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Sixty-two years of fighting hunger: personal recollections

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Abstract International wheat breeding began 60 years ago in the Mexican-Rockefeller Foundation Office of Special Studies. A novel technique of shuttle breeding was adopted in Mexico, enabling photoperiod sensitivity to be overcome, a pivotal step in creating internationally adapted spring wheat germplasm that eventually spread throughout the world. The high-yielding technologies developed in Mexico helped revolutionize cereal production during the 1960s and 1970s, and came to be known as the "Green Revolution." In the process, a highly effective system of international agricultural research centers evolved under the umbrella of the Consultative Group for International Agriculture (CGIAR). This international system has weakened in recent decades, despite the enormous challenges facing humankind to expand food production in environmentally sustainable ways. Biotechnology holds great promise to develop improved crop varieties to deal with new pests and diseases, drought, and to enhance nutritional content. Those on the food front still have a big job ahead of us to feed the world. There is no room for complacency.

Keywords Wheat · Green revolution · CIMMYT · Rockefeller foundation

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Before I move on to the subject of my speech, I want to pay special tribute to the people and farmers of the Yaqui valley and the young wheat researchers that helped to develop the high-yielding wheat cultivars and crop management technologies that revolutionized wheat production in Mexico and later in many parts of the world. In a very real way, the Yaqui valley is the birthplace of the Green Revolution. So it is fitting that this conference on wheat yield potential be held here.

I came to Mexico in 1944 to join the first cooperative international program in agriculture, namely the Rockefeller Foundation-Mexican Government program, called the *Oficina de Estudios Especiales (OEE)*. This program grew out of an official visit of US Vice-President elect Henry Wallace in 1940, who also was the founder of Pioneer Hybrid Co., now owned by the DuPont Co, and quite an agricultural researcher and statistician in his own right. When he visited Mexico in 1940, officially to represent the US at the inauguration of President Avila Camacho, Wallace drove from Iowa with his wife in his own car, no security, stopped in farmers' fields all along the way, and talked with them in Spanish about production problems. After the inauguration ceremony, Wallace spent 2 days in the Bajio region between Guadalajara and Queretaro with the incoming Secretary of Agriculture, Marte R. Gomez, and the outgoing Mexican president, Lazaro Cardenas. Here, he saw the impact on production of worn-out soils, some of which were probably cultivated long before the Spaniards came to Mexico in the early 1500s. The three talked about ways that the US government might help the Mexican government revitalize its agriculture. Wallace said he wanted to help, but he doubted that the US government could help at that time, since WWII was underway in Europe and the Pacific, and it was only a matter of time before the US would be directly engaged as well. However, Wallace did have an idea.

Upon his return to the USA, Wallace got in touch with Raymond Fosdick, President of the Rockefeller Foundation, which already has medical assistance programs in China underway. Wallace hoped that perhaps a private foundation could be mobilized to do something. The Rockefeller Foundation responded by sending a team of three eminent US agricultural scientists, geneticist Paul Mangelsdorf from Harvard University, agronomist Richard Bradfield from Cornell University, and plant pathologist E.C. Stakman from the University of Minnesota, to conduct a feasibility study. Their report in 1942 led to the creation of the Rockefeller Foundation-Mexican government OEE program in 1943. I joined in 1944, through the efforts of my major professor, Dr. Stakman.

The OEE began 6 years before the Marshall Plan was established to help rebuild Europe after WWII, and 5 years before President Truman's Point 4 program which evolved into USAID. CIMMYT's wheat research program is a spin-off from this original OEE program. Indeed, this could also be said for the whole network of international centers under the umbrella of the Consultative Group for International Agricultural Research (CGIAR). All of this institutional development can be traced back to Mexico, and in many important ways, to this valley.

Our mission in OEE was to train a new generation of Mexican scientists across all the disciplines to address the research and production challenges in Mexico's main food crops, namely maize, beans, wheat, and later potatoes. There was no agricultural extension organization in Mexico, so we researchers, when we thought we had something superior to demonstrate, took the technology to farmers' fields for testing, where it was evaluated, modified, and when superior, promoted more widely among farmers.

My charge was to improve national wheat production. A pretty tall order, especially since I didn't even speak a word of Spanish. At the time, Mexico's population was 22 million and wheat consumption in Mexico was around 500,000 tons, with imports accounting for 55% of the total (See Fig. 2). As I toured the traditional wheat-producing areas of the central highlands and the mid-elevation *Bajio* region between Queretaro and Guadalajara, I was discouraged. The soils, many of which had been cultivated long before the Spaniards colonized Mexico, were depleted of nutrients, and farmer wheat yields were typically 500 kg/ha or less. Frankly, I didn't see how Mexico could become self-sufficient in wheat production if it only depended upon the traditional wheat-producing areas. But I also heard about some of the new irrigated areas that were opening up in northwest Mexico, fruits of major water resource development projects of the government. In particular, the newly irrigated Yaqui valley of Sonora was mentioned as a potential location for expanded wheat production. My first trip to the isolated northwest revealed that there were several hundred thousand hectares, with irrigation, that were highly suitable for wheat production during the cooler winter season, from November to April.

When I began working in Mexico there were no Mexican agricultural scientists with an advanced degree in the entire country, so training was one of the major Rockefeller Foundation objectives from the outset. Our final goal was to pass the research program over to a cadre of trained Mexican scientists as soon as possible. I should point out that at that time there were no graduate schools in the agricultural sciences anywhere in Latin America. Indeed, one of the last activities under the Rockefeller Foundation programs was to establish the *Colegio de Postgraduados* at *Chapingo* University in Texcoco, near Mexico City. Later on, other Mexican universities established graduate programs in agricultural sciences.

The late Roldolo Elias Calles, son of the famous Mexican President, Plutarco Elias Calles, and in his own right, a former governor of the state of Sonora as well as a farmer, set up in 1930s what must have been an outstanding experiment station in the Yaqui valley. A physical plant was constructed, fields were laid out for crop research, and good races of cattle, swine, and poultry were acquired. The first research director, Edmundo Taboada, screened many wheat cultivars, and selected Mentana for commercial use. During 1939–1941, there were three consecutive epidemics of stem rust that took all of the wheat in the valley. Hence, developing stem rust resistant varieties was one of our first research objectives. The first trials were planted in the fall of 1945 and harvested in the spring of 1946, almost 60 years ago to the day of this conference.

When I arrived in 1945, the original Yaqui valley experiment station was in shambles. There was no machinery left, no electricity, and the windows were broken. Nevertheless, that's where I stayed, sleeping on a cot and cooking over an outdoor stove. The station superintendent, Ing. Ricardo Leon Manso, had little or no budget but was still eager to support our work. Critical to our success, however, were several Yaqui farmers. I would like to acknowledge two in particular. One was the late Ing. Rafael Angel Fierros, a new farmer just getting started; who helped us with machinery. The other was Aureliano Campoy, who farmed the next door neighbor to the experiment station. He too loaned us machinery and helped us in many ways.

The need to develop rust-resistant varieties as quickly as possible led to the genesis of "shuttle breeding." Initially, our objective was to speed up the breeding process. It took 10–12 years to breed a rust-resistant variety I knew that I would never have 10–12 years in the RF program to do this. I had to speed up the process. Since it was far too hot to grow wheat in the northwest during the summer, we searched for a site in the central highlands near Mexico City; we found ideal locations in the Toluca valley and at Chapingo. However, the summer and winter season locations were move 10° latitude apart, from 22° N in the Yaqui valley to 12° N in Atizapan in the Toluca valley and to Chapingo in the valley of Mexico City, and more than 2,000 meters different in elevation—from near sea level in the north to more 2,200–2,600 m elevation around Mexico City. Thus, the climates differed greatly between the two growing environments, from relatively hot temperatures in the north, where virtually all moisture was supplied through irrigation, to cool mountain climates in central Mexico, where it rained heavily two to three times a week and where there was always dew in the morning, ideal conditions for the build up of disease inoculums (Fig. 1).

By planting segregating generations and selected plants in the Yaqui Valley, when the days are shorter, and then in central Mexico, when the days are longer, we were able to overcome photoperiod sensitivity. Achieve photoperiod insensitivity was a case of serendipity, since this was before much was known about photoperiodism. We selected the best plants from segregating populations in each location and shuttled them back and forth between northwest and central Mexico over successive cycles. Within 4 years (eight seasons), we had promising cultivars selected, which we continued to yield test for two more cycles before we made the final decision. So we more than cut in half the time traditionally needed to produce a stem rust resistant variety.

Some might be able to imagine the criticism I received from my former professors at the University of Minnesota and many other breeders. They thought my shuttle breeding scheme was madness. "One step forward and one backwards," most said. But we forged ahead, and look what happened.

After we released the first new varieties in 1948–1950, we turned our attention to the soil fertility issue. Most farmers in the Yaqui valley said, "this is the best soil in the world and it doesn't need fertilizer." It was good soil but it still needed nitrogen, and in some place phosphorus. The first field day I guess was in

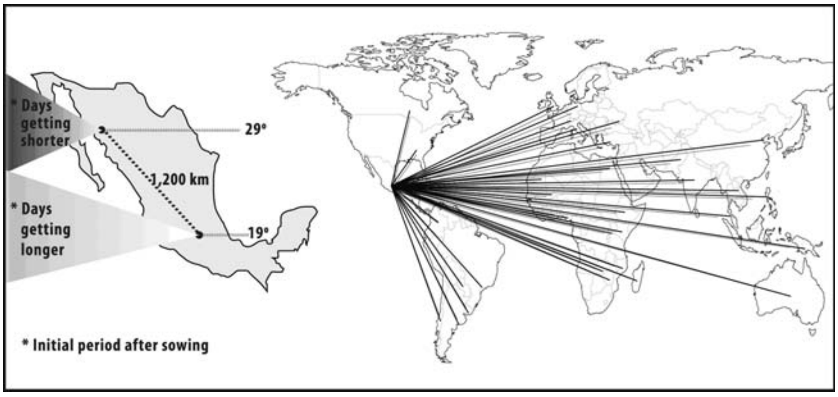

Fig. 1 Shuttle breeding and multi-location international testing produced the broadly adapted Mexican wheat that triggered the green revolution

1947. We put notices in the newspaper and radio, saying that after the field day, we would also have barbecue and beer at the end of the tour. I think only about two farmers and about 20 government employees showed up. But the demonstration plots spoke for themselves. We had the new varieties, had applied fertilizer properly, and practiced good weed control.

By 1948, suddenly there were hundreds of farmers and then Rodolfo Calles said, "We are convinced that this is a serious program, there are no schools for the agronomists' families, there's no market to buy the food, I am going to look for land." He did and this is the land where CIANO is located today. Soon the farmers' organization, the Patronato of Sonora, was formed and farmers contributed part of their profits to build the CIANO station and support the various research programs.

Race 15b stem rust epidemic

The Yaqui valley played another important role—as the major off-season nursery site for US and Canadian wheat breeders. How this came to be is another interesting story. In North America in 1950 there was an explosion of very virulent stem rust race, known as 15b, which had been known since 1939, but had remained relatively dormant. But in 1950 all of sudden it was everywhere. How it spread so rapidly no one knows? What we do know is that it caused disastrous epidemics for four successive years between 1951 and 1954. The 15b stem rust epidemic was so serious and so widespread in the North America, that it changed attitudes among plant breeders. An emergency program was put into place that involved collaboration among wheat breeding programs throughout North America and Latin America.

Funds were provided by the milling industry, farm machinery companies, the railroads, USDA, Canada Agriculture, and the Rockefeller Foundation to help finance growing the segregating materials from wheat breeding programs in Canada and the US. Here in Mexico we participated in the program. Farmer Roberto Maurer of the Yaqui Valley helped to find land to grow these winter nurseries for the first 2 years, in order to speed up their breeding program. The third year, arrangements were made so that these off-season nurseries from the USA and Canada could be planted on CIANO.

This collaboration was the beginning of the international germplasm development networks that became core activities of CIMMYT, IRRI and other CGIAR centers. The panic caused by the race 15b rust pandemic brought people together. Dr. H.A. Rodenhiser, USDA's chief plant pathologist, set up an international wheat rust nursery, first in 17 countries in the Americas from Canada to Argentina and Chile; later it became a world testing organization. From this nursery, different sources of resistance not only the stem rust race 15b stem but also to leaf and stripe rust were identified. It became accepted practice that any participating breeder anywhere could select materials—either advanced lines or early-generation materials—and use them, providing the source of where it came from was acknowledged.

Now, some 50 years later, an extremely virulent new race, Ug99 from East Africa, has come onto the wheat production scene. While there is more of an international wheat breeding network in place today than there was in the early 1950s, this international network is much weaker today than it was 20 years ago. Once again, world wheat production is seriously threatened. Once again, the best way to ensure that a stem rust pandemic does not occur will be through the re-establishment and/or strengthening of the international research and training networks that previously ensured dynamic germplasm development programs and effective disease surveillance systems.

Mexico became self-sufficient in wheat production in 1958, about 15 years after the Mexican-Rockefeller Foundation program began (Fig. 2). Self-sufficiency was reached in two ways: increasing the cultivated area, especially in Sonora and Sinaloa, where wheat production became a money-making venture, and restoring soil fertility to the worn-out soils in the traditional wheat-producing areas in central Mexico. I have seen the Bajio soils, even when irrigated and well prepared, producing much less than 1 t/ha, even with the best varieties. Today, with adequate soil fertility and high-yielding varieties, these lands are producing 7.5–8 t/ha at the present time.

Birth international agricultural research centers

Few may know that the model for IRRI, the first international research institute founded by the Rockefeller Foundation and the Ford Foundation, was the OEE

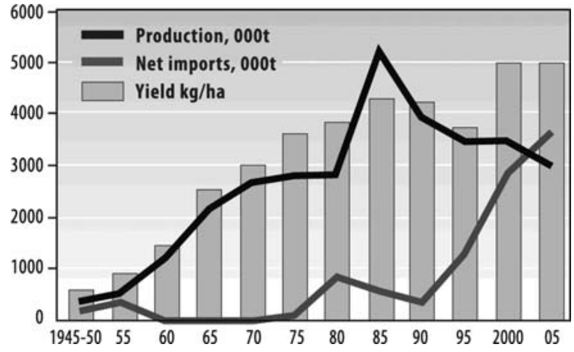

Fig. 2 Wheat production, yields and net imports in Mexico

wheat program. In 1961, Mexican President, the late Adolfo Lopez Mateos, made a trip through South East Asia. When he arrived in the Philippines, the country's President, Diosdado Macapagal, insisted that he go to see IRRI, which had been established in 1960.

A few months later in Mexico City, at a farewell banquet for the few RF staff still in Mexico, President Lopez Mateos said, "recently I visited the Philippines and was taken to the International Rice Research Institute, with its new buildings, laboratories, field research plots and enthusiastic staff. I was very impressed. As I was leaving, IRRI's director general, Dr. Chandler, said to me, 'of course Mr. President, you know that IRRI is modeled after the Mexican-Rockefeller Foundation agricultural program."

President Lopez Mateos then told us, "So I am perplexed. Why are we closing the Rockefeller's maize and wheat programs in Mexico, instead of establishing here an international maize and wheat institute, to help other Third World countries to benefit the way Mexico has, and in a way, show our gratitude." This set the wheels in motion to create the second, fully-fledged international agricultural research center, namely CIMMYT. However, this proposal didn't crystallize for several more years.

Before the decision was made, I was sent by the Rockefeller Foundation on my last consulting trip in 1960, as I began to look for a new job, as part of a FAO expert team, charged with reviewing national wheat programs from Morocco to Pakistan. Joining me on this trip were Jim Harrington of Canada and Jose Vallegas of Argentina. James Harrington, from Sasakachewan, Canada, had been the professor of late Glenn Anderson and late Frank Zillinsky, both outstanding CIMMYT scientists in the wheat program, and Leonard Shebeski, who eventually became the Dean of Agriculture at the University of Manitoba. Vallegas had been head of Argentine national wheat program.

Our FAO team visited 15 countries. What we saw almost everywhere, was a shortage of trained people, except in India and Egypt, which had quite a few well-trained scientists but with too many of them wearing white coats, staying in their laboratories, continuing to do research on some basic study that they had done for their doctorate degree, with little relevance to producing more wheat. In our report, we proposed the establishment of a practical wheat-training program in Mexico for young researchers from Near and Middle Eastern countries.

The Mexican government agreed to make its wheat research facilities and staff available to support the in-service training program and the Rockefeller Foundation agreed to finance it. FAO also agreed to participate and assigned one of its program officers, Abdul Hafiz, who was based in the FAO Cairo office, to help pick the best young recently graduated agricultural students. We wanted young researchers, fresh out of school and still flexible and open to new ideas. We designed a 9-month training program that covered two crops cycles—one in Toluca and Chapingo during the rainy summer season and one in Ciudad Obregon during the irrigated winter season.

We also established an international yield nursery that eventually became the international spring wheat yield nursery (ISWYN) under CIMMYT, which operated for more than 30 years. Each year, the new wheat trainees handled those plots—from planting to harvesting, the breeding, the fertilizer, the irrigation, harvesting. Each new group of trainees assembled the international nursery. They were trained in genetics and plant breeding, pathology, agronomy, irrigation management, and even got some training in economics.

Asian green revolution

After 5 years, we already had a cadre of graduates from Near Eastern and Middle Eastern countries from our wheat-training program in Mexico, and a growing body of research data that these young scientists had generated on the performance of the new semidwarf varieties and associated management practices in their home countries. Soon these young scientists were about to make history.

By 1965, South Asian cereal production was in dire straights. Population was outstripping wheat and rice production, and more than 10 million tons of grain were regularly being imported to make up for the deficits. Hunger was widespread, and government leaders in Pakistan (which then included East Pakistan, now Bangladesh) and India were desperate to turn national cereal production around. As the hunger worsened, armed with the data collected by our former trainees, we moved to convince the government leaders to aggressively promote the new high-yielding wheat and rice production technologies. Malik Khuda Bakhsh Bucha, Minister of Agriculture in Pakistan, with the complete support of President Ayub Khan, and the Minister of Agriculture and Food C. Subramaniam in India, with full support of Prime Minister Indira Ghandi, made the tough and crucial decisions that led to what soon came to be known as the Green Revolution.

In 1965, we shipped 250 tons of seed of the two best semidwarf wheat varieties to Pakistan and 200 tons of seed to India. There were myriad problems in getting the seed from Mexico to Asia—all along the way. Eventually it arrived in Indian and Pakistani it arrived 6 weeks too late. Nevertheless, we had no time to check into germination, which almost ended in disaster. It turned out that the seed had been improperly fumigated in Mexico, which had damaged viability. We had to double seeding rates. With a little help from Mother Nature, the highest-yielding wheat fields ever seen in that part of the world were produced. The next year Indian agricultural minister C. Subramaniam decided to import 18,000 tons of HYV wheat seed from Mexico and Pakistani agriculture minister Malik Khuda Baskh Bucha decided to import 42,000 tons of seed a year later. Thousands of demonstrations were established throughout the wheat-growing areas of both countries. Emergency imports of fertilizer were made. The Green Revolution was on. I should point out that the Green Revolution in China happen a decade later, but then moved even faster.

Table 1 shows what has happened to cereal production in the developing countries of Asia between 1960 and 2000. High-yielding semidwarf wheat and rice varieties, from CIMMYT and IRRI, respectively, were the catalyst for this agricultural revolution. But it was the combination of factors—variety, fertilizer, timely weed control, and optimum irrigation schedules—that makes the difference. There is no magic in varieties alone. It has to be the whole package to achieve significant impact.

Bureaucracies and the fear of change

There are three bureaucracies you have to deal with when you are trying to change agriculture in developing nations: the political bureaucracy, the scientific bureaucracy, and the administrative bureaucracy. The higher a public servant—and this includes agricultural scientists—climbs in organizational hierarchy, the more conservative he generally becomes, evermore fearful that in changing something—a variety or technology—the greater the risk that something might go wrong. Rather, status quo, doing nothing, becomes more comfortable and often the preferred course of action.

Table 1 Changes in factors of production in developing Asia

	Adoption of modern varieties			Fertilizer nutrient		
	Wheat	Rice	Irrigation	Consumption	Tractors	Cereal production
	M ha/% Area		Million ha	Million tons	Millions	Million tons
1961	0/0%	0/0%	87	2	0.2	309
1970	14/20%	15/20%	106	10	0.5	463
1980	39/49%	55/43%	129	29	2.0	618
1990	60/70%	85/65%	158	54	3.4	858
2000	70/84%	100/74%	175	70	4.8	962
2005	72/87%	102/76%	178	77	6.4	1,017

Sources: Variety adoption from CIMMYT and IRRI data and authors' estimates; other factors of production based on FAOSTAT data

When I have challenged such conservatism, pointing out that rapid population growth doesn't allow us in agricultural science to settle for the status quo, I frequently have been told, "Ah, but population growth is somebody else's problem not mine as a scientist." How comfortable to be free of this responsibility but how untrue. We need bold changes to keep the food supply ahead of growing population demand. Small incremental changes just won't get the job done. Nor will small incremental changes in technology induce smallholder farmers to abandon traditional crop management practices. A yield improvement of 10%—especially when yields are very low—doesn't mean much to a small-scale farmer, since such a variation would likely be attributed to the weather. What is needed are technologies that can increase traditional yields by 50, 100, or 200%. Even an illiterate smallholder farmer can calculate the benefits from such increases, and they themselves become the best advocates for policy changes with political decision-makers, and with economic policy-makers.

High yield agriculture and the environment

Figure 3 shows the contribution of high yield agriculture to environmental conservation. In 1950 world cereal production—largely produced using organic means—was 650 million tons. By 2000, it was 1.9 billion tons. This tripling was achieved through only a 10% increase in area planted to cereals. They rest of the gain came from yield increases. Had we tried to produce the harvest of the year 2000 with the technology of 1950, an additional 1.1 billion ha of land, of the same quality, would have been needed. This would have required the cutting down of vast areas of forest and the plowing up of grasslands.

Agroforestry in the Punjab

Today there is a thriving agro forestry industry in the southern Punjab, something that 40 years ago I would have never thought possible in my wildest dreams. Fast-growing plantations of poplar trees growing intensively under irrigation, inter-cropped with wheat, which is planted in the fall when the leaves were falling off the poplars. This cropping system is producing high yields of wheat and wood on a 10-year harvest rotation for the trees. There are now a large number of wood processing industries in the area, with output approaching US$ 1 billion per year.

In the early 1960s, irrigated wheat yields in India were usually less than 1 t/ha and irrigated rice was about 1.5 t/ha. Harvests were inadequate to feed the 400 million people. Today, wheat yields in this area are 4–5 t/ha and rice yields are 5–6 tons, and the country has been able to feed a population of one billion, and still find land to produce wood in combination with cereals. This is the power of agricultural technology and of the entrepreneurial spirit of farmers.

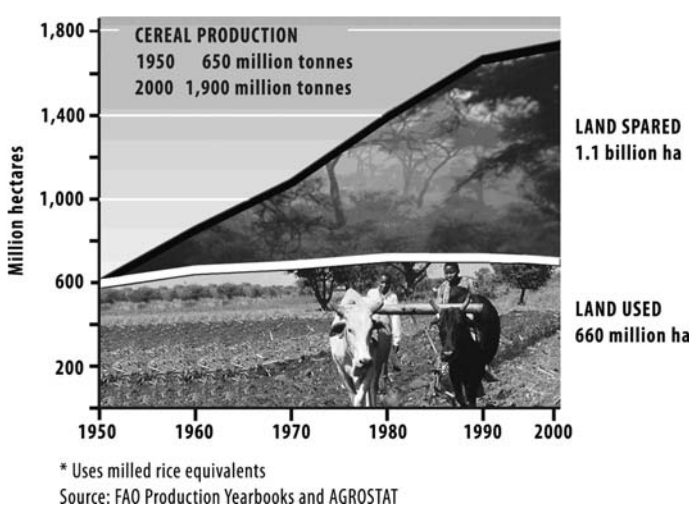

Fig. 3 World cereal* production areas saved through improved technology, 1950–2000

Expanding world food supply

Over the next 20 years, world cereal demand will likely increase by 50%, driven strongly by rapidly growing animal feed use and meat consumption. With the exception of acid-soil areas in South America and Africa, the potential for expanding the global arable land area is limited. Future expansions in food production must come largely from land already in use. The productivity of these agricultural lands must be sustained and improved. Central to achieving these productivity gains will be a "Blue Revolution," one in which water-use productivity is much more closely wedded to land-use productivity. Significant improvements in water-use efficiency can be achieved through conservation tillage, planting on beds, and drip irrigation.

The Brazilian *Cerrados*

The "*Cerrados*" area of Brazil is one of the last great agricultural areas still to be developed. The largest block of contiguous land comprises about 100 ha of land to the south of the Amazon tropical rain forest. Most of the *Cerrados* has good rainfall, very similar to what is found in the US corn belt. Historically, most of the *Cerrados* was never cultivated. It ranges from forage grasses into a combination of grass, brush and a few small twisted trees. In the areas adjacent to the tropical rainforest, there are some medium-size trees with closed canopy. The soils are highly acidic and leached of most nutrients. Twenty-five years ago, *Cerrados* land was worth $10–15 per hectare. Today, with the proper use of lime, fertilizer, and weed control, these former "wastelands" have become some of the most productive and highly valuable farm lands in the world.

Crop management research

For reasons I have never been able to fully understand, wheat agronomy research has never been given the proper financial support, neither at CIMMYT nor any other wheat research institute, for that matter. The CIMMYT wheat program began to build such a program in the 1980s, under the leadership of Glenn Anderson, who succeeded me as CIMMYT wheat director, creating several regional agronomy programs. Matt McMahon and Pat Wall were stationed in South America, a little later Peter Hobbs in Asia, and Ken Sayre and Ivan Ortiz-Monasterio in Mexico. But as soon as there is budget pressure, the first areas to suffer are agronomy and training. This has been a major error in research investment decisions, since much of the gains in productivity must come from improvements in crop management, not genetic yield potential, per se.

Conservation tillage (no-tillage, minimum tillage) is spreading rapidly in the agricultural world, and probably now covers more than 100 million ha. The first widespread application of conservation tillage was in South America—most notably in Argentina and Brazil. From there it spread throughout North America and Australia, and is now gaining ground in Europe as well. In the Indo-Gangetic plains of South Asia, conservation tillage is now practiced on several million ha.

Conservation tillage offers many benefits. By reducing and/or eliminating the tillage operations, turnaround time on lands that are double- and triple-cropped annually can be significantly reduced, especially rotations like rice/wheat and cotton/wheat. This leads to higher yields and lower production costs. Conservation tillage controls weed populations, an especially welcome contribution for small-scale farm families who must devote long hours to this back-breaking work. Finally, the mulch left on the ground reduces soil erosion, increases moisture conservation, and builds up the organic matter in the soil—all very important factors in natural resource conservation. It does, however, require modification in crop rotations to avoid the build up of diseases and insects that find a favorable environment in the crop residues for survival and multiplication.

An outstanding example of new Green/Blue Revolution technology in irrigated wheat production is the "bed planting system," which has multiple advantages over conventional planting systems. Plant height and lodging are reduced, leading to 5–10% increases in yields and better grain quality. Water use is reduced 20–25%, a spectacular savings, and input efficiency (fertilizers and herbicides) is also greatly improved by 30%.

Drought tolerance

Roughly 50% of the world's 800 million hungry people live in marginal lands and depend upon agriculture for their livelihoods. These food-insecure households face frequent droughts, degraded lands, remoteness from markets, and poor market institutions. Investments in science, infrastructure and resource conservation are needed to increase productivity and lower their production risks. Some of the problems farmers in marginal lands face will be too formidable for science to overcome. However, significant improvements should be possible. Moreover, biotechnology can play a major role, through developing new crop varieties with greater tolerance to pests and diseases, drought, and with higher nutritional content.

Increasing genetic yield potential

Continued genetic improvement of food crops—using both conventional as well as biotechnology research tools—is needed to shift the yield frontier higher and to increase stability of yield. While biotechnology research tools offer much promise, it is also important to recognize that conventional plant breeding methods are continuing to make significant contributions to improved food production and enhanced nutrition. In rice and wheat, three distinct, but inter-related strategies are being pursued to increase genetic maximum yield potential: changes in plant architecture, hybridization, and wider genetic resource utilization. In wheat, new plants with architecture similar to the "super rices" (larger heads, more grains, fewer tillers) could lead to an increase in yield potential of 10–15%. Introducing genes from related wild species into cultivated wheat—can introduce important sources of resistance for several biotic and abiotic stresses, and perhaps for higher yield potential as well, especially if the transgenic wheats are used as parent material in the production of hybrid wheat. Actually, I am of the belief that triticale, because of its extended large anthers, has greater promise for hybrid production than wheat.

The promise of biotechnology

Despite formidable opposition in certain circles to transgenic crops, commercial adoption by farmers of the new varieties has been one of the most rapid cases of technology diffusion in the history of agriculture. Between 1996 and 2006, the area planted commercially to transgenic crops has increased from 1.7 to 100 million ha.

Herbicide resistance is revolutionizing soybean production. Genes from a soil bacterium, *Bacillus thuringiensis*, or Bt, confers excellent resistance to several classes of damaging insects in maize, soybeans and cotton.

There are always those in society who resist change and who prefer to romanticize the past. However, the intensity of the attacks against GM crops from some quarters has been unprecedented, and in certain cases, even surprising, given the potential environmental benefits that such technology can bring by reducing the use of pesticides. Indeed, the use of Bt cotton alone has reduced insecticide use by more than 30,000 tons annually, and saved thousands of farmers from poisoning, plus untold numbers of other life species.

Current GM crop varieties help to control insects and weeds and are lowering production costs and increasing harvests. Future GM products are likely to carry traits that will improve nutrition and health, help guard against drought, heat and cold, and allow plants to access and more efficiently utilize plant nutrients. All of these technologies have more benefits to offer society, and especially poor farmers and consumers even more than rich ones.

However, since most of this research is being done by the private sector, which patents its inventions, agricultural policy makers must face up to potentially serious problems. How will resource-poor farmers of the developing world, for example, be able to gain access to the products of biotechnology research? How long, and under what terms, should patents be granted for bio-engineered products? Further, the high cost of biotechnology research is leading to a rapid consolidation in the ownership of agricultural life science companies. Is this desirable? These issues are matters for serious consideration by national, regional and global governmental organizations.

At the same time, developing country governments need to be prepared to work with—and benefit from—the new breakthroughs in biotechnology. First and foremost, governments must establish a regulatory framework to guide the testing and use of genetically modified crops. These rules and regulations should be reasonable in terms of risk aversion and cost effective to implement. Let's not tie science's hands through excessively restrictive regulations.

Since much of the biotechnology research is underway in the private sector, the issue of intellectual property rights must be addressed, and accorded adequate safeguards by national governments.

I believe that it is also important for governments to fund significant programs of biotechnology research in the public sector. Such publicly funded research is not only important as a complement and balance to private sector proprietary research, but it is also needed to ensure the proper training of new generations of scientists, both for private and public sector research institutions.

Dark clouds gathering over world wheat economy

Today, the world's wheat farmers face a dangerous situation. For the last 53 years we've had no major change in stem rust organism any place in the world. But in 1999, first reported in Uganda, then in Kenya and Ethiopia, and now in Yemen and Sudan, a new races of stem rust, called Ug99 (and several variant strains) has evolved that is capable of severely damaging perhaps 90% of the world's commercial bread wheat.

The publicly funded international disease screening and testing system we had 25 years ago has broken down, partly a victim of the malaise that has led to steady declines in real public sector research funding. We better wake up before it's too late.

Public agricultural research systems threatened

Agricultural research has become a substantial enterprise in both the public and private sectors over the past century, so extensive that no research director can keep abreast of the many advances in science nor can any scientist stay on top of all the changing conditions in agricultural production. Certainly, there are many management problems that must be addressed to improve the efficiency of agricultural research. But what needs to be done is far from clear.

The international agricultural research centers (IARCs) and national agricultural research systems (NARS) in the developing world certainly have advanced the frontiers of knowledge over the past four decades. However, I believe their more significant contribution has been the integration of largely known scientific information and its application in the form of improved technologies to raise farmers' incomes in order to overcome pressing crop production problems and food shortages. This should continue to be their primary mission. Moreover, impact on farmers' fields should be the primary measure by which to judge the value of IARC and NARS work. Sadly, the twin organizational evils of bureaucracy and complacency have begun to invade many international and national research institutions today.

I agree with the late Nobel Economist T. W. Shultz, that most working scientists are research entrepreneurs and that centralized control is an anathema to progress.

> "In the quest for appropriations and research grants all too little attention is given to that scarce talent which is the source of research entrepreneurship. The convenient assumption is that a highly organized research institution firmly controlled by an administrator will perform this important function. But in fact a large organization that is tightly controlled is the death of creative research. No research director...can know the array of research options that the state of scientific knowledge and its frontier afford. Organization is necessary. It too requires entrepreneurs...But there is an ever-present danger of over-organization, of directing research from the top, of requiring working scientists to devote ever more time to preparing reports to 'justify' the work they are doing, and to treat research as if it was some routine activity."

Unfortunately, agricultural science—like many other areas of human endeavor—is subject to changing fashions and fads, generated from both within the scientific community and imposed upon it by external forces, especially the politically-induced ones. Increasingly, I fear, too much of international and national research budgets are being directed towards "development bandwagons" and increasing bureaucratic red tape that will not solve Third World food production problems, and for which scientists are ill equipped to deal with.

The farmers' association of Sonora—*the Patronato*—was formed by farmers who levy a fee upon themselves to support agricultural research. They have committees that sit down with INIFAP, CIANO, and CIMMYT scientists and establish priorities, and then the *Patronato* releases funds to help support such work. Much of the land used for wheat research was purchased by the *Patronato*. They also provide various forms of financial support to those researchers and their families that they deem most helpful to the needs of farmers. It has been a tremendously effective organization. It has not been easy, however, to transplant the model to other states in Mexico. Nevertheless, this sort of farmer involvement and farmer management and oversight over public sector research is extremely important to keeping research programs on target. The importance of strong farmer-researcher partnerships cannot be overemphasized.

World peace will not be built on empty stomachs

Although the proportion of the world's population that is hunger has dropped dramatically since the 1960s—from 40% of world population to about 17%—because of rapid population growth there are still 850 million hungry people in the world and 800 million in developing countries. We still have close to 900 million adults who are illiterate—and nearly twice as many women illiterate as men—and there are 150 million primary school-age children still not in school. This is appalling in this day and age. And yet, look how the world's nations spend there money. Nearly one trillion US dollars—with the USA accounting for 56%—is spent annually on military and armaments. Is it any wonder that we see civil unrest and the growing threat of global terrorism?

Too many people live in hunger and sickness. As Lord John Boyd Orr, the first director general of FAO and a Nobel Peace Laureate said in 1950 in his Nobel acceptance speech, "peace cannot be built on empty stomachs" to which I add "and human misery."

Those of us on the food front still have a big job ahead of us. So let's get on with the job. Most of those who are in attendance today will face the challenge of producing the science and technology to increase world cereal production by at least 50% over the next two decades, and to do so in environmentally more sustainable ways. There is no room for complacency.