The Human Right to Food and Livelihoods: The Role of Global Wheat Research

Dr. Sanjaya Rajaram[*]

> *When there are millions starving, I think that there must be something fundamentally wrong.*
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> **–Nobel Laureate Archbishop Desmond Tutu**

Distinguished hosts, colleagues, Crawford Fund Chairman Tim Fischer, Professor Derek Tribe, and Tim Besley, President of ATSE, I am honored to speak with you today on the occasion of receiving the first Derek Tribe Award from the Crawford Fund. My own institution, CIMMYT (the International Maize and Wheat Improvement Center), and the farmers for whom CIMMYT works, are greatly indebted to Professor Tribe and to the Crawford Fund for consistently raising awareness of the importance of international agricultural research. On a more personal note, I would like to emphasize how rewarding it is for me to receive this recognition in Australia. I arrived in this country in the mid-1960s as a Narrabri Rotary Club scholarship student from India. It was here that I received my doctorate in wheat genetics, and it was here that I was directed towards my life's work at CIMMYT.

I am a scientist who has spent all of his life in applied agricultural research: in other words, I have had the true privilege of participating in work that has had practical, vital benefits for human beings. As the epigraph of this paper indicates, the continued existence of hunger on our planet is an ethical issue. In my talk, I will stress that agricultural researchers, particularly in the public sector, have a special mission to ensure that the world deals with problems of hunger, poverty, and environmental degradation in a socially responsible manner. More specifically, I will describe what the CIMMYT Wheat Program is doing to meet the many challenges that will emerge in the coming years, and to ensure that more people secure two of the most basic human rights: the right to food and a secure livelihood.

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The power of research to change individual and social welfare

The achievements of the Green Revolution in wheat are so well known that it is unnecessary to review them in detail here. Suffice it to say that, in the short space of a few years in the late 1960s, wheat and rice production, especially in South Asia, increased rapidly enough to banish the specter of famine from the Subcontinent and to forestall a great deal of suffering elsewhere in the world.

The Green Revolution wheats were both novel and productive because they possessed a “dwarfing gene” from a wheat variety called Norin 10. The new “semidwarf” wheats were much shorter than other wheats: they put more of their energy into producing grain rather than straw, and they would not fall over if fertilizer was applied. As one observer concluded, “A single gene from a seemingly unimportant variety of wheat has saved 100 million lives” (Raeburn 1995).

Wheat varieties developed by CIMMYT and its partners worldwide now cover more than 64 million hectares in developing countries—more than three-fourths of the area planted to modern wheat varieties in those countries (Heisey, Lantican, and Dubin, forthcoming). Depending on numerous economic and technical assumptions, the value of the current additional grain production attributable to this international wheat breeding effort has been roughly estimated to range from US$ 2 billion to US$ 4 billion per year (Cassaday et al., forthcoming).

Although critics of the Green Revolution often fail to acknowledge its impact on human and ecological survival, millions of rural people can attest to the difference that it made in their lives. They know they have more food and (in some instances) more income. The additional grain produced by the new semidwarf wheats is one reason why malnutrition in developing countries declined from 46.5% in 1970 to 31% in 1995 (Smith and Haddad 2000). Children born today are likely to live eight years longer than children born 30 years ago (UNDP 2001). Better access to food certainly has had something to do with increasing their life expectancy.

CIMMYT’s focus is to help the developing world, but it is important to note that many developed nations, Australia among them, have also benefited from the products of the international breeding system. More than three decades ago, Australian researchers started using CIMMYT wheats in their breeding programs, primarily because the CIMMYT wheats could improve the yield potential and disease resistance of Australian wheats. Starting in 1973, several CIMMYT-derived wheats have been released for commercial production in Australia. (My own work contributed to the development of at least five of them.) Since then, CIMMYT-derived varieties have made an enormous contribution to Australia’s wheat industry, as evidenced by the A$ 2.6 billion in total benefits generated from 1973 to 1994. On an annual basis, CIMMYT-derived wheats produced between

A$ 62 and A$ 81 million for Australia's wheat industry from 1973 to 1993 (Brennan and Fox 1995).

The Green Revolution has also benefited the environment in developing countries and the rest of the world. By breeding plant varieties with genetic resistance to pests and diseases, CIMMYT and its research partners in developing countries made farmers' use of harmful, expensive agrochemicals unnecessary. If the developing world had attempted to meet its food requirements in 1995 without the improved varieties of food crops[1] developed since the Green Revolution, an additional 426 million hectares of cropped area would be needed (a five-fold increase over cropped area in 1965) (Grace et al. 2000). Even more importantly, this land savings helped reduce greenhouse gas emissions by 35%. Grace et al. concluded that, "without the Green Revolution…the atmospheric concentration of greenhouse gases would be significantly higher than…at present."

All of the benefits of global wheat research cannot be described in detail here, but the previous paragraphs have given some idea of their immense scope.[2] What is less clear is how those benefits came about. Before we turn our attention to the challenges for the future, I think it is important for us to reflect briefly on the collaborative arrangements that have made international research successful.

Breeders without borders: "Globalization" for the public good

Long before we had Doctors without Borders, we had breeders without borders. Long before the term "globalization"—which has been defined as "the global circulation of goods, services, and capital, but also of information, ideas, and people" (World Bank 2000)—was invented, a complex but informal international network of researchers and policy makers was marshaling public resources to feed poor people. This goal was not to be accomplished through charity, but through collaborative research such as the research that earned Norman Borlaug the Nobel Peace Prize in 1970.

I have had direct experience of that research effort, which can be viewed as an early experiment in globalization for the public good. Both the inputs and products of that research were global: the research partnerships that extended across nations, the experimental wheats that were crossed in countless fields all over the world, the new wheat varieties, and the large effects on food security. Let me provide an extremely simple example of global inputs and results. If you look at a segment of the pedigree of Sonalika, one of the Green Revolution wheats, you will see that this variety is the product of genetic resources from literally every continent where wheat can grow—and this is *only a part* of the full

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[1] Chiefly wheat, rice, barley, maize, sorghum, millet, rye, and oats.

[2] Readers who would like more information should see Lipton and Longhurst (1989), Byerlee and Moya (1993), Evenson (2001), and Heisey, Lantican, and Dubin (forthcoming).

pedigree (Figure 1). Thanks to international cooperation in breeding research, Sonalika was developed and made available to farmers all over the world, where it came to cover a great deal of ground in the 1970s and 1980s. A later and even more successful series of varieties, the Veery wheats, were made available through these same international partnerships (note that 64 cultivars were released from the Veery family of wheats). Without that global collaboration, I would not be receiving this award today.

The crux of the global collaboration in wheat research is the exchange of seed by CIMMYT and public research programs worldwide. Every year, CIMMYT's wheat breeding program makes about 19,000 crosses. Products of these crosses, as well as seed from CIMMYT's genetic resources center, are made available to breeders throughout the world. Between 1994 and 2000, CIMMYT distributed 1.2 million samples of bread wheat, durum wheat, triticale, barley, and other seed (Cassaday et al., forthcoming) (Figure 2). In each year, 65-77% of these samples were sent to developing countries, with 71.3% of the total distributed to developing countries over the six-year period. All but a very minor share of these materials was transferred to public agencies.

More than 80% of the spring bread wheats released by national programs in the developing world between 1966 and 1997 are the products of interaction between CIMMYT and national wheat scientists (Heisey, Lantican, and Dubin, forthcoming).

Facing reality: Doing much, much more with less

In recent years, even as the economic and social benefits of agricultural research in developing countries have become increasingly apparent, support for this research has diminished drastically. Pinstrup-Andersen and Cohen (1998) reported that from 1986 to 1996, development assistance directed specifically at agriculture fell almost 50% in real terms. Much of the reduction occurred as the seven wealthiest countries that provided development assistance reduced their contributions.

Although these sorts of public policy decisions seem to indicate that agriculture is not critical to our common future, the projections for food demand in developing countries indicate exactly the opposite. In the next two decades, the world's farmers will have to produce 40% more grain to meet demand for cereals, including wheat (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999). In developing countries, the demand for wheat and maize will rise faster than demand for rice, the other major food staple.[3] By 2020, 67% of the wheat consumed in the world will be consumed in developing countries. Even with projected production increases, by 2020 wheat will make up *more than half* of the developing world's net cereal imports (Rosegrant et al. 1997).

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[3] Demand for wheat will grow by 1.58% per year; demand for maize will grow by 2.35% per year.

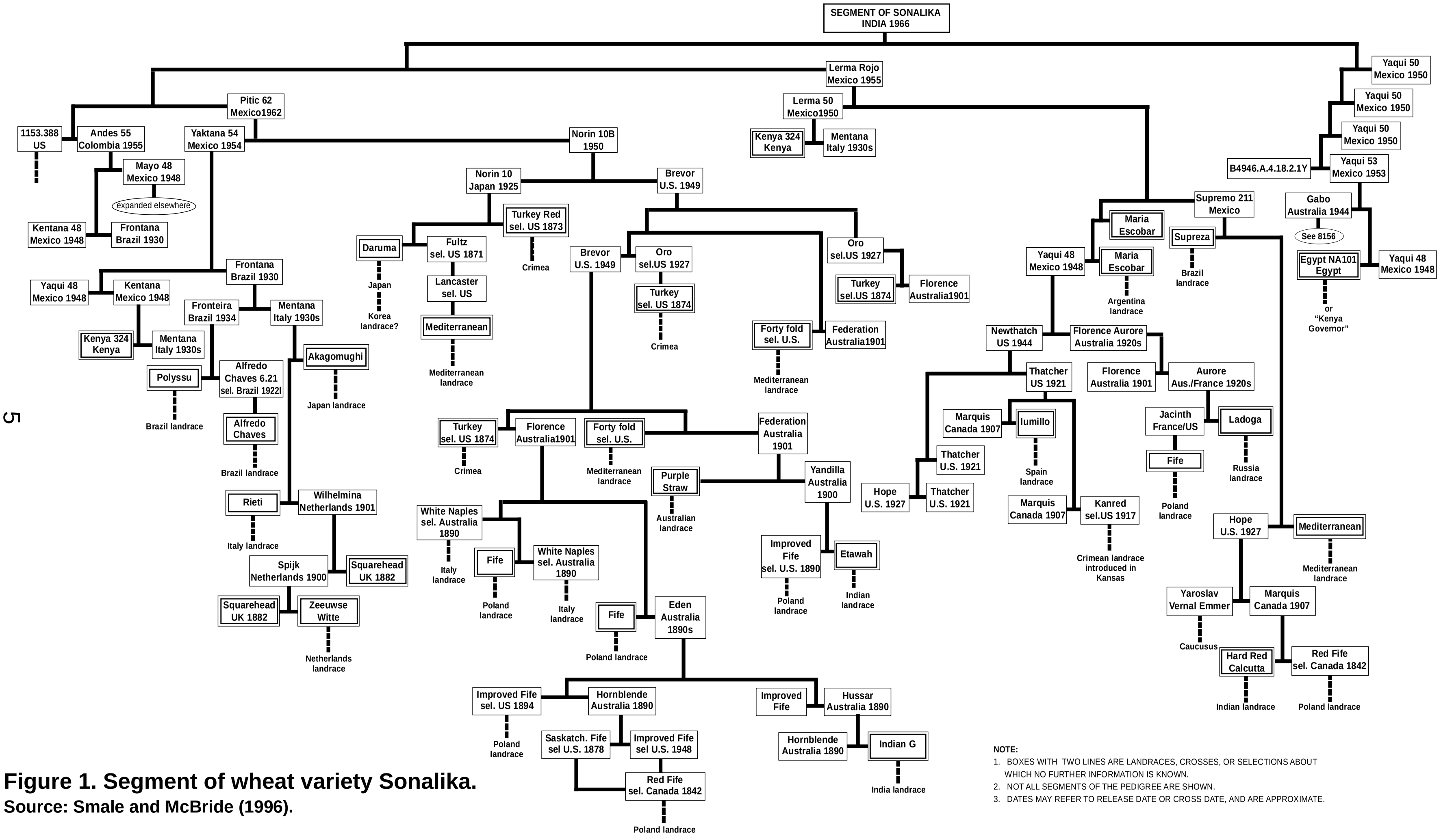

Figure 1. Segment of wheat variety Sonalika.

Source: Smale and McBride (1996).

NOTE:

1. BOXES WITH TWO LINES ARE LANDRACES, CROSSES, OR SELECTIONS ABOUT WHICH NO FURTHER INFORMATION IS KNOWN.
2. NOT ALL SEGMENTS OF THE PEDIGREE ARE SHOWN.
3. DATES MAY REFER TO RELEASE DATE OR CROSS DATE, AND ARE APPROXIMATE.

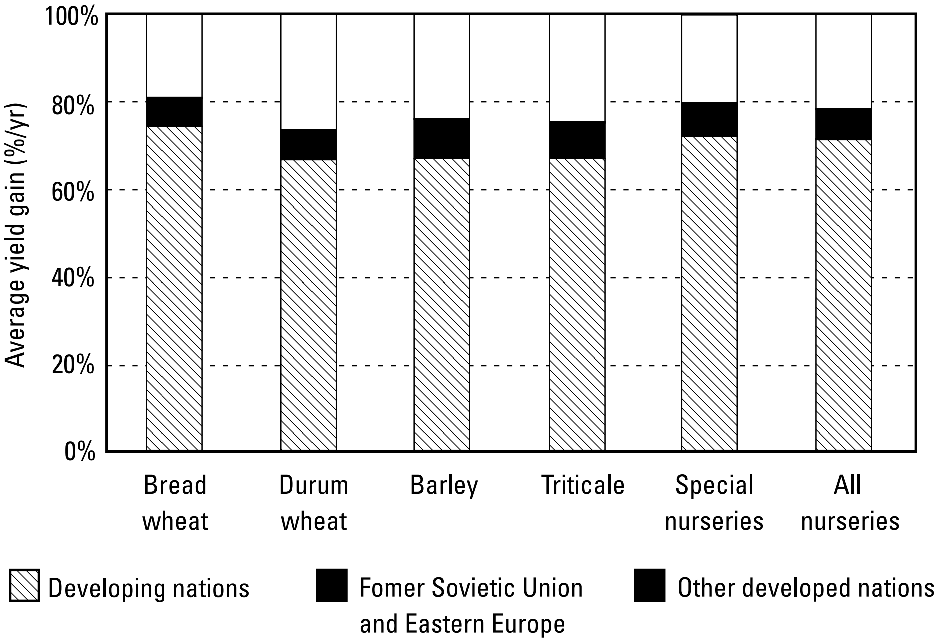

Figure 2. Percent distribution of wheat seed samples sent by CIMMYT International Nurseries to developed and developing countries, 1994-99.

Source: Calculated from data provided by CIMMYT International Nurseries. Note: "Developed" or "developing" nation status follows FAO classification. Data represent the total number of seed samples sent for each species in all nursery sets.

Whether this much wheat can actually be imported by developing countries is not clear. McCalla (2000) has observed that although world grain trade has more than doubled since 1960, “the share of world grain consumption that is traded has remained constant at about 10%.” Furthermore, he has noted that “if grain demand over the next 25 or 30 years increases 50-60%, and if trade increases only proportionately, to say 300 million tons, then it is clear that most of the increase in food production must come from production systems in the countries where the additional people will live.” In other words, the challenge of supplying food to those who need it most is not as simple as producing more food and shipping it to hungry consumers. As Falcon (2000) has stated, increasing the “pile of food…is by no means sufficient to assure food security among the poor. If developing countries with a large percentage of undernourished people are to solve employment, income, and food-access problems, most of the increased agricultural output must be grown within the borders of these nations.”

It is within the borders of those nations that the benefits of cross-border research will become even more important, despite declining international support for agricultural research in developing countries. The agricultural problems of developing nations are serious and appear likely to worsen with climate change. They range from biophysical problems such as diseases and pests, drought, floods, and infertile soils to larger institutional problems, such as underfunded research and extension organizations, poor access to agricultural inputs, and poorly developed markets.

As Professor Tribe has indicated in his address today, applied agricultural scientists continue to work at the interface between human and environmental survival. Professor Tribe discusses the dilemmas facing society very clearly; here I would like to highlight what we are doing in the CIMMYT Wheat Program to promote economically and ecologically sound development at a time when agricultural research is seriously underfunded.

Several global issues facing wheat research are at the heart of our research agenda. These include the basic need to increase yields, the threat of drought and climate change, the challenge to prevent malnutrition in the most disadvantaged members of the population, the challenge to raise productivity yet ensure environmental security, and the need to ensure that developing countries can produce the quality wheats that will enable them to become competitive in world markets. I will deal with each of these in turn.

Raising yields: The search for “paramount” germplasm

In some ways, farming has not changed over the millennia. The earliest farmers, like today’s farmers, probably scanned their fields before harvest and wondered, “Is this as good as it gets?” Researchers eventually joined farmers in the quest for higher crop yields, and periodically, since the breakthrough years of the Green Revolution when yields rose at an unprecedented rate, the alarm is still raised: Have yields reached a plateau?

This question is crucial, because some experts estimate that demand for wheat cannot be met in the future unless yields grow by more than 1% per year—the steady rate of growth that has been registered among CIMMYT wheats since the 1950s. (This translates into an additional 60 kilograms per hectare per year.)

In CIMMYT’s wheat germplasm we have evidence that yield potential is far from exhausted. In the late 1970s, for example, I participated in an effort to bring genetic diversity from winter wheats into the spring wheats that are most commonly grown in developing countries. Our crosses of spring and winter wheats produced the Veery wheats, which represented a yield increase of 15% over wheats currently grown in developing countries.

Today we are pursuing three lines of research that promise to bring higher yields to farmers throughout the world, including farmers in some of the world’s more difficult production environments: accessing genetic diversity in the grass species that are wheat’s wild relatives; the development of hybrid wheat; and the development of wheat plants that are literally built to yield more. All of this research takes advantage of what has been called “paramount” germplasm—the plants that express important traits better than any others (Rasmusson 1996).

Wheats bred from wild grass species. Breeders are constantly looking for new sources of useful genetic diversity. Species that grow in the wild and are closely related to wheat are a novel source of genetic diversity for many traits associated with high yield, especially disease resistance. By crossing durum wheat with some of these wild relatives, researchers have created “synthetic” wheats that allow them to tap into the desirable genes present in wild species. (They are called “synthetics” because they bring together the diversity in wild species in a form that breeders can use.)

Synthetic wheats possess resistance to many diseases (e.g., Karnal bunt, fusarium head scab, helminthosporium spot blotch) as well as tolerance to environmental stresses such as heat and drought. Though not adequate for farm production, synthetics can be crossed readily with high yielding wheats, thereby acting as a “genetic bridge” that allows useful traits to be transferred to improved wheat. Disease resistance can be extremely valuable for preserving yields; for example, scab alone has been reported to cause losses of billions of dollars and millions of tons of grain in the US and China. To date, CIMMYT has formed about 800 synthetics, and of these several lines have shown very high levels of resistance to scab (e.g., infection rates of only 5–10%, compared to 45–60% in susceptible checks).

Hybrid wheat. Interest in hybrid wheat production was renewed at CIMMYT in the 1990s in response to the expressed interest of the national agricultural research systems of client countries such as India and China. The main advantage of hybrids is that they allow the exploitation of heterosis (hybrid vigor) to increase wheat grain yields.

CIMMYT was able to take up hybrid research because new, more effective chemical hybridizing agents (CHAs) for creating male sterility have made hybrid development less difficult. Effective CHAs such as Genesis®[4], approved by the US Environmental Protection Agency in 1997, permit the production of large numbers of hybrids from very diverse germplasm in a short period of time. At CIMMYT, Genesis® is being used to develop bread wheat hybrids from high yielding, widely adapted advanced lines. Results indicate that positive heterosis for grain yield exists in CIMMYT bread wheat lines under irrigated conditions. Recent hybrids produced at CIMMYT have yielded up to 21% higher than the best commercial cultivars. If successful, these efforts will ultimately lead to materials that could increase yields by 10-15% above those of currently planted commercial varieties.

Getting developing world farmers to adopt hybrid wheat will depend on many factors, not the least of which is the cost of hybrid seed. Hybrid seed costs more than conventional wheat seed because of the extra costs associated with male sterilization and cross-fertilization. To solve this problem, CIMMYT is working on improving seed set of female lines in the field. Hybrid production is also strongly affected by climatic conditions such as temperature, rain, relative humidity, and

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[4] Genesis is a registered trademark of the Monsanto Company.

wind. CIMMYT is therefore studying different locations to determine their suitability for hybrid seed production.

A new wheat plant type. CIMMYT wheat breeders are also literally constructing a new kind of wheat plant with a higher yielding capacity than current wheats. They are using such strategies as creating plants with bigger spikes and the capacity to hold twice as many grains as current wheats. These plants are a blend of genetic resources from origins as diverse as Europe, North America, and North Africa. They are the result of 25 years of research and careful observation—a fact that serves as a useful reminder that the development of a new variety is simply not an overnight phenomenon, even in an age of biotechnology.

Options for farmers. If the new wheats described previously become reality, the actual gains that farmers will experience will not depend on yield potential alone, of course. In temperate and semi-temperate areas where temperatures are cooler and long, sunny days prevail, as in some parts of Chile, farmers will get wheat yields of 15-17 tons per hectare (Hewstone 1996). In the more ordinary circumstances encountered in semi-tropical and semi-temperate areas, such as the Yaqui Valley of northwestern Mexico and the Punjab of India, farmers will see yields of 10-11 tons per hectare. It is likely that farmers in semi-arid areas, where wheat is a staple and drought is endemic, will see the most dramatic increases, moving from 1.5 tons per hectare to 3 or 3.5 tons. By blending traditional drought-tolerant wheats, improved high-yield-potential wheats from CIMMYT, and our synthetics, we have bred experimental wheats in the Yaqui Valley of northwestern Mexico that yield well on a single irrigation of 120 millimeters of water for the entire growing season. (Note that as much as 50 millimeters of additional moisture may be present in the soil or atmosphere.) Advances in the Yaqui Valley—which is where the original Green Revolution wheats were bred—have implications for wheat-growing areas all over the world, so these new wheats promise to become important for wheat farmers worldwide.

The role of genetic diversity in raising yields

Wheat genetic diversity is a compendium of genes inherited from wild grass ancestors and primitive wheats that evolved in natural settings and then became the subject of breeding by farmers and, eventually, researchers. As seen in the pedigree of Sonalika, discussed earlier, a single wheat variety can represent the blending of lineages of wheats from several continents.

The debate over the role of scientific agriculture in biodiversity reflects a concern for loss of “complexity” in natural and agricultural systems. But “complexity” means different things to different groups, including biological and social scientists, ecologists, farmers, and conservationists. However, it is important to recognize that despite their differences, these varied groups share a common interest. All of them wish to ensure the level of genetic diversity in wheat needed to maintain global, regional, and national food security.

CIMMYT's research on genetic diversity in wheat seeks to clarify what "diversity" means by systematically identifying, applying, and comparing the indicators of genetic diversity used by social and biological scientists. We are also seeking to sketch historical patterns in the use of genetic resources and their impact on the genetic diversity of bread wheats grown in the developing world today. Through this research, we hope to improve our understanding of how international agricultural research, such as CIMMYT's wheat breeding, has affected diversity in the past and can enhance it in the future. This kind of understanding can help CIMMYT work more effectively with its partners to foster wheat genetic diversity for the benefit of present and future generations in developing countries.

There is growing evidence that this active research network has actually helped to increase the genetic diversity of wheat. Before the Green Revolution, a small number of improved wheats tended to cover very large areas, partly because an international wheat breeding system did not yet exist to offer a greater range of genetic resources to breeders all over the world. Since the first Green Revolution wheats have been replaced by newer improved varieties, the trend has been for smaller areas to be covered by a more diverse array of wheats with more diversity in their pedigrees. The original Green Revolution wheats were based on two to three crosses and from 10 to 20 landraces. (Landraces—the building blocks of modern wheat varieties—are wheats that were selected by farmers from primitive wheats over a long period, and they often contain unique and valuable genetic characteristics, such as the ability to resist a particular disease or to tolerate drought). In contrast, one of the most popular wheats grown today in India, PBW-342, has 50 landraces in its pedigree. Wheats such as PBW-342 get their yield capacity not just from many landraces but also from hundreds of other wheats that have been bred into them. The experimental wheats on research stations have pedigrees that reflect tens of thousands of crosses that bring even more genetic variability into play.

Smale et al. (2001) have found that between 1965 and 1990, developing countries (including China) released 151 wheats whose pedigrees were known, but which had no identifiable CIMMYT ancestry. For these varieties, the average number of distinct landrace ancestors per pedigree was 19. Over the same period, developing countries released 999 CIMMYT-related wheats. The average number of distinct landrace ancestors per pedigree for these varieties was 45, over twice as high.

Researchers are attempting to measure the value of genetic diversity in various ways, partly because it is important for national policy makers to appreciate the considerable value of the genetic resources that a collaborative, open breeding system makes available to countries worldwide. One recent study (Smale et al. 1998) sought to determine the value of an unusual strategy that CIMMYT adopted about 30 years ago to breed wheats that were resistant to leaf rust, which is the major disease of wheat worldwide. CIMMYT's strategy for breeding for resistance to leaf rust differed from the prevailing strategy of relying on resistance based on one major gene (called “race-specific resistance). Genes conferring race-specific resistance tend to produce a resistant reaction in the host plant, but their effects are overcome in a relatively short period as the rust pathogen mutates. In contrast, CIMMYT bred complexes of many minor genes for resistance (called “race-nonspecific resistance”) into its wheat varieties. This greater diversity of genes had partial and additive effects. Although the wheat plant may succumb slightly to rust disease, the many minor genes work together to slow the progress of the disease, with the result that farmers’ yields are protected. For the last 20 years, wherever this race-nonspecific resistance has been used, it has prevented major leaf rust epidemics, serving as valuable genetic insurance against economic losses.

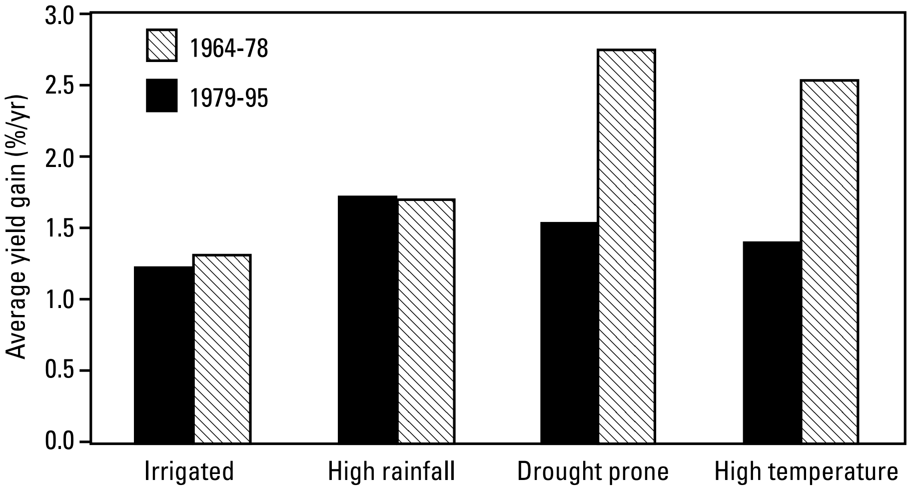
Smale et al. (1998) found that the economic benefits of breeding for nonspecific resistant to leaf rust in bread wheats are substantial. Using extremely conservative assumptions, they estimated that the gross benefits generated between 1970 and 1990 through CIMMYT’s strategy for incorporating nonspecific disease resistance into wheat in the Yaqui Valley of Mexico were US$ 17 million (in 1994 real terms). This translates into an internal rate of return on capital of 13%, which satisfies even the most stringent investment criteria. However, when Smale et al. based their calculations on less conservative assumptions, they estimated a 40% rate of return for the Yaqui Valley. About 150,000 hectares of wheat are grown in the Yaqui Valley. Throughout the developing world, where wheat covers many millions of hectares, the rate of return to leaf rust resistance research is probably considerably higher. Presently a study is underway to estimate those returns.

Some may wonder if some day we will run out of useful genetic diversity to feed into our breeding efforts, including our search for higher yield potential. I do not think that this day will come any time soon. Much of the diversity in wheat genetic resources has yet to be identified, let alone used. As the tools of biotechnology become increasingly available—for example, as genomics begins to unlock information on the function of genes, and as the technology to develop transgenic wheat improves—we can expect to see a greater use of wheat genetic diversity than before. In some cases we could also see impressive yield gains: for example, if genetically modified, herbicide-resistant wheat could be developed, I believe that farmers in the developing world could see yield gains of 20%.

In the final analysis, yield increases and, consequently, productivity increases, will not be the result of any one technology, but rather of a combination of factors. New, even higher yielding varieties must be inserted in diversified and environmentally sound agricultural systems managed by farmers who make efficient use of water, soil, and fertilizer. I will discuss some of those technologies later.

Raising yields in marginal areas

In the last two decades, wheat yield potential has been rising at a more rapid rate in marginal areas than in favorable environments (Lantican and Pingali, forthcoming) (Figure 3). Data generated from CIMMYT's International Spring Wheat Yield Nursery (ISWYN) and the Elite Spring Wheat Yield Trial (ESWYT) indicate that growth in wheat yield potential in drought-prone environments has been rising at the rate of about 3.1% from 1979-99 or approximately 80 kilograms per year. In contrast, wheat yield potential in favorable environments (irrigated and high rainfall areas) has been rising at a rate of 1% a year or 62 kilograms per year in irrigated areas and 70 kilograms per year in high rainfall areas.



Rate of yield Gains in favorable and marginal wheat environments, 1964-95.

Source: Lantican and Pingali (Fourthcoming).

What caused wheat yield potential to grow so fast in marginal areas? In some cases, newer, higher yielding wheat varieties developed for favored areas finally became available (or "spilled over") to farmers in more marginal areas. CIMMYT's Veery wheats, for example, were originally developed for favorable environments about two decades ago, but they have adapted well to marginal environments). The Veery wheats and their descendants, which yield extremely well in favorable environments and are well adapted to drought in marginal areas, have yielded better than other cultivars in both high yielding environments and under reduced irrigation.

In other cases, innovative breeding programs for marginal environments crossed varieties with high yield potential to drought-resistant cultivars. For example, Nesser, a wheat bred from the high-yielding CIMMYT variety Jupateco 75 and the drought-tolerant Australian variety W3918A, has performed well in the dryland environments of West Asia and North Africa**.**

Drought tolerance

It is unlikely that the anticipated productivity growth in high-potential environments will meet the growth in demand for wheat from the present to 2020. Attention should also be paid to gains in wheat productivity in marginal areas, many of which are either prone to drought or experience high temperatures. With increasing population pressure in the developing world and declining investment in irrigation, improved agricultural productivity in marginal areas could be one of the key means of attaining food security in the coming years.

Though significant progress has been made during the past 30 years in developing wheats suitable to marginal areas, can we improve upon or maintain these rates of progress? Early CIMMYT varieties developed for favorable environments were useful for breeding wheats for marginal environments, but there are indications that progress can accelerate through breeding wheats specifically for moisture stress conditions (Figure 4).

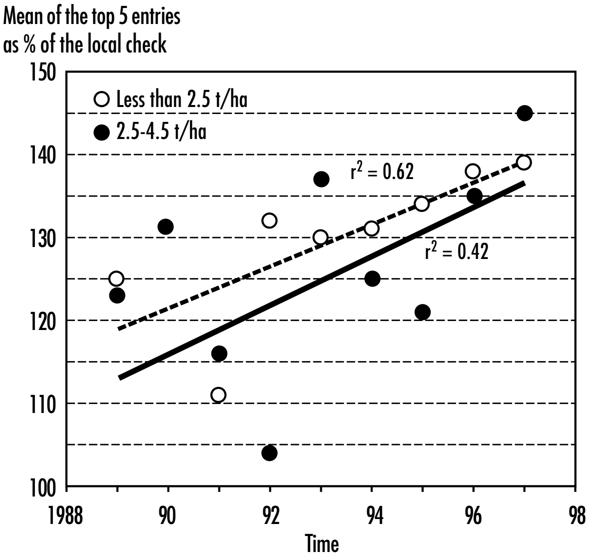


Figure 4. Trends in yield over time in low and intermediate yielding environments.

Already, 55% of the area sown to wheat in developing countries is periodically drought stressed, and analysts predict that drought caused by reduced water availability will increase in the irrigated areas where most developing country wheat is produced. A serious concern is what this implies for the developing world's food supply, especially in regions where a large portion of the population's diet is based on wheat. Rising populations place greater demands on water supplies while requiring more food to subsist. Burgeoning populations also drive urban development and industry, which siphon off increasing amounts of water, leaving less for food production.

CIMMYT's response: Breeders are improving the capacity of CIMMYT wheats to yield well under drought. Crop varieties that yield more per unit of water will improve water productivity in arid areas. Since drought occurs in different patterns, breeders are working on early-maturing varieties that are able to escape moisture stress at the end of the cycle, as well as late-maturing wheats that slow their development so as to benefit from late rains when there is drought early in the season. New, hardy bread wheats in the pipeline at CIMMYT have been designed for dry locations. These wheats are descended from crosses between different types of wheat and goat grass, one of wheat's wild relatives. Though still under development, the new wheats have produced up to 30% more grain for two years running in tests comparing them to one of their parents under tough dryland conditions. Drought tolerance genes inherited from their wild ancestor have made all the difference. Seedlings of the new wheats are so vigorous they can force their way up through crop residues and from lower soil depths. This vitality comes from deep roots that anchor them firmly in the ground and from long, strong coleoptiles that push through the soil and any stubble on the surface. Plants also protect themselves from drought by producing numerous leaves that extend outward horizontally and quickly cover the ground, shading the soil and conserving moisture.

Developing drought-tolerant wheat is just one of several water-related research areas investigated at CIMMYT. CIMMYT is also developing methods that improve irrigation water use efficiency and agronomic practices to help farmers cope with diminishing water supplies; these projects will be discussed below.

Nutrition: Feeding the hidden hunger

A fundamental wrong perpetrated on the world's most vulnerable people—namely, women and children—is to deprive them of an adequate diet. Each year millions of children die from "hidden hunger" caused by their unsatisfied need for minerals and vitamins. Though micronutrients are needed in minute amounts, their lack can have disastrous effects. For example, anemia caused by insufficient iron can affect young children's cognitive and learning abilities and diminish work productivity in adults. Zinc-deficient women may suffer more complications and mortality during childbirth, while children may present retarded growth and skeletal deformities. These problems are severe in Asia, Africa, and Latin America.

Traditionally nutritional problems have been combated through health education programs, vitamin supplementation, and fortification of staple foods. Although successful in the industrialized world, these approaches tend to be costly and unsustainable in developing nations. Grain that is bred to be naturally rich in micronutrients may be a complementary, inexpensive, and sustainable means of preventing malnutrition (IFPRI 2000).

Cereal grains, wheat among them, furnish the energy people need to survive, but they are not particularly good sources of micronutrients. Because wheat is the most widely consumed crop in the world, improving its nutrient content could have significant impact on human nutrition, and there are indications that iron and zinc levels can be increased through plant breeding. If micronutrient-rich wheat were widely available in developing countries, the malnourished poor who eat wheat every day would automatically receive iron and zinc without having to take supplements or purchase more expensive foods. This would have the added advantage of producing considerable economic benefits, since it is becoming increasingly clear that better-nourished, healthier people have higher incomes and contribute more to national income growth.

CIMMYT has started addressing the challenge of developing nutrient-rich wheat in collaboration with the University of Adelaide, using seed money provided by the CGIAR Micronutrients Project. So far, the groundwork has been laid for further research on raising micronutrient levels in wheat grain. For example, good variability for iron and zinc levels, which is essential to breed for enhanced content of these nutrients in wheat, was found in wheat landraces and wild relatives. The results also show that increased micronutrient content in wheat is not linked to lower wheat yields, indicating that it is possible to breed varieties that will produce high quantities of micronutrient-rich grain. CIMMYT hopes one day to incorporate the genes that increase grain protein content into all CIMMYT wheats, but additional support is needed to continue this valuable research.

Ecologically wise agronomic practices

What can we do to encourage ecologically conscious farming, especially among farmers with few resources? CIMMYT has not overlooked the development of sound cropping practices. Appropriate practices are indispensable if modern varieties are to realize their full genetic potential. Such practices help farmers make more efficient use of inputs such as water and fertilizers, reduce their production costs, increase their income, and produce high quality wheat. But beyond that, sound cropping practices can greatly reduce the impact of agriculture on the environment.

Water use. As water scarcity becomes more common in irrigated environments, the source of 40% of developing world wheat production, helping farmers make wise use of available moisture is of the highest priority. Now available are CIMMYT-derived varieties that possess tolerance to different types of moisture stress; however, they are only one part of the equation, and should be complemented by cropping techniques that promote more efficient water use. A very promising technology for reducing the amount of water used in farming is bed planting, a technology developed by farmers in irrigated areas in Mexico’s Yaqui Valley. Bed planting is being improved and adapted for use in different environments by CIMMYT researchers in collaboration with our partners in the national agricultural research systems (NARSs) of the developing world.

Used in conjunction with reduced tillage and residue retention, bed planting has resulted in higher yields (at least 10%) and dramatic reductions in production costs (possibly as much as 50%). More importantly, researchers working to adapt the technology to irrigated wheat production systems in Asia have reported water savings of 30% or more, a major achievement in a region where water scarcity will be acutely felt in the coming decades.

Conservation agriculture. CIMMYT researchers have also been very active in developing and disseminating other resource-conserving technologies. These technologies usually involve reducing or eliminating plowing and keeping crop residues on the soil surface. Their benefits may include reduced erosion, labor and fuel savings, more timely land preparation, better water infiltration, and increased soil organic matter.

An example of an effective resource-conserving technology is surface seeding, which allows farmers in South Asia to sow wheat right after, or even before, the rice harvest. Prompt planting is important because yields diminish 1.3% for every day that sowing is delayed. This simple method requires no plowing and is especially suited to poorly drained land with heavy soils that impede normal tillage. It also reduces production costs by one-third and requires no implements, making it ideal for the poorest farmers.

In some instances, conservation agriculture systems can be made more efficient if farmers have access to more appropriate wheat varieties. In Brazil and Argentina, for example, where wheat is grown in zero-tillage systems, productivity will be considerably improved when farmers have wheats that resist a complex of foliar diseases that includes Septoria, helminthosporium, and fusarium head scab. Such resistance would go a long way to holding back the evolution of the pathogens that cause these diseases.

Reducing nitrogen losses into the environment. Experts predict that by 2025, two-thirds of all nitrogen fertilizer applications will occur in the developing world. If the efficiency of those applications is not improved, this will result in increased leaching of nitrogen into fresh water and marine ecosystems and the emission of nitrogen-containing gases into the atmosphere.

Aware of the difference cropping practices could make in reducing nitrogen losses, CIMMYT has initiated studies aimed at improving the way nitrogen is used and reducing the amount that is lost into the environment. Working jointly with University of California and Stanford University scientists, CIMMYT researchers did an integrated assessment of the ability of different fertilizer management alternatives to reduce nitrogen gas emissions and at the same time produce economically attractive results, which is essential if farmers are to adopt them. They also tracked what happens to applied nitrogen that is not taken up by the crop.

Results revealed that the amount of nitrogen fertilizer farmers apply can be reduced by almost 30% without affecting yield, and if nitrogen is applied when the crop starts taking it up quickly from the soil, yield goes up and the amount of nitrogen that leaches into the soil diminishes substantially (Matson, Naylor, and Ortiz-Monasterio 1998). They also found that by applying nitrogen at a certain crop development stage, grain protein concentration increases, which means higher quality, more nutritious grain.

As noted earlier, an essential, but often forgotten, benefit of higher yielding semidwarf varieties is that thanks to their capacity for producing more yield per unit area, it has been possible to preserve fragile ecosystems that otherwise would have been brought into cultivation to meet growing food demands. Another advantage implicit in modern varieties is their genetic resistance to many diseases and pests, which means that producers do not have to spray chemicals for control, thereby reducing the risks to human health and the damage to local ecosystems.

Wheat quality

During the late 1980s, the quality of CIMMYT's bread wheat germplasm was satisfactory for producing hearth breads (e.g., French-type bread) using semi-mechanized methods and for producing diverse flat breads, chiefly by hand. Few advanced lines possessed enough gluten strength and extensibility for the mechanized manufacture of pan-type breads. At that time, wheat germplasm was targeted mainly to areas where increasing wheat production and productivity were more important than improving wheat grain quality. Since there is a direct, inverse relationship between yield and quality (i.e., the higher the yield, the lower the quality, and vice versa), improving end-use quality could not be justified as a major breeding goal. Besides, at that time higher quality wheat did not fetch higher prices than regular wheat.

In the early 1990s, quality improvement became more important in wheat breeding programs around the world, especially in countries where wheat markets were liberalized and end-use quality traits such as protein content and gluten strength determined the commercial value of the wheat crop. In 1995 CIMMYT's bread wheat program gradually increased quality selection pressure and started using genotypes with strong, extensible gluten in new crosses. Selecting for quality parameters is now fully integrated into CIMMYT’s wheat breeding programs.

Modern methodologies such as biotechnology offer the possibility of investigating the genetic and biochemical basis of individual protein subunits and other molecules contributing to the end-use quality of wheat. Using genetic transformation, new cultivars with improved quality can be developed through the insertion of genes coding for key grain quality attributes. Molecular marker technology is expected to increase the efficiency and speed of breeding for quality.

Towards a broader vision for agricultural research

These research efforts, encouraging as they are, must be weighed in the balance with the challenges that face a globalizing world. It is all too clear that unless rural people—who still form 70% of the population of developing countries—gain wider opportunities to improve their lives and nutritional status, society and the environment will pay a price. As I have heard Nobel Laureate Norman Borlaug say, “Hungry people are angry people.” We know that they will not stay in the countryside and starve; they will migrate into protected ecological reserves, to urban areas, or other countries to stay alive. As agricultural researchers, we have the responsibility to convince society, especially its more privileged members, that we must do everything we can to offer these people a better choice. In other words, we must continue to demonstrate that global endeavors on behalf of poor people are valuable for all of society. Agriculture is not marginal to the major economic, social, and environmental issues confronting a globalizing world. It is even more relevant than before.

At a time when there is a great deal of weariness over the plight of poor people, especially those trapped in unremitting conflict and famine, it is time for some new energy and new thinking. A plant breeding program such as the CIMMYT Wheat Program cannot afford—indeed, does not have the right—to pursue a single-minded agenda; we need a broader vision and a broad range of partners. The traditional thinking that has partitioned development efforts into discrete areas (“agriculture,” “health,” and so on) is as limiting, in my opinion, as research that focuses solely on one discipline, or one crop. It is high time that more flexible and better-funded coalitions for development are formed and given the freedom to act.

This need for active, broad involvement is particularly important when we consider the plight of many of our partners in public research organizations worldwide. In the wake of repeated downsizing, they have been left with little financial and human capital to accomplish their goals, and in many cases the private sector has not stepped in to assume some of their functions. When I first came to CIMMYT in the 1969, just a few years after the Green Revolution, it would never have occurred to me that by the first decade of the 21st century the need to train young researchers would be just as urgent as it was in my early CIMMYT days. But it is. The great technological divide between developing and industrialized nations has made it imperative to provide more practical, technical education to our peers in developing countries, because these people are the foundation of our knowledge base.

As mentioned in this year’s *Human Development Report* (UNDP 2001), “investment in agricultural research has rarely been seen as a central tool for development,” and “the notion of global programming is still unfamiliar in many [development assistance] agencies.” Development strategies are crippled by “too many small initiatives” and a “short-term demand for results.” Support for “research excellence for an alternative agenda,” which pursues objectives that are not necessarily relevant to industrialized world, is lacking. The progress of the AIDS epidemic is a good example of where this lack of global collaboration and vision can take us. It has taken the world two decades to start responding to the needs of AIDS victims in developing countries, and the conscience of society has been moved less by activists in the public sector than by decisive intervention by one powerful, private philanthropist. I would not like to see this happen with agricultural development. One of our most important roles is to serve as advocates and partners for international development research for the public good.

Just as we need to expand our partnerships with the public sector, we need to form constructive alliances with the private sector that improve rather than constrain poor people’s access to the best new options for their future. We have several examples of these sorts of alliances at CIMMYT. Our policy is to enter into such agreements only if they enhance CIMMYT’s ability to achieve its mandate of service to the resource-poor and the environment. A particular agreement is suitable if it helps us to speed the development of new, appropriate technologies and deliver them to farmers’ fields in developing countries.

The CIMMYT Wheat Program has a few arrangements with private companies, some based in developed and others in developing countries. Under all of these agreements, our private-sector partners help to fund areas of our research in which they have a particular interest—for example, hybrid wheat, or disease resistance, or particular quality traits. Although we make the products of that research available to these private companies, we also make them freely available to all of our partners in developing countries. It is essential to point out that these partnerships work for two reasons: first, because CIMMYT’s research products have value for private organizations, and second, because our agreements with the private sector do not restrict us in any way with respect to our primary research partners in developing countries.

I am aware that alliances with a broader range of organizations, especially private organizations, raise fears over the negative aspects of globalization, such as the potential for manipulation by large corporate interests, and cynicism about private corporations’ claims that they are “good global citizens.” I would like to think, however, that just as plant breeders were the forerunners of an ethical, global approach to development, we can continue to forge agreements with research partners, including the private sector, that build upon our research strengths and also serve the interests of the world’s poorest people.

In our work over the years in developing countries, my colleagues and I have seen that many basic human rights—to health, income, education, a clean environment, women’s advancement, children’s protection, and even peace—depend on stable, productive agriculture. Whether we like it or not, globalization is a reality, simply because we are all living on the same planet and using its resources. It is my great hope that the existence of this Award, and the continuing recognition it will provide for people who are working towards human rights through agriculture, will continue to emphasize the benefits of collaborating for the public good and not simply for private interests, and generate support for those efforts.

References

Brennan, J.P., and P.N. Fox. 1995. *Impact of CIMMYT Wheats in Australia: Evidence of International Research Spillovers.* Economics Research Report No. 1/95. Wagga Wagga: New South Wales Agriculture.

Byerlee, D., and P. Moya. 1993. *Impacts of International Wheat Breeding Research in the Developing World, 1966-90.* Mexico City: International Maize and Wheat Improvement Center (CIMMYT).

Cassaday, K., M. Smale, C. Fowler, and P.W. Heisey. Benefits from giving and receiving genetic resources: The case of wheat. *Planet Genetic Resources Newsletter* (forthcoming).

Evenson, R.E. 2001. Economic impacts of agricultural research and extension. In B.L. Gardner and G.C. Rausser (eds.), *Handbook of Agricultural Economics*. Amsterdam: Elsevier.

Falcon, W.P. 2000. Globalizing germplasm: Barriers, benefits, and boundaries. Presented at the 24th International Conference of Agricultural Economists, 13-18 August 2000, Berlin, Germany.

Grace, P., P. Sanchez, J. Ingram, C. Palm, Reiner Wassman, M. Fisher, R. Thomas, F. Chandler, W. Bowen, R. Reid, M. Wopereis, and S. Waddington. 2000. The consequences of international agricultural research on greenhouse gas emissions and global climate change. Unpublished report prepared for the Inter-Center Working Group on Climate Change, Consultative Group on International Agricultural Research (CGIAR), Washington, DC.

Heisey, P.W., M. Lantican, and H.J. Dubin. *Assessing the Benefits of International Wheat Breeding Research in the Developing World: The Global Wheat Impacts Study, 1966-1997.* Mexico City: International Maize and Wheat Improvement Center (CIMMYT) (forthcoming).

Hewstone, C.R. 1996. Advances in breeding winter and facultative wheat for southern Chile. In *Abstracts*, 5th International Wheat Conference, 10-14 June 1996, Ankara, Turkey. Ankara, Turkey: Ministry of Agriculture and Rural Affairs, International Maize and Wheat Improvement Center (CIMMYT), and International Center for Agricultural Research in Dry Areas (ICARDA). P. 34.

IFPRI (International Food Policy Research Institute). 2000. Improving human nutrition through agriculture: The role of international agricultural research. *IFPRI Research Perspectives* 22(1).

Lantincan, M., and P.L. Pingali. Growth in wheat yield potential in marginal environments. In *Proceedings of the Warren E. Kronstad Memorial Symposium, 15-17 March 2001.* Mexico City: International Maize and Wheat Improvement Center (CIMMYT) (forthcoming).

Lipton, M., with R. Longhurst. 1989. *New Seeds and Poor People*. London: Unwin Hyman.

Matson, P.A., R. Naylor, and I. Ortiz-Monasterio. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science* 280: 112-114.

McCalla, A.F. 2000. *Agriculture in the 21st Century.* CIMMYT Economics Program 4th Distinguished Economist Lecture. Mexico City: International Maize and Wheat Improvement Center (CIMMYT).

Pinstrup-Anderson, P., and M.J. Cohen. 2001. Rich and poor country perspectives on biotechnology. Presented at the Pre-Conference Workshop, “Agricultural Biotechnology: Markets and Policies in an International Setting,” at the Annual Conference of the Australian Agricultural and Resource Economics Society, 22 January 2001, Adelaide, Australia.

Pinstrup-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. 1999. *World Food Prospects: Critical Issues for the Early Twenty-first Century.* Washington, DC: International Food Policy Research Institute (IFPRI).

Raeburn, P. 1995. *The Last Harvest: The Genetic Gamble that Threatens to Destroy American Agriculture.* New York: Simon and Schuster.

Rasmusson, D.C. 1996. Germplasm is paramount. In M.R. Reynolds, S. Rajaram, and A. McNab (eds.), *Increasing Yield Potential in Wheat: Breaking the Barriers.* Mexico City: International Maize and Wheat Improvement Center (CIMMYT). Pp. 28-35.

Rosegrant, M.W., M.A. Sombilla, R.V. Gerpacio, and C. Ringler. 1997. Global food markets and US exports in the twenty-first century. Presented at the Illinois World Food and Sustainable Agriculture Program Conference, Meeting the Demand for Food in the 21st Century: Challenges and Opportunities, 28 May, University of Illinois, Urbana-Champaign.

Smale, M., R.P. Singh, K. Sayre, P. Pingali, S. Rajaram, and H.J. Dubin. 1998. Estimating the economic impact of breeding nonspecific resistance to leaf rust in modern bread wheats. Special Report. *Plant Disease* September 1988: 1055-1061.

Smith, L., and L. Haddad. 2000. *Overcoming Child Malnutrition in Developing Countries: Past Achievements and Future Choices.* Washington, DC: International Food Policy Research Institute (IFPRI).

UNDP. 2001. *Making New Technologies Work for Human Development.* Human Development Report 2001. New York: Oxford University Press.

World Bank. 2000. *Poverty in an Age of Globalization.* Washington, DC: World Bank. (Check internet site to see if complete cite.)