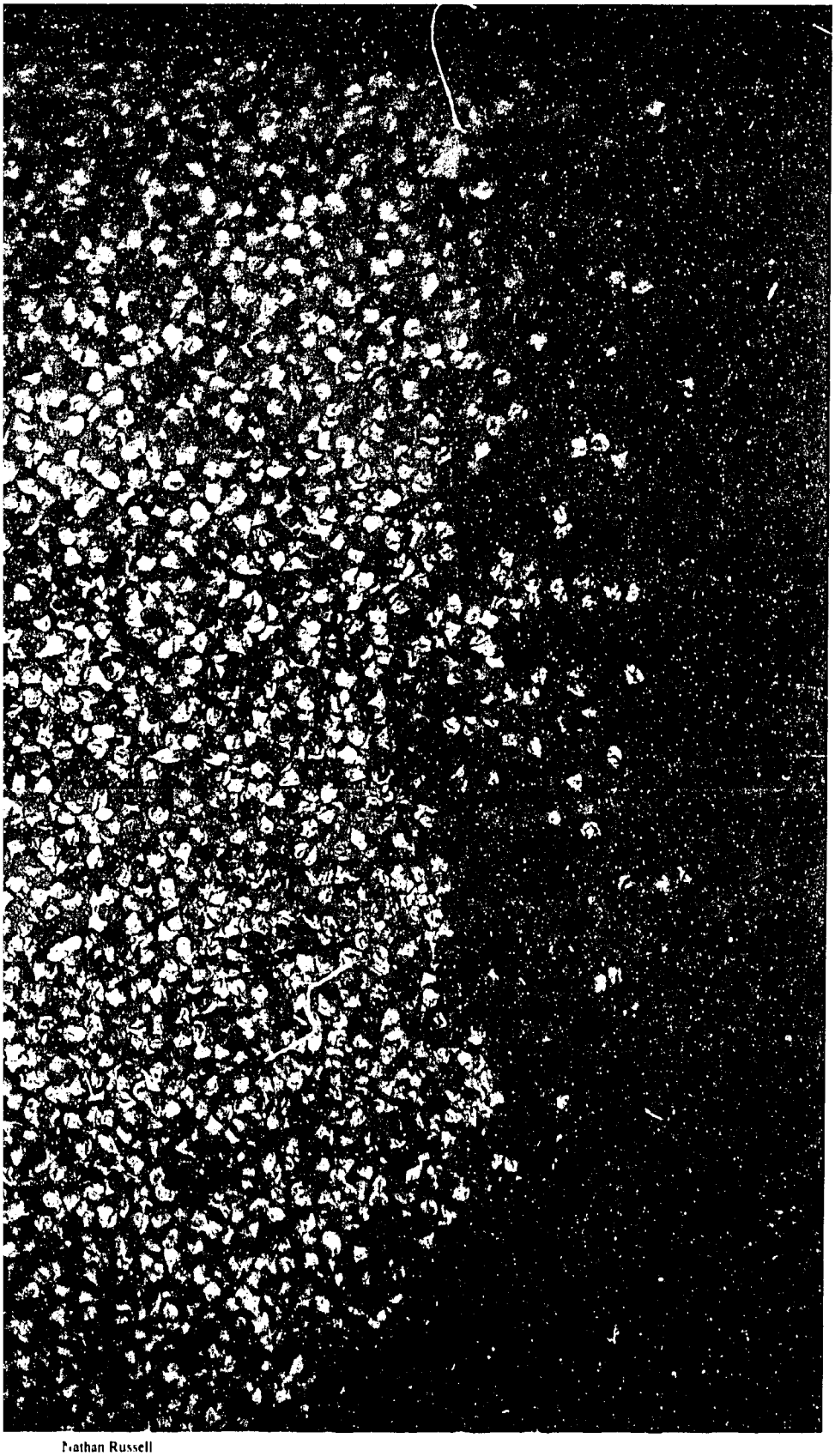
Our major activities often span program divisions (see diagram). For example, the main pursuit of our crop programs obviously involves germplasm improvement, but Economics staff contribute to this activity in numerous ways (see pages 46-50). Our increasingly strategic research on crop management cuts across programs as well (see pages 37-50).

Work related to genetic resources is well represented in this *Report*. Our maize and wheat banks are described on pages 25-26 and research on wheat wide crosses is highlighted on page 44.

Pathologists and entomologists conduct crop protection research on disease and insect pests affecting our crops. The Wheat Program highlight on developing resistance to *Septoria tritici* (see pages 43-44) serves as an example of these efforts. Our crop programs also conduct grain quality research and, through their global germplasm testing networks, distribute over 3,000 nurseries each year to participating national programs.

CIMMYT also pursues training, information, and consulting work. Training of different kinds is offered in nearly all aspects of our research. Publishing by CIMMYT staff and information work in general is now receiving greater attention (see pages 52-53 and 58-65). A limited amount of consulting by senior scientific staff is also available to national programs.

Maize Research



Nathan Russell

CIMMYT's primary challenge in maize research over the coming decades will be to help developing countries achieve higher rates of growth in average yields at reduced environmental costs. To aim for less would amount to postponing development for many people in the Third World.

There is a strong feeling in some quarters that the kinds of crop research that have contributed to past gains in maize production may not be adequate to the formidable task that lies ahead of us today. Many people are banking instead on new developments in biotechnology, which should eventually lead to more rapid progress in crop breeding. Others are counting more on crop management research that places special emphasis on long-term trends in the output, resource requirements, and environmental impacts of crop production. The CIMMYT Maize Program is aggressively pursuing both these lines of work in the belief that they are essential for maintaining an adequate pace of development in maize while conserving the resources upon which production depends. At the same time, we remain strongly committed to more conventional approaches in crop research and are featuring some of them in this report on recent developments in our work.

We believe that, far from having exhausted its usefulness, this research will account for a large share of future gains in yield and in more efficient use of farmers' resources. We are also convinced that the more successful this work is in the near term, the greater will be the eventual impact of newer research initiatives of the sort mentioned above. After all, the best candidates for collaborative research on restriction fragment length polymorphism (RFLP) technology will be those national research programs that have already fielded successful improved varieties and hybrids, and our most likely partners in the development of sustainable cropping systems will be countries that have already brought about substantial improvement in farmers' crop management.

Population Improvement for the Subtropics

CIMMYT maintains a wide array of improved maize populations, some of which have been undergoing full-sib recurrent selection for well over a decade. In an effort to further diversify its offerings to developing countries, the Maize Program is also generating some new populations and employing other breeding schemes. Meanwhile, the currently available populations continue to be an extremely valuable source of improved germplasm for national programs and, even after many years of selection, appear to offer ample scope for further gains in yield and stress resistance.

A case in point is the Program's group of advanced populations for subtropical areas, which are quite extensive in Brazil, Egypt, India, Mexico, Pakistan, southern China, and the midaltitude areas of eastern and southern Africa. By the early 1980s, it had become abundantly clear to us that the subtropical materials would not be very widely accepted until they had good resistance to turcicum leaf blight, a disease that thrives under conditions of high humidity and low temperatures, giving the maize plant a burned appearance and reducing its yield drastically.

Turcicum resistance was initially not improved in our subtropical germplasm because of limitations inherent in selection at CIMMYT's experiment station in Tlaltizapán, Mexico. Although this site qualifies as subtropical in most respects, it lacks the conditions needed for development of the leaf blight pathogen, *Exserohilum turcicum*. In the absence of disease pressure, we naturally made little or no progress in improving the resistance of our germplasm at that location. In the 1980s, though, a way was found around this problem. We are still improving the subtropical populations at Tlaltizapán but in combination with selection at a lowland tropical site during the winter season and a highland site during the summer, where uniform turcicum infection can be achieved through inoculation. Resistance to this disease as well as common maize rust (*Puccinia sorghi*) has been given particular emphasis during the later cycles of selection.

Table 3. Gains per cycle for yield and disease resistance in CIMMYT's advanced subtropical maize populations

	Percent gain in:		
		Reduction of:	
Pop.	Grain yield	Turcicum	Rust
33	4.0*	-3.0**	--
44	4.6	-4.0	-4.1
45	3.8*	-3.8	-3.0
48	4.0*	-1.9	--

*, ** Significant at the 0.05 and 0.01 levels, respectively.

The effectiveness of this strategy was confirmed recently by the results of a multilocational evaluation of cycles of selection in four advanced subtropical populations. The gains per cycle for grain yield ranged from 3.8 to 4.6%, and all populations showed improvement for resistance to turcicum. Three of them also registered gains in resistance to common rust and two to ear rots caused by *Fusarium moniliforme* and *Gibberella zeae* (Table 3). We now consider Population 44 to have a high level of resistance to the two leaf diseases and Population 45 an intermediate level. It is particularly noteworthy that this resistance was achieved in relatively few cycles of selection and that it is polygenic or quantitative. Unlike the monogenic or major gene type, polygenic resistance is effective against various races of the pathogen and is fairly durable over time as the pathogens evolve.

In addition to helping us document progress from selection for yield and disease resistance, the cycles-of-selection study demonstrated rather convincingly that our breeding methodology is very effective. One key feature of this scheme (which is applied both to the subtropical and all of our other advanced populations) is that during each two-year cycle of improvement progeny are sent for evaluation at up to five locations around the developing world. A primary advantage of this approach is that it allows many cooperators to sample the populations under different types and

levels of stress and to identify progeny that are well suited to those conditions; based on cooperators' progeny selections we develop experimental varieties for further, more widespread evaluation. A potential disadvantage of this approach is that the diversity of the test sites may contribute to a large genotype x environment interaction, which could limit progress from selection. If that is the case, however, it is not apparent from the results of this study, in which the average improvement in grain yield of four subtropical populations was 4.1% per cycle or about 2.0% per year. This is a quite respectable rate of gain and coincides with the experience of other researchers.

Improving Maize Performance Under Drought

Maize is unique among cereals in being highly susceptible to stress at flowering. If the crop is short of moisture then, as is all too common in many parts of the tropics, farmers can expect yield losses of more than 50% unless they are among the fortunate few in developing countries that can irrigate maize.

According to CIMMYT physiologists, the damage seems to result from competition between the plant's male and female flowers (the tassel and ear). Under favorable conditions the two exist in harmony, because the plant is able to produce enough carbohydrates through photosynthesis to easily meet the requirements of both tassel and ear development. Thus, within about two days after the tassel begins to shed pollen at anthesis, the ear will normally have exposed silks to capture the pollen for fertilization and development of seed.

Under drought (or high density), however, this fine tuned system goes awry: The supply of photosynthate is drastically reduced, triggering a battle of the sexes over control of diminished supplies of this resource. In genetically variable populations of tropical maize, it is apparent that at least in some plants the female floral parts gain the upper hand, showing, in the parlance of physiologists, greater "sink strength." These plants channel enough photosynthate into the ear, perhaps at the expense of stem growth, to ensure that, even under drought stress, the ear accumulates the required amount of biomass within a short enough time after anthesis to produce viable silks and fertile seed. But a substantial number of plants give the female flower short shrift, causing a high degree of barren plants and thus greatly reduced grain yields.

This hypothesis would be of little value for the purposes of maize improvement if it did not have some outward expression in crop development that we can easily measure and manipulate through selection. The most visible sign that tropical maize is guilty of male favoritism in partitioning carbohydrates is the phenomenon of a widened anthesis-silking interval (ASI) under drought. Increased ASI results from a postponement of silking, which in turn is a consequence of inadequate supply of photosynthate to the ear. For each day of delay beyond the normal ASI of more or less two days, grain yield per plant drops by about 10% for up to eight or nine days. We now know that it is possible to reverse this trend by selecting plants that show a narrower ASI under severe drought stress at flowering. The survivors of this ordeal have improved partitioning of carbohydrates to the developing ear, resulting in fewer barren plants and higher yields under stress.

The effectiveness of this approach has been borne out by recent studies conducted by Maize Program physiologists with the population Tuxpeño Sequía. Largely as a result of eight cycles of selection for reduced ASI under drought stress, this population now shows a grain yield advantage of some 30% over nontolerant genotypes under a drought severe enough at flowering to reduce yield potential by about two-thirds. The data further indicate that the improved performance of the population's later cycles results from a higher rate of ear growth near flowering, which means that more plants achieve a minimum ear dry weight required to produce viable silks.

Data on Tuxpeño Sequía also suggest that changes in the partitioning of photosynthate are quite independent of environment. An important implication of this finding is that genetic gains achieved in stressed environments apparently translate into improved performance under more favorable conditions as well. The link between ASI and grain yield has been further confirmed by other CIMMYT studies of a wide array of germplasm, ranging in level of improvement from landraces to single-cross hybrids. There is evidently considerable variability for ASI in lowland tropical maize, and it is fortunately a highly heritable trait that responds readily to selection.

Tuxpeño Sequía is now available to national maize research programs, and in the next few years we will be providing additional improved populations that our cooperators in developing countries can employ as sources of drought tolerance. Perhaps even more important, though, we can now recommend with confidence the technique of selecting for reduced ASI under severe stress as an efficient means of improving maize performance, certainly under drought but evidently under more favorable conditions as well. At a minimum the products of this approach will not merely survive drought but survive to produce extra grain.

Hybrid Maize Development

Developing superior maize hybrids for the lowland tropics is an ambition to which a growing number of national maize research programs aspire. Their chances of success are good in countries that have viable seed production industries and sizeable areas where growing conditions are favorable and where farmers' crop management is better than average. Even under those circumstances, however, hybrid development can be seriously hindered by the relative scarcity of vigorous

inbred lines (which are primary components in the most common types of hybrids) developed from tropical germplasm.

This is not much of a problem with maize of temperate adaptation, since researchers have been inbreeding it and fitting the inbreds into hybrid combinations for some 70 years. Tropical maize, in contrast, has a shorter history of science-based improvement, and efforts have generally been oriented toward the development of open-pollinated varieties (OPVs), which are more suitable than hybrids for the harsh conditions of many tropical environments. During recent years maize scientists in the lowland tropics have generated only a relatively small number of lines that can survive beyond the initial cycles of inbreeding. This has greatly limited their chances of identifying combinations of lines that offer a distinct yield advantage in the more favorable tropical environments and show promise for commercial hybrid development. Because superior inbreds are so scarce, some hybrids available in developing countries, while performing well compared with released varieties, are composed of lines whose low vigor and yield, among other problems, make cost-effective seed production almost impracticable.

Recently the CIMMYT Maize Program has taken various steps to reduce the frequency of such cases by providing breeders with a much wider range of options in hybrid development. One move in this direction was to initiate projects for generating what we term "hybrid-oriented source germplasm." A key requirement of this material is that it have an improved ability to withstand successive generations of inbreeding. We have just completed two cycles of improvement in several tropical and subtropical populations for the various traits (including yield, vigor, and disease resistance) that contribute to inbreeding tolerance and will study changes in the inbreeding behavior of this germplasm over cycles.

Apart from standing up under prolonged inbreeding, it is extremely important that source populations employed in hybrid development show a high degree of heterosis, or hybrid vigor, with one another. In an effort to provide such materials, we are further improving the cross performance of two populations, Tuxpeño-1 and ETO Blanco, that already fit a well-known heterotic pattern. After improving the inbreeding tolerance of these materials, by growing out S_1 lines and recombining the superior ones, we placed them in an interpopulation improvement scheme, in which lines from each population are selected partially according to their performance when crossed with a tester from the other population. While attempting to make better use of known heterotic groups, we are also seeking to develop new populations that combine well with each other. Toward that end we have conducted a multilocational evaluation of test crosses and on the basis of combining ability data will recombine selected lines during 1991 to form two tropical and two subtropical heterotic groups.

Thomas Luba

Leocadio Martínez, Maize Program technician, indicates the marked difference between ears from drought susceptible and tolerant lines. Low grain yield under this stress results from fierce competition between the male and female flowers (i.e., the tassel and ear). A selection technique developed by CIMMYT physiologists tilts this battle of the sexes in favor of the female flower, resulting in higher grain yields under stress.

The projects described above are designed to generate germplasm as quickly as possible that is specifically suited to hybrid formation. In some of its other breeding projects, the Maize Program has also taken measures (particularly the adoption of S_1 and S_2 selection schemes) that over the long term will enhance the utility of our germplasm for both OPV and hybrid development programs. By these various means, we hope to ensure that, rather than just making do with a limited collection of suitable lines, national programs will have far more numerous choices in developing more productive genotypes for farmers.

Tuxpeño Sequía is now available to national maize researchers, and in the next few years we will be providing additional improved populations that our cooperators can employ as sources of drought tolerance.

Late Planting of Maize in Southern Africa

Adopting a new variety is usually a farmer's first step toward increasing yields, but this seldom brings marked improvement unless accompanied by some modifications in crop management. In many maize production systems, it is still far from obvious what those changes should be. And this fact is symptomatic of the continuing need throughout the developing world for research aimed at assessing agronomic problems, identifying their causes, and generating effective solutions that are within the farmer's reach.

Some of the many opportunities for such research are being explored by CIMMYT's regional maize program in southern Africa in cooperation with national research organizations in Zimbabwe and Zambia. One problem they are confronting is late planting of maize on about 350,000 of the estimated total of 1.2 million hectares grown by smallholder farmers, using ox tillage, in these countries' subhumid areas. Though responsible for large reductions in grain yield each year—anywhere from a quarter to a half million tons in Zimbabwe and Zambia—late planting has not yet been thoroughly researched.

Previous work has concentrated on devising ways to bring farmers' planting dates forward, since it is well known that earlier sowing gives better yields in the subhumid areas under study. But this effort has foundered on several facts about farmers' circumstances that are difficult to alter: labor and seed are in short supply at the start of the growing season in mid-November; many farmers cannot obtain oxen for plowing until well after the optimum planting date; and growers pursue a deliberate strategy of staggering maize plantings, delaying some by a month or more, to manage the risk associated with unreliable rainfall. That late planting invariably translates into yield loss (at a rate of about 3.7% per day according to one study) is due to a combination of environmental and crop management factors. One of the former is that late plantings are deprived of a nitrogen mineralization flush, or release of nitrates, which coincides with the onset of the rains and then rapidly diminishes. Other environmental factors are lower irradiance and shorter daylengths, waterlogging during crop establishment, and shortage of rainfall during grain filling. Even more damaging, though, are the stiffer weed competition and later fertilizer applications at lower rates that are typical of late plantings.

Current research on this problem is based on a different assumption from previous work, namely that, rather than changing the circumstances that account for late planting, farmers are better off trying to make the most of them. In accordance with this more realistic approach, agronomists have begun research aimed at reducing the negative effects of late planting on maize yields. Between 1987 and 1989, detailed agronomic monitoring was conducted in Zimbabwe to better characterize this practice and its causes. More recently, widespread surveys of farmers were carried out in Zambia and Zimbabwe to determine the extent of the problem, and an experiment was planted at CIMMYT's experiment station in Harare to examine environmental effects on late plantings.

Based on the monitoring and survey results, further research has been planned by Center staff and cooperators in Zimbabwe; the work will also be relevant to farmers in Mozambique and Zambia. First, agronomists will concentrate on distinguishing the environmental effects on crop performance in late plantings from the management effects. Then, they will begin seeking improvements in farmers' crop management, with emphasis on modifications in plant density and in fertilization and weeding practices. Within a few years, new, early and intermediate maturity varieties should be available, and these will be tested on-farm under improved management practices for late plantings. While generating technologies that promise almost immediate gains, researchers will also examine longer term alternatives for enhancing soil fertility, such as rotations of groundnuts, sunflower, and other crops with late planted maize and the incorporation of agroforestry species into this system.

Wheat Research

Thomas Luba

Productive and sustainable agricultural systems are necessary to ensure farmers adequate incomes over time and consumers continued access to quality food at affordable prices. Through the development of high-yielding, disease-resistant varieties, the Wheat Program's work has had a tremendous direct impact on productivity, farmers' welfare, and the real price of wheat.

Less obvious, though certainly no less important, are the large positive impacts on agricultural sustainability of our research. During the 1990s, the Program will more directly address selected sustainability issues, while continuing to emphasize the productivity-enhancing aspects of its work.

We are aware of sustainability issues in major cropping systems in which wheat plays a role, such as the rice-wheat rotation in South Asia, soybean-wheat in South America, cotton-wheat in Egypt, and maize-wheat in the highlands of Mexico. We are beginning to invest resources in research specifically aimed at such systems. One new collaborative project investigates the extent to which the productivity of South Asia's vast (over 13 million hectares) rice-wheat system may be declining and looks for relevant underlying causes (see box, page 31).

The rice-wheat work is but one of more than 240 research projects currently underway in the Wheat Program. To manage all these efforts more effectively, we have revamped our activity review process and initiated a computerized project database. In addition to an annual in-house review of the Program's research agenda, in-depth assessments of selected activities will be conducted each year by external reviewers. In June 1990, we initiated this process with an intensive, 11-day evaluation of our collaborative work on winter/facultative wheats based in Turkey and Syria.

The Program's numerous endeavors range from continuing efforts to breed spring bread wheats for irrigated environments to an array of "upstream" research undertakings designed to support this essential breeding work. The latter involve exploring, for example, the genetic basis of durable resistance to leaf rust, or the use of callus culture for inducing wheat-rye chromosomal exchange. Many of the Program's projects directly involve our colleagues in developing countries, as well as institutions in the developed world. We also have cooperative agreements with the International Center for Agricultural Research in the Dry Areas (ICARDA), for work on spring and facultative bread wheat and durum wheat for the dryland areas of West Asia and North Africa; and the International Rice Research Institute (IRRI), for studies on sustaining the productivity of the rice-wheat system.

Rice-Wheat Surveys in India's *Tarai*

The rice-wheat cropping pattern is prevalent in the swampy lowlands (*tarai*) of western Uttar Pradesh, India. This region is one of the study areas selected as part of the CIMMYT/IRRI/national program collaborative research project mentioned above. In 1990, two preliminary diagnostic surveys were conducted in the area; one in February focused on wheat and one in September focused on rice. The surveys occurred in three districts around the G.B. Pant University of Agriculture and Technology (Pantnagar University).

The diagnostic surveys are aimed at evaluating the productivity, profitability, and sustainability of a given area's rice-wheat system, to identify productivity problems and their causes, and to suggest research that may help. Participants in the Pantnagar surveys included senior researchers from the All-India Coordinated Wheat and Cropping Systems Research Programs of the Indian Council of Agricultural Research (ICAR), Pantnagar University, IRRI, and CIMMYT. This group represented a unique cross section of disciplines, including agricultural anthropology, agronomy, economics, engineering, entomology, extension, pathology, soil physics, water management, and weed science.

During the surveys interviews with farmers indicated that wheat tends to yield better after sugarcane than after rice. This may be because cane cultivation improves soil fertility due to the relatively high levels of fertilizer and farmyard manure that this high-value crop receives and because of the abundant organic matter (crop residues) left behind. Moreover, sugarcane cultivation improves soil structure in that it requires no puddling and relatively little tillage. Many farmers told the survey teams that nutrient deficiencies currently do not restrict wheat or rice yields as long as zinc is included in the fertilizer package. Several farmers stated that they apply more fertilizer now than previously to get the same yield. Data from longer term rice-wheat trials at Pantnagar University show gradual declines in rice yield over four fertilizer treatments. Yields have declined at constant fertilizer levels in other parts of the region where the rice-wheat rotation prevails.

Various hypotheses were developed during the surveys on problems affecting rice and wheat productivity in the *tarai*. The survey teams assigned tentative priorities to problems, hypothesized about causes, diagrammed interactions, and suggested follow-up research activities. Much of this methodology is described in detail in Tripp and Woolley (1989).

Problems were classified as either long term—meaning a number of crop cycles will be required for adequate assessment—or near term—meaning they can be fairly well analyzed within a crop cycle. Two long-term sustainability issues were identified in these surveys: an increasing limit on the yields of wheat and rice due to nutrient deficiencies and an increasing reduction in rice and wheat yields due to pests, diseases, and weeds. Near-term problems cited for wheat include yield reductions due to late planting or late harvesting, the weed *Phalaris minor*, waterlogging and excess moisture, and poor plant stands. For rice, near-term problems include infestations by brown planthoppers, bacterial leaf blight, and delayed transplanting. For both crops, near-term difficulties include rats, inefficient use of nitrogen, sheath blight, and soilborne pathogens. The survey teams generated ideas for research directed at each of the pro-blems listed above. For example,

for the problem of yield reductions due to late wheat planting, suggested avenues of research include:

- Designing improved tractor-drawn implements that allow reduced or zero tillage (e.g., cultivators using horizontal sweeps, shallow rotovators, or specialized equipment for zero tillage) and more efficient handling of rice straw residues.
- Developing establishment procedures for rice that reduce puddling or its deleterious effects on soil structure and plow-pan formation.
- Identifying wheat varieties for late planting (heat tolerance during grain filling will be an important trait of these varieties).
- Identifying earlier maturing rice varieties for late rice planting.

The final report on the surveys' findings (Hobbs et al. 1991) indicates that one challenging aspect of the rice-wheat collaborative project will be to establish long-term monitoring in the Pantnagar region and at other key sites. But the data obtained from such work will prove invaluable in assessing the sustainability of this important cropping system.

Improved Resistance to *Septoria tritici*

In the late 1960s, when semidwarf wheat germplasm was first introduced to the rainy coastal areas of Turkey and North Africa, including Tunisia, Algeria, and Morocco, most of it was found to be extremely susceptible to leaf blotch caused by the fungus *Septoria tritici*. Epidemics were so severe that some researchers felt there was a genetic linkage between susceptibility to the disease and reduced plant height.

Favorable environmental conditions (splashing rain and moderate temperatures) and additional fertilizer, combined with susceptible varieties, caused yield losses of up to 50% in farmers' fields. Today, septoria tritici blotch is an important disease of wheat in large portions of the environments characterized as temperate, high-rainfall areas: the Mediterranean Basin; the highlands of East Africa, Mexico, and the Andean region; and the Southern Cone of South America.

Crop residues can play an important role in the survival of the pathogen from one wheat crop to the next. Such cultural practices as burning the stubble break the disease cycle, but these conflict with desirable practices, such as retaining stubble for erosion control. Fungicides can provide effective control and are used in Europe, but few farmers in developing countries can afford them—not to mention the potential environmental costs associated with their use. CIMMYT's primary control strategy is to breed for resistance.

During the last 18 years, our breeders have developed materials that combine reasonably good levels of septoria leaf blotch resistance with high yield potential, broad adaptation, and resistance to other diseases. The best sources for resistance to date have been the spring x winter crosses (e.g., Bobwhite, Bagula, and Milan) and germplasm emanating from the shuttle breeding project between Brazil and Mexico (e.g., Frontana-derived lines and Thornbird). Recently, germplasm derived from our partnership with China to develop fusarium head scab-resistant germplasm and from our wide cross program has given a boost to the search for genetic variability for resistance to septoria diseases.

In a collaborative effort that dates from about 1985, CIMMYT has drawn on the expertise of the Plant Protection Institute (IPO) in the Netherlands and Tel Aviv University in Israel. One objective of this project has been to confirm the diversity of resistance in some of the more important sources of resistance that the Program has been using in its breeding efforts. We are looking for as many different resistance genes as possible; we will then determine which ones are the most useful for combining and incorporating

Gene Hettel

J.S. Chatraverdi, Pantnagar University extensionist (left), and Dennis Lawn, CIMMYT pathologist (right), discuss possible soilborne disease problems in the field of small-scale Indian farmer during the February diagnostic wheat survey near Pantnagar, India.

into superior wheat phenotypes. So far, it appears the sources of resistance derived from the winter wheats and the Brazilian germplasm are quite different in their genetic backgrounds.

Through laboratory testing of more than 100 *S. tritici* isolates collected by our staff and colleagues around the world on a set of wheat varieties developed in Israel, IPO has been able to confirm the existence of virulence differences in the pathogen. Dutch and Israeli scientists are studying virulence patterns and developing specific markers so that isolates of the *S. tritici* pathogen can be differentiated more precisely. For example, they are looking at the possibility of using micro-viruses found in the cytoplasm of the pathogen as markers to distinguish one isolate from another. If a specific pathogen or isolate carries the same virus all the time, technicians will be able to determine the isolate by identifying the virus that afflicts it. Our colleagues are also developing restriction fragment length polymorphisms (RFLPs) for use in the identification of specific isolates.

In 1990, our wheat wide crosses laboratory had a 23% recovery rate of haploids from wheat-maize crosses—considered to be exceptional by scientists working in this area.

Wheat-Maize Crosses in RFLP Work

In 1986, researchers in the UK demonstrated that it was possible, through the use of laboratory techniques, to recover embryos and obtain plants from wide crosses using wheat as the female parent and maize as the male parent. After fertilization, the maize chromosomes are eliminated from the zygote resulting in wheat haploids. Australia and, more recently, the Netherlands are funding a three-year collaborative project between Cornell University (USA) and CIMMYT in an effort to develop an RFLP linkage map for hexaploid bread wheat. Wheat-maize crosses are playing an important role in this work.

A promising area of biotechnology is the use of RFLPs to identify and track genomic loci for traits of interest, an application that can greatly improve the efficiency of selection in conventional breeding (see Research Support, page 53). Hence, the focus of the Cornell-CIMMYT collaboration on the development of RFLP maps for wheat and barley. However, the genetic material that CIMMYT provides to Cornell for trait mapping must be homozygous. The haploids generated by wheat-maize crossing shortens the time required to obtain homozygosity, since a homozygous plant results when a haploid's chromosomes are doubled. Up to now, researchers have relied mostly on more cumbersome anther culture and crosses with the perennial barley relative *Hordeum bulbosum* to produce haploids of Triticeae species. Both techniques have constraints of genotypic specificity that wheat-maize crossing does not have.

Researchers in the UK and Japan, as well as at ICARDA and in our own wheat wide crosses laboratory, have found it possible to recover haploids across a wide array of wheat genotypes using wheat-maize crosses. In 1990, we obtained 58 embryos from about 200 maize-pollinated wheat florets. Of these embryos, 81% resulted in haploid plants, which translates to a 23% recovery rate of haploids from the original pollinations. This recovery rate is considered to be exceptional by scientists working in this area.

Recently, we made crosses between bread wheat varieties assessed to be reasonably polymorphic with respect to DNA, and reconstituted wheat hexaploids (synthetics developed from crossing tetraploid durum wheat and the wild relative *Aegilops squarrosa*). We then pollinated the F_1 hybrid progeny with maize pollen to produce haploids. We currently have more than 400 haploids from several wheat populations undergoing chromosome doubling using the standard colchicine technique. Homozygous individuals will be produced and used in the continuing effort to construct an RFLP map for useful traits in bread wheat.

Progress in Durum Wheat Improvement

Durum wheats—a staple food of the poor in West Asia/North Africa (WANA), Ethiopia, the Asian Subcontinent, and the Andes of South America—are cultivated by these regions' farmers on about 11 million hectares. About 70% of this durum area is dryland and concentrated in WANA. Our major objective is to increase the efficiency with which durum wheat is grown, both in favorable and unfavorable environments, by supplying improved germplasm to national wheat research programs. In Mexico, our durum breeding emphasizes the development of high-yielding materials, as well as improved disease resistance and better grain quality. The CIMMYT/ICARDA breeding effort in Aleppo, Syria, focuses on greater tolerance to abiotic stresses, particularly drought and cold.

Since the 1950s, as Figure 5 shows, durum varieties released in Mexico have exhibited steady progress in yield potential, by which we mean the yield of these varieties under irrigation and good management. Yield potential is an important measure of progress because

numerous studies with both CIMMYT durum and bread wheats reveal that increased yield potential is associated not only with more efficient land use (yield/day), but also more efficient use of specific inputs of solar radiation, of nutrients (see Review of CIMMYT Programs, page 30), and of water—both when present at optimal or sub-optimal levels. The progress achieved with durum wheats derives from both increased biomass as well as increased harvest index (Figure 5). The 9.0 and 9.4 t/ha yield potentials of the Mexican varieties, Altar 84 and Aconchi 89, during the 1989-90 cycle at our northwestern Mexico station are the highest ever measured at this location. We expect to improve yield potential even further, in particular by increasing the harvest index from its current level of about 42%.

In irrigated locations like northwestern Mexico's Yaqui Valley, it is obvious that higher yield potential will be reflected in higher on-farm yields even though the general level of durum yields obtained by progressive farmers may be 25% below those quoted above.

Farmers there and in other irrigated areas like central Chile and Egypt (not to mention developed countries like Spain and the USA) are adopting these varieties. However, what is less well understood, although derived from the efficiency considerations above, is that the outstanding Mexican varieties like Cocorit 71, Mexicali 75, and Yavaros 79 or their very close relatives dominate among the improved modern durum varieties occupying more than half of the durum area grown under rainfed conditions in the developing world; the remainder are mostly landraces.

With the joint CIMMYT/ICARDA durum breeding effort underway since the early 1980s and specifically targeted to the dry WANA region, it remains to be seen whether the Mexico-derived germplasm and the landraces will continue to prevail in dryland areas. This effort in the WANA region, in fact, emphasizes the utilization of landraces as parents in crosses with improved high-yielding types. The joint program also selects for specific traits associated with stress resistance and uses multilocation testing. In spite of the difficulties in breeding for areas subjected to drought and other abiotic stresses associated with dryland conditions, we are making good progress. For example, after the release of the outstanding drought-tolerant line, Korifla, in Syria (as Cham 3) and Jordan (as Petra), our joint program has recently identified an even better genotype, Omrabi 17, which demonstrates the successful combination of drought tolerance and responsiveness to favorable conditions. Omrabi 17 has yielded significantly more than Haurani, a widely grown landrace in the dry areas, in both favorable (by as much as 59%) and unfavorable (by 14%) growing seasons. Omrabi 5, a sister of Omrabi 17, is performing very well in western North Africa and in northwestern Mexico, where we use it as a check for drought tolerance in reduced irrigation trials.

Aggressive, highly virulent, and durum wheat-specific races of stem rust (*Puccinia graminis*) are found in the durum areas of Ethiopia and Kenya. The evolution of stem rust races in these highlands is favored by the climatic conditions and because durums have been grown there for millennia. In the early 1980s, almost all of our advanced durum germplasm succumbed to the high disease encountered in the region. In 1984, we entered into a collaborative arrangement with the durum research team at the Debra Zeit Agricultural Experiment Station of Alemaya University. The project has involved crossing Mexican and Ethiopian germplasm (landraces and improved lines) and shuttling the segregating populations between the two countries for selection. This shuttle breeding work has enabled the incorporation of stem rust resistance genes into the Mexican durum germplasm. This collaborative effort is continuing and has already started to show dividends. During the 1987-88 cycle, only 3% of the advanced lines tested at Debra Zeit were found to be resistant to prevalent races of stem rust. By 1989-90, in contrast, 20% of the lines were resistant, in addition to having high yield potential and good agronomic type.

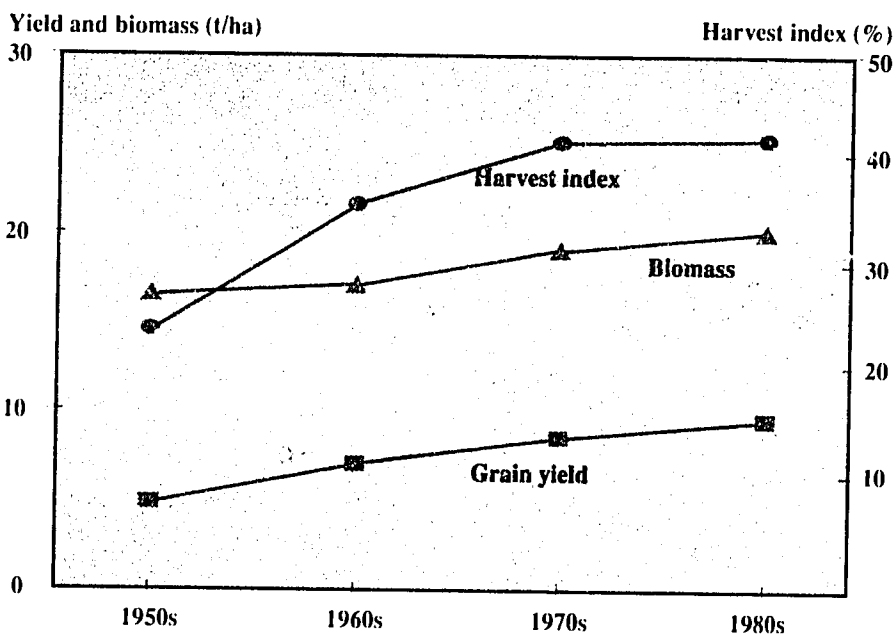


Figure 5. Progress in grain yield (t/ha), biomass (t/ha), and harvest index (grain yield/biomass, %) for selected Mexican durum wheat varieties over the last four decades. Source: CIANO 1989-90 optimum agronomy, results for eight varieties averaged by decade of release.

Economics Research

Kathrin Elsesser

Nowhere is the need for sustainable systems more readily apparent than in marginal areas. In these increasingly fragile environments, people living at the edge of subsistence often depend on several enterprises to maintain themselves on their land.

Each crop grown requires numerous and often difficult decisions from farmers. Decisions about what to plant, where to plant, and when are in turn often affected by unseen, unimagined events, such as the mutation of a pathogen; may be threatened by unpredictable and variable weather; and may suffer at different stages of the growing cycle from farmers' lack of resources needed to perform agricultural operations.

Under almost any conditions, the complex of factors affecting agriculture is imposing, especially considering that one cannot predict all of the consequences of technological change. For this reason, social scientists at CIMMYT focus much of their research, from farm-level studies to global analyses, on developing methods for understanding the results of technological change and determining how research resources should best be allocated to meet the developing world's growing need for maize and wheat. As the following highlights indicate, economics research is concerned with marginal as well as favored production environments.

Designing and Evaluating New Technologies at the Farm Level

During 1990, the Economics Program, working with researchers from national programs and colleagues in CIMMYT's Maize and Wheat Programs, assisted in monitoring maize and wheat production at the farm level in many settings. Social scientists in Pakistan continued to amass data on the production of maize, wheat, and other crops, thereby adding to an already detailed set of data spanning several years. For example, a survey in the remote mountainous area of Gilgit recorded an increase in farmers' use of improved wheat varieties, which were disseminated through a non-governmental organization that had conducted on-farm research (OFR) in Gilgit. Some 63% of the wheat area in the double cropping zone was planted to semidwarf wheats in 1988-89 (mostly Pak-81), compared with 36% three years earlier. The change from local to semidwarf varieties has probably increased annual wheat production by over 1,000 metric tons on the 5,000 ha sown to wheat in the double cropping zone. The additional wheat production raised net income by about 10%, a sizeable increment given that wheat represents about 40% of farm income.

Pakistan's maize sector was the subject of a comprehensive formal survey whose results quantify two problems impeding progress in raising maize production: the low use of improved germplasm and the low use of commercial maize seed as a share of all maize seed planted. The share of total maize area in Pakistan planted to improved open-pollinated maize and hybrids was 26%, fairly low compared to the 1985-86 average of 51% for all developing countries. Furthermore, only about 10% of the maize area has been planted with commercial maize seed in recent years, compared with an average of 43% for all developing countries. Other survey results should help guide the work of breeders, agronomists, and social scientists by clarifying farmers' requirements for maize varieties (for example, their need for dual-purpose maize for grain and fodder production, or their need for earlier maturing or drought resistant maize). Survey results may also alert research managers to other problems, such as the unavailability of improved maize seed, that must be addressed by policy makers.

In two other countries where CIMMYT social scientists have long worked with national research teams—Ghana and Indonesia—adoption surveys provided a way to measure the efficacy of OFR. The objective of the Ghanaian survey, which covered about 400 farmers in six maize-growing areas of the country, was to assess the degree of adoption and diffusion of recommendations developed through OFR. The results will be published in 1991, but preliminary evidence shows a steady increase in the use of improved maize varieties (about 50% of total area) and a growing knowledge and use of improved management practices.

Preliminary results of the survey in Malang, Indonesia are also positive. The Malang Institute for Food Crops (MARIF) started OFR in 1984 in an area characterized by extremely small farms, where people relied on maize as a staple food and their major source of income. The OFR program developed recommendations to cope with insect pests (shootfly, *Atherigona* spp.) and to encourage better planting practices. In April 1990, MARIF staff conducted a formal survey in 20 villages; of the 20 villages, six never participated in the OFR program. Most of the farmers surveyed had taken up the recommended planting practice and shootfly control method.

Still other work began in 1990, including a survey in Ethiopia to gather information on durum wheat production. Durum wheat, which is indigenous to Ethiopia, covers about 60% of the total wheat area and is grown exclusively by peasant farmers. The survey should identify more precisely which agronomic and quality characteristics farmers seek in durum varieties.

The demand for different maize types is the subject of a study in Malawi, where national program and CIMMYT staff are synthesizing five years' data on smallholder maize production in the five important maize-producing areas of the country. The analyses will look at factors affecting farmers' demand for flint maize varieties compared to dent types, and for open-pollinated varieties versus hybrids. Other research with a maize component started in Brazil in 1990. This work, which focuses on the potential economics of using quality protein maize as an animal feed, will be expanded to El Salvador in 1991.

Technological Change in Favored and Marginal Areas

Researchers charting the progress of technological change in the wake of the Green Revolution have observed that, although science has furthered agricultural productivity tremendously over the past 25 years, new technologies

have disseminated more slowly to marginal production environments. The added difficulty that the effects of technological change are often attenuated in marginal areas raises questions about how to equitably and efficiently allocate research resources to meet the needs of all members of society. Is it advisable to invest in agricultural research in marginal areas, when the same resources might produce results more quickly in favorable areas? Is it fair to focus on more favorable areas, where people are better off, instead of marginal areas, whose residents may be much poorer?

In 1990, the Economics Program finished a case study of how the benefits of past and potential technological change (such as the adoption of new semidwarf wheat varieties) have been distributed between favored and marginal areas of Pakistan (Renkow, forthcoming 1991). The methodology used in this study should allow research managers to better understand how alternative allocations of research resources might affect different groups of producers and consumers through influences on grain markets and labor markets.

In Pakistan, wheat production has predictably risen faster in favorable irrigated areas than in marginal rainfed areas. Rural incomes, on the other hand, have generally grown more in rainfed areas than in irrigated ones, particularly since the mid-1970s. (As explained below, this trend is more the effect of changing opportunities in labor markets than of changes in wheat production technology.) In both rainfed and irrigated areas, large-scale farmers have consistently enjoyed the highest incomes from all sources (including crop production, agricultural labor, and nonagricultural employment). Nevertheless, during the past 25 years, poorer small-scale farmers and landless households registered faster real income growth (Figure 6). Particularly striking is the rapid growth of the incomes of poorer households in rainfed areas.

Aside from directly improving production, technological change can have indirect benefits, possibly with different consequences for various socioeconomic groups. For example, by increasing wheat production, a new technology may help make wheat cheaper than it would have been in the absence of technological change. If wheat is an important staple food, net consumers of wheat—both nonproducers, such as urban dwellers, and rural producers for whom household consumption requirements exceed annual production—stand to benefit from lower wheat prices.

In Pakistan, two-thirds of the population are net consumers of wheat. A high proportion of producers (all but large-scale farmers) in marginal areas do not produce enough wheat to meet their needs. Because poor consumers in urban and rural areas tend to spend a greater proportion of their incomes on food, declining real producer and consumer prices of wheat and wheat products over the past 25 years are likely to have benefited poorer consumers to a greater extent than the more well-to-do.

As well as affecting yields and prices, the adoption of modern technologies can influence wage rates because those technologies usually require more labor for crop operations. As long as the supply of agricultural labor remains limited, increased labor requirements push up agricultural wage rates. Higher wages obviously have positive effects on the incomes of poorer rural dwellers who rely on agricultural labor for a large share of their incomes. Moreover, wage increases need not be confined to the areas where labor-intensive technologies are adopted, if differences in wage rates cause agricultural laborers to migrate from low-wage to high-wage areas.

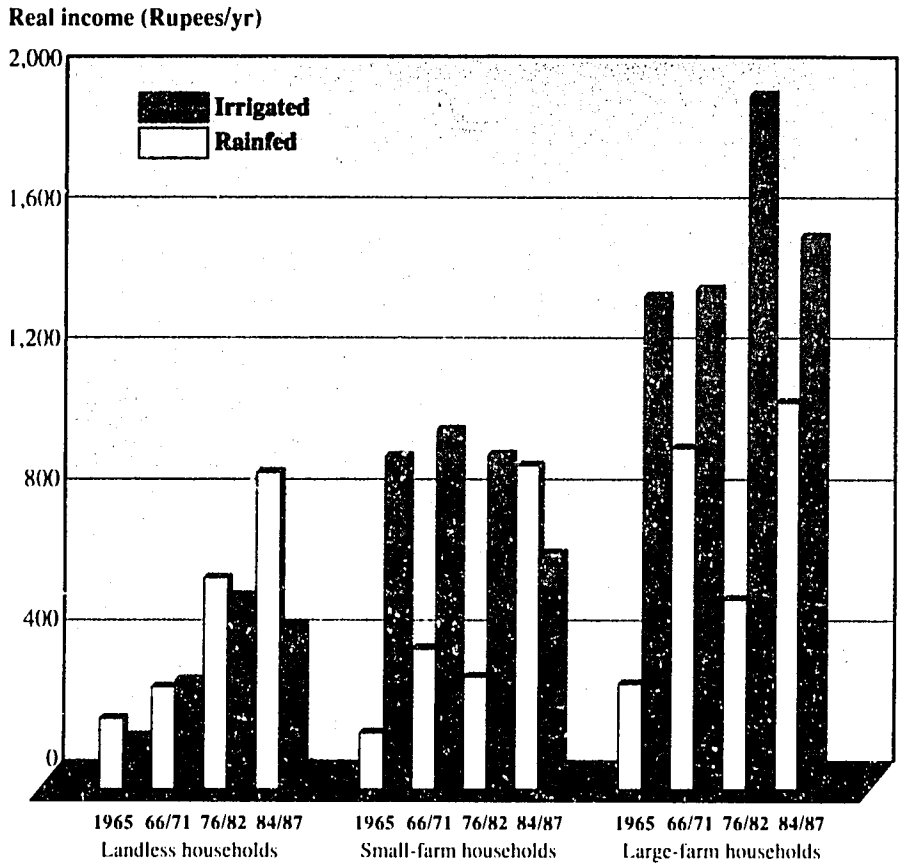


Figure 6. Relative real incomes in the Punjab, Pakistan, 1965-67.

In Pakistan, real agricultural wages in rainfed and irrigated areas have increased steadily, supporting the idea that the increased labor requirements of Green Revolution technologies benefited agricultural laborers in both favorable and marginal production environments. However, wages in nearly all sectors of Pakistan's economy have risen dramatically since the mid-1970s, when large-scale migration to the Middle East began, creating labor shortages in many key sectors of Pakistan's economy (including agriculture). That the rate of income growth has been greater in rainfed areas than in irrigated areas over the past 15 years indicates that those nonagricultural opportunities proved to be even more remunerative than agricultural opportunities in the irrigated areas. An interesting implication of this finding is that differences in wheat production across environments may actually have provided a strong incentive for people living in Pakistan's less productive rainfed areas to broaden their income-generating activities outside of the agricultural sector.

The results of this study suggest that continued investment in research for favored areas is a reasonable strategy to pursue. However, the study does not imply that research in marginal areas should be ignored. Given that people in marginal areas may not benefit indefinitely from employment opportunities off of the farm, it is important to investigate priority research issues in marginal environments.

A Closer Look at Marginal Environments for Wheat

As the Pakistan study indicates (see preceding section), agriculture is influenced not only by localized events at the farm level but also by the more unsettling changes brought on by upheavals in the larger maize and wheat economies. To understand how trends in the world maize and wheat economies influence or manifest events at the farm level, and how those trends might affect the setting of research priorities, the Economics Program regularly assembles and analyzes data on the production, trade, and utilization of maize and wheat throughout the world. Much of this information is contained in the Program's growing database and published in the *Facts and Trends* series.

Because marginal environments present a special challenge to research, a careful assessment of the possibilities for success is warranted.

For example, in 1990 CIMMYT and the International Center for Agricultural Research in the Dry Areas (ICARDA) initiated a study of wheat and barley production in the rainfed marginal environments of West Asia and North Africa (WANA) and South Asia (Morris et al., forthcoming 1991). Two compelling reasons prompted CIMMYT and ICARDA to take a closer look at production trends as well as research and policy options for improving wheat and barley production in rainfed marginal areas. First, millions of poor people subsist on the products of agriculture in rainfed marginal areas, and research institutions are naturally committed to improving the productivity of rainfed cropping. Second, because marginal environments present a special challenge to develop production technologies that will not further deplete the resource base, a careful assessment of the possibilities for successful research is warranted, to avoid expending scarce resources on problems that ultimately prove intractable.

Marginal environments for wheat and barley were defined as areas where irremediable climatic or soil conditions limit potential yields to less than 40% of the potential yields as determined by available solar radiation. (Conditions are irremediable when the costs of ameliorating them are prohibitive.) Severe drought stress, often exacerbated by extreme heat or cold, is the major constraint on wheat and barley yields in marginal areas. Average rainfall during the growing season does not surpass 350 mm and may be far lower: in some locations wheat and barley grow on residual moisture alone. Average yields in marginal areas remain relatively low, while the rate of yield improvement consistently lags behind the rate at which yields have grown in favored areas.

If more resources are allocated to research aimed at marginal areas, where will future gains in productivity come from? Given that moisture is the key constraint, three strategies offer the most hope for increasing and stabilizing yields: 1) irrigation to improve the supply of water, 2) practices that conserve moisture, and 3) practices that use moisture more efficiently. India has long adopted the strategy of expanding irrigated area, and more recently Syria and Turkey have followed suit. But the two remaining strategies should not be overlooked: converting rainfed to irrigated land is costly, and even where irrigation is successful, its sustainability may be doubtful, depending on groundwater supplies.

As for breeding research, although improved germplasm may help raise wheat and barley yields in marginal areas, improvements in crop and soil management practices will often precede changes in variety (as has already happened in Turkey). Traditional

research programs focusing exclusively on cereal crops may not be as successful in marginal areas as in favorable locations, because intercropping, crop rotations and fallowing, and crop-livestock interactions are so important. Instead, a more integrated systems approach to crop and soil management is needed. The role of extension will also be critical. The "technology package" approach often favored by extension is not so relevant in marginal areas, where high agroclimatic variability means that farmers must be able to select among an array of technological options to meet the requirements of a specific field or season.

Likewise, appropriate policies are needed to encourage farmers to adopt improved crop and soil management practices, especially since many marginal areas lack effective input delivery systems and marketing infrastructure. Since economic incentives in many marginal areas favor livestock, price policy reforms may be necessary to increase the expected returns to cereal production and/or to reduce its riskiness. Precisely because they are characterized by a high level of climatic variability, rainfed marginal environments will require a stronger technology/policy effort if cereal production practices are to change significantly.

Monitoring Trends in National Maize and Wheat Economies

Other commodity sector and policy studies in 1990 emphasized maize and wheat production at the national rather than the global or regional level. In Sudan, an intensive survey of wheat producers elicited data for an analysis of the tradeoffs likely to be involved in devoting more resources to improving domestic wheat production. The Sudanese government has determined to raise local wheat self-sufficiency because of limited domestic supplies of wheat, serious shortages of foreign exchange for importing wheat, and reductions in food aid. This is an ambitious goal in a country which, aside from being the warmest place in the world where wheat is grown commercially, produces every grain of its wheat under irrigation. Results of this study and a similar one in Kenya, evaluating the efficiency of domestic wheat production compared to maize and dairying, should be available in 1991. Along with earlier work in Zimbabwe, these studies should offer a clearer perspective on options for encouraging domestic wheat production and self-sufficiency throughout eastern and southern Africa, and for determining how much emphasis should be given to wheat research.

In Paraguay, a preliminary study of the maize sector was completed (Morris et al. 1990). Results of the study highlighted issues in maize production and marketing that require further investigation. In 1991, a more extensive national survey of maize producers will offer researchers more precise information for developing a suitable national maize research strategy.

Training and Information Sharing

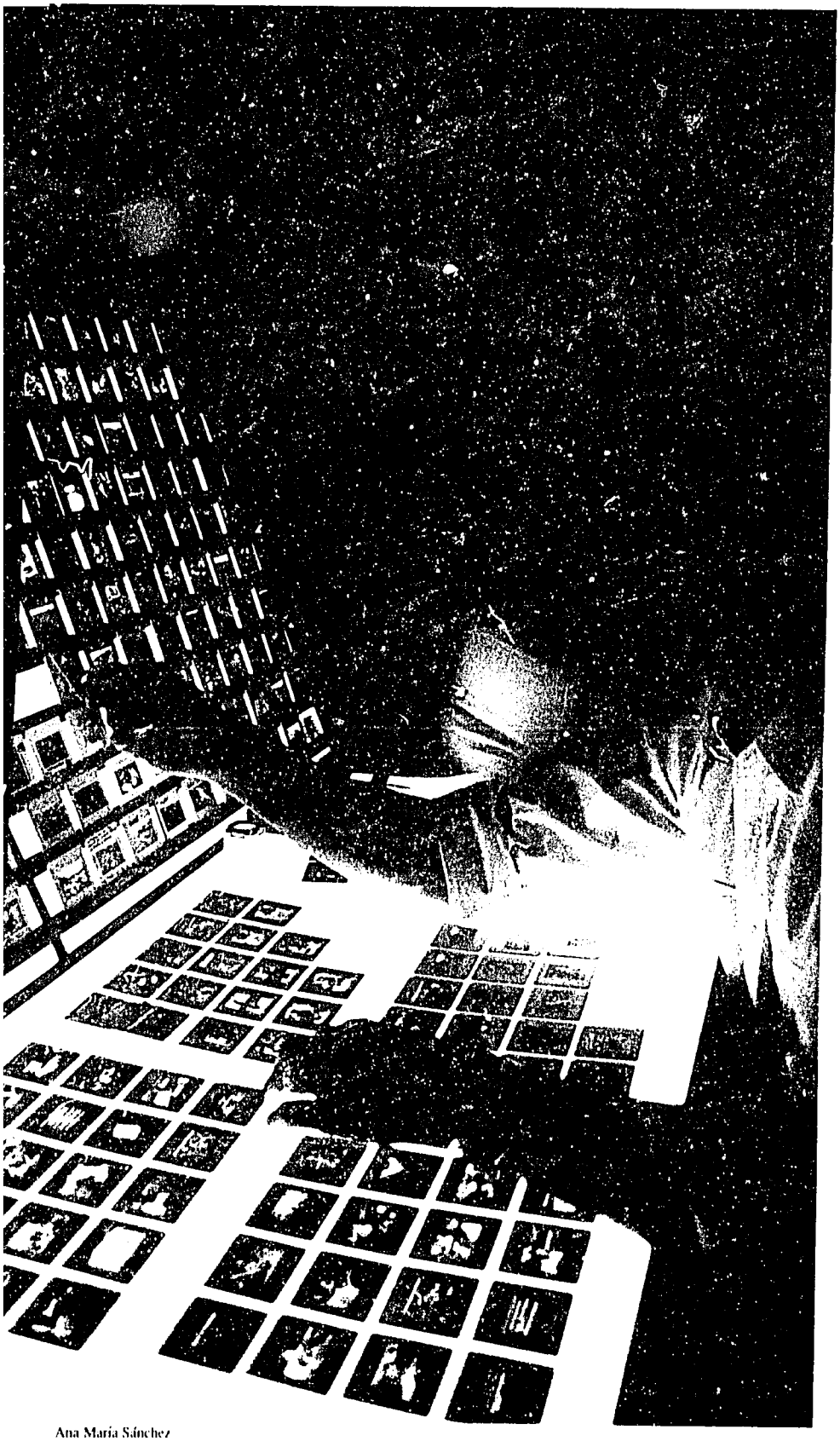
The Economics Program conducted many and varied training courses during 1990, including a regional training workshop in eastern and southern Africa designed to address the needs of the region's growing number of social scientists. Two networks of social scientists were also formed, one in Central America and the Caribbean and the other in eastern and southern Africa (in collaboration with the International Crops Research Institute for the Semi-Arid Tropics). The Central American network should improve communication among social scientists in the region, whereas the African network is specifically intended to foster work in policy analysis.

The past year saw increased progress toward the institutionalization of training in OFR; it is now part of the curricula of several eastern and southern African universities. Finally, CIMMYT social scientists in all regions continued to work with colleagues in the university system to supervise thesis research by advanced degree students.

Kathryn Elsesser

Research to improve crop and soil management practices in marginal as well as favored areas can benefit from a systems approach that considers factors such as crop-livestock interactions, intercropping, and crop rotations and fallowing.

Research Support



Ana María Sánchez

Our research support staff assist scientists and decision makers at CIMMYT and elsewhere with products and services designed to help them meet the challenges of their work in creative and efficient ways. In this *Report* we feature highlights drawn from Information Services, Seed Health, and Applied Molecular Genetics.

Information Services

A noted thinker about trends in information management recently wrote about "information anxiety"—the stress caused by a constant bombardment of seemingly important yet elusive or unintelligible information (Wurman 1989). Agricultural researchers in prosperous, industrialized countries experience this apprehension as they sort through a deluge of journals, reports, and personal communications in search of results relevant to their work. But information anxiety carries a different connotation for scientists in developing countries, who often face a lack of current scientific information, along with difficulties in disseminating results from their work. CIMMYT Information Services staff are striving to aid both groups of researchers, as well as key decision makers in governments and the donor community, to overcome these problems. They are doing so through the selective application of new electronic tools that help manage more information more effectively, and through a better conceptualization and targeting of information intended for those who can truly gain from receiving it.

To facilitate the production of CIMMYT publications, for example, the Center recently invested in a "desktop" system that allows staff to explore quickly and inexpensively a broad range of possibilities for merging form with function. We have changed our production procedures to fit the system, bringing writers, editors, and designers together as creative "project teams," and the result is more appealing and accessible publications produced more swiftly and at lower costs. New information technologies are yielding other benefits as well, such as the capacity for rapidly generating attractive support materials for presentations, again at lower cost, and a computer-based "image bank" that will permit the efficient retrieval of the over 3,000 color transparencies and black and white prints in CIMMYT's collection.

As our production tools and methods have evolved, so too has the array of information products and the relative emphasis among them, to better reflect changes in Center priorities and the expressed needs of those we seek to serve. A growing focus, for example, on elucidating the science that underlies our germplasm research is leading to more publishing by CIMMYT staff, especially in refereed journals (see pages 58-60). Likewise, among the roughly 50 CIMMYT imprimatur publications produced each year our emphasis has shifted from general information toward technical publications and practical manuals and guidebooks.

The Center has inaugurated several publishing initiatives designed to reach specific audiences:

- *CIMMYT Research Reports* provide syntheses of ideas and experience resulting from extended work on major research activities. *Research Report No. 1*, "Accelerating the Transfer of Wheat Breeding Gains to Farmers: A Study of the Dynamics of Varietal Replacement in Pakistan," was released in late 1990 and contains information relevant to developing country research, seed production, and extension systems. Subsequent titles in this series will cover advances in highland maize breeding and our decade-long activity in wheat wide cross research, among other topics.

- Another new series is entitled *CIMMYT Economics Papers*, which are written by our Economics Program staff and are intended primarily for their colleagues in developed and developing countries. These publications cover work by our staff alone or in collaboration with others, and focus on methodologies or empirical results that bear on the Center's research priorities. The first two in this series, which treat the themes of domestic resource cost analysis and triticale utilization, are now available.

- A series of *Training Working Documents*, designed for training course participants and researchers, has been started to encourage the timely distribution of training-related materials developed by Center staff and colleagues. The first six of these documents focus on the application of statistical methods to agricultural research and were prepared by Dr. Roger Mead, professor of applied statistics at the University of Reading, UK, during a 1990 consultancy and with the help of several CIMMYT staff. The next in the series focuses on conservation tillage methodologies for maize.

- Finally, we are implementing a public awareness strategy that provides information to decision makers in developed and developing countries and, often in direct collaboration with donors, to key public constituencies. Our efforts emphasize improved targeting of specific groups with accessible, useful, and relatively inexpensive products. This perspective is increasingly evident in our *Annual Reports*. Whereas the series once featured general coverage of all Center activities (only some of which were of interest to any one group of readers), our *Reports* are now organized around themes of current interest and carry highlights on only a limited selection of research topics. We are complementing this approach to annual reporting with a series of inexpensive fact sheets that describe individual Center activities and subprograms. We are also stepping up efforts to reach the "general public," by placing interesting stories about CIMMYT's work in various mass media.

These information products and delivery strategies are intended to make the results of CIMMYT's efforts more accessible to external clients of the Center. But Center staff themselves, as well as their developing country colleagues, are concerned about access to information relevant to their work. In this regard, our scientific information

unit (SIU) applies selected computer-based tools and systems to offer a range of services once unimaginable in traditional libraries. These include bibliographies, abstracts, tables of contents, full-text copies of articles, searches through more than a score of databases on compact discs, and the monthly automatic dissemination of information on specific topics, among other services. Line scientists and developing country libraries provide the focus for these services.

To ensure that potential users are mindful of those offerings, SIU staff conduct "awareness" seminars for trainees, visiting scientists, and administrators, and have developed a variety of instructional and promotional materials. One 1990 project, for example, which was produced with the help of a consultant and other Information Services staff, involved the creation of an audiovisual presentation describing the information resources of 20 international agricultural research centers, including CIMMYT. Entitled *Seeds of Knowledge*, this program and its accompanying information packet are aimed at visitors, trainees, students in communication, and the faculties of agricultural universities worldwide. The SIU is also participating in the development of a full-text compact agricultural library on compact discs containing some 3,000 documents from those centers, including books, serials, and conference proceedings.

But scientists of developing countries will feel much less anxious about information when they can count on adequate support at home. Toward that end, SIU staff participate in various national, regional, and global networks that promote the growth of such expertise, including the Mexican National Association of Agricultural Librarians (ANBAGRO), the Inter-american Association of Agricultural Librarians and Documentalists (AIBDA) in Latin America, and a network of the information units from 20 international agricultural research centers. The latter group recently produced a union catalog of over 3,600 journal holdings at 14 centers, which is being made available to interested developing country libraries in either electronic or printed form. This catalog will allow users of those libraries to request copies of specific articles that can be provided by the international centers.

Seed Health

Germplasm improvement research at CIMMYT depends upon the international exchange of maize and wheat seed. The Seed Health Unit was instituted in 1989 to help augment fundamental health standards in Center operations. In this way, we protect agriculture in host countries and ensure our germplasm unencumbered transit worldwide.

In 1990, Seed Health staff began to focus attention on another key aspect of our breeding programs: the collection and storage of germplasm. Seed for our banks has generally been grown out under the careful observation of breeders and genetic resources staff, who culled any samples showing signs of possible infection. Now, as part of an initiative endorsed generally by the principal CGIAR commodity centers and IBPGR, we are exploring new ways to guarantee the health and long-term viability of the seed in CIMMYT banks and, ultimately, ensure the quality and free movement worldwide of the germplasm we ship.

Seed Health personnel are examining the effect of surface disinfestation with sodium hypochlorite on the storage life of seed of maize and wheat. It is expected that the removal of pathogens from the seed coat will improve viability after long-term storage in the case of both maize and wheat. The work is especially significant for wheat, since most bank materials are grown out on experiment stations in the south of Mexico, where wet conditions favor pathogen development.

In 1990, Seed Health staff began exploring new ways to guarantee the health and long-term viability of seed in CIMMYT germplasm banks, including washing and laboratory testing of samples for storage and the inspection of current bank contents.

CIMMYT researchers have also begun laboratory analyses of wheat bank holdings to inventory pathogens on the seed. This will allow us to certify the health of bank accessions, recommend suitable chemical treatments where necessary, and assess the effect of pathogens on the long-term viability of seed in storage. Our methodology involves grouping like accessions by species, location, and cycle, bulking samples from each accession, and removing and testing replicates from the bulk. We are looking for fungi in general, bacteria such as *Xanthomonas campestris* pv. *undulosa*, and barley stripe mosaic virus. A similar study for maize will take place in the near future.

Applied Molecular Genetics

In classical breeding, plant DNA is manipulated and viewed "from the outside in." Observable traits of whole plants in massive numbers and over many cycles of crossing and selecting are used to evaluate changes at the

genome level. Recently, though, molecular genetics staff are applying restriction fragment length polymorphism (RFLP) technology to give breeders a glimpse inside the cell nucleus, allowing them to track genes for traits of interest.

The RFLP technique compares minute snippets produced when nuclear DNA is placed in solution with a "restriction" enzyme that cleaves it at particular sites. The fragments can be sorted by length and individual ones detected using molecular probes. Each probe binds to a specific DNA sequence and is previously labelled with a substance that registers on film. The RFLP technique helps researchers locate genomic segments associated with particular traits in a given crop. The probes can serve as markers, permitting breeders to follow segments of interest over many crosses. In this way, selection need not depend solely on phenotypic characteristics, which often vary as a result of environment, plant growth stage, and interactions between traits.

In applying RFLPs to breeding, we have tried to increase our efficiency through collaboration with leading institutes worldwide. Current projects include work with Cornell University, USA, to develop an RFLP map for hexaploid bread wheat (see page 44); with the Mexican Center for Research and Advanced Studies (CINVESTAV) of the National Polytechnic Institute (IPN) to determine relationships between RFLP probes and genomic segments associated with drought resistance in maize; and with an international group studying the use of RFLPs in research on quantitative traits of maize, such as resistance to southwestern corn borer (*Diatraea grandiosella*).

The latter undertaking is CIMMYT's contribution to a project conducted by seven European laboratories engaged in a network supported through the Pan-European Funding Organization (EUREKA). During the project's initial phase, which was completed this year, our researchers characterized 51 inbred lines of tropical and subtropical maize. The results indicate great diversity in the materials, substantiate pedigree information, and have allowed researchers to identify genomic regions shared by related lines. Subsequent work will focus on generating RFLP "maps" to locate specific genomic regions that control resistance to borers, so that the corresponding probes may be employed as selection tools.

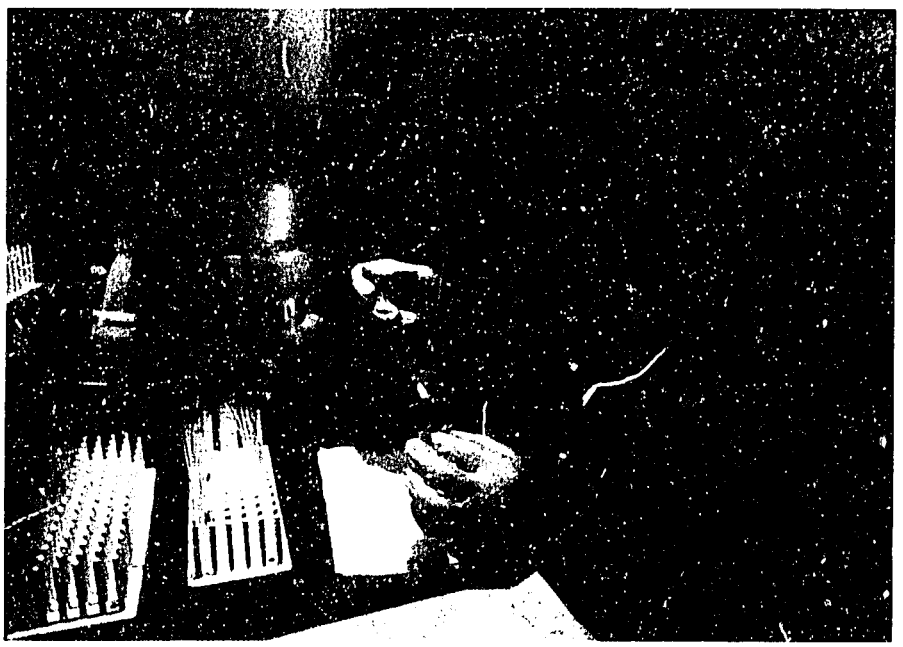
An outgrowth of this project is software developed by our researchers for reading and analyzing RFLPs. The banding patterns used in RFLP studies are normally scored visually, a method that can be time-consuming and highly subjective. To remedy this, molecular genetics personnel developed a computer program that allows rapid and precise data entry with a digitizing pad and expedites the statistical analyses crucial to interpreting RFLP patterns.

In addition, the laboratory is adopting the following innovations suited to RFLP studies and related work:

- The polymerase chain reaction (PCR) technique for copying a specific DNA segment, which will allow a technician to quickly make billions of copies of a selected probe. Over 100 different probes can be replicated and labeled in a few hours in the same operation, whereas prior methods for reproducing probes were much longer and laborious and entailed a separate step for labeling.

- A protocol for detecting RFLPs that does not use radioactive substances, but rather involves first labeling probes with a nonradioactive compound, attaching enzyme-linked antibodies to probes bound to DNA fragments, and locating the enzyme by means of a light-emitting substrate.

- Randomly amplified polymorphic DNA probes (RAPDs), which are used for detecting polymorphisms in plant and insect species. Unlike RFLP probes, RAPDs are not unique to a given species and can thus be used to fingerprint varieties and inbreds from any plant species, or even pests of crops. The technique is being explored in a collaborative project conducted at CIMMYT by two scientists from the Mexican National Institute of Forestry, Agriculture, and Livestock Research (INIFAP). They are comparing the utility of RAPDs and RFLPs in studying the purity of highland maize varieties and hybrids produced in different environments in Mexico.



DNA from a few grams of green leaf tissue will later be mixed with an enzyme that clips it into millions of fragments for RFLP analyses.

Thomas Luba

References: Review of CIMMYT Programs

Anderson, J.R., and Hazell, P.B.R. 1989. Synthesis and needs in agriculture research and policy. In *Variability in Grain Yields*. Anderson, J.R., and Hazell, P.B.R., eds., 339-356. Baltimore: Johns Hopkins.

Bolaños, J., and Edmeades, G.O. 1988. CIMMYT's strategies in breeding for drought tolerance in tropical maize. Paper presented at the International Conference on Dryland Farming, 15-19 August, Amarillo, Texas.

Bolaños, J., and Edmeades, G.O. 1991. The value of osmotic adjustment and osmotic potential as drought adaptive traits in lowland tropical maize. *Agronomy Journal* (forthcoming).

Bosque-Perez, N.A., Mareck, J.H., Dabrowski, Z.T., Everett, L., Kim, S.K., and Efron, Y. 1989. Screening and breeding maize for resistance to *Sesamia calamistis* and *Eldana saccharina*. In *Towards Insect Resistant Maize for the Third World*. 163-169. Mexico, D.F.: CIMMYT.

Brown, L.R. 1988. *State of the World 1988*. New York: W.W. Norton.

Byerlee, D. 1989. Food for thought: Technological challenges in Asian agriculture in the 1990s. Paper presented at the USAID Conference of Asian and Near East Bureau's Agriculture and Rural Development Officers, 19-24 February, Rabat, Morocco.

Byerlee, D., and Siddiq, A. 1990. *Sources of growth in wheat yields in Pakistan's Punjab, 1965-2000: Is there a sustainability issue?* CIMMYT Economics Working Paper No. 90/04. Mexico, D.F.: CIMMYT.

CIMMYT. 1989. *CIMMYT 1988 Annual Report: Delivering Diversity*. Mexico, D.F.

Crossa, J., Westcott, B., and González, C. 1988a. The yield stability of maize genotypes across international environments: Full season tropical maize. *Experimental Agriculture* 24:253-263.

Crossa, J., Westcott, B., and González, C. 1988b. Analysing yield stability of maize genotypes using a spatial model. *Theoretical and Applied Genetics* 75:863-868.

Crossa, J., Westcott, B., and González, C. 1989. The yield stability of CIMMYT's maize germplasm. *Euphytica* 40:245-251.

Crossa, J., Fox, P.N., Pfeiffer, W.H., Rajaram, S., and Gauch Jr., G.H.. 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. *Theoretical and Applied Genetics* 81:27-37.

Duvick, D.N. 1991. Technologies for the nineties: Rate and potential limitations of technology generation. Paper presented at the World Bank's 11th Agricultural Symposium, Agricultural Issues in the Nineties, 9-11 January, Washington, D.C.

Fischer, R.A. 1988. Plant breeding and some broader issues in agriculture. Paper presented at the 9th Australian Plant Breeding Conference, 27-31 June, Wagga Wagga.

Hettel, G.P. 1989. *Wheat production advances in South America's colossus: The gains from 20 years of Brazilian/CIMMYT collaboration*. Mexico, D.F.: CIMMYT.

Hobbs, P.R., Hettel, G.P., Singh, R.P., Singh, Y., Harrington, L., and Fujisaka, S., eds. 1991. *Rice-wheat cropping systems in the tarai areas of Nainital, Rampur, and Pilibhit districts in Uttar Pradesh, India*. Mexico, D.F.: Mexico.

Kohli, M.M., and Rajaram, S., eds. 1988. *Wheat Breeding for Acid Soils: Review of Brazilian/CIMMYT Collaboration, 1974-1986*. Mexico, D.F.: CIMMYT.

Lafitte, H.R., and Edmeades, G.O. 1987. An update on selection under stress: Selection criteria. Paper presented at the 2nd Eastern, Central, Southern African Regional Maize Workshop, 16-20 March, Harare, Zimbabwe.

Lafitte, H.R., and Edmeades, G.O. 1989. Adaptive strategies in low N environments: A comparison of improved and unimproved maize genotypes. *Agronomy Abstracts*.

Mihm, J.A. 1985. Breeding for host plant resistance to maize stem borers. *Insect Science and Its Application* 6:369-377.

_____. 1986. Development of multiple insect resistance. In *CIMMYT Research Highlights, 1985*, 20-27. Mexico, D.F.: CIMMYT.

Morris, M.L., with Alvarez, M., and Espinzoa, M.A. 1990. *The maize subsector in Paraguay: A diagnostic overview*. CIMMYT Economics Working Paper 90/05. Mexico, D.F.: CIMMYT.

Morris, M.L., Belaid, A., and Byerlee, D. 1991. *1990/91 CIMMYT World Wheat Facts and Trends: Wheat and Barley Production in Rainfed Marginal Environments of the Developing World*. Mexico, D.F.: CIMMYT (forthcoming).

National Research Council Board on Agriculture. 1989. *Alternative Agriculture: The Report of the Committee on the Role of Alternative Farming Methods in Modern Production Agriculture*. Washington D.C.: National Academy Press.

Ortiz-Monasterio, I., Sayre, K.D., Rajaram, S., and McMahon, M. 1990. Genetic progress of CIMMYT germplasm under different levels of nitrogen. *Agronomy Abstracts*.

Pfeiffer, W.H., and Braun, H.J. 1989. Yield stability in bread wheat. In *Variability in Grain Yields*. Anderson, J.R., and Hazell, P.B.R., eds., 157-174. Baltimore: Johns Hopkins.

Pham, H.N., Waddington, S., and Crossa J. 1989. Yield stability of CIMMYT maize germplasm in international and on-farm trials. In *Variability in Grain Yields*. Anderson, J.R., and Hazell, P.B.R., eds., 185-205. Baltimore: Johns Hopkins.

Pingali, P.L. 1988. Intensification and diversification of Asian rice farming systems. Paper presented at the International Rice Research Conference, Los Baños, the Philippines.

Rajaram, S., Singh, R.P., and Torres, E. 1988. Current CIMMYT approaches in breeding wheat for rust resistance. In *Breeding Strategies for Resistance to the Rusts of Wheat*. Simmonds, N.W., and Rajaram, S., eds., 101-118. Mexico, D.F.: CIMMYT.

Renkow, M. 1991. CIMMYT Economics Paper No. 4. Mexico, D.F.: CIMMYT (forthcoming).

Roelfs, A.P. 1988. *Resistance to leaf and stem rusts in wheat*. In *Breeding Strategies for Resistance to the Rusts of Wheat*. Simmonds, N.W., and Rajaram, S., eds., 10-22. Mexico, D.F.: CIMMYT.

Singh, A.J., and Byerlee, D. 1990. Relative variability in wheat yields across countries and over time. *Journal of Agricultural Economics* 45:21-32.

Smith, M.E., Mihm, J.A., and Jewell, D.C. 1989. Breeding for multiple resistance to temperate subtropical and tropical maize insect pests at CIMMYT. In *Towards Insect Resistant Maize for the Third World*, 222-234. Mexico, D.F.: CIMMYT.

Tripp, R., and Woolley, J. 1989. *The Planning Stage of On-Farm Research*. Mexico, D.F., and Cali: CIMMYT and CIAT.

Wolf, E.C. 1986. *Beyond the Green Revolution: New approaches for Third World agriculture*. Worldwatch Paper 73. Washington, D.C.: Worldwatch.

World Commision on the Environment and Development. 1986. *Food Security Report of the Advisory Panel on Food Security, Agriculture, Forestry and Environment*. Geneva: WCED.

Worrell, W.D., Scott, N.H., Klatt, A.R., and Rajaram, S. 1980. Performance of CIMMYT wheat germplasm in optimun and suboptimum production environments. In *Proceedings of the 3rd International Wheat Conference*. Nebraska Agricultural Experiment Station Miscellaneous Publication 41. 5-29.

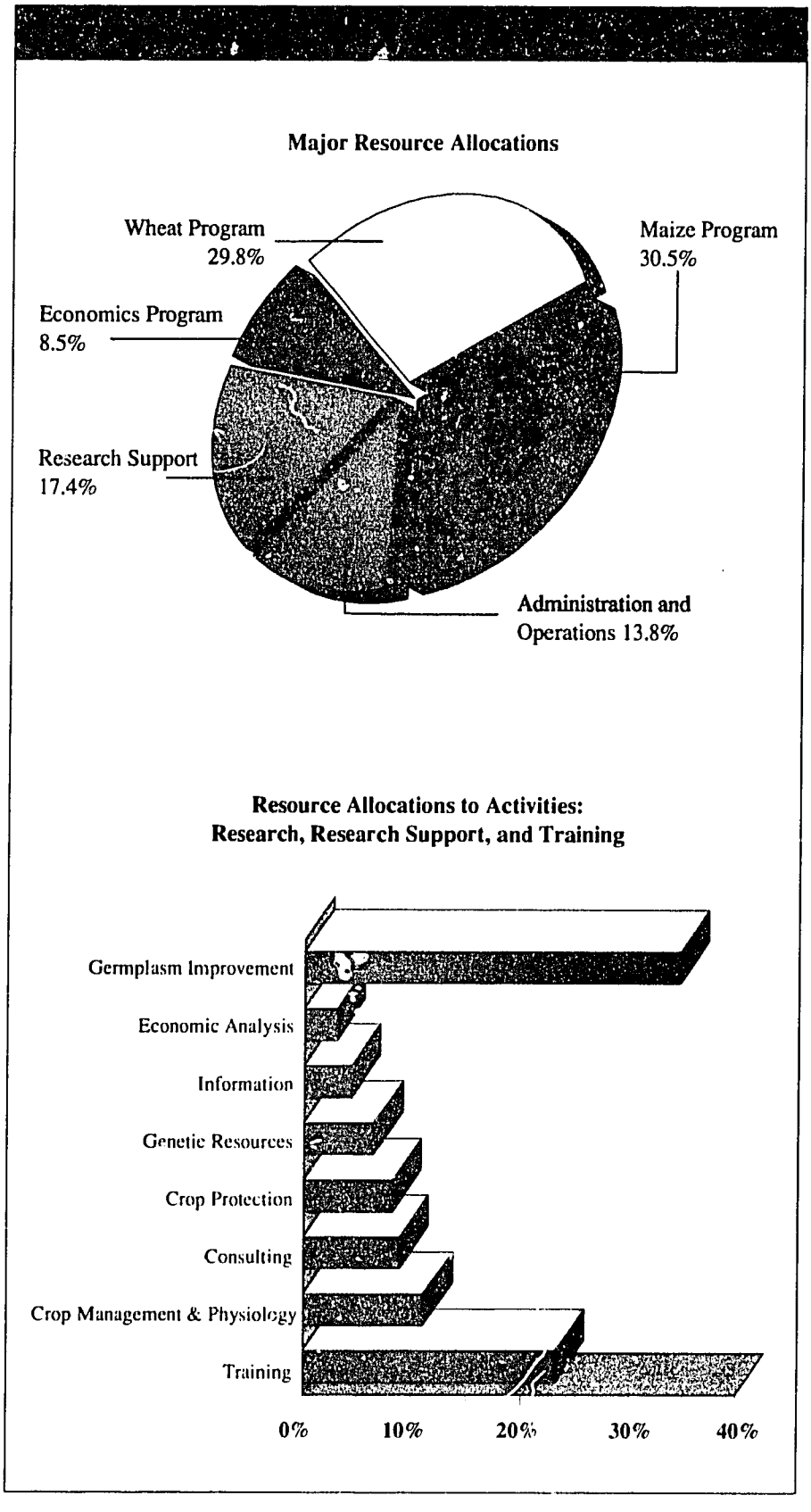
Wurman, R.S. 1989. *Information Anxiety*. New York: Doubleday.

Other Recommended Reading

Plucknett, D.L., Smith, N.J.H., Williams, J.T., and Anishetty, N.M. 1987. *Gene Banks and the World's Food*. Princeton: Princeton University Press.

Winkelmann, D.L. 1987. Diversification, sustainability, and economics. Paper presented at the World Bank's 7th Agricultural Symposium, 8-9 January, Washington, D.C.

Financial Highlights



CIMMYT allocates its total resources (CGIAR and special project) among five major units, which in turn assign resources to various activities. The majority of those funds are earmarked for research. Matters of sustaining agricultural resources figure significantly in resource allocation decisions.

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 34.7% of the Center's resources at this time (see diagrams at left). Crop management, crop protection, and genetic resources activities together account for 25.8% of research resources. Training is also a major activity occupying 23.2% of the budget.

Donor contributions (includes special projects).

	US $ (000s)
Australia, Government of	889
Austria, Government of	250
Belgium, Government of	106
Canadian International Development Agency	3,644
China, People's Republic of	50
Danish International Development Agency	834
European Economic Community	2,504
Finland, Government of	818
France, Government of	572
Germany, Government of (BMZ)	495
India, Government of	49
Inter-American Development Bank	4,370
International Crops Research Institute for the Semi-Arid Tropics	330
Islamic Republic of Iran, Government of	23
International Board for Plant Genetic Resources	116
Italy, Government of	385
Japan, Government of	1,955
Norwegian Agency for International Development	261
Spain, Government of	115
Switzerland, Government of	1,090
The Ford Foundation	100
The Netherlands, Government of	377
The Philippines, Government of	75
The Rockefeller Foundation	108
The United Kingdom, Government of	1,295
The World Bank	3,888
United Nations Development Programme	1,005
United States Agency for International Development	6,561
Miscellaneous Training and Research Grants	570
Total income from grants	**32,835**

CIMMYT's ability to fulfill its international research and training obligations depends on donor funding of core and complementary projects. The Center derives those funds from more than 28 donors from many different countries around the world.

Our financial statements for this year show an increase in total assets. Cash and short-term investments increased, reflecting the decrease in accounts receivable and the increase in payments received in advance from donors. Although total accounts receivable declined, receivables from donors continue to be higher than in previous years due to several major core donations left outstanding. Property, plant, and equipment increased by 9% with replacement of existing fixed assets contributing to most of the expenditures made for capital items. It should be noted that the apparent growth in capital assets is largely due to the CGIAR policy of zero depreciation.

Donor pledges in currencies other than US dollars are recorded at their dollar equivalent on the date of deposit. In 1990, the relative weakness of the dollar against other major currencies resulted in higher than expected dollar revenues from donations denominated in other currencies. In Mexico, the combined effect of exchange rates and inflation continue to erode the purchasing power of our dollar revenues.

These financial highlights describe and summarize how funds were disseminated by the Center in its continuing effort to effectively meet the objectives of its mandate.

As in the previous year, CIMMYT's complete audited financial statements have been published as a separate document and sent to all donors. Additional copies of these statements are available from the Center upon request.

Balance sheet (US $ 000s)

	Year ended December 31	
	1990	**1989**
Assets	**36,593**	**33,905**
Cash and short-term investments	4,306	2,487
Accounts receivable	7,595	8,790
Inventories	145	118
Property, plant, and equipment	24,547	22,510
Liabilities	**7,956**	**8,762**
Accounts payable and other liabilities	1,736	2,960
Accrued staff obligations	882	889
Payments in advance from donors	5,338	4,913
Fund balances	**28,637**	**25,143**
Property, plant, and equipment	24,547	22,510
Capital	3,645	1,980
Operating	2,765	2,765
Auxiliary services	192	361
Cumulative translation effect	(2,512)	(2,473)
Total liabilities and fund balances	**36,593**	**33,905**

Publishing by CIMMYT Staff

Selected CIMMYT Publications

The following are selected publications released by CIMMYT from May, 1990, to April, 1991. A more complete listing is available from Information Services.

CIMMYT. 1990. *1989 Annual Report: International Maize and Wheat Improvement Center. Beyond Subsistence: New Options for Asian Farmers.* Mexico, D.F. (Also available in Spanish.)

_____. 1990. CIMMYT International Maize Testing Program: 1988 Report. Mexico, D.F..

_____. 1990. *1989/90 CIMMYT World Maize Facts and Trends: Realizing the Potential of Maize in Sub-Saharan Africa.* Mexico, D.F. (Also available in French.)

_____. 1990. *Farming Systems Bulletin* (Eastern and Southern Africa), Nos. 5-7. Nairobi, Kenya: CIMMYT.

_____. 1990. Training at CIMMYT. Mexico, D.F. (Also available in Spanish.)

_____. 1990. Wheat and triticale international nursery reports (1987-88). Mexico, D.F.

CIMMYT Maize Program. 1990. Information Packet: A compilation of documents giving details of Maize Program research activities. Mexico, D.F.: CIMMYT.

Brennan, J.P., and Warham, E.J., with Hernández, J. Byerlee, D., and Coronel, F. 1990. *Economic losses from Karnal bunt of wheat in Mexico.* CIMMYT Economics Working Paper 90/02. Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Burnett, P.A., ed. 1990. *World Perspectives on Barley Yellow Dwarf.* Mexico, D.F.: CIMMYT.

Byerlee, D. 1990. *Technical change, productivity, and sustainability in irrigated cropping systems of south Asia: Emerging issues in the post-green revolution Asian era.* CIMMYT Economics Working Paper 90/06. Mexico, D.F.: CIMMYT.

Byerlee, D., and Siddiq, A. 1990. *Sources of growth in wheat yields in Pakistan's Punjab: Is there a sustainability issue?* CIMMYT Economics Working Paper 90/04. Mexico, D.F.: CIMMYT.

Echeverría, R.G. 1990. *Public and private investments in maize reserach in Mexico and Guatemala.* CIMMYT Economics Working Paper 90/03. Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Heisey, P.W., ed. 1990. *Accelerating the transfer of wheat breeding gains to farmers: A study of the dynamics of varietal replacement in Pakistan.* CIMMYT Research Report No. 1. Mexico, D.F.: CIMMYT.

Kohli, M.M., and Beuningen, L.T. van., eds. 1990. *Conferencia regional sobre la septoriosis del trigo.* Mexico, D.F.: CIMMYT.

Mead, R. 1990. Training Working Documents Nos. 1-6. Mexico, D.F.: CIMMYT.

Morris, M.L. 1990. *Determining comparative advantage through DRC analysis: Guidelines emerging from CIMMYT's experience.* CIMMYT Economics Paper No. 1. Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Morris, M.L., with Alvarez, M., and Espinoza, M.A. 1990. *The maize subsector in Paraguay: A diagnostic overview.* CIMMYT Economics Working Paper 90/05. Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Mujeeb-Kazi, A., and Sitch, L.A., eds. 1989. *Review of Advances in Plant Biotechnology 1985-88.* Mexico, D.F.:CIMMYT/IRRI.

Snowball, K., and Robson, A.D. 1991. *Nutrient Deficiencies and Toxicities in Wheat: A Guide for Field Identification.* Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds. 1990. *VI Regional Wheat Workshop for Eastern, Central and Southern Africa.* Mexico, D.F.: CIMMYT.

Tripp, R., Anandajayasekeram, P., and Sain, G. 1990. *The design and management of call system training in on-farm research.* CIMMYT Economics Working Paper 90/01. Mexico, D.F.: CIMMYT. (Also available in Spanish.)

Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds. 1990. *Research Methods for Cereal/Legume Intercropping.* Mexico, D.F.: CIMMYT.

Journal Articles, Monographs, and Book Chapters

Aggarwal, P.K., Fischer, R.A., and Liboon, S.P. 1990. Source sink relations and effects of post-anthesis canopy defoliation in wheat at low latitudes. *Journal of Agricultural Science* 114(2):93-99.

Austin, R.B., Craufurd, P.Q., Hall, M.A., Acevedo, E., Silveira, B. da, and Nguci, E.C. 1990. Carbon isotopes discrimination as a means of evaluating drought resistance in barley, rice and cowpeas. *Bulletin de la Societé Botanique de France: Actualités Botaniques* 137(1):21-30.

Badebo, A., Stubbs, R.W., Ginkel, M. van, and Gebeyehu, G. 1990. Identification of resistance genes to *Puccinia striiformis* in seedlings of Ethiopian and CIMMYT bread wheat varieties and lines. *Netherlands Journal of Plant Pathology* 96(4):199-210.

Bebbington, A., and Carney, J.A. 1990. Geography in the International Agricultural Research Centers: Theoretical and practical concerns. *Annals of the Association of American Geographers* 80(1):34-48.

Beck, D.L., Vasal, S.K., and Crossa, J. 1990. Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize (*Zea mays* L.) germplasm. *Maydica* 35(3):279-285.

Beuningen, L.T. van, and Kohli, M.M. 1990. Deviation from the regression of infection on heading and height as a measure of resistance to *Septoria tritici* blotch in wheat. *Plant Disease* 74(7):488-493.

Blackie, M.J. 1990. Maize, food self-sufficiency and policy in East and Southern Africa. *Food Policy* 15:383-394.

Bolaños, J.A., and Edmeades, G.O. 1990. La importancia del intervalo de la floración en el mejoramiento para la resistencia a sequía en maíz tropical. *Revista Agropecuaria* 1:45-50.

Byerlee, D. 1990. Technological challenges in Asian agriculture in the 1990s. In *Agricultural Development in the Third World*, Eicher, C.K., and Staatz, J.M., eds., 2nd edition, 424-433. Baltimore, MD, USA: The Johns Hopkins University Press.

Byrne, P.F., Darrah, L.L., Simpson, K.B., Keaster, A.J., Barry, B.D., and Zuber, M.S. 1990. Relationship of maize tissue pH and resistance to whorl leaf feeding and stalk tunneling by the European corn borer (Lepidoptera: Pyralidae). *Environmental Entomology* 19(4):1091-1096.

Caceros, O.A., González, P., Hidalgo, I., Moscoso, B., and Raun, W.R. 1990. Ensayo exploratorio de métodos e interacciones de elementos en la aplicación de fertilizantes en el cultivo de maíz. *Agronomía Mesoamericana* 1:7-13.

Carney, J. 1990. *Triticale production in the central Mexican highlands*. CIMMYT Economics Paper No. 2. Mexico, D.F.: CIMMYT.

Ceballos, H., and Graeen, V.E. 1990. Effect of nuclear resistance and multiplasms on yield losses of maize to *Bipolaris maydis* race T.1. *Maydica* 35(3):241-246.

Crossa, J. 1990. Statistical analyses of multilocation trials. *Advances in Agronomy* 44:55-85.

Crossa, J., Gauch, H.G., Jr., and Zobel, R.W. 1990. Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. *Crop Science* 30(3):493-500.

Crossa, J., Taba, S., and Wellhausen, E. 1990. Heterotic patterns among Mexican races of maize. *Crop Science* 30(6):1182-1190.

Crossa, J., Vasal, S.K., and Beck, D.L. 1990. Combining ability estimates of CIMMYT's tropical late yellow maize germplasm. *Maydica* 35(3):272-278.

Dittrich, U., Hock, J., Renfro, B.L., and Kranz, J. 1990. Germination of *Phyllachora maydis* and *Microdochium maydis*, the anamorph of *Monographella maydis*. *Grypto Botany* 2(1):1-4.

Drepper, W.J., and Renfro, B.L. 1990. Comparison of methods for inoculation of ears and stalks of maize with *Fusarium moniliforme*. *Plant Disease* 74(12):952-956.

Duveiller, E. 1990. Bacterial sheath rot of wheat caused by *Pseudomonas fuscovaginae* in the highlands of Mexico. *Plant Disease* 74(11):932-935.

Duveiller, E., Notteghem, J.P., Rott, P., Snacken, F., and Maraite, H. 1990. Bacterial sheath brown rot of rice caused by *Pseudomonas fuscovaginae* in Malagasy. *Tropical Pest Management* 36(2):151-153.

Fischer, R.A., Armstrong, J.S., and Stapper, M. 1990. Simulation of soil water storage and sowing day probabilities with fallow and no-fallow in Southern New South Wales: I. Model and long term mean effects. *Agricultural Systems* 33:215-240.

Fischer, R.A., and Armstrong, J.S. 1990. Simulation of soil water storage and sowing day probabilities with fallow and no-fallow in southern New South Wales: II. Stochasticity and management tactics. *Agricultural Systems* 33:241-255.

Fischer, R.A., O'Brien, L.O., and Quail, K.J. 1989. Early generation selection in wheat: II. Grain quality. *Australian Journal of Agricultural Research* 40(6):1135-1142.

Fischer, R.A., and Quail, K.J. 1990. The effect of major dwarfing genes on yield potential in spring wheats. *Euphytica* 46(1):51-56.

Fox, P.N., Skovmand, B., Thompson, B.K., Braun, H.J., and Cormier, R. 1990. Yield and adaptation of hexaploid spring triticale. *Euphytica* 47(1):57-64.

Harrington, L.W., Hobbs, P.R., Pokhrel, T.P., Sharma, B., Fujisaka, S., and Lightfoot, C. 1990. The rice-wheat pattern in the Nepal terai: Issues in the identification and definition of sustainability problems. *Journal for Farming Systems Research-Extension* 1(2):1-27.

Hassan, R.M., D'Silva, B., and Hallam, A. 1990. Testing for decreasing risk aversion in traditional farming: The case of Sudan. *East African Journal of Rural Development* 16(3):18.

Hassan, R.M., and Hallam, A. 1990. Stochastic technology in a programming framework: A generalized mean-variance farm model. *Journal of Agricultural Economics* 41(2):196-206.

Heisey, P.W. 1990. Comment: Maize research in Malawi. *Journal of International Development* 2(2):243-253.

Hoisington, D.A., and Coe, E.H. 1990. Mapping in maize using RFLPs. In *Chromosome Structure and Function*. Gustafson, J.P. ed., 331-352. New York, NY, USA: Plenum Press.

Jahan, Q., ter Kuile, N., Hashmi, N., Aslam, M., Vahidy, A.Z., and Mujeeb-Kazi, A. 1990. The status of the 1B/1R translocation chromosome in some released wheat varieties and the 1989 candidate varieties of Pakistan. *Pakistan Journal of Botany* 22:1-10.

Lawn, D.A., and Noel, G.R. 1990. Effects of temperature on competition between *Heterodera glycines* and *Pratilenchus scribneri* on soybean. *Nematropica* 20(1):57-69.

López-Pereira, M.A., Baker, T.G., Sanders, J.H., and Meckenstock, D.H. 1990. Farming systems and adoption of new agricultural technologies: An economic evaluation of new sorghum cultivars in Southern Honduras. *Journal for Farming Systems Research Extension* 1(2):82-103.

Maredia, K.M., and Mihm, J.A. 1990. Damage by southwestern corn borer (*Diatraea grandiosella* Dyar) on resistant and susceptible maize at three plant growth stages in Mexico. *Tropical Pest Management* 36(2):141-144.

McCauley, E., Breden, F.J., Chippendale, G.M., and Mihm, J.A. 1990. Genetic differentiation of populations of the southwestern corn borer *Diatraea grandiosella* (Lepidoptera: Pyralidae) from the United States and Mexico. *Annals of the Entomological Society of America* 86(3):586-590.

Mujeeb-Kazi, A., and Asiedu, R. 1990. Wide crosses: Potential of alien genetic transfers for *Triticum aestivum* improvement. In *Biotecnology in Agriculture and Forestry*. Vol. 13 Wheat. Bajaj, Y.P., ed., 111-127. Berlin: Springer-Verlag.

Mwangi, W.M. 1990. Fertilizer demand functions under varying levels of prices and operating capital in Kenya. *Eastern Africa Journal of Rural Development* 16(1,2):78-89.

Ordorica-Falomir, C., Paredes-López, O., and Peña, R.J. 1990. Production of safflower protein isolates: Gel filtration and electrophoretic patterns. *Lebensmittel Wissenschaft und Technologie* 23(2):122-125.

Pashley, D.P., Hardy, T.N., Hammond, A.M., and Mihm, J.A. 1990. Genetic evidence for sibling species within the sugarcane borer (Lepidoptera: Pyralidae). *Annals Entomological Society of America* 86(6):1-6.

Peña, R.J., Amaya, A.A., Rajaram, S., and Mujeeb-Kazi, A. 1990. Variation in quality characteristics associated with some spring 1B/1R translocation wheats. *Journal of Cereal Science* 12(2):105-112.

Pierre, R., Robles, A., Celado, R., Raun, W.R., and Barreto, H.J. 1990. Maize yield response to sulphur and phosphorus applied under different tillage systems in the Dominican Republic. *Sulphur in Agriculture* 14:16-19.

Quail, R.J., Fischer, R.A., and Wood, J.T. 1989. Early generation selection in wheat: I. Yield potential. *Australian Journal of Agricultural Research* 40(6):1117-1133.

Raab, R.T., and Bell, M.A. 1990. Assessing a research training course for wheat crop management. *Journal of Agronomic Education* 19(1):72-76.

Ransom, J.K., Eplee, R.E., Langston, M.A., and Norris, R.S. 1990. Methodology for establishing witchweed (*Striga asiatica*) in research plots. *Weed Technology* 4(3):581-584.

Renkow, M. 1990. Household inventories and marketed surplus in semisubsistence agriculture. *American Journal of Agricultural Economics* 72(3):664-675.

Singh, A.J., and Byerlee, D. 1990. Relative variability in wheat yields across countries and over time. *Journal of Agricultural Economics* 41(1):21-32.

Singh, R.P., and McIntosh, R.A. 1990. Genetics of resistance to *Puccinia graminis tritici* and *Puccinia recondita tritici* in four South African wheats. *Theoretical and Applied Genetics* 79(3):401-410.

Skovmand, B., and Rajaram, S. 1990. Utilization of genetic resources in the improvement of hexaploid wheat. In *Wheat Genetic Resources: Meeting Diverse Needs*. Srivastava, J.P., and Damania, B., eds., 259-267. ICARDA: John Wiley and Sons.

Stapper, M., and Fischer, R.A. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. I. Phasic development, canopy growth and spike production. *Australian Journal of Agricultural Research* 41(6):997-1019.

_____. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. II. Growth, yield and nitrogen use. *Australian Journal of Agricultural Research* 41(6):1021-1041.

_____. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. III. Potential yields and optimum flowering dates. *Australian Journal of Agricultural Research* 41(6):1043-1056.

Taba, S. 1990. Conservation and use of maize genetic resources at CIMMYT. *Maydica* 35(2):183-186.

Tetlay, K., Byerlee, D., and Ahmad, Z. 1990. Role of tractors, tubewells and plant breeding in increasing cropping intensity in Pakistan's Punjab. *Agricultural Economics* 4(1):13-25.

Tripp, R. 1990. Does nutrition have a place in agricultural research? *Food Policy* 15(6):467-474.

Tripp, R., Anandajayasekeram, P., Byerlee, D., and Harrington, L.W. 1990. Farming systems research revisited. In *Agricultural Development in the Third World*. Eicher, C.K., and Staatz, J.M., eds., 2nd edition, 384-399. Baltimore, MD, USA: The Johns Hopkins University Press.

Tripp, R., and Anandajayasekeram, P. 1990. Building institutional capacity for on-farm research: Call system training courses. *Journal of Agronomic Education* 19(2):131-136.

Tripp, R., and Woolley, J.N. 1990. Training in farming systems research: Review and prospects. *Experimental Agriculture* 26(3):247-262.

Villareal, R., Varughese, G., and Abdalla, O. 1990. Advances in spring triticale breeding. *Plant Breeding Reviews* 8:43-90.

Warham, E.J. 1990. Effect of *Tilletia indica* infection on viability, germination, and vigor of wheat seed. *Plant Disease* 74(2):130-132.

Warham, E.J., and Burnett, P.A. 1990. Influence of media on pathogenicity and morphology of secondary sporidia of *Tilletia indica*. *Plant Disease* 74(7):525-527.

Published Proceedings/Abstracts

Anandajayasekeram, P., Low, A., and Durr, G. 1990. Economic evaluation and interpretation of intercropping trials. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 147-153. Mexico, D.F.: CIMMYT.

Arias, F.R., Dapaah, H., Ennin, S., and Gyampoh, M. 1990. Effect of chronological arrangement, spatial arrangement and varietal combination on yield and economic feasibility of maize + cowpea intercropped. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 81-88. Mexico, D.F.: CIMMYT.

Asiedu, R., Mujeeb-Kazi, A., and ter Kuile, N. 1989. Marker assisted introgression of alien chromatin into wheat. In *Review of Advances in Plant Biotechnology 1985-88*. Mujeeb-Kazi, A., and Sitch, L.A., eds., 133-144. Mexico, D.F.: CIMMYT/IRRI.

Asiedu, R., ter Kuile, N., and Mujeeb-Kazi, A. 1989. Diagnostic markers in wheat wide crosses. In *Review of Advances in Plant Biotechnology 1985-88*. Mujeeb-Kazi, A., and Sitch, L.A., eds., 293-299. Mexico, D.F.: CIMMYT/IRRI.

Bolaños, J., and Edmeades, G.O. 1990. The relationship between the anthesis-silking interval and yield in tropical maize under drought. *Agronomy Abstracts*, 119.

Brennan, J.P., and Warham, E.J. 1990. Economic importance of karnal bunt of wheat in Mexico. In *VI Assembly Wheat Breeding Society of Australia*, 307-310. Tamworth, Australia.

Broers, L.H.M. 1990. Partial leaf rust resistance in wheat. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 39-44. Mexico, D.F.: CIMMYT.

Bruno, O., Manzano, M., Córdova, H.S., and García, C.M. 1990. Progreso en la investigación en tecnología de producción de semillas en el Centro Nacional de Tecnología Agrícola. In *XIII Seminario Panamericano de Semillas*, 25. Cd. de Guatemala, Guatemala: Ministerio de Agricultura, Ganadería y Alimentación.

Burnett, P.A. 1990. What is barley yellow dwarf? In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 9-10. Mexico, D.F.: CIMMYT.

Burnett, P.A., Edmeades, G.O., Brennan, J.P., Eagles, H.A., McEwan, J.M., and Griffin, W.B. 1990. CIMMYT contributions to wheat production in New Zealand. In *VI Assembly Wheat Breeding Society of Australia*, 311-316. Tamworth, Australia.

Burnett, P.A., and Mezzalama, M. 1990. The barley yellow dwarf screening program at CIMMYT.In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 434-440. Mexico, D.F.: CIMMYT.

_____. 1990. Barley yellow dwarf virus and aphids in Mexico.In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 21-24. Mexico, D.F.: CIMMYT.

Byerlee, D., and Morris, M.L. 1990. An overview of economic issues in wheat research and development in Sub-Saharan Africa. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 312-326. Mexico, D.F.: CIMMYT.

Byerlee, D., and Tripp, R. 1990. Impacts of farming systems research in the Third World. In *Farming Systems Research in Pakistan*, 1-15. Islamabad, Pakistan: Pakistan Agricultural Research Council.

Byrne, P.F., Bolaños, J., Eaton, D.L., and Edmeades, G.O. 1990. Selection for drought tolerance versus selection based on multilocation yield trials in maize (*Zea mays* L.). *Agronomy Abstracts*, 82.

Calhoun, D.S., Robinson, J., Burnett, P.A., and Pfeiffer, W.H. 1990. Field screening of triticale for resistance to Russian wheat aphid. *Agronomy Abstracts*, 83.

Conti, M., D'Arcy, C.J., Jedlinski, H., and Burnett, P.A. 1990. The "Yellow Plague" of cereals, barley yellow dwarf virus. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 1-6. Mexico, D.F.: CIMMYT.

Crossa, J., Pfeiffer, W.H., Fox, P.N., and Rajaram, S. 1990. Multivariate analysis for classifying sites: Application to an international wheat yield trial. In *Genotype-by-Environment Interaction and Plant Breeding*. Kang, M.S., ed., 214-232. Baton Rouge, LA, USA: Louisiana State University.

Dejenne, D., Tanner, D.G., and Mwangi W.M. 1990. On-farm verification of four bread wheat varieties under high and farmers weed management levels. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 96-102. Mexico, D.F.: CIMMYT.

Delgado, R., Peña, R.J., Krattiger, A.F., ter Kuile, N., Amaya, A.A., and Mujeeb-Kazi, A. 1990. Quality characteristics of advanced lines derived from wheat (*Triticum aestivum* L.) and alien combinations. *Agronomy Abstracts*, 186-187.

Eaton, D.L., Byrne, P.F., and Sosa, G. 1990. Progress from full-sib recurrent selection in four subtropical maize populations. *Agronomy Abstracts*, 87.

Edmeades, G.O., Bolaños, J., and Martínez, L. 1990. Divergent selection for drought adaptative traits in tropical maize populations. *Agronomy Abstracts*, 87.

Eskridge, K.M., Mumm, R.F., and Byrne, P.F. 1990. Comparing cultivars with checks using a safety-first screening approach. *Agronomy Abstracts*, 88.

Fessehaie, R., Tanner, D.G., Sahile, G., and Parker, C. 1990. The efficacy of various grass herbicides in bread wheat in the Ethiopian highlands. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 140-145. Mexico, D.F.: CIMMYT.

Fischer, R.A. 1990. CIMMYT's Wheat Program activities in 1989. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 6-13. Mexico, D.F.: CIMMYT.

Fischer, R.A., and Howe, G.N. 1990. Response of irrigated spring wheat to timing and amount of nitrogen fertilizer. *Agronomy Abstracts*, 142.

Fischer, R.A., and Rajaram, S. 1990. Progress and plans in spring wheat breeding in CIMMYT. In *VI Assembly Wheat Breeding Society of Australia*, 163-169. Tamworth, Australia.

Fox, P.N. 1990. Use of CIMMYT international data in wheat breeding: History and prospects. In *Genotype-by-Environment Interaction and Plant Breeding: Poster Paper Abstracts*, 6. Baton Rouge, LA, USA: Louisiana State University.

Fox, P.N., Tola, J., and Chicaiza, O. 1990. Barley yellow dwarf in the Andean countries of South America. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 25-28. Mexico, D.F.: CIMMYT.

García, C.M., Bruno, O., Manzano, M., and Córdova, H.S. 1990. Estrategias de la División de Certificación de Semillas del Centro Nacional de Tecnología Agrícola: Un enfoque orientado al fortalecimiento de la industria de semillas en El Salvador. In *XIII Seminario Panamericano de Semillas*, 65-66. Cd. de Guatemala, Guatemala: Ministerio de Agricultura, Ganadería y Alimentación.

Gebeyehu, G., Ginkel, M. van, Haregewoin, M., Hulluka, M., Andnew, Y., and Badebo, A. 1990. Wheat rust virulences in Ethiopia in 1988. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 28-38. Mexico, D.F.: CIMMYT.

Gebeyehu, G., Ginkel, M. van, Kebede, T., Haregewoin, M., Desta, R., Bainbridge, A., Hulluka, M., Andnew, Y., Tadesse, D., Gorfu, A., and Badebo, A. 1990. Wheat disease survey in Ethiopia in 1988. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 153-165. Mexico, D.F.: CIMMYT.

Geleto, T., Elias, E., and Tanner, D.G. 1990. The effects of different sowing dates and fertilizer rates on the agronomic characteristics of three Ethiopian varieties of bread wheat. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 191-197. Mexico, D.F.: CIMMYT.

González de León, D., Hoisington, D.A., Jewell, D.C., Deutsch, J.A., and Mihm, J.A. 1990. RFLP analysis of MBR S4 maize lines. *Agronomy Abstracts*, 196.

Gorfu, A., Tanner, D.G., Zewde, L., Geleto, T., Yilma, Z., and Elias, E.M. 1990. Derivation of economic fertilizer recommendations for bread wheat in the Ethiopian highlands: On-farm trials in the peasant sector. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 63-72. Mexico, D.F.: CIMMYT.

Hailu, B., Franzel, S., and Mwangi, W.M. 1990. Constraints to increasing wheat production in Ethiopia's small-holder sector. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 284-293. Mexico, D.F.: CIMMYT.

Jaime, R., Mezzalama, M., Burnett, P.A., and Rodríguez, R. 1990. Evaluation of cereal aphid traps in barley in the Valley of México. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 350-352. Mexico, D.F.: CIMMYT.

Jewell, D.C. 1990. Tecnología genética y fitomejoramiento en el CIMMYT. In *¿Biotecnología para el progreso agrícola de México?* Suárez, B., comp., 137-147. México, D.F.: Centro de Ecodesarrollo.

Kang, M.S., Gorman, D.P., and Pham, H.N. 1990. Application of stability statistics to international maize yield trials. In *Genotype-by-Environment Interaction and Plant Breeding: Poster Paper Abstracts*, 12. Baton Rouge, LA, USA: Louisiana State University.

Krattiger, A.F. 1990. Genetics of endosperm proteins in rye (*Secale cereale* L.): Allelic variation, allele frequencies and their breeding importance in hexaploid triticale. *Agronomy Abstracts*, 189.

Kronstad, W., and Rajaram, S. 1990. Winter x spring germplasm management and exploitation. In *VI Assembly Wheat Breeding Society of Australia*, 123-130. Tamworth, Australia.

Longmire, J.L., and Farooq, U. 1990. The economics of rainfed versus irrigated wheat production in Pakistan. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 264-271. Mexico, D.F.: CIMMYT.

Longmire, J.L., and Lugogo, J. 1990. The economics of small-scale wheat production technologies for Kenya. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 335-342. Mexico, D.F.: CIMMYT.

Low, A. 1990. Overview of procedures for diagnosis. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 18. Mexico, D.F.: CIMMYT.

Manzano, M., Bruno, O., Córdova, H.S., and García, C.M. 1990. La Unidad de Semilla Básica del Centro Nacional de Tecnología Agrícola: Un modelo integrado para resolver el problema de abastecimiento de semilla de fundación en El Salvador, C.A. In *XIII Seminario Panamericano de Semillas*, 67-68. Cd. de Guatemala, Guatemala: Ministerio de Agricultura, Ganadería y Alimentación.

Mezzalama, M., and Burnett, P.A. 1990. Vector relationships of isolates of barley yellow dwarf virus in Mexico.In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 296-299. Mexico, D.F.: CIMMYT.

Mujeeb-Kazi, A. 1990. *Thinopyrum bessarabicum* for wheat improvement. *Agronomy Abstracts*, 102.

Nsembo, L.L., Tanner, D.G., Mwitirwa, K., Ngirabose, B., and Holmes, L. 1990. A review of soil fertility studies on bread wheat in North Kivu, Zaire. In *VI Regional Wheat Workshop of Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 204-207. Mexico, D.F.: CIMMYT.

Ortíz-Monasterio, I., Sayre, K.D., Rajaram, S., and McMahon, M.A. 1990. Genetic progress of CIMMYT germplasm under different levels of nitrogen. *Agronomy Abstracts*, 60.

Palmer, A.F.E., and Kirkby, R.A. 1990. Elements of an integrated intercropping research program. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 27-31. Mexico, D.F.: CIMMYT.

Peña, R.J., Amaya, A.A., Rajaram, S., and Mujeeb-Kazi, A. 1990. Quality characteristic variations in some spring 1B/1R translocation wheats. *Agronomy Abstracts*, 191.

Rajaram, S., and Villegas, E. 1990. Breeding wheat (*Triticum aestivum*) for aluminium toxicity tolerance at CIMMYT. In *Genetic Aspects of Plant Mineral Nutrition*. El Bassam, N, Dambroth, M., and Loughman, B.C. eds., 489-495. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Rajaram, S., Singh, R.P., Pfeiffer., W.H., Albarrán, M., and Peña, R.J. 1990. Pre-harvest sprouting tolerance in CIMMYT bread wheat germplasm. In *V International Symposium on Pre-Harvest Sprouting in Cereals*, Ringlund, K., Mosleth, E., and Mares D.J., eds.), 213-219. Boulder, Colorado: Westview Press.

Rajaram, S., Villareal, R., and Mujeeb-Kazi, A. 1990. The global impact of 1B/1R spring wheats. *Agronomy Abstracts*, 105.

Ransom, J.K. 1990. Agronomic interpretation of on-farm agronomic trials. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 143-146. Mexico, D.F.: CIMMYT.

Ransom, J.K., Eplee, R.E., and Norris, R.S. 1990. Striga control with dicamba. In *Proceedings, Southern Weed Science Society* 43:55-59.

Ransom, J.K., Eplee, R.E., and Palmer, A.F.E. 1990. Estimates of the competitive and phytotoxic effects of Striga on maize. *Agronomy Abstracts*, 61.

Raun, W.R., Fox, P.N., and Burnett, P.A. 1990. Preliminary comparisons of barley yellow dwarf scores on CIMMYT nurseries in contrasting environments using nonparametic correlations. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 485-488. Mexico, D.F.: CIMMYT.

Reynolds, M.P., Sayre, K.D., and Fischer, R.A. 1990. Physiological factors limiting yield potential in high and low yielding bread wheat varieties. *Agronomy Abstracts*, 129.

Roldán, S., Rosas, V., Jahan, Q., Vahidy, A.A., Rosas, A., and Mujeeb-Kazi, A. 1990. Production and utilization of synthetic hexaploids for wheat improvement. *Agronomy Abstracts*, 107.

Rosas, V., and Mujeeb-Kazi, A. 1990. The *ph1b* locus of *Triticum aestivum* L. and wide hybridization in cereals. *Agronomy Abstracts*, 107.

Sayre, K.D., Ortíz-Monasterio, I., Rajaram, S., and McMahon, M.A. 1990. Changes in nitrogen use efficiency of CIMMYT bread wheat germplasm after 35 years of breeding under high levels of nitrogen. *Agronomy Abstracts*, 130.

Sosa, G., Eaton, D.L., and Byrne, P.F. 1990. Progress from full-sib recurrent selection for resistance tolerance to fall armyworm. *Agronomy Abstracts*, 111.

Soto, N., Pérez, C., Quemé, J.L., Alvarado, A., Aguiluz, A., Celado M., R., Jiménez, K., Urbina, R.J., and Córdova, H.S. 1990. Progresos de producción de híbridos en el proyecto cooperativo Centroamericano y del Caribe: Una contribución al fortalecimiento de la industria semillera en la región. *XIII Seminario Panamericano de Semillas*, 72-73. Cd. de Guatemala, Guatemala: Ministerio de Agricultura, Ganadería y Alimentación.

ter Kuile, N., Jahan, Q., Rosas, V., Vahidy, A.A., and Mujeeb-Kazi, A. 1990. Development of 1B/1R based genetic stocks associated with *Triticum aestivum* and *T. turgidum*. *Agronomy Abstracts*, 112.

Trethowan, R., Abdalla, O., and Varughese, G. 1990. Pre-harvest sprouting tolerance in triticale. In *V International Symposium on Pre-Harvest Sprouting in Cereals*, Ringlund, K., Mosleth, E., and Mares D.J., eds., 220-226. Boulder, Colorado: Westview Press.

Trinidad, C.R., Burnett, P.A., Mezzalama, M., and Rodríguez, R. 1990. The effect of barley yellow dwarf virus on barley yields in Mexico. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 494-496. Mexico, D.F.: CIMMYT.

Velázquez, A., and Córdova, H.S. 1990. Resultados en la investigación en tecnología de semilla en el Instituto de Ciencia y Tecnología Agrícolas: Su efecto en la industria semillera de Guatemala. In *XIII Seminario Panamericano de Semillas*, 19. Cd. de Guatemala, Guatemala: Ministerio de Agricultura, Ganadería y Alimentación.

Villareal, R., Rajaram, S., Mujeeb-Kazi, A.A., and Toro, E. del. 1990. The effect of chromosome 1B/1R translocation on the yield potential of certain spring wheats (*Triticum aestivum* L.) *Agronomy Abstracts*, 114.

Waddington, S.R. 1990. The need for the workshop: Its aims and structure. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 3-4. Mexico, D.F.: CIMMYT.

Waddington, S.R., Low, A., and Kunjeku, P. 1990. Planning of on-farm intercrop trials. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 89-93. Mexico, D.F.: CIMMYT.

Wangai, A.W., and Torres, E.A. 1990. Barley yellow dwarf virus situation report for Eastern Africa with special emphasis on Kenya. In *World Perspectives on Barley Yellow Dwarf*. Burnett, P.A., ed., 71. Mexico, D.F.: CIMMYT.

Waskom, R., Mujeeb-Kazi, A., and Nabors, M. 1990. *In vitro* selection for salt tolerance in wheat. *Agronomy Abstracts*, 204.

Woolley, J.N. 1990. The diagnosis of intercropping problems in farmers' fields and its relation to planning research. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 19-26. Mexico, D.F.: CIMMYT.

_____. 1990. Implementation of on-farm intercrop experiments. In *Research Methods for Cereal/Legume Intercropping*. Waddington, S.R., Palmer, A.F.E., and Edje, O.T., eds., 147-153. Mexico, D.F.: CIMMYT.

Zewde, L., Tanner, D.G., , Elias, E.M., Gorfu, A., Tarekegne, A., Geleto, T., Yilma, Z., and Gebre, H. 1990. The relative importance of yield limiting factors on bread wheat in the Ethiopian highlands. In *VI Regional Wheat Workshop for Eastern, Central and Southern Africa*. Tanner, D.G., Ginkel, M. van, and Mwangi, W.M., eds., 214-223. Mexico, D.F.: CIMMYT.

Presentations and Other Publications

Acevedo, E. 1990. Improvement of winter cereal crops in Mediterranean environments: Use of yield, morphological and physiology traits. International Symposium of Physiology/ Breeding of Winter Cereals for Stressed Mediterranean Environments. July, Montpellier, France.

Acevedo, E., Nachit, M.M., and Ortiz-Ferrara, G. 1990. Selection tools for heat tolerance in wheat: Potential usefulness in breeding. Wheat for the Nontraditional Warmer Areas. July, Iguazu, Brazil.

Ahmad, Z., Tetlay, K.A., Asghar, C., and Longmire, J.L. 1990. Wheat technologies and the impact of AKRSP wheat development in the double cropping zone of Gilgit, 1988-89. PARC/CIMMYT Paper No. 90-6. Islamabad, Pakistan: PARC, CIMMYT.

Anandajayasekeram, P. 1990. Institutionalization of on-farm research with farming systems perspectives (OFR-FSP) in Eastern and Southern Africa Region: Achievements and future direction. On-Farm Research Training Institutionalization Workshop. November, Morogoro, Tanzania.

_____. 1990. Some reflections on agricultural economics research and its integration with post graduate training and agricultural research centre in Eastern and Southern Africa. Agricultural Economics Subject Matter Workshop. October, Harare, Zimbabwe.

Anandajayasekeram, P., ed. 1990. Research Extension Administrators Workshop. CIMMYT Network Report No. 16. November, Nairobi, Kenya.

Asghar, C., and Longmire, J.L. 1990. Chartbook of maize in Pakistan and AJK 1989. PARC/CIMMYT Paper No. 90-5. Islamabad, Pakistan: PARC, CIMMYT.

Bell, M.A., Ortiz-Monasterio, I., and Limón, A. 1990. Leaf and yield loss study. *Annual Wheat Newsletter* 36:97.

Bjarnason, M.S. 1990. El programa de maíz con calidad de proteína del CIMMYT: Estado presente y estrategias futuras. XVIII Congresso Nacional de Milho e Sorgo. July, Victoria, Brazil.

Bolaños, J., Edmeades, G.O., and Martínez, L. 1990. Mejoramiento para tolerancia a sequía en maíz tropical: La experiencia del CIMMYT. XVIII Congresso Nacional de Milho e Sorgo. July, Victoria, Brazil.

Brennan, J.P., Warham, E.J., Byerlee, D., and Hernández, J. 1990. Evaluating the economic impact of quality-reducing, seed-borne diseases: Lessons from Karnal bunt of wheat. XXXIV Annual Conference of the Australian Agricultural Economics Society. February, Brisbane, Australia.

Burnett, P.A. 1990. Breeding for resistance to barley yellow dwarf. International Symposium on Aphid-Plant Interactions: Populations to Molecules. August, Stillwater, OK, USA.

Byerlee, D. 1990. La función de los economistas en los institutos nacionales de investigación agrícola. Reunión de Organización de la Red de Socioeconomía para Centroamérica y el Caribe. June, San José, Costa Rica.

_____. 1990. Monitoring farmers' practices and fields as a continuing activity in on-farm research for envolving cropping systems. Asian Farming Systems Research and Extension Symposium on Sustainable Farming Systems 21st Century. November, Bangkok, Thailand.

_____. 1990. Technical change, productivity and returns to wheat breeding research in Pakistan's Punjab in the post-green revolution period. PARC/ CIMMYT Paper No. 90-7. Islamabad, Pakistan: PARC, CIMMYT.

Byerlee, D., and Morris, M.L. 1990. Calculating measures of protection: Is it always appropriate to use world reference prices? Joint Annual Meeting of the American Agricultural Economics Association and the Canadian Agricultural Economics Association. August, Vancouver, Canada.

Byerlee, D., and Taylor, D. 1990. Food aid and food security: A cautionary note. Joint Annual Meeting of the American Agricultural Economics Association and the Canadian Agricultural Economics Association. August, Vancouver, Canada.

Cafati, C.R. 1990. La semilla como factor de la seguridad alimentaria. XIII Seminario Panamericano de Semillas. August, Cd. de Guatemala, Guatemala.

Calhoun, D.S., Robinson, J., Burnett, P.A., and Pfeiffer, W.H. 1990. Field resistance to Russian wheat aphid in selected triticale, rye and wheat genotypes. II International Triticale Symposium. October, Passo Fundo, Brazil.

Calhoun, D.S., Robinson, J., Burnett, P.A., Vivar, H.E., and Pfeiffer, W.H. 1990. Field screening for Russian wheat aphid resistance in small grains in Mexico. IV Russian Wheat Aphid Worl shop. October, Bozeman, MO, USA.

Castañón, D., and Sain, G. 1990. Análisis económico de medidas de política agrícola y ventajas comparativas de la producción de trigo en dos áreas de Guatemala. XXXVI Reunión Anual del PCCMCA. March, San Salvador, El Salvador.

Ceballos, H., and Deutsch, J.A. 1990. Herencia de la resistencia en maíz al complejo "mancha de asfalto". XVIII Congresso Nacional de Milho e Sorgo. July, Victoria, Brazil.

Curtis, B.C., Ortíz-Ferrara, G., and Nachit, M.M. 1990. CIMMYT/ICARDA joint wheat breeding. *Annual Wheat Newsletter* 36:97.

Córdova, H.S. 1990. La biotecnología y sus implicaciones paralelas al mejoramiento convencional de plantas: Métodos, logros y perspectivas en granos básicos. XIII Seminario Panamericano de Semillas. August, Cd. de Guatemala, Guatemala.

_____. 1990. Estimación de parámetros de estabilidad para determinar la respuesta de híbridos de maíz (*Zea mays* L.) a ambientes contrastantes de Centro América, Panamá y México. XXXVI Reunión Anual del PCCMCA. March, San Salvador, El Salvador.

_____. 1990. El fitomejoramiento como un medio de lograr la autosuficiencia en la producción de granos básicos. IX Congreso Panamericano de Nutrición. June, Cd. de Guatemala, Guatemala.

_____. 1990. El papel del CIMMYT en la preservación de los recursos fitogenéticos en maíz. IEPES Conference. June, San José, Costa Rica.

Devkota, R.N., Regmi, P.P., Thapa, B.R., and Dubin, H.J. 1990. Breeding. *Annual Wheat Newsletter* 36:99.

Eaton, D.L., González, F., and Cruz, J.M. 1990. Resistencia al gusano cogollero del maíz (*Spodoptera frugiperda*) en poblaciones de maíz (*Zea mays*) en CIMMYT. XIII Congreso Anual de Fitogenética. September, Cd. Juárez, Chih., Mexico.

Edmeades, G.O. 1990. Significant accomplishments of the Ghana Grains Development Project during phase I, 1979-1983. X Annual Maize and Cowpea Workshop of the Ghana Grains Development Project. March, Kumasi, Ghana.

Edmeades, G.O., Bolaños, J., and Lafitte, H.R. 1990. Selecting for drought tolerance in maize adapted to the lowland tropics. Egyptian National Maize Program Seminar. September, Giza, Cairo.

_____. 1990. Selection for abiotic stress tolerance in maize with special reference to drought. Golden Jubilee of the Indian Society of Genetics and Plant Breeding. October, Udaipur, India.

_____. 1990. Selecting for drought tolerance in maize adapted to the lowland tropics. IV Asian Regional Maize Workshop. September, Islamabad, Pakistan.

Edmeades, G.O., Lafitte, H.R., and Bolaños, J. 1990. Selection for abiotic stress tolerance in maize. IV Asian Regional Maize Workshop. September, Islamabad, Pakistan.

Fischer, R.A., and Byerlee, D. 1990. Trends in wheat production in the warmer areas: Major issues and economic considerations. Wheat for the Non-Traditional Warm Areas. July, Iguazú, Brazil.

Fischer, R.A., and Varughese, G. 1990. Developments in CIMMYT wheat program in 1989. *Annual Wheat Newsletter* 36:94-95.

Fuentes, G. 1990. Karnal bunt research at CIMMYT, Mexico. VII Biennial Workshop on Smut Fungi. June, Frederick, MD, USA.

Furini, A., and Jewell, D.C. 1990. Callus culture and somatic embryogenesis of tropical and subtropical maize and maize-*Tripsacum* hybrids. VII International Congress on Plant Tissue and Cell Culture. June, Amsterdam, The Netherlands.

González de León, D., Hoisington, D.A., Jewell, D.C., Deutsch, J.A., and Mihm, J.A. 1990. RFLP analysis of S4 lines selected for multiple borer resistance. *Maize Genetics Cooperation Newsletter* 64(1):84-85.

Hailu, B., Mwangi, W.M., and Negatu, W. 1990. Review of research on wheat production constraints in Ethiopia. National Wheat Research Review Workshop. October, Addis Ababa, Ethiopia.

Harrington, L.W. 1990. World and regional trends in maize production, productivity and demand. Thailand National Corn and Sorghum Reporting Session. August, Chumphon, Thailand.

Hassan, R.M. 1990. Technological options and policy incentives for higher self-sufficiency in wheat for Eastern and Southern Africa. Rockefeller Foundation Social Science Research Fellows Workshop on Space and Time: Social Perspectives on Agricultural Development. October, Ibadan, Nigeria.

Heisey, P.W., Ahmad, M., Stevens, E.J., Khan, K., Zeb, J., and Javed, H.I. 1990. Diagnosing research priorities for higher-altitude maize-based farming systems in Swat. PARC/CIMMYT Paper No. 90-3. Islamabad, Pakistan: PARC, CIMMYT.

Hernández, E.M., and Sain, G. 1990. Estudio de la política de precios para frijol y maíz en Costa Rica. XXXVI Reunión Anual del PCCMCA. March, San Salvador, El Salvador.

Hesse, E., and Cassaday, K.A. 1990. Third World's growing appetite for wheat. *Shell Agriculture* (6):11-13.

Hobbs, P.R. 1990. Analysis of a long term rice-rice-wheat experiment. *Annual Wheat Newsletter* 36:99-100.

_____. 1990. Wheat technical issues needing coordinated research in rice-wheat systems. National Wheat Conference. January, Chiang Rai, Thailand.

Hobbs, P.R., Harrington, L.W., Fujisaka, S., Sharma, B., and Pokhrel, T.P. 1990. The diagnostic survey as a tool for developing a relevant research program: A study from the Terai of Nepal. Farming Research Systems Conference. November, Bangkok, Thailand.

Immonen, A.S.T. 1990. Comparative study on callus induction of immature embryos of five genotypes of triticale. VII International Congress on Plant Tissue amd Cell Culture. June, Amsterdam, Netherlands.

Immonen, A.S.T., and Varughese, G. 1990. Use of callus culture in primary triticale production. II International Triticale Symposium. October, Passo Fundo, Brazil.

Immonen, A.S.T., Pfeiffer, W.H., and Trethowan, R.H. 1990. 4x and 6x wheat and rye progenitors in triticale primary production. II International Triticale Symposium. October, Passo Fundo, Brazil.

Jeffers, D.P., and Burnett, P.A. 1990. Evaluation of CIMMYT maize germplasm for susceptibility to BYDV PAV and MAV like isolates. *Barley Yellow Dwarf Newsletter* (3):45.

Khushk, A.M., Memon, M.Y., Lashari, M.I., and Longmire, J.L. 1990. Wheat in the cotton-based cropping systems of the irrigated Sindh. PARC/CIMMYT Paper No. 90-4. Islamabad, Pakistan: PARC, CIMMYT.

Kohli, M.M., Singh, R.P., and Rajaram, S. 1990. Mejoramiento de trigo para resistencia a las royas: Estrategias del CIMMYT y su visión para el Conosur. Reunión PROCISUR sobre Desarrollo del Proyecto Regional de Investigación de Royas de Trigo. May, Passo Fundo, Brazil.

León, C. de, Wedderburn, R.N., and Granados, G. 1990. Grains in selection for downy mildew resistance and other agronomic characters in several maize populations. Department of Agriculture Annual Technical Conference. April, Pattaya, Thailand.

Longmire, J.L., and Hussain, S.S. 1990. The economics of maize seed production and utilization in Pakistan. IV Asian Regional Maize Workshop. September, Islamabad, Pakistan.

López, R., Pixley, K., and Bjarnason, M.S. 1990. Maíz de alta calidad proteínica. Conferencia sobre la Incorporación del QPM en Maíz. March, Cuautitlán Izcalli, México.

Low, A., and Waddington, S.R. 1990. Maize adaptive research: Achievements and prospects in Southern Africa. *Farming Systems Bulletin* (Eastern and Southern Africa) (6):29-41.

Martínez, L., Edmeades, G.O., and Lafitte, R.N. 1990. Respuesta a la selección para prolificidad en tres poblaciones tropicales de maíz (*Zea mays* L.) del CIMMYT. XIII Congreso Anual de Fitogenética. September, Cd. Juárez, Chih., Mexico.

Mataruka, D.F., Makombe, G., and Low, A. 1990. The contribution of economic analysis in developing promising research agendas: A maize nitrogen x phosphorus trial in Zimbabwe. *Farming Systems Bulletin* (Eastern and Southern Africa) (5):1-5.

Mezzalama, M., Webby, G.N., Lister, R.M., and Burnett, P.A. 1990. Purification of barley yellow dwarf virus from dried leaf tissue, and the production of antisera. *Barley Yellow Dwarf Newsletter* (3): 39-40.

Morris, M.L. 1990. Diagnóstico de las limitaciones del subsector mediante métodos de sondeo rápido: El caso del maíz en Paraguay. Workshop on Methods for Agricultural Marketing Research. June, Lima, Peru.

Morris, M.L., and López-Pereira, M.A. 1990. Acontecimientos recientes en la economía mundial del maíz: Implicaciones para los investigadores latinoamericanos. Reunión de Maiceros de la Zona Andina. September, Maracay, Venezuela.

Mudhara, M., and Low, A. 1990. Comparative economics of maize production in risky environments in Zimbabwe. *Farming Systems Bulletin* (Eastern and Southern Africa) (6):14-28.

Mujeeb-Kazi, A., Riera-Lizarazú, O., William, M.D., ter Kuile, N., and Krattiger, A. 1990. The wheat wide crosses program in CIMMYT and its potential. II Congreso Nacional de Trigo. October, Pergamino, Argentina.

Mwangi, W.M., Dadi, L., and Franzel, S. 1990. Socioeconomic constraints to maize production in Ethiopia. III Eastern and Southern Africa Regional Maize Workshop. Nairobi, Kenya.

Nachit, M.M. 1990. Selection and yield performance of durum wheat under different moisture regimes. *Annual Wheat Newsletter* 36:98.

Oliva, L.P., Burgos, N.R., Mate, S.R., and Harrington, L.W. 1990. Designing and assessing weed control strategies for maize-based cropping systems in Mindanao, Philippines: The role of farmers. AFSR-E Symposium. October, East Lansing, MI, USA.

Ransom, J.K. 1990. The haustorium and biotechnology in Striga research. National Striga Weed Workshop. June, Kisumu, Kenya.

Ransom, J.K., Eplee, R.E., and Langston, M.A. 1990. The potential for controlling *Striga asiatica* in maize with genetic resistance. IV Tropical Weed Science Conference towards Improved Productivity through More Efficient Weed Management. December, Kuala Lumpur, Malaysia.

Ransom, J.K., Wawire, N.W., and Thomas-Compton, M.A. 1990. Yield losses due to Striga. National Striga Weed Workshop. June, Kisumu, Kenya.

Razzaq, A., Hashmi, N.I., Khan, B.M., Khan, B.R., and Hobbs, P.R. 1990. Wheat in Barani areas of Northern Punjab: A synthesis of on-farm research results 1982-1988. PARC/CIMMYT Paper No. 90-2. Islamabad, Pakistan: PARC, CIMMYT.

Razzaq, A., Khan, B.R., Khan, B.M., Hobbs, P.R., Hashmi, N.I., and Heisey, P.W. 1990. Irrigated wheat in North West Frontier Province: A synthesis of on-farm research results 1983-86. PARC/CIMMYT Paper No. 90-1. Islamabad, Pakistan: PARC, CIMMYT.

Robinson, J., Calhoun, D.S., Burnett, P.A., and Vivar, H.E. 1990. Relative levels of tolerance to Russian wheat aphid (Homoptera: Aphididae) in five barley genotypes in Mexico. International Symposium on Aphid-Plant Interactions: Populations to Molecules. August, Stillwater, OK, USA.

Robinson, J., Burnett, P.A., Calhoun, D.S., and Vivar, H.E. 1990. The Russian wheat aphid program at CIMMYT, Mexico. International Symposium on Aphid-Plant Interactions Populations to Molecules. August, Stillwater, OK, USA.

Sain, G., and Borbón, E. 1990. Algunas características de las unidades de socioeconomía en los sistemas nacionales de investigación agropecuaria en Centroamérica. Meeting of the Social Scientist Network. June, San José, Costa Rica.

Sain, G., and Gracia, R. de. 1990. Generación y transferencia de tecnología agrícola a través de metodología de investigación en fincas de agricultores: El modelo de Caisán-San Andrés, Panamá. IICA Seminar on Strategies for Transferring Technology in Central America. March, San José, Costa Rica.

Short, K., Wedderburn, R., and Pham, H. 1990. CIMMYT's Maize Research Program in Africa. IX South African Maize Breeding Symposium. March, Pietermaritzburg, South Africa.

Skovmand, B., Taba, S., and Crossa, J. 1990. Essentials of regeneration. Conference on Preserving Our Plant Genetic Diversity. May, Washington, D.C.

ter Kuile, N., Mujeeb-Kazi, A., and Nabors, M. 1990. Potential of tissue culture applications in some Triticeae via callus induced variation, alien introgression and amphiploid production. International Symposium on Genetic Engineering and Biotechnology. January, Karachi, Pakistan.

Traxler, G. 1990. The economic returns to crop management research in a post-green revolution setting. Joint Annual Meeting of the American Agricultural Economics Association and the Canadian Agricultural Economics Association. August, Vancouver, Canada.

Traxler, G., Renkow, M., and Harrington, L.W. 1990. Assessing the impact of new technology: Three levels of analysis. Symposium on Sustainable Farming Systems in 21st Century Asia. November, Bangkok, Thailand.

Vahidy, A.A., Jahan, Q., and Mujeeb-Kazi, A. 1990. Genetic manipulation in wheat (*Triticum aestivum* L.) mediated by the chromosome 5B *Ph* locus and its significance for the transfer of alien genes influencing Karnal bunt resistance. International Symposium on Genetic Engineering and Biotechnology. January, Karachi, Pakistan.

Varughese, G. 1990. Future of triticale in the developing countries. V Reunioa Portuguesa sobre Triticale. May, Elvas, Portugal.

_____. 1990. Recognizing triticale's proper place among the world's cereals. II International Triticale Symposium. October, Passo Fundo, Brazil.

Vasal, S.K., Han, G.C., Vergara, N., Ahuja, V., and Espinoza, M. 1990. Desarrollo de germoplasmas orientados en híbridos: Producción de líneas vigorosas y resultados de ensayos. XXXVI Reunión Anual del PCCMCA. March, San Salvador, El Salvador.

Villareal, R.L., Rajaram, S., and Briceño, G.A. 1990. High yielding candidates for the 1990 international nursery system. *Annual Wheat Newsletter* 36:95.

Villegas, E., Vasal, S.K., and Bjarnason, M.S. 1990. Quality protein maize: What is it and how was it developed? LXXV Annual Meeting of the American Association of Cereal Chemists. October, Dallas, TX, USA.

Wall, P.C. 1990. Degradación del suelo en el área triguera-sojera del Cono Sur. II Congreso Nacional de Trigo. October, Pergamino, Argentina.

_____. 1990. Aspectos históricos de la siembra directa. Jornadas Binacionales de Cero Labranza. October, Florida, Chile.

Webby, G.N., Lister, R.M., and Burnett, P.A. 1990. Survey of barley yellow dwarf viruses in bread wheat nurseries in South America during 1988 and 1989. *Barley Yellow Dwarf Newsletter* (3):20-23.

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CIMMYT

International Maize and Wheat Improvement Center

1990 Audited Financial Statement

International Maize and Wheat Improvement Center, A.C.

International Maize and Wheat Improvement Center, **International**

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Price Waterhouse

México, D. F., February 20, 1991

To the Boards of Trustees of
Centro Internacional de Mejoramiento
de Maíz y Trigo, A. C. and of Centro
Internacional de Mejoramiento de Maíz
y Trigo, International

1. We have examined the combined statements of financial condition of Centro Internacional de Mejoramiento de Maíz y Trigo, A. C. (CIMMYT) and of Centro Internacional de Mejoramiento de Maíz y Trigo, International (CIMMYT, INT.) (See Notes 1 to 3 to the combined financial statements) at December 31, 1990 and 1989, and the related combined statements of activity, and of cash flows, expressed in United States dollars, for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

2. As described in Note 3 to the financial statements CIMMYT follows the "write off, then capitalize" method of recording purchases of property and equipment and therefore depreciation is not provided. However, since January 1, 1990, accounting principles generally accepted in the United States of America require the recognition of depreciation by not-for-profit organizations. The accompanying financial statements do not include the recording of depreciation, and it was not practical to determine the effects of this omission.

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3. In our opinion, except for the effects of the accounting practices described in paragraph 2 above, the combined financial statements examined by us present fairly the combined financial position of Centro Internacional de Mejoramiento de Maíz y Trigo, A.C. (CIMMYT) and of Centro Internacional de Mejoramiento de Maíz y Trigo, International (CIMMYT, INT.) at December 31, 1990 and 1989, and the combined results of their operations and their combined cash flows for the years then ended in conformity with accounting principles generally accepted in the United States of America, consistently applied.

4. Our examinations were made primarily for the purpose of forming our opinion on the combined financial statements taken as a whole. We also examined the additional information presented in Exhibits 1 to 4, expressed in United States dollars, by similar auditing procedures. In our opinion, except for the effects of the accounting practices described in paragraph 2 above, this additional information is stated fairly in all material respects in relation to the combined financial statements taken as a whole.

   Although not necessary for a fair presentation of financial position this information is presented as additional data.

PRICE WATERHOUSE

C.P. Ignacio Vélez

Combined Statement of Financial Condition

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Assets, Liabilities, and Fund Balances — **US dollars (000s)**

	Note*	Year ended December 31 1990	1989
Assets			
Cash and short-term deposits	3	4,306	2,487
Accounts receivable			
Donors	7	6,569	8,025
Others	7	1,026	765
Inventories	3	145	118
Property, plant, and equipment	3	24,547	22,510
Total assets		**36,593**	**33,905**
Liabilities and fund balances			
Liabilities			
Accounts payable and other liabilities		1,736	2,960
Accrued staff obligations	3	882	889
Payments in advance from donors	7	5,338	4,913
Total liabilities		**7,956**	**8,762**
Fund balances			
Property, plant, and equipment	3,5	24,547	22,510
Capital	5	3,645	1,980
Operating	5	2,765	2,765
Auxiliary services	5	192	361
Cumulative translation effect	4,5	(2,512)	(2,473)
Subtotal		4,090	2,633
Total fund balances		**28,637**	**25,143**
Total liabilities and fund balances		**36,593**	**33,905**

*The attached notes numbered 1 to 7 form an integral part of these financial statements.

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Combined Statement of Activity

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Revenue and Expenses — **US dollars (000s)**

	Note[a]	Year ended December 31 1990	1989
Revenue	6		
Grants		32,835	33,570
Sale of crops		41	55
Interest on short-term investments		281	294
Auxiliary services		767	740
Other income		5	2
Total revenue		**33,929**	**34,661**
Operating expenses	6		
Research programs		19,607	19,324
Conferences and training		4,012	4,635
Information services		1,167	1,217
General administration		2,020	2,547
Plant operations		1,826	1,835
Capital acquisitions		2,474	3,186
Auxiliary services		929	851
Staff obligations		398	310
Total operating expenses		**32,433**	**33,905**
Excess of revenue over operating expenses		**1,496**	**756**
Allocated as follows:			
Capital and operating equalization fund	5	1,471	
Major repair/renovation fund	5	194	
Capital fund	5		880
Auxiliary services fund	5	(169)	(124)
Translation effect for the year	4,5	(39)	15
Net excess of revenue over expenses		**1,457**	**771**
Opening fund balances		2,633	1,862
Closing fund balances as per statement of condition		**4,090**	**2,633**

[a] The attached notes numbered 1 to 7 form an integral part of these financial statements.

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Combined Statement of Cash Flows

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International
(Notes 1 to 3)

Operating Activities — **US dollars (000s)**

	Note[a]	Year ended December 31 1990	1989
Cash flows from operating activities:			
Grants from donors	6	32,835	33,570
Other	6	1,094	1,091
Subtotal		**33,929**	**34,661**
Translation effect for the year	4,5	(39)	15
Capital fund	5	1,665	880
Subtotal		**35,555**	**35,556**
Cash used in:			
Salaries and allowances		16,343	17,196
Travel		2,334	2,151
Training, conferences, and publications		4,489	4,506
Field and laboratory		2,807	3,483
Office and vehicle		2,719	2,482
Others		3,369	3,395
Subtotal		**32,061**	**33,213**
Cash flows from operating activities		**3,494**	**2,343**
Cash flows (used in) from other activities:			
Additions to property, plant, and equipment	3	(2,037)	(1,572)
Accounts receivable from others	7	(261)	352
Accrued benefits	3	(7)	291
Inventories	3	(27)	14
Payments in advance from donors	3,7	425	112
Accounts receivable from donors	3,7	1,456	(7,158)
Accounts payable and other liabilities		(1,224)	2,242
Cash used for other activities		**(1,675)**	**(5,719)**
Increase (decrease) in cash and short-term deposits		**1,819**	**(3,376)**
Cash and short-term deposits at beginning of year		**2,487**	**5,863**
Cash and short-term deposits at end of year		**4,306**	**2,487**

[a] The attached notes numbered 1 to 7 form an integral part of these financial statements.

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Notes to the Combined Financial Statements
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International

December 31, 1990 and 1989
US Dollars

Note 1: Statement of Purpose
The Centro Internacional de Mejoramiento de Maíz y Trigo, A.C. (CIMMYT, A.C.) is a private, autonomous, not-for-profit, scientific and educational institution chartered under Mexican law to engage in the improvement of maize and wheat production everywhere in the world, with emphasis on developing countries.

Note 2: Creation of Centro Internacional de Mejoramiento de Maíz y Trigo, International (CIMMYT INT.)
CIMMYT INT. was formally created through an agreement signed by the United Nations Development Programme and the International Bank of Reconstruction and Development, both cosponsors of the Consultative Group on International Agricultural Research (CGIAR). A Headquarters Agreement, signed by the Government of Mexico on May 9, 1988 and ratified by the Mexican Senate on December 22, 1988, recognized CIMMYT INT. as having the status of an international organization.

CIMMYT INT. began operations in 1989 with a partial transfer of personnel from CIMMYT A.C. The transfer of the remaining personnel was completed. All funding in 1990 was channeled to CIMMYT INT.

Note 3: Summary of Significant Accounting Policies
CIMMYT follows accounting policies recommended by the CGIAR. In 1986 these policies were revised and a standard presentation was adopted for all research centers supported by the CGIAR. These policies are in accordance with accounting practices generally accepted in the United States of America for not-for-profit organizations, except for the no recording of depreciation mentioned in paragraphs f and g, and are summarized below:

a. The financial statements of CIMMYT A.C. and CIMMYT INT. are combined for reporting purposes since their activities constitute a single operation (CIMMYT).

b. CIMMYT uses the accrual method of accounting for transactions and its books of account are kept principally in US dollars. Transactions in other currencies (mainly Mexican pesos) are recorded at the rates of exchange prevailing on the dates they are entered into and settled. Assets and liabilities denominated in such currencies are translated into US dollars applying Statement No. 52 of the Financial Accounting Standards Board of The United States of America (FAS 52). As required by that statement, CIMMYT has adopted the US dollar as its "functional currency" considering that the Mexican economy has been hyperinflationary, i.e., with a cumulative inflation rate for the three last years greater than 100% as measured by the National Consumer Price Index, published by Banco de Mexico.

c. Purchase orders issued prior to December 31 are treated as operating expenses of the year in question and are shown on the statement of condition under vouchers payable. This is in accordance with guidelines issued by the CGIAR.

d. During periods of cash surplus, CIMMYT makes short-term investments in marketable securities. Those denominated in dollars are transacted in the US money market. Interest is credited to income when the security matures or is sold. The security is recorded at cost, which approximates market, and any gain or loss from its sale is recorded at that time. Investments in pesos are held in a short-term interest-bearing account in a Mexican bank or in government securities. Interest is credited to income as accrued.

e. Inventories are stated at cost (first-in, first-out method), which is not in excess of market.

f. Fixed assets are stated at acquisition cost. Until 1971 all purchases of property and equipment were recorded as expenses. In 1972 the CGIAR requested that the International Agricultural Research Centers change to the "write off, then capitalize" method of recording purchases of property and equipment. Accordingly, all property and equipment purchased under capital grants as from January 1, 1972, was recorded as an asset and credited to capital grants. Prior to 1980, replacements of capital items were recorded as expenditures of the related programs, and in no way formed part of CIMMYT's capital grants, shown in the statement of condition. In 1980, that policy was revised to conform with the accounting policies of the CGIAR. Under this set of guidelines, the incremental value of a capital replacement item, i.e. the amount by which the historical cost of the replacement item is greater (less) than the historical cost of the item being replaced, is credited (debited) to capital grants fully expended

on fixed assets. In this way, the statement of condition reflects the historical cost of the fixed assets actually in use. In accordance with accounting principles generally accepted in The United States of America commencing January 1, 1990, not-for-profit organizations must recognize the cost of using up the future economic benefits or service potentials of their long-lived tangible assets (depreciation). This accounting principle has not been followed by CIMMYT and its effect has not been determined.

CIMMYT's buildings at certain locations in Mexico are constructed on land owned by the Mexican government, and will be donated to the government when CIMMYT ceases operations in Mexico.

g. Depreciation - In accordance with the "write off, then capitalize" method, no depreciation is provided since the assets have already been written off at the time of purchase (see paragraph f).

h. Seniority premiums, to which employees are entitled upon termination of employment after fifteen years of service, are recognized as expenses as such premiums accrue. The estimate of the accrued benefit, determined on the basis of an actuarial study as of the year end, amounted to $143,000 in 1990 ($322,000 in 1989), and CIMMYT has recorded a liability of $258,000 in 1990 ($233,000 in 1989). The charge to income for the year amounted to $98,000 in 1990 ($50,000 in 1989).

Other compensation based on length of service to which employees may be entitled in the event of dismissal or death, in accordance with the Mexican Federal Labor Law, is charged to income in the year in which it becomes payable.

Since 1985, CIMMYT has recorded an accrual for certain obligations to staff such as leave time. That amounted to $623,000 in 1990 ($657,000 in 1989).

i. Revenue Recognition - Core unrestricted grants are given annually and are charged to accounts receivable when the amount of the donation becomes known. The receivable is cancelled when the funds are received. Any uncollected portion of the pledge applicable to the current year remains charged to accounts receivable and forms part of the institution's income in that year. If the pledge is later judged to be uncollectible it is written off against income of the year in which it is cancelled.

Pledges in currencies other than US dollars are recorded at their dollar equivalent at the date of deposit.

Core-restricted and extra-core pledges, which are often for more than one year, are treated somewhat differently. In these cases the amount recognized as a receivable is equal to the expenses incurred under the grant. The uncollected portion of the pledge is not recognized as a receivable and consequently does not contribute to income. Only when expenses are incurred under the grant is an account receivable created and income recorded. This treatment matches revenues and expenses in accordance with the level of activities carried out under the grant.

This accounting policy permits CIMMYT to distinguish between income and amounts pledged in core-restricted and extra-core grants. This is necessary since these grants often cover more than one year's activities or contain carry-forward provisions in cases of underexpenditure. Recognizing the total pledge in a given year as income could result in an overstatement of income. Core-unrestricted grants do not require this treatment since they are given annually and the amount pledged represents income of that year.

Note 4: Mexican Peso Transactions

The foreign exchange system existing in Mexico permits the parallel existence of a controlled market and a market handled through exchange brokerage houses with rates in the latter case set on the basis of supply and demand.

At December 31, 1990, CIMMYT had Mexican peso (Ps) assets and liabilities amounting to Ps1,017,742,000 (Ps672,564,000 in 1989) and Ps 3,617,941,000 (Ps 3,442,739,000 in 1989) respectively which were included in the statement of condition at their US dollar equivalents resulting from applying the year-end rate of Ps 2,930 per dollar.

In 1990, the value of the Mexican peso compared to the dollar fell from Ps 2,675 to Ps 2,930 to the dollar (Ps 2,270 to Ps 2,675 in 1989).This devaluation gave rise to a translation effect aggregating a loss of $39,000 (a gain of $15,000 in 1989). In accordance with FAS 52, when an entity is judged to be operating in a hyperinflationary environment and the dollar is judged to be the functional currency, the translation effect in each year is charged to current income.

At February 20, 1991, the date of issuance of the Financial Statements, the free exchange rates with the US dollar were Ps. 2,951 (buy) and Ps. 2,981 (sell).

Note 5: Fund Balances

The CGIAR permits CIMMYT (and all other international agricultural research centers funded through it) to maintain certain fund balances. The largest of these is the total investment in property, plant, and equipment. By the end of 1990, that had reached $24,547,000. The Capital Development fund has been modified as follows:

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	1990	1989
	(000s)	
Capital Development (CD)Fund:		
Beginning balance	1,980	1,100
Additions from operation	0	880
Withdrawals (to C&OE fund)	1,174	0
Withdrawals (to MR/R fund)	806	0
Ending balance	0	1,980
Major Repair/Renovation (MR/R)Fund:		
Beginning balance	0	0
Additions from operations	194	0
Additions from CD	806	0
Ending balance	1,000	0
Capital and Operating Equalization (C&OE)Fund:		
Beginning balance	0	0
Additions from operations	1,471	0
Additions from CD	1,174	0
Ending balance	2,645	0

An Operating Fund may also be kept for the purpose of smoothing out cash flows and year-to-year revenue streams.

	1990	1989
	(000s)	
Operating Fund:		
Beginning balance	2,765	2,765
Additions	0	0
Withdrawals	0	0
Ending balance	2,765	2,765

The surplus from CIMMYT's auxiliary services, such as food and housing, of $192,000 is shown under fund balances.

	1990	1989
	(000s)	
Auxiliary Services Fund:		
Beginning balance	361	485
Additions	0	0
Withdrawals	169	124
Ending balance	192	361

The accumulated effect of the translation of Mexican pesos and other currencies is listed under fund balances and in 1990 amounted to $2,512,000.

Note 6: Revenue and Expenses

A. Revenue - CIMMYT's revenues are grouped into five categories:

i) Grants. These are funds received from donors and are used to support two types of programs at CIMMYT: core and extra-core. Core programs must fall within the mandate of the center and be approved by the Board of Trustees. These must also be approved by the members of the CGIAR, who then provide the funding (see Exhibit 2). Core programs are divided into two groups: unrestricted and restricted. Unrestricted grants come with only one requirement: that the funds be used to support core activities.

Restricted grants also support core activities, but they must be used for an activity mutually agreed upon by CIMMYT and the donor.

Extra-core programs must also fall within CIMMYT's mandate and also must be approved by the Board of Trustees. They fall outside of any direct funding through the CGIAR and may be considered related, but distinct sets of activities from the core program. In general, they are of four types: 1) direct assistance (i.e., posting of staff) to national programs, 2) training at CIMMYT for persons from a specific country, 3) collaborative research arrangements with other institutions, and 4) special exploratory research activities. Coordination of this type of funding takes place between CIMMYT and the donor.

ii) Sale of crops. CIMMYT operates four experiment stations in Mexico. Grain and other produce not required for continuance of the research programs is sold from time to time, depending on availability and quality, and revenues received are recorded as income for the period.

iii) Interest on short-term investments. Surplus cash is invested in short-term interest-bearing securities and any interest earned is recorded as income. Similarly, interest expense arising from short-term borrowing to cover cash deficit positions is charged to this account.

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iv) Auxiliary services. These comprise revenues from the following areas within CIMMYT: Cafeteria, Laundry, Guest House, Dormitories, and Staff Residences. As a whole, they are intended to be self-supporting.

v) Other income. This is a grouping of miscellaneous revenues received from the sale of surplus items such as used tires and other small pieces of equipment no longer needed by CIMMYT.

B. Expenses - The breakdown of CIMMYT's expenses as shown in its statement of activity is largely self-explanatory. Included under Research Programs, the largest single expenditure, are the expenses of the Maize, Wheat, Economics, Experiment Stations, Laboratories, and Systems and Computing Services units. In 1990 and 1989, their expenses were as follows:

	1990	1989
	(000s)	
Maize	7,250	7,365
Wheat	6,980	6,623
Economics	1,814	1,831
Experiment Stations	2,308	1,971
Laboratories	381	464
Systems and Computing Services	798	1,070
Others	76	
Total	**19,607**	**19,324**

ii) Indirect costs. CIMMYT recovers indirect costs on restricted and extra-core grants. This permits CIMMYT to offset the cost of administering these grants which by design only fund specific research activities. In 1990 and 1989, the indirect cost rate was generally 15%, although for some on-campus activities it was 25%.

Note 7: Accounts Receivable and Payments in Advance

Accounts receivable from donors	**1990**	**1989**
	(000s)	
Canadian International Development Agency	19	173
European Economic Community	822	1,752
France, Government of	400	397
Germany, Government of (BMZ)	28	79
International Crops Research Institute for the Semi-Arid Tropics	16	122
Inter-American Development Bank	4,421	4,610
OPEC Fund for International Development		15
Switzerland, Government of		21
The Netherlands, Government of	105	
The Philippines, Government of	33	
The Rockefeller Foundation	13	10
United Nations Development Programme	31	448
United States Agency for International Development	648	386
Other donors	33	12
Total	**6,569**	**8,025**
Payments in advance from donors		
Australia, Government of	(46)	(135)
Austria, Government of	(10)	(10)
Belgium, Government of	(124)	(43)
Canadian International Development Agency	(504)	(293)
Danish International Development Agency	(30)	(72)
Finnish International Development Agency	(25)	(15)
France, Government of	(3)	(4)
Germany, Government of (BMZ)	(18)	(222)
International Development Research Centre	(7)	(1)
Iran, Government of	(198)	(222)
Italy, Government of	(298)	(482)
Japan, Government of	(1,177)	(983)
Norwegian Agency for International Development	(224)	(245)
Switzerland, Government of	(113)	(40)
The Ford Foundation		(100)
The Netherlands, Government of	(523)	(716)
The Rockefeller Foundation	(160)	(45)
The World Bank	(1077)	(900)
United Nations Development Programme	(701)	
United States Agency for International Development	(27)	(109)
Other donors	(73)	(276)
Total	**(5,338)**	**(4,913)**
Other receivables (payables)		
Loans to senior staff*	265	116
Personal charges to employees	98	92
Official expenses advances	696	541
Employee credit union	(96)	(54)
Miscellaneous debtors	63	70
Total	**1,026**	**765**

* A program of loans to senior staff, mainly to provide partial financing for housing purchases, was initiated in 1982. These loans carry an interest rate of prime plus 1.75%.

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Combined Detailed Statement of Activity

For the period from January 1 to December 31, 1990.
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 1 — **US dollars (000s)**

	Note	Core Unrestricted	Core Restricted	Extra Core and Cooperative	Auxiliary Services	Total
Revenue	6					
Grants		22,499	4,217	6,119		32,835
Sale of crops		41				41
Interest on investments		281				281
Auxiliary services					767	767
Other income		5				5
Total revenue		**22,826**	**4,217**	**6,119**	**767**	**33,929**
Expenses	6					
Research programs		13,492	2,944	3,171		19,607
Conferences and training		1,607	651	1,754		4,012
Information services		1,167				1,167
General administration		2,020				2,020
Plant operation		1,826				1,826
Capital acquisitions		1,897	35	535	7	2,474
Auxiliary services					929	929
Indirect costs		(1,246)	587	659		0
Seniority premiums		98				98
Accrual benefits		300				300
Total operating expenses		**21,161**	**4,217**	**6,119**	**936**	**32,433**
Excess of revenue over operating expenses		**1,665**			**(169)**	**1,496**
Allocated as follows:						
Capital and operating equalization fund	5	1,471				1,471
Major repair/renovation fund	5	194				194
Auxiliary services fund	5				(169)	(169)
Translation effect for the year	4,5	(39)				(39)
Net excess (deficit) of revenue over expenses		**1,626**			**(169)**	**1,457**

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Sources of Income from Grants

For the period from January 1 to December 31, 1990.
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 2

US dollars (000s)

	Unrestricted	Restricted	Extra Core and Cooperative	Total
Australia, Government of	750		139	889
Austria, Government of	250			250
Belgium, Government of			106	106
Canadian International Development Agency	1,524		2,120	3,644
China, People's Republic of	50			50
Danish International Development Agency	792		42	834
European Economic Community	2,504			2,504
Finland, Government of	748		70	818
France, Government of		541	31	572
Germany, Government of (BMZ)	475		20	495
India, Government of	49			49
Inter-American Development Bank	4,370			4,370
International Crops Research Institute for the Semi-Arid Tropics			330	330
Islamic Republic of Iran, Government of			23	23
International Board for Plant Genetic Resources			116	116
Italy, Government of		256	129	385
Japan, Government of		1,800	155	1,955
Norwegian Agency for International Development	229		32	261
Spain, Government of	115			115
Switzerland, Government of		458	632	1,090
The Ford Foundation	100			100
The Netherlands, Government of		157	220	377
The Philippines, Government of	75			75
The Rockefeller Foundation			108	108
The United Kingdom, Government of	1,295			1,295
The World Bank	3,888			3,888
United Nations Development Programme		1,005		1,005
United States Agency for International Development	5,285		1,276	6,561
Miscellaneous Training and Research Grants			570	570
Total income from grants	**22,499**	**4,217**	**6,119**	**32,835**

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Core-Restricted Pledges and Expenses

For the period from January 1 to December 31, 1990
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 3

US dollars (000s)

	Grant Period[a] (mo/day/yr)	Grant pledged[a]	Expenses Prior years	Expenses This year	Expenses Total
Government of France					
Collaborative Highland-Maize	01/01/90-12/31/90			252	252
Bread Wheat	01/01/90-12/31/90			76	76
Triticale	01/01/90-12/31/90			76	76
Economics	01/01/88-12/31/91		96	79	175
Genetic Tripsacum	01/01/88-12/31/91			28	28
Plant Protection	01/01/90-12/31/90			30	30
Total		**572[b]**	**96**	**541**	**637**
Government of Italy					
Barley Yellow Dwarf Virus, Phase II	11/01/88-10/31/91	922	276	256	532
Government of Japan					
Wheat Crop Management	01/01/90-12/31/90			628	628
Wheat and Maize Plant Pathology/Protection	01/01/90-12/31/90			651	651
Wheat Plant Protection Southern Cone	01/01/90-12/31/90			145	145
Wheat Seed Health	01/01/90-12/31/90			376	376
Total		**1,800[c]**		**1800**	**1,800**
Government of Switzerland					
Central America & Caribbean-Maize	01/01/90-12/31/91	714		332	332
Central America & Caribbean-Economics	01/01/90-12/31/91	201		126	126
Total		**915[d]**		**458**	**458**

[a] For information purposes only
[b] Equivalent to FF 2'900,000
[c] Equivalent to YEN 235,890,000
[d] Includes US$10,979 of interest earned in 1990
[e] Equivalent to DFL 300,000
N/A = Not applicable

Core-Restricted Pledges and Expenses

For the period from January 1 to December 31, 1990
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 3 (continued)

US dollars (000s)

	Grant Period[a] (mo/day/yr)	Grant pledged[a]	Expenses Prior years	Expenses This year	Total
Government of The Netherlands					
Economics Thailand-Ethiopia	01/01/90-12/31/90	157[e]		57	157
United Nations Development Programme					
Development of Wheat Varieties for Marginal Areas	07/01/87-06/30/90	2,467	1,872	595	2,467
Increasing Wheat Production in Warmer and Stressed Environments	07/01/90-06/30/93	3,415		410	410
Total		**5,882**	**1,872**	**1,005**	**2,877**
Total Core Restricted		**10,248**	**2,244**	**4,217**	**6,461**

[a] For information purposes only
[b] Equivalent to FF 2'900,000
[c] Equivalent to YEN 235,890,000
[d] Includes US$10,979 of interest earned in 1990
[e] Equivalent to DFL 300,000
N/A = Not applicable

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Extra-Core Pledges and Expenses

For the period from January 1 to December 31, 1990
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 4 — **US dollars (000s)**

	Grant Period[a] (mo/day/yr)	Grant pledged[a]	Expenses Prior years	Expenses This year	Total
Government of Australia					
Wheat RFLP Map Development	04/13/89-12/31/90	119[b]	36	83	119
Development of Karnal Bunt	03/01/89-03/01/90	75[c]	23	52	75
Boron Deficiency in Cereals	01/01/90-12/31/91	101[d]		4	4
Total		**295**	**59**	**139**	**198**
Government of Belgium					
Wheat Bacterial Disease Project	11/01/87-12/31/91	714	404	106	510
Canadian International Development Agency					
Haiti-Economics	01/01/90-02/28/91	122[e]		91	91
East Africa Cereal Program, Phase II	05/20/88-05/19/92	4,060[f]	1,284	947	2,231
Ghana Maize, Phase II	10/01/83-03/31/90	4,395[g]	3,859	536	4,395
Ghana Maize, Phase III	07/13/90-07/12/95	7,040[h]		231	231
Bangladesh Wheat	04/01/82-06/30/91	3,832[i]	3,236	315	3,551
Total		**19,449**	**8,379**	**2,120**	**10,499**
Danish International Development Agency					
DPS Associate Scientist	04/24/89-04/23/91	126	39	42	81
Finnish International Development Agency					
Wheat Genetic Resourses	03/30/89-03/09/92	271	72	70	142
Government of France					
Maize Associate Scientist	09/02/87-02/28/90	60	59	1	60
FRANCE/IRAT/MRT Pre-Doc	11/01/89-10/31/91	64[j]	3	30	33
Total		**124**	**62**	**31**	**93**
Government of Germany (BMZ)					
African Students Post Graduate Fellowships	01/09/87-07/31/90	120	82	20	102
Government of Islamic Republic of Iran					
Improvement of Maize and Triticale	01/01/89-08/01/91	744	27	23	50
Government of Italy					
Barley Yellow Dwarf Virus	01/01/88-10/31/91	428	131	129	260
Government of Japan					
Fellowships Program	09/01/86-12/31/92	1,288	280	155	435
Cafeteria, Building	09/01/87-12/31/90	325	2		2
Total		**1,613[k]**	**282**	**155**	**437**

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Extra-Core Pledges and Expenses

For the period from January 1 to December 31, 1990
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 4 (continued)

US dollars (000s)

	Grant Period[a] (mo/day/yr)	Grant pledged[a]	Expenses: Prior years	Expenses: This year	Total
Norwegian Agency for International Development					
Predoctoral Fellowship	01/01/88-01/31/89	64[l]	30		30
Training Wheat & Maize	01/01/88-12/31/91	238[m]	15	32	47
Total		**302**	**45**	**32**	**77**
Government of Switzerland					
Central America & Caribbean-Maize	01/01/90-12/31/91	497[n]		260	260
Central America & Caribbean-Economics	01/01/90-12/31/91	399[n]		244	244
Biotechnology Science	06/13/88-06/30/91	254	117	111	228
Associate Expert Nepal	09/01/90-08/01/93	151		17	17
Total		**1,301**	**117**	**632**	**749**
Government of The Netherlands					
Durable Resistance in Wheat	03/03/89-03/04/94	1,000[o]	17	27	44
Wheat RFLP Map Development-Maize RFLP Network	01/01/89-12/31/92	700[p]	107	102	209
Pathogenicity of Yellow Rust isoletes from Third World	01/01/90-12/31/90	91[q]		91	91
Total		**1,791**	**124**	**220**	**344**
The Rockefeller Foundation					
Social Science Research Macro-Level	10/15/88-10/14/90	73	37	36	73
Social Science Research Fellowship Kenya	11/01/89-11/01/91	80	6	34	40
Social Science Research Fellowship Malawi	11/01/89-10/30/92	300		7	7
Research Fellowship	10/01/90-09/30/92	94		10	10
Research Fellowship	11/01/90-10/31/92	95		3	3
N.E. Borlaug	11/01/89-10/30/91	96	14	18	32
Total		**738**	**57**	**108**	**165**
United States Agency for International Development					
Pakistan Agricultural Research Council:					
Wheat, Maize and Economics	10/01/84-09/30/91	3,517[r]	3,256	437	3,693
Africa Farming Systems Research, Phase II	01/01/86-09/28/92	6,500	3,980	823	4,803
Maize Insect Pests	09/30/87-05/31/89	56	40	16	56
Total		**10,073**	**7,276**	**1,276**	**8,552**
Biotechnology Laboratory					
Government of Germany (BMZ)	01/01/88-12/31/90	413[s]	284	129	413
Government of Japan	01/01/88-12/31/90	554[t]	432	122	554
Government of Italy	01/01/88-12/31/89	300	300		300
Canadian International Development Agency	01/01/88-12/31/89	142[u]	142		142
Government of Belgium	01/01/89-12/31/89	26[v]	26		26
Government of France	01/01/90-12/31/90	150		150	150
Total		**1,585**	**1,184**	**401**	**1,585**

Extra-Core Pledges and Expenses

For the period from January 1 to December 31, 1990
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.
Centro Internacional de Mejoramiento de Maíz y Trigo, International.
(Notes 1 to 3)

Exhibit 4 (continued)

US dollars (000s)

	Grant Period[a] (mo/day/yr)	Grant pledged[a]	Expenses Prior years	Expenses This year	Total
Miscellaneous Training and Research Grants	w	N/A		169	169
Cooperative Projects					
IBPGR-Research Associate	01/01/90-12/31/91	59		22	22
IBPGR-Latin America	01/01/90-12/31/90	68		68	68
IBPGR Global Passport Database for Maize	04/06/89-12/31/91	78	24	26	50
ICRISAT-Sorghum Project	01/01/90-12/31/90	330		330	330
Total		**535**	**24**	**446**	**470**
Total Extra Core			**18,364**	**6,119**	**24,483**

a For information purposes only
b Equivalent to AD 137,000
c Equivalent to AD 100,000
d Equivalent to AD 127,800
e Equivalent to CA 142,365
f Equivalent to CA 4,765,000
g Equivalent to CA 5,681,400
h Equivalent to CA 8,167,514
i Equivalent to CA 4,900,000
j Equivalent to FF 344,000
k Equivalent to YEN 229,085,506 plus US 53,537 of interest earned in 1990
N/A = Not applicable
l Equivalent to NOK 400,000
m Equivalent to NOK 1,500,000, plus US 12,556 earned interest
n Includes US 10,979 of interest earned in 1990
o Equivalent to DFL 1,936,000
p Equivalent to DFL 1,400,000
q Equivalent to DFL 190,000
r Includes RPs 29,844,206 equiv. US 1,642,910
s Equivalent to DM 600,000 plus US 59,844
t Equivalent to YEN 76,183,304
u Equivalent to CA 180,000
v Equivalent to BEF 1,000,000
w Grant period not applicable