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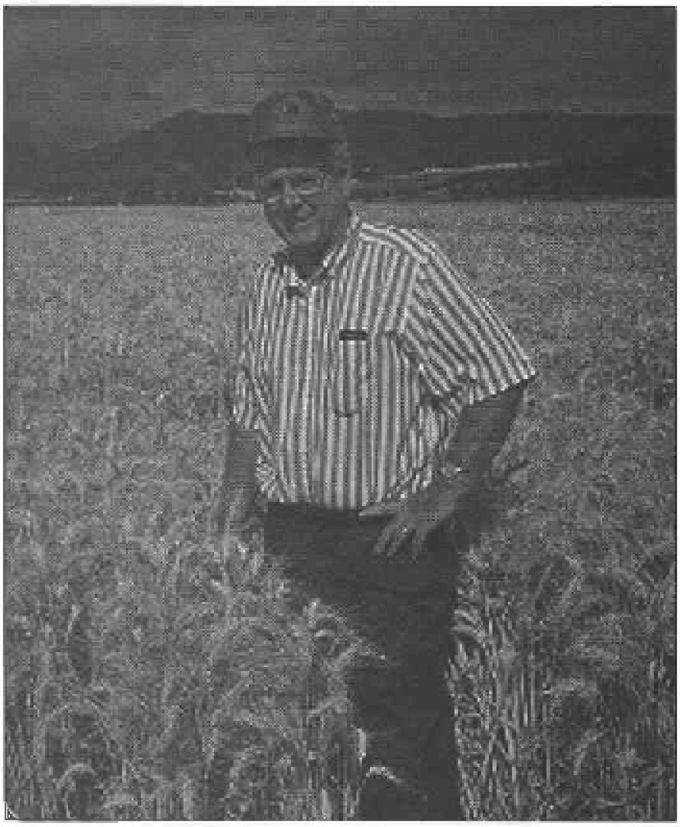
June 2000

Warren E. Kronstad Honorary Symposium

February 18, 1999



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Warren E. Kronstad Honorary Symposium

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and
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gift

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Warren E. Kronstad

Warren E. Kronstad was born March 3, 1932, in Bellingham, Washington. Following active military service from 1952-1954, he attended Washington State University, receiving a BS degree in Agronomy in 1957. In 1959, he was awarded an MS degree in Plant Breeding and Genetics from the same institution. He then joined the ARS-USDA wheat breeding program at Washington State University as a research assistant with the late Dr. O.A. Vogel. From 1959 to 1963, Dr. Kronstad served as an instructor in the Farm Crops Department at Oregon State University and received his Ph.D. degree in 1963. He remained at Oregon State University and was appointed project leader for cereal breeding and genetics in 1963. He continued to serve in this role, and many others, until his retirement on December 31, 1998.

Dr. Kronstad was an early innovator in the field of biometrical modeling to gain insight into parental selection and genetic variation within segregating populations. This contribution was cited as one of the major accomplishments in plant breeding during the 20th century at the First International Plant Breeding Symposium held at Iowa State University in 1965. Information gained through this basic research was a significant contribution in itself, but Dr. Kronstad was able to apply this knowledge through the development of genetically superior cultivars. These have included the soft white winter wheats Yamhill, Hyslop, McDermid, Stephens, Hill, Malcolm, Gene, Temple, Weatherford, and Foote; the hard white wheats Winsome and Ivory; the hard red winter wheat Hoff; the winter durum wheat Connie; three winter barleys, Casbon, Adair and Scio; and two winter oats, Lane and Amity. By utilizing suitable environmental stresses to understand more fully the nature of the interaction between genotype and environment, Dr. Kronstad and his research team have been successful in developing winter wheat varieties that not only have superior yield potential but also have yield stability when grown across environmentally diverse locations and over years.

The Wheat Breeding Project under Dr. Kronstad's leadership has generated grant funds in excess of $15 million. Monies have come from a diverse set of granting agencies including the Oregon Wheat Commission, USDA, USAID, NIH, NASA, the Rockefeller Foundation, and others.

The wheat producers of Oregon and the American Farm Bureau Federation have recognized Dr. Kronstad's contribution to agriculture on many occasions and with numerous awards such as the Distinguished Service Award, the Outstanding Achievement Award, the Service to Agriculture Award, and the Agriculturist of the Year Award. But perhaps the highest tribute to his success is evidenced by the establishment of the Wheat Research Endowed Chair, a $1,000,000 endowment, funded by the Oregon wheat producers and matched by the Oregon legislature.

Dr. Kronstad's contributions extend far beyond the domestic arena. He has been actively involved in international wheat improvement activities since the 1960s. He began his work in Turkey and was part of a team that led Turkey from deficit to surplus wheat production. For the past 20 years, Dr. Kronstad has directed a large international program focusing on the systematic crossing of winter and spring wheat germplasm to produce high-yielding, widely adapted germplasm for the less developed countries of the world. In concert with CIMMYT in Mexico, and funded by the Rockefeller Foundation and USAID, germplasm from this hybridized pool has given rise to released varieties by national programs in at least 20 developing countries.

When asked about his research contributions, Dr. Kronstad is always quick to point out that his success is due to the success of his team. His are the accomplishments of many dedicated people including project staff, graduate students, and the hundreds of young people who have worked with the project over countless summers.

Dr. Kronstad has not been content in the field of research alone. For more than 30 years, he has been an educator both in and out of the classroom. He has taught undergraduate classes in cytogenetics, plant breeding, genetics, and cereal production. He is a recipient of the "Outstanding Teacher Award" in the Department of Crop and Soil Science. He has served as major professor for more than 100 graduate students representing more than 27 countries. A high percentage are now leaders in their native country, including the U.S., making a lasting impact on agriculture.

Dr. Kronstad's achievements have been recognized by many awards. He has received the Oregon State University Distinguished Professor Award, the Alexander von Humboldt Foundation Prize, the CSSA Crop Science Research Award, the Oregon State University Alumni Association Distinguished Professor Award, the Distinguished Service and Graduate Training Award, awards from the Governments of Mexico and Turkey, the USDA Distinguished Service Award for Education and Information, the 1991 Presidential End Hunger Award, and is a Fellow of the ASA, CSSA, and AAAS.

Last but not least, Warren is a friend to students, colleagues, and growers, both near and far, and is a husband, father, and proud grandfather. His contributions will be remembered for generations to come.

Tribute: Dr. Warren Kronstad

Norm Goetze, Chairman,
Oregon Wheat Commission

Dr. Warren Kronstad is retiring from his position of leadership in the Oregon State University Wheat Breeding Program. His contributions to our industry have been legendary. He has been deeply appreciated by producers and all other segments of the industry.

Warren got his professional start at Washington State University just as Dr. Vogel and team were developing the first semi-dwarf soft white wheats. He joined the Oregon ranks in 1959. His first effort was to study the combining ability and heritability of agronomic traits among a wide diversity of white wheats. His Ph.D. thesis served as a stimulus to his entire career of successfully combining traits from large numbers of widely different sources of germplasm. His "shuttle" testing program in the various PNW agronomic zones resulted in varieties that have broad genetic bases and wide adaptation.

Early in his career, Warren stressed lodging resistance, yield, and disease resistance. Later he added winter hardiness, herbicide tolerance, and quality. He cooperated with scientists in related disciplines in order to obtain the best possible varieties suited to local areas of production.

During his career, his varieties have increased Oregon's average yield from 33.6 to 66 bushels per acre. Dr. Kronstad has made profound scientific and practical contributions, which in turn contributed significantly to increasing the world's supply of food. Locally, his wheat varieties have been grown on an average of 68 percent of Oregon's acreage in the past 26 years. Assuming that 50 percent of the yield increases were from his varieties, the increased Oregon production would supply wheat for an additional 2.5 million people per year. His varieties also are grown in Idaho and Washington, but at lower percentage of acreage. Assuming conservative production increases equal to those in Oregon, the Pacific Northwest in total had increased production to supply the needs of 5 million people per year. Since most of the wheat produced in the Pacific Northwest is exported to countries that have higher per capita wheat consumption than the United States, an estimated 4.2 million foreign customers per year receive their wheat food needs from Dr. Kronstad's wheat variety improvements.

Warren's leadership in the international winter and spring programs and the AID training programs had many benefits to our industry. First of all, he obtained access to thousands of genetic material, that could be evaluated here. Secondly, progeny of the multitude of crosses with these materials when evaluated throughout the world gave Warren some major insights into which he should use for his domestic improvement programs.

Perhaps the most significant outcome of these international efforts was the motivational training accorded to more than 100 outstanding graduate students. In addition to professional training in plant breeding and agronomy, they all received "hands-on" experience in team research and project leadership. Dr. Kronstad taught by example. Most of his students are now leaders in their respective disciplines and are practicing what they learned by Warren's examples.

Besides being an outstanding formal University teacher, Warren was equally effective in working with producers and industry leaders. He related very well to all of us. He never talked "to" us; he always talked "with" us in a very understanding manner.

Warren will not be leaving us. He will continue to be active like other devoted scientists and teachers. We hope to have opportunities to continue receiving his counsel and to share our appreciation.

Thanks for a job well done, Warren! Take time to smell a few roses.

A Historical Perspective of International Programs and their Interaction with the Program at Oregon State University

A transcription of the Symposium presentation by
Norman Borlaug

President Risser, Dean Dutson, and above all, Warren Kronstad, my good friend and colleague. It's a real privilege to be here today to participate in this symposium honoring Warren's undying dedication to the improvement of wheat, one of the very basic commodities, and moreover through wheat to the improvement of the standards of living of many peoples in the world.

I have tried to condense in these couple of pages the lifetime that I have seen Warren dedicate to international agricultural programs. With that, let me say, Dr. Kronstad, we owe you a great debt of appreciation and gratitude for your contributions. You're one of the greatest wheat scientists and most effective teachers in this century. You have evidence of this by the vast number of your students who now occupy or have occupied key positions in different organizations and governments around the world, including the U.S. Dr. Kronstad is a peerless teacher and this is why this broad representation around the world of leaders in agriculture exist, not just in wheat, but in the more general context. Warren brings forth a vision into all of his courses and training of young scientists that is much broader than genetics and plant breeding. As I look at the world problems, especially in the developing nations, this unique ability to bring together the various disciplines that bear on production all too often is unique among today's leaders in world agriculture.

I think the tendency has been for the past 30 to 40 years to become specialized earlier and earlier in our careers, and this makes it absolutely necessary to have a few outstanding people like Warren who can put all of these pieces together and check them under field conditions and on the basis of this, assist in transplanting the interdisciplinary knowledge across the world map where wheat is especially important.

He's a visionary; he doesn't just work with the major problems of the time, but he has the broad outlook over many years of time, which is vital for research programs to move forward rather than making an impact and then stopping and stagnating.

Above all, he's a friend to these students and colleagues around the world. Over the past 3 decades, we have had the privilege in our international program to have Dr. Kronstad visit, time and again, in Mexico. Both at the international CIMMYT wheat nursery, in Sonora, Mexico, and also in Toluca and Chapingo. On each occasion, he always speaks to the young trainees from around the world, as well as to our international staff. This spark and ignition that he brings to their attention, not only to the young, but also to the older scientists to remind them not to stagnate, nor sink into mediocrity. He is a very great catalyst to keeping research organizations viable.

I would like to say that I admire what he has done in the international program, especially the new international winter wheat shuttle program with my colleague, Dr. Rajaram. To me, that this program now is really at the payoff stage and you will see in the next 8 to 10 years a great impact of that program across Turkey, other Middle Eastern countries, and especially the eastern European countries and the former states of the Soviet Union.

Warren, I want to congratulate you for all you've accomplished in helping to make this world a little better place in which to live for millions of people in different nations around the world.

I have been asked to make some comments about the early history of the international agricultural research and training program in Mexico. The first program in the international agricultural system was the cooperative Mexican government program with the Rockefeller Foundation. This was initiated in 1943. I joined the program in '44, and in one way or another I've been involved in international agriculture in various organizations from that day up to the present time. I'll try to give you a little insight into some of the problems that you have to cope with when trying to bring improved technology to the service of people in the developing nations; however, I think the payback has been as great for developed nations, especially in the U.S. and Canada, from such collaboration. What were some of the approaches that were necessary, since the cooperative Mexican government /Rockefeller Foundation program was established some 56 years ago? At that time there was not a single graduate school in any of the countries in Latin America. All too often, especially typified by the situation in Mexico, most of the young people who came to study agricultural sciences came from urban areas, not from rural areas. Why was this so? Because the rural schools were so poor that their students could not pass the entrance exam to enter the colleges of agriculture. As that first program in Mexico began, we had young trainees from developing countries participating in the research program. This activity continues today to overcome the shortage of trained manpower. To put together a functioning research and production program, both in Mexico and in other countries, we eventually were training people on two levels, those obtaining college degrees and others at the nonprofessional level. After receiving their Bachelor of Science from the agricultural colleges in Mexico and later other developing countries, the new graduates were required to have some practical hands-on apprenticeship-type of training. The most qualified, we sent to foreign graduate schools mostly in the U.S. and Canada since there were none in Latin America. Thus, English or European language competency was important. To establish a critical mass of trained people takes time. Starting from scratch it takes 15 years to develop the scientific staff for developing nations. In such a short period of time you not only have to train people to carry on the research programs, but to establish graduate schools in developing countries to continue to train people in more or less their natural environment.

Now, at the nonprofessional level, we found young boys with very low levels of training, who often had dropped out of school, generally in fifth, sixth, or seventh grades. These young people were trained to become master technicians and they played this role, but at the same time, we encouraged them to get back into school and finish at least the equivalent of high school education. These technicians have been very active in training many Ph.D.s and people coming for postdoctoral training from the U.S., Africa, and Asia. Over the years, they showed these visiting scientists how to put the pieces of science together so they can make a meaningful impact. I've always admired these technicians, what they could do and what they have done.

Now, just briefly, some of the things that I think were important that we learned from that program.

It was obvious that we could not expect great impact from breeding alone to enhance wheat production in Mexico. We were dealing with some of the oldest, longest cultivated soils in the Western Hemisphere. The level of fertility was at such levels that when improved varieties were grown according to what we thought were the best agronomic practices, even under irrigation, the highest yields were 7 bushels per acre. That meant we had to work across disciplines from the beginning and especially if we were going to invest in fertilizer. We also had to have security of harvest and to avoid the most damaging epidemic diseases, with stem rust being the prime consideration. Now, how was this done? I think it was a stroke of luck in some ways due to a disaster in 1956, when across the U.S. and Canada, all of the commercial varieties of wheat became susceptible to the race 15B of stem rust. Before that, there was very little collaboration between nations, other than a lot of talk, but this epidemic changed things. A meeting was held in Canada, in early winter of '53, and the late Dr. H.A. Rodenhiser organized the first international stem rust wheat nursery to identify sources of resistance. At that time, unlike now, when we know there are a lot of genes that control the stem rust organism, there was a belief by many of the scientists that we were running out of genes to control this disease. There also was a reluctance of wheat breeders, and for that matter other crop breeders, to participate in any collaboration where materials from their program might be released by others without their receiving credit. We broke that logjam by putting all of our materials developed in Mexico into the international nursery to provide for greater genetic diversity. We didn't know much about the races of stem rust in Latin America. Maybe it was by luck, because I was so ignorant about wheat in general, as I had never worked on wheat a day in my life. I was trained in forestry and had my Masters in forest pathology. But in that Department of Plant Pathology at Minnesota, even if you weren't working on wheat, you soon learned a lot about the variability in the pathogens from Dr. Stakman. By force feeding, you acquired a background to respect the diversity of microorganisms that attack our crop.

The wheat improvement strategies we employed in Mexico were first to hybridize many varieties of different genetic backgrounds to enhance the genetic diversity in the program. This was followed by ruthlessly discarding progeny that were not acceptable in terms of plant type or were susceptible to the various diseases in subsequent segregating generations. Another significant factor was the use of shuttle breeding, which some people at the time we initiated this approach referred to as "disruptive breeding." I often was criticized for taking one step forward and one backward by systematically selecting materials under two extreme environments. However, the consequences of this approach changed our whole knowledge about photoperiodism and vernalization requirements, thus uncovering flexibility or adaptability like we had never seen or thought possible. The shuttle breeding approach took advantage of the mountainous country of Mexico. During the months from October through April, one generation of segregating material was grown at 28° north latitude at about 100 feet above sea level under irrigated conditions near Ciudad Obregon in the State of Sonora. Following harvest at this location, the next generation was planted at about 18° north latitude at about 8,500 feet elevation near Toluca, which is located northeast of Mexico City. North to south, these two experimental sites are approximately 700 miles apart. By employing such an approach, two generations could be obtained per year, but even more importantly it suddenly became apparent that varieties with broad adaptation emerged. Despite what the textbooks said, the shuttle breeding approach also provided varieties, that were widely adapted to many other parts of the world especially countries such as India and Pakistan.

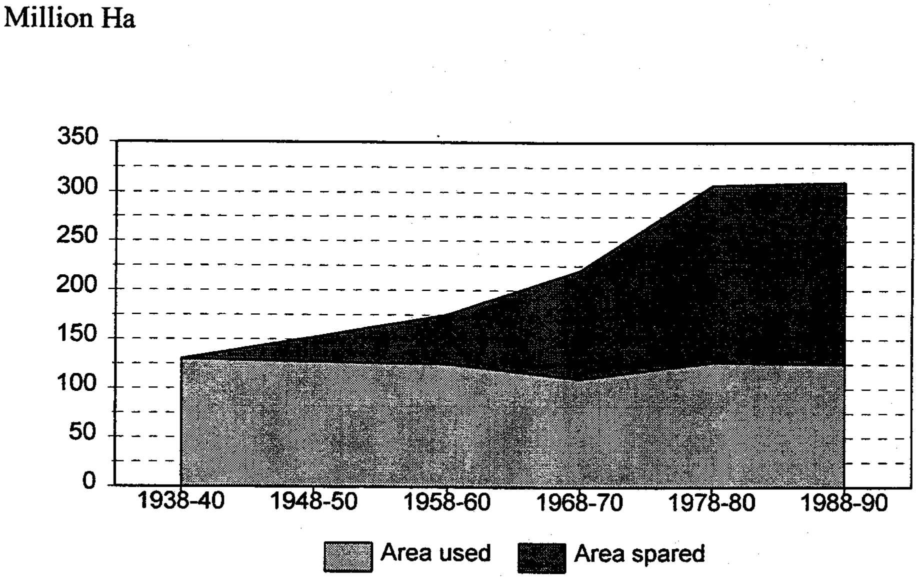
When the Rockefeller Program on wheat in Mexico was about to be terminated, I turned the program over to the national scientists who had been trained in 1959. So I was looking for a job. I should have pointed out that that first collaborative program in agriculture by the Rockefeller Foundation was thought to have been a one-job opportunity for me in Mexico. Two foundations, Ford and Rockefeller, established the International Rice Research Institute in the Philippines, as they could foresee the emerging crisis in rice production in Asia. However, as far as wheat was concerned, it looked like the end of the road for me in Mexico. Dr. Al Moseman, who was in the New York office of the Rockefeller Foundation, was trying to discourage me from joining the United Fruit Company to breed bananas, of all things. So he sent me on this trip across North Africa with FAO, and I saw the opportunities and needs for trained people in all of those countries from Tunisia to India. With the exception of India and Egypt, there were virtually no trained scientists of any number, and all too often in the two countries I just mentioned, they were back doing research that had very little to do with filling hungry, empty stomachs. Many of those scientists were engaged in prolonging their thesis problem that they did at some foreign university, either in Europe, here in the U.S., or in Canada. So, I said that if the Rockefeller Foundation would fund apprentice scholarships for young graduates from those schools, and a capable FAO representative would select those young people and send them to Mexico, I would train them as best I could in 6 months to a year across all of the disciplines that bear on wheat production. This proposal was accepted, and the Foundation initiated this program, with the first group coming to Mexico in 1961. Some of these became famous scientists. One of them, Dr. Narvice, took over the responsibilities of that program. The result of this was that these people not only gained hands-on training, but became co operators as we set up an international spring wheat yield nursery in 15 countries in the Near and Middle East. The number of countries and locations soon grew to about 80. This was one of the largest shipments internationally of genetic materials and contributed to the so-called "Green Revolution." The cooperators collected appropriate data and sent it back to Mexico so we could see all of the broad adaptation first observed in Mexico. Such material found homes in many parts of the spring wheat areas of the world, including having the desired disease resistance. In South Asia, India, and Pakistan, starting in the middle '60s, the most promising lines from the international spring wheat yield trial were moved after 3 or 4 years of testing into small plots on many farms. In 1961, the production of India of all cereals was 87 million tons, by 1990 it was 197. In the case of wheat, it went from about 11 million tons to, at the present time, approximately 68 million tons.

Let me say that sometimes ignorance in the beginning makes you disrespectful of things that have grown stagnant, not true, not because the original decisions were not correct, but because they were based on mini-truths and partial truths. As more research was done on microorganisms and also the genetic variations observed in crop species, it brought new insights into many complex problems. For that reason, I'm a firm believer in cross-pollination across scientific disciplines. It's truer today with all of the activists that we have in the environmental movements from the standpoint of the very special interests. One group gets overly enthusiastic about one species; others focus on another, and if you were going to legislate and try to provide for all those specific things we'd never get anything done.

A story we should have told the world would have avoided much of the misunderstanding today with many of the extremists in the environmentalist movement was the amount of land saved. In Figures 1 and 2, the impact of new technologies on reducing the amount of land necessary to produce cereals is presented for the United States, China, and India. In 1940, the production of the 17 most important food, feed, and fiber crops in the United States totaled 252 million tons grown on 129 million hectares. Compare these statistics with 1990, when American farmers harvested approximately 600 million tons from only 119 million hectares, 10 million hectares less than 50 years previously. If the United States attempted to produce the 1990 harvest with the technology that prevailed in 1946, it would have required an additional 188 million hectares of land of similar quality. This theoretically would have been achieved either by plowing up 73 percent of the nation's permanent pastures and rangelands, or by converting 61 percent of the forest and woodland area to crop land. This is a fact often overlooked by extremist environmentalists who hold that modern technology is poisoning consumers out of existence and wish to return to the good old days of "low impact" technology.

Equally impressive savings in land use can be observed in China and India as the result of high-yielding cultivars that are responsive to improved management (Fig. 2). In a recent World Bank News publication (Petrucci 1995), people in developing countries now consume half the world's wheat, and within 10 years they will consume three-fifths of all wheat produced. Since the 1960s, wheat consumption has risen almost 5 percent a year in developing countries. As standards of living increase, people tend to turn toward more convenience foods, e.g., sandwiches, especially for the noon meal. This increased interest in wheat was observed when, in 1994, Asia harvested 217 million tons of wheat, far outpacing Europe's 119 million tons and the 90 million tons produced jointly by the United States, Canada, and Mexico. During this same period, developing countries also accounted for over two-thirds of the world's total wheat imports, suggesting that demand in the developing world has risen even faster than domestic output.

Today, from that little program that was started in Mexico back in 1943, there are now 16 of these international programs scattered around the world. The budget about 3 years ago was $300 million. A lot of money, until you stop and look at it and realize that it's about the cost of seven F-18 fighter jets. Thank you.

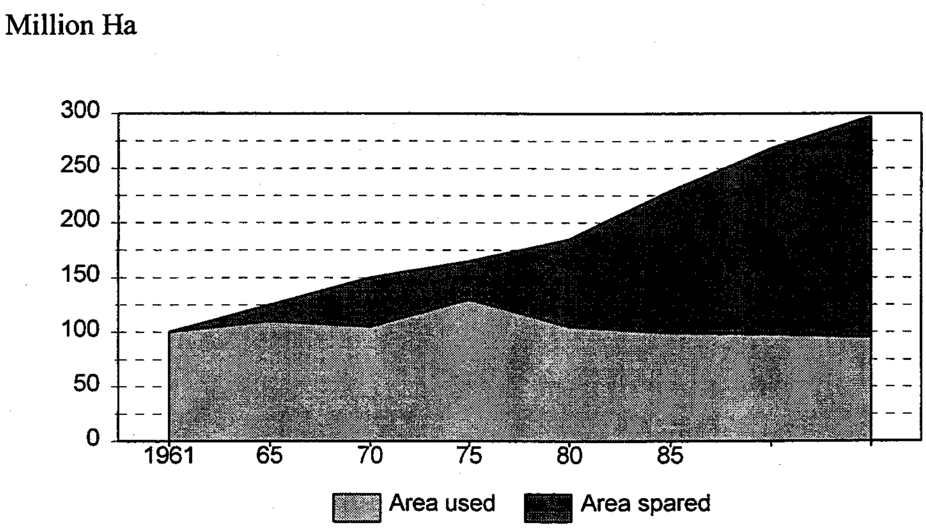


1938-40 Production: 252 million tons

1988-90 Production: 596 million tons

Fig. 1. U.S. total crop area spared by application of improved technology on 17 food, feed, and fiber crops in period 1938-40 to 1988-90 (taken from Borlaug and Dowswell 1996).

China - All Cereals



India -All Cereals

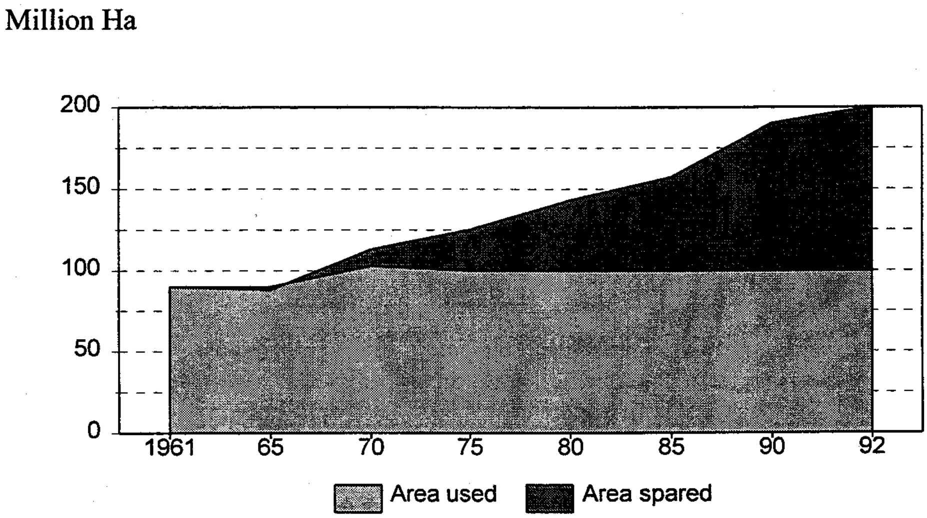


Fig. 2. The land that Chinese and Indian farmers spared through raising cereal yields* (Borlaug and Dowswell 1996).

* The upper curve shows the area that would have been needed to produce 1992 cereal production, had 1961 yields still prevailed. The lower curve shows the area that actually was harvested (Borlaug and Dowswell 1996).

A Salute to Dr. Warren Kronstad for Three Decades of Dedicated Effective Service on Scientific and Educational Fronts Toward Improving Food Production and the Well-being of Humankind

Norman Borlaug

It is a great privilege and honor for me to participate in this symposium honoring my close friend Dr. Warren Kronstad–one of the great wheat scientists and most effective teachers of this century. Dr. Kronstad is a man of many talents. Above all, he is a kind, understanding, friendly and good human being. As a teacher/professor, he is peerless, as is manifest by the large number of former students who currently occupy important positions in public sector research and/or educational institutions or in private sector research organizations, not only in the U.S., but around the world. As a research scientist, Warren has superb imagination and vision. Moreover, he is an excellent organizer of research, as is indicated by the genetic diversity and magnitude and efficiency of his breeding program and by the phenomenal commercial success on farmers' fields of the varieties he has produced. Dr. Kronstad is labeled, by most of his scientific colleagues, as a wheat breeder and wheat geneticist who has produced some of the best wheat varieties in the Pacific Northwest; he is much more. He is an all-inclusive agricultural scientist–an integrator across all scientific disciplines that bear on wheat production, e.g., varietal improvement; agronomic practices; disease, insect, and weed control; and grain quality. Because of this breadth of interest and understanding, he has been highly effective in assisting Pacific Northwest farmers' organizations increase wheat yields, production, and family income. These same skills have made him very effective as a consultant in many developing countries, where his counsel has improved the orientation and focus of research programs as well as improved crop management practices on farmers' fields, which in turn has increased wheat yields and production. For example, Dr. Kronstad (and several members of the Oregon Extension staff) played a key role in the successful introduction of the high-yielding semidwarf Mexican spring wheat varieties into Turkey, which dramatically increased wheat production. Without this introduction of improved agronomic and crop management practices, the high-yielding Mexican varieties would have had only minor impact.

Over the past 3 decades, Dr. Kronstad has visited the Mexican Wheat Research Program (CIMMYT/INIFAP) many times. On each occasion, he has stimulated our staff with lively seminars and discussions for which we are grateful. Over the years, his lectures and seminars have made important impacts on hundreds of young wheat scientists from developing nations around the world who have been studying and training at CIMMYT. As a result of this inspiration, many of these young scientists subsequently have studied and received graduate degrees at Oregon State University or at many other Universities.

I am fascinated with the progress now being made by the Cooperative International Winter Wheat Shuttle Breeding Program, being jointly developed by Oregon State University and the International Maize and Wheat Improvement Center (CIMMYT), under the joint leadership of Dr. Warren Kronstad and Dr. Sanjaya Rajaram, Director of the CIMMYT Wheat Program. I predict that this breeding program will have a big impact on wheat production in the winter wheat production of the Middle East, eastern Europe, former Soviet Union countries, and China within the next decade.

Dr. Rajaram, in a few minutes, will report on the progress being made by that important program.

The Early Years of International Agricultural Research Programs to Assist Food-Deficit Developing Nations

I have been requested to give a brief summary of the early years of international agricultural research programs and something about their contributions to increasing world food production.

The first foreign technical assistance program in agriculture, initiated in 1943, was the Cooperative Mexican Government-Rockefeller Foundation Agricultural Program (known as the Office of Special Studies [OEE] of the Secretaria de Agricultura y Ganaderia). It was a pioneering adventure. It preceded by 5 years the establishment of the Marshall Plan, which assisted in the rehabilitation of war-torn Europe, and President Truman's Point 4 Foreign Assistance Program (which later evolved into USAID) by 6 years.

The OEE had four major objectives: 1) to train a corps of young Mexican scientists in all of the scientific disciplines that influence crop production; 2) to conduct the research to produce the varieties and the information needed to increase the production of the three most important food crop-maize, wheat, and beans; 3) to transfer the improved technology to farmers' fields to increase production; and 4) to transfer leadership for continuation of the research program to the new team of Mexican scientists as soon as scientifically feasible. Later, potatoes, vegetables, oilseeds, and forage were added; still later, poultry and animal sciences were added.

I joined the program in 1944 and have been continuously involved in international agricultural research and production programs ever since. In 1945, I assumed the leadership of the wheat research and production program, organized to develop information to support an integrated wheat crop production management system, including: varietal improvement (breeding), restoration and maintenance of soil fertility, improved agronomic practices, plant protection (diseases, insects, and weed control), and economic policy.

When the wheat research program was initiated, 55 percent of total national wheat consumption was imported. Although most of the wheat was grown under irrigation, yields were low and stagnant, the national average being 750 kg/ha (11 bushels per acre)–with yields as low as 500 kg/ha (7.5 bushels per acre) in the "worn-out" soils of central Mexico. There had been three devastating stem rust epidemics in the State of Sonora (the best wheat production area in the country) in 1939, 1940, and 1941. This indicated breeding high-yielding varieties with resistance to this pathogen had to be given top priority, especially if the use of fertilizer was to be introduced to increase yield on "worn-out" soils.

Let me describe several key factors that strongly impacted wheat production in Mexico during the Quiet Wheat Revolution of the 1950s, when Mexico became self-sufficient and in the 1960s, which gave rise to the so-called Green Revolution (wheat) in Pakistan, India, China, Turkey, Chile, Argentina, Portugal, Spain, Australia, Brazil, and in the spring wheat regions of U.S. in the late 1960s and early 1970s.

Training of Mexican Agricultural Scientists

The great shortage of agricultural scientists qualified for conducting agricultural research in the country indicated that training of a new generation of scientists had to be given high priority. Filling the short-term need was the establishment of a "hands-on internship" type training of recent agricultural graduates, so they could effectively assist in developing the research programs. Then, the brightest and well-motivated young scientists were sent abroad for graduate training. It took 16 years before sufficient staff had been trained to the master and doctorate levels to meet the needs of the ongoing research program and, in addition, provide staff for the Graduate College in Agricultural Sciences in Chapingo–the first in Mexico, and the second in Latin America.

Shuttle Breeding Method of Varietal Development

The *shuttle breeding* was a method based on necessity to save time in the development of stem-rust-resistant varieties; later it was also shown to have other valuable benefits. With the breeding methods then in use in the world, only one segregating generation (of breeding materials) was grown each year. The breeding dogma of the era dictated that this was necessary to assure good adaptation and success of a new variety–a good fit between genotype and the environment. The dogma implied that the segregating populations had to be grown and the individual plants in segregating generations selected in the area and during the crop cycle where the new variety was to be grown commercially. Therefore, it took 10 to 11 years to cross; select; and evaluate for yield, yield, disease-resistance, and milling and baking quality, before beginning to multiply seed of a new variety for release to farmers. At that time, little was known about the importance of photoperiodism in the adaptation of wheat and other cereal crop varieties.

Recognizing the frequency and destructiveness of recent stem rust epidemics, it was absolutely essential to cut in half the time required to breed a new improved variety. This theoretically was possible by locating two contrasting environments favorable for the development of the wheat plants in two different seasons of the year. This was achieved by planting on the Coastal Plain of Sonora at an elevation of 39 meters and 29°N latitude, in early November, when the days were growing shorter. Artificial epidemics of stem and leaf rust were generated, and plants with the best agronomic type combined with adequate rust-resistance were selected in April; those with good plump seed were shuttled to Toluca Valley, about 700 miles to the south at 19°N latitude and at an elevation of 2640 m, where they were planted in early May when day length was increasing. At this elevation, temperatures are ideal for the development of the wheat plant during the summer season; moreover, frequent rains foster the development of heavy epidemics of stripe, leaf, and stem rusts and Septoria leaf blight. In October, the best disease-resistant plants were selected, and seed of those with good plump grain were shuttled back to Sonora for planting in November. Through the shuttle breeding method for handling segregating populations, the first stem-rust-resistant varieties were produced in 4 years and grown in farmers' fields in the fifth year, half the time normally required with the orthodox methods of the era. These varieties also proved to be well adapted and high yielding throughout all wheat-growing areas of Mexico. Mexico became self-sufficient in wheat production in 1956.

Breadth of Scope of Genetic Diversity in the Mexican Wheat Breeding Program

From the beginning–and continuing to the present in the CIMMYT program–large numbers of crosses are made each year, involving genetically diverse parents. Strong vigorous selection pressures are exerted for agronomic type and disease resistance in all segregating generations. Early-generation, multilocation yield testing is employed to identify outstanding lines, while all others are eliminated.

Expansion of the Rockefeller Foundation Mexican Experience to Other Countries

The original purpose of the Cooperative Agricultural Program was to see what could be accomplished to improve the agriculture *in one country*–Mexico. When the positive results of the Mexican maize and wheat began to appear, requests were made to the Rockefeller Foundation by many other countries for similar assistance in agricultural research and training programs. Then, similar programs were established in Colombia (1950), Chile (1955), and a maize-breeding program in India in 1956. In 1958, the Rockefeller Foundation and Ford Foundation, under the leadership of Drs. J.G. Harrar and F.F. Hill, jointly established the International Rice Research Institute (IRRI), the first of the IARCs.

Training of Wheat Scientists from the Near and Middle East Countries in Mexico

In 1960, an exploratory trip, sponsored jointly by FAO and the Rockefeller Foundation, was made across North Africa and Near and Middle East countries to determine whether any of the wheat research information and improved varieties developed in Mexico might be of value in these countries. As a first step, a "hands-on" interdisciplinary training program for young wheat scientists from that vast region was initiated in Mexico in 1961. As part of this training and research program, an International Spring Wheat Yield Nursery was established. Included in this nursery were the best of the new Mexican semidwarf varieties as well as the best commercial spring wheat varieties of Canada, the U.S., Mexico, Argentina, Chile, Egypt, Pakistan, and India. The International Yield Nursery was soon being grown at more than 100 locations around the world. Within 3 years, it clearly had established the superiority of the Mexican varieties in many countries, including Pakistan and India.

As the food shortages in South Asia worsened in 1963, 200 kilograms of seed of the best varieties were sent by air to Pakistan and India for testing on small plots on many farms. As a result of very positive results, in 1965, 300 tons of seed were imported into Pakistan and India. Despite many problems (including the Pakistan-Indian war), the results again were excellent in both countries. Then, with famine worsening–in 1966 India imported 18,000 tons of seed and in 1967 Pakistan imported 42,000 tons, and Turkey 21,000 tons. From this seed, improved agronomic practices, including use of right kind and amounts of fertilizer and with a change in policy to stimulate the adoption of the new technology, the so-called Green Revolution was born.

To give you an idea of the impact, wheat production in India rose from 12 million (metric) tons in 1965, to 68 million tons in 1998, and from 4.5 million tons in Pakistan to 18 million tons. Major impacts also were achieved in China, Turkey, Chile, Argentina, and many other developing countries.

These successes led to the creation of the CGIAR and the expansion to 16 IARCs. Today, there is an international system of agricultural research involving the public and private universities, and national and international research institutes. This system, though currently suffering budgetary problems and the effects of the "bureaucracy" virus, still is the best hope for keeping world food production increasing faster than population growth, and for reducing the humiliating and degrading poverty that haunts too many in this world of ours.

In summary, Dr. Kronstad for the past 3 decades has been both an inspirational counselor and mentor to our CIMMYT staff and to many hundreds of young agricultural scientists studying in Mexico. He has kept us attuned to the important new scientific developments in academia from around the world. In addition, he has kept us informed about new developments in his efficiently well-organized wheat-breeding program at Oregon State University, which in addition to developing new better wheat varieties for farmers in the Pacific Northwest, *also is producing a new generation of outstanding wheat scientists for the world.*

I wish him well in his well-earned retirement. I hope that from time to time we will be able to induce him to come out of retirement for short periods, so that his expertise can be utilized as a special consultant to solve problems in developing African and Asian nations.

The Role of Public Agricultural Research in International Development

Dana G. Dalrymple

1. Introduction

It is a great pleasure for me to participate in the W.E. Kronstad Honorary Symposium. I have known of Warren's work for more decades than either of us might wish to admit, and in the past few years drew closer as I served as USAID project manager for the Spring x Winter Wheat Project. My great professional respect has come to be matched by great personal respect. Warren has indeed made a significant difference in Oregon, the United States, and the world.

My assignment as part of the Symposium honoring his contributions is, as I have interpreted it, to say something about the role of the public sector in stimulating agricultural and ultimately international economic development. I will focus principally on public agricultural research—the sector in which Warren has spent his career—in the context of serving the developing countries of the world.

This is not a new topic, and portions of it have been touched on in many talks and papers. But it is broad and complex, and continually evolving. There are not many introductory treatments that are both comprehensive and current. And few are written from the perspective of someone with experience in the public system. This Symposium provides an opportunity for me to try to respond to this challenge.

The subject is not easily summarized in a few pages. I have attempted to tackle it in a two-stage process: a summary type text backed up by fairly extensive notes, documentation, and suggestions for further reading. While portions of the text will be familiar to some readers, other portions—particularly many of the notes and references—may be less well known. I hope that this approach will provide something useful for a wide spectrum of readers.

2. Agriculture and International Development

The purpose of development, as I see it, is to improve human welfare or the human condition. I am thinking of welfare in the same terms as my dictionary: (a) health, happiness, and general well-being; and (b) prosperity. Just as there are several components of welfare, there are several paths to its betterment. In terms of government programs, three components particularly come to mind: economic development, health improvement, and the betterment of education. In the developing countries, agriculture is the principal source of livelihood and offers a key means of promoting economic development and improving the nutritional side of health.

Agriculture in this context is defined as including the production of food and non-food products and the utilization and preservation of natural resources (including soil, water, and forestry). Food products, which accounted for about 95 percent of the value of agricultural production in the world (excluding fish and forest products) in 1997, play an important role in: (a) the economies of families and society, and (b) the nutritional status of individuals.[1] Non-food agricultural products—most notably cotton, followed by tobacco, wool, coffee, tea, and rubber—clearly play an economic, if not nutritional, role in society. Natural resources are linked to agricultural production, but in the case of forest products also may have some economic value.

In view of its importance, it is logical to focus the bulk of our attention on food. Food production is a major source of income and employment and has spin-off benefits for local communities. Food processing and marketing also is of major importance, especially in more developed countries. Food purchases represent a major expenditure, especially in the poorest areas of the world, reaching 50 percent or more (60 to 80 percent in some cases[2]) of disposable income. Food obviously is the major force in determining nutritional status, which in turn can influence human health, learning (cognitive skills), productivity, and well-being. Thus, anything that materially affects the supply, availability, and access to food is of major importance to society. This seems like a simple and obvious point, but it has eluded many governments and political leaders in both developed and developing countries.

The result has had both visible and less visible manifestations. The extreme and most visible cases, aggravated by civil crises, are famine and critical food crises, which appear in headlines and which prompt expensive and short-term food aid programs. Less obvious but more critical in terms of numbers are the large number of individuals in the developing world—currently estimated by FAO at 828 million—who are chronically undernourished. FAO recently reported that 17 countries have severe food shortages, leaving their populations with severely low energy intake, not to mention other nutritional deficiencies.[3] Recent press accounts have highlighted extreme problems in Cambodia, North Korea, and Somalia.[4]

UNICEF reports that more than half of the almost 12 million children under 5 who die in developing countries each year from preventable causes are victims of malnutrition. They also report that vitamin and mineral deficiencies are estimated to cost some countries the equivalent of more than 5 percent of their gross national product (GNP) in lost lives and disability.[5] Less visible is the opportunity cost—the opportunities missed—when economic growth does not obtain the levels that it might due to a neglect of agriculture.

Agricultural development is a long-term process and is not always the answer to the more severe short-run problems of nutrition brought about by, say, civil or natural disasters. But it can play an important role in helping countries avoid these problems or in reducing their severity. More significantly, it can lay the basis for economic development and the improvement of lives of a much broader sector of society.

3. Agricultural Research and Development

Agricultural research is the linchpin of agricultural development. It generally is a necessary, but certainly not sufficient, condition. It is the key to increasing productivity, which is at the heart of the development process. But to be adopted and prove effective it must be accompanied by a host of other factors and forces.

A. Scope of Agricultural Research

Agricultural research encompasses many forms of science—principally biological and physical science, but also social and economic science. Agricultural science, to the extent that it exists, is a mélange of many forms of knowledge that commonly are brought together in research institutions or research funding organizations that have an agricultural focus. Boundaries are primarily professional and probably are diminishing. As Peter Doherty, a Nobel Prize laureate, recently has noted: "The current reality is that all science is convergent, and the categories do not much matter."[6]

Another way of looking at the components of agricultural research is to think of its three main functional components: science, technology, and policy. Science is the basic stock of knowledge, the mother lode. Technology is the application of science to some productive purpose. Policy, inter alia, provides the framework for the conduct and application of research in science and technology. Research is needed to expand our knowledge of science and to develop useful technologies and improved policies.

B. Institutional Components and Effect on Society

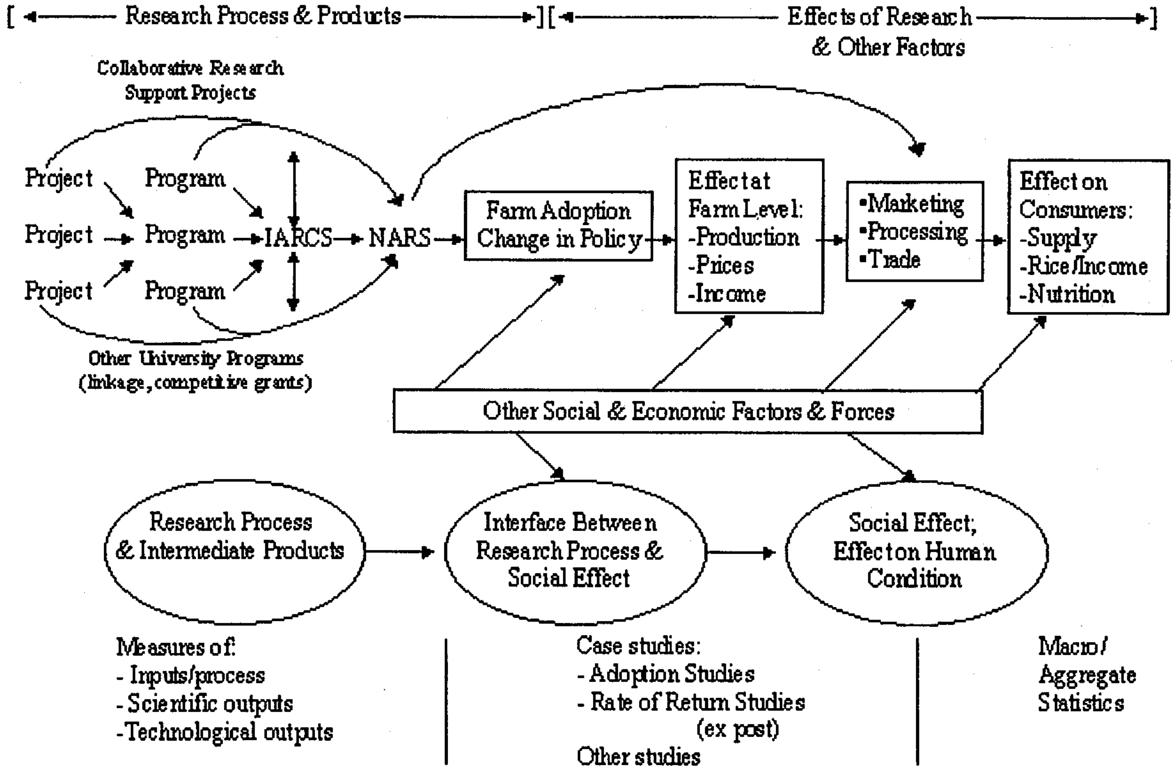
The key components of the international agricultural research system are: (1) research institutions in developed countries; (2) international agricultural research centers (IARCs); and (3) research programs in the developing countries. The country programs take a variety of forms and may be in the public and private sectors. USAID, to some degree, supports public programs in all three areas (further details will be provided in Section 5). Other bilateral and multilateral donors have similar activities.

The relationships between these programs and the chain of events, which takes place in terms of their interaction with society, are summarized from a USAID perspective in Figure 1. As noted, the research structure is outlined in the left side of the diagram, while the subsequent process that leads to the ultimate efforts on society is depicted on the right side.

Clearly, research is just the first step in the process depicted. The products of research must be adopted, at first on the farms, but also, where relevant, by the marketing process. Adoption of output-expanding technology will increase yields and production, reduce farm prices, probably increase the income of early adopters (it may well not increase the income of late adopters because of lower prices), and stimulate local employment.[7] The effect on consumers is more generally positive: the increased supply and lower prices (see Figure 2) are equivalent to an increase in income and normally will lead to increased purchases and improved nutrition among the poor (the nutritional effect may be less pronounced at higher income levels). The overall benefits to consumers may exceed those to producers. All of these effects in turn have positive influence on the local economy.

Figure 1

International Agriculture Research and Its Effects on Society: Structure and Measures*



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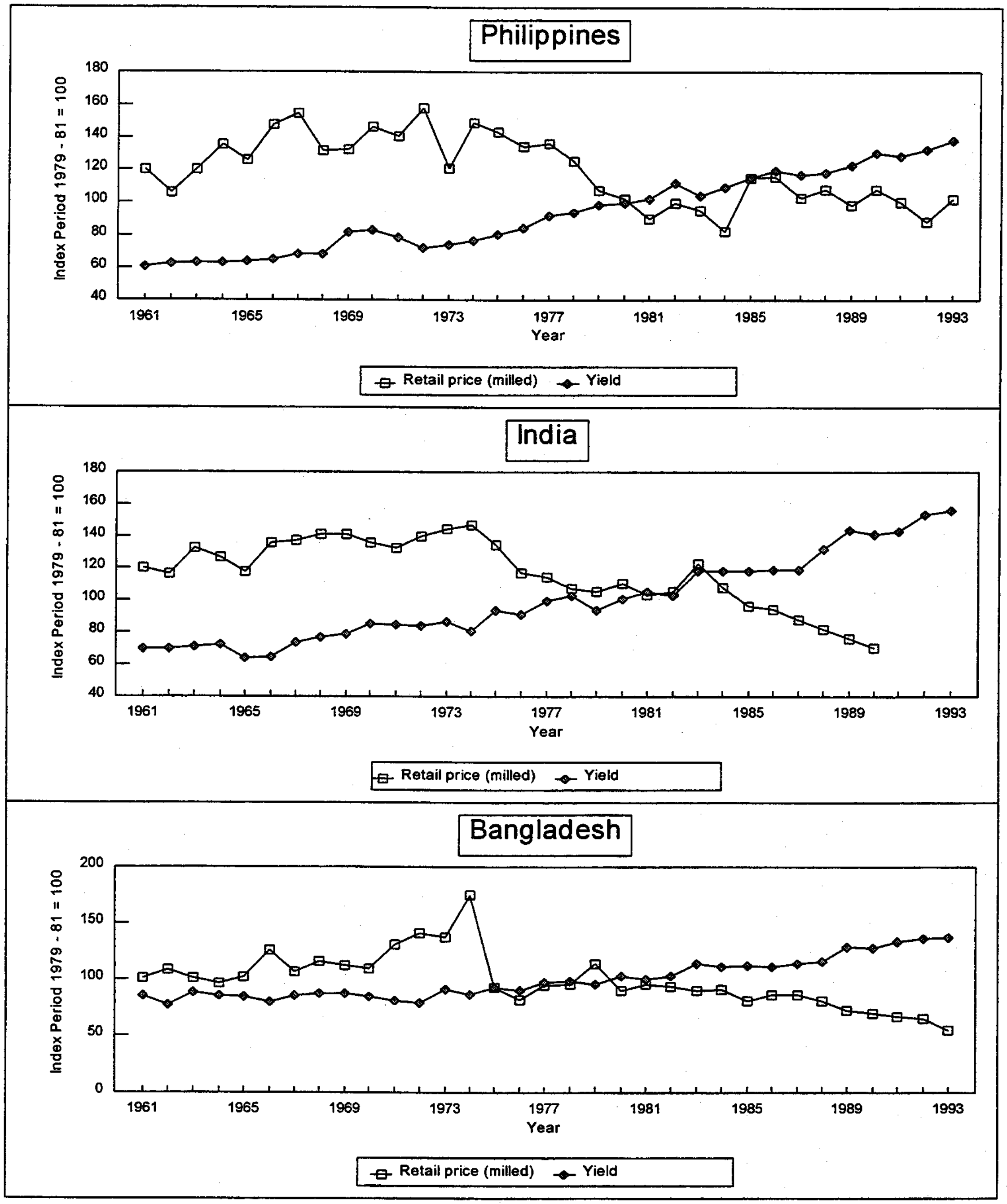
*Does not specifically include natural resources.

Figure 2. Changes in Rice Yields and Domestic Retail Prices
Philippines, India and Bangladesh, 1961 - 1993



Note:

Retail prices deflated by consumer price index for country.

Sources:

Yields: FAOSTAT, April 1998.
Prices: Calculated from data provided in World Rice Statistics, 1993-94, IRRI, 1995.

The social returns to this process generally are quite high. Many economic studies have been made of the rates of return to agricultural research. A recent summary of 294 studies, covering 1,858 research programs, revealed that the estimated rates of return for research averaged 88 percent.[8] Not every research project falls into this category; some are clear failures and the impact of some may await a long incubation process (such as was/is the case with quality protein maize or with much natural resources research). With the tightening of public funding for research, increased effort is being given to documenting the effects of research—especially at the international level.

4. Relative Roles of Public and Private Research

The traditional distinguishing characteristic between the public and private sectors is the nature of the product they produce. The public sector focuses on public goods that are freely available to all. The private sector produces proprietary products that are available to those who purchase them. Generally, the public sector has been seen as the source of both basic and applied research and the private sector as a source of applied research. But the real world situation is more complex and is in the process of shifting.

A. Public Research

The key players in the public sector at the national level—universities and government research organizations—have somewhat different positions in developed and developing nations. Universities generally play a much more important role in research in developed than in developing nations, while government research units are relatively more important in developing countries.[9] The U.S. model—which combines teaching, research, and extension at state universities—is not so prevalent in developing countries. Hence, research in developing nations has tended to be divorced from teaching and extension or outreach. The structure of governmental agricultural research has changed rather significantly in some developed nations in recent years—although not yet in the United States—and may be modified in others in the future.[10]

The key players at the international level are the IARCs, most of whom are sponsored by the Consultative Group on International Agricultural Research (CGIAR). They produce international public goods in cooperation with all kinds of public research organizations at the national level. The IARCs draw from and utilize the scientific resources in developing countries and conduct their own research, generally in collaboration with research groups in developing nations. The IARCs also provide some training for developing country scientists and technicians, and conduct some participatory research with farmers.

These national groups in developing nations, however, often are not in very strong condition and extension or outreach programs may be weak. External assistance, which played a big role in providing support, is thought to have declined in many countries (this certainly is true of USAID; see Table 3). Moreover, public support at the national level often is weak or declining. And even where staffing levels are maintained, funding for research support, equipment, and facilities frequently is lagging. We often talk of a global agricultural research network, but the components—especially at the developing country end—are becoming frayed. Thus, when IFPRI reports that "Developing countries now account for more than half of all global, public R&D investments,"[11] we have reason for concern.

B. Private Research[12]

The private sector, defined here as the business community, plays a major role in agricultural research in developed countries—accounting for half or more of the total in the U.S.—and has recently stepped up its investments in biotechnology research. The private sector is, however, much less important in the research arena in developing countries. The reason is simple: there is much more money to be made in developed countries with their more advanced forms of agriculture and their more highly developed systems of intellectual property rights, related policies, and infrastructure.

Clearly, the major interest of the private sector is a profitable product. In the past, this has largely led to concentration on inputs such as machinery, farm chemicals (fertilizers, pesticides), and seeds. With the increased emphasis on biotechnology, the nature of the last two categories is changing. The traditional definition of a profitable product is shifting, and industry is getting more involved in high-tech research.[13] This new emphasis has blurred the traditional model of having basic research carried out in the public sector and applied research in the private sector, especially in the area of molecular biology and involving DNA. The private sector, however, is less active in other areas such as plant biology, physiology, or chemistry. In any case, this changing pattern applies much more to developed than developing countries.

One important area where the private sector has played little role is in research, which would lead to the development of improved public policies—such as is carried out by IFPRI or universities. But even here, the situation is changing to some extent. The increased involvement of the private sector in biotechnology has raised the importance of public policies relating to intellectual property rights and food safety. The agenda for policy research is being modified—and in a way that will emphasize the need to interact with the private sector. While the policy problems in the case of biotech are most notable in terms of the developed countries, they will continue to overflow into the developing countries.

C. Interactions

There is a considerable and probably increasing amount of interaction between the public and private sectors. Herdt recently has noted six forms of special relationships being pursued by private companies with public sector researchers.[14] Some of this interaction involves complementarities, and some presents complications. And in either case, some gaps may remain.

Complementarities can benefit both parties. The private sector has long made free use of the basic or applied research done in the public sector (the seed industry is a case in point) or has paid to have various types of research carried out by universities.[15] The reverse—public research benefiting from research by the private sector— perhaps has been the case less often, but this may be changing. The public sector now may be increasingly able to buy or borrow some research products or processes developed by the biotech industry for use in their own programs. In addition, the public sector in some cases may be the recipients of fairly unrestricted grants for research or research facilities.[16] Public-private consortiums also are being developed,[17] and the philanthropic side of the private sector conceivably could play a larger role.[18] All of these examples, however, are found far more often in developed than in developing countries.

Complications abound in the area of intellectual property rights (IPR). Genetic resources, which used to be considered the "heritage of mankind," increasingly are tied up in IPR and nationalistic issues. The same is true of biotechnology more generally. And there can be substantial public relations problems for both public and private sectors when they face groups or individuals who are opposed to at least some forms of biotech, or are concerned about its food safety dimensions.

Although increased interaction will, even in the face of difficulties, likely be the prevalent model, there probably will be some areas where gaps will persist. The private sector is unlikely to ever show much interest in doing research on self-pollinated crops such as wheat or rice (except in their hybrid variants), and some new innovations—even one as striking as quality protein maize—may go neglected by the private sector if it does not foresee a significant market. Similarly, the private sector also is not likely to do much research on minor crops or natural resource management.

Overall, the public and private sectors, and ultimately society, benefit from each other. The challenge is to maintain the public side of this balance in both developed and developing nations.

5. Major Forms of International Public Research

There are many international agricultural research efforts sponsored by many donors around the world. I will confine my remarks to a brief summary of these sponsored by USAID. (Several other U.S. government agencies, including USDA, EPA, and NOAA also support international research activities that directly or indirectly relate to agriculture.)

A. Major Types and Funding Patterns

Over time, there have been two major types of research efforts in USAID: (a) funding of individual country research programs by the regional bureaus; and (b) funding of multi-country research programs by a central bureau (presently the Global Bureau). In some cases, there has been a cross-over: regional bureau funding of activities administered by the central bureaus or the programs it sponsors. Research projects presently funded by the central bureau are of three main types:[19]

- IARCs. Principally under the aegis of the CGIAR.
- CRSPs (Collaborative Research Support Programs). All managed by U.S. universities.
- Other. Generally involving U.S. universities.

The specific IARC and CRSP centers and programs are listed in Tables 1 and 2. The most relevant project in the Other category is titled Agricultural Biotechnology for Sustainable Productivity (ABSP); it is managed at Michigan State University and involves a consortium of public sector institutions and private companies in the U.S. and developing countries.[20]

The USAID funding patterns for these programs from 1956 to 1996 are summarized in Table 3. It will be seen that for the years listed, there was a gradual rise to an overall peak of nearly $218 million in 1986, and then a sharp drop to $73 million in 1996, a decline of two-thirds. The decline was largest, in dollar terms, for research sponsored by the regional bureaus and the CGIAR. As a proportion of the total in 1996, regional bureaus represented 42.3 percent, followed by the CGIAR, CRSPs, and others. Since 1996, the CGIAR contribution has risen to about $26.4 million.

B. Expanding CGIAR Linkages With U.S. Researchers

We long have felt that both the CGIAR centers and U.S. researchers would benefit from closer ties. There has been, as documented by Collins, considerable interaction at the scientist-to-scientist level, often involving joint training of graduate students. Some centers have had contracts with U.S. institutions.[21] Oregon State, for instance, long has maintained close relations with CIMMYT through the Spring x Winter Wheat program. But these ties largely have been ad hoc and seldom have been encouraged in any formal way.

A few efforts have, however, been made to make greater use of U.S. scientific capacity. The first, initiated in 1986, was informally called the constraints program and was oriented to scientific problems identified by the IARCs. U.S. universities were invited to make proposals for work on selected constraints and were selected on a competitive basis. Altogether, 32 grants were made involving 24 U.S. institutions and 12 centers before funding ran out after a few years.[22] Nothing more was done until 1998, when the availability of some resources ($2 million) from the Africa Food Security Initiative made possible the establishment of a very similar activity: a Competitive Grants Program. Eight constraints were selected involving seven U.S. universities working in cooperation with seven IARCs (including one that is not a member of the CGIAR). This is a promising program, but future funding is uncertain.

Another action involving the CGIAR centers, which didn't require any additional funding, was to make use of what is called a soft earmark. Starting in 1997, the centers were asked to set aside 8 percent of the grant they received from USAID (or about $2.1 million in total) for research linkages with U.S. universities. The centers were entirely free to select the area of work and the universities. This led, as expected, to smaller programs than were established under the constraints program, but many more of them and with many universities (more than 40 in 1997).

Table 1. International Agricultural Research Centers Supported by USAID, 1997.

Center	*Headquarters*	*Founded*
CGIAR		
CIAT—Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)	Colombia	1967
CIFOR—Center for International Forestry Research	Indonesia	1992
CIMMYT—Centro Internacional de Mejoramiento de Maiz y Trigo (International Center for the Improvement of Maize and Wheat)	Mexico	1966
CIP—Centro Internacional de la Papa (International Potato Center)	Peru	1971
ICARDA—International Center for Agricultural Research in the Dry Areas	Syria	1977
ICLARM—International Center for Living Aquatic Resources Management	Philippines	1977
ICRAF—International Center for Research in Agroforestry	Kenya	1977
ICRISAT—International Crops Research Institute for the Semi-Arid Tropics	India	1972
IFPRI—International Food Policy Research Institute	United States	1975
IITA—International Institute of Tropical Agriculture	Nigeria	1967
ILRI—International Livestock Research Institute	Kenya	1995
IPGRI—International Plant Genetic Resources Institute	Italy	1974
IRRI—International Rice Research Institute	Philippines	1960
ISNAR—International Service for National Agricultural Research	Netherlands	1979
IWMI—International Water Management Institute	Sri Lanka	1984
WARDA—West African Rice Development Association	Cote d'Ivoire	1970
Non-CGIAR		
IFDC—International Fertilizer Development Center	United States	1975

Table 2. Collaborative Research Support Programs Sponsored by USAID, 1997.

CRSP	*Year of Inception*	*Management Entity*	*Number of Collaborating U.S. Institutions*[1]
Bean/Cowpea	1980	Michigan State Univ.	12
BASIS (Input Systems)[2]	1996	Univ. of Wisconsin	15
Integrated Pest Management (IPM)	1993	Virginia Tech.	10
Peanut	1982[3]	Univ. of Georgia	9
Pond Dynamics/Aquaculture	1982[3]	Oregon State Univ.	9
Small Ruminants	1978[4]	Univ. of California, Davis	10
Soil Management	1981[3]	Univ. of Hawaii	5
Sorghum/Millet (INTSORMIL)	1979	Univ. of Nebraska	4
Sustainable Agriculture (SANREM)[5]	1992	Univ. of Georgia	9
Postharvest (CASP)[6]	1993	Mississippi State	3
West Africa Natural Resource Management InterCRSP[7]	1995	Virginia Tech.	

1. In addition to Management Entity. A number of developing country institutions are involved as well.
2. Broadening Access and Strengthening Input Market Systems.
3. Reorganized in 1995/96.
4. Reorganized in 1998.
5. Sustainable Agriculture and Natural Resource Management.
6. Postharvest Collaborative Agribusiness Support Program (not formally a CRSP but very similar).
7. Composed of seven CRSPs.

Source: *Global Research for Sustainable Agriculture*, CRSP Council, 1997, 52pp. (Copies available from Office of Agriculture and Food Security, EGAD, Global Bureau, USAID.)

Table 3. USAID Expenditures on Agricultural Research, 1956-1996.

Year	Central Bureau				Regional Bureaus	Total
	IARCs	CRSPs[1]	Other	Total		
	- millions of dollars -					
1956	-	-	0.10	0.10	0.90	1.00
1961	-	-	-	0.11	1.13	1.24
1966	-	-	-	.87	7.94	8.81
1971	3.00	-	2.60	5.60	20.95	26.55
1976	15.70	-	9.39	25.09	44.67	69.76
1981	36.00	8.30	13.10	57.40	87.51	144.91
1986	48.30	14.20	24.52	87.02	130.68	217.70
1991	43.30	17.80	19.38	80.48	115.31	195.79
1996	22.45	17.45	2.03	41.93	30.85	72.78
Change 1986-1996	-25.85	+3.25	-22.49	-45.09	-99.83	-144.85
	-53.5%	+22.9%	-91.7%	-58.8%	-76.4%	-66.6%

1. Other, more recent, internal data place the CRSP totals as follows: 1981, 10.95; 1986, 15.45; 1991, 16.94; and 1996, 17.47. This would place the change from 1986 to 1996 at +2.02 or +13.1%.

Source: Gary Alex, USAID and Agricultural Research; Review of USAID Support for Agricultural Research, World Bank, ESDAR, 1997, pp. 60-63.

Feedback on the program from both the IARCs and the centers has been excellent and it is planned to continue the program.

The competitive grants and linkages programs complement each other nicely, and it is to be hoped that funding can be found to continue the grants program.

C. Types of Relationships With Developing Countries

USAID-sponsored research programs with the various research entities in developing countries generally encourage or involve collaboration. The exact mode varies somewhat between the IARCs and the CRSPs. The IARC research nearly always is carried out in developing nations, in some cases through networks of national programs (this is particularly true in Africa).[23] CRSP research usually has a higher proportion carried out in the U.S., but with a strong tie to developing countries (the target proportions are 50/50, but this may not reflect the actual allocation of funds due to cost differences). There recently has been some interest in encouraging more Center involvement in participatory research, but there are limitations on how far relatively small international research groups can go in this direction.

While the emphasis is on longer term research activities, the programs also may be of value in a shorter time span or in ways not initially contemplated. For example, IRRI has helped replenish the genetic resources in Asian nations which had been lost to wars or other civil problems. In the 1980s, for example, seeds of lost Cambodian rice varieties, which were part of the IRRI genebank, were returned to the country; following further improvement, eight varieties recently have been released. A variant of this process, known as "Seeds of Hope," has been carried out in Africa for several years; it initially proved to be very successful in Rwanda[24] and has expanded to other nations—including, most recently, Honduras and Nicaragua.[25] In Honduras, it was reported that a digital atlas of the country compiled by CIAT shortly before the arrival of Hurricane Mitch for agricultural and environmental planning may "play a key role in restoring the country's agricultural capacity," and that this kind of technology is "likely to play an increasingly important role in disaster relief in the future."[26] The Office of Foreign Disaster Assistance in AID's Bureau of Humanitarian Response is very supportive of efforts of this nature.

D. Changing Motivations

The motivation for providing longer term assistance to agricultural development and agricultural research in USAID has changed somewhat over time. In the early years, it was very much humanitarian.[27] This interest still remains to some extent but, perhaps paralleling broader changes in the climate for foreign assistance, has tended to include a greater mutual interest component.

Mutual interest essentially means doing well by doing good and has both direct and indirect aspects. Agricultural research, as we have noted, helps stimulate economic growth in developing countries, which helps expand the market for U.S. agricultural exports. It also produces technology that sometimes can be used in U.S. agricultural programs to increase our own productivity. Cummings has referred to this process as reverse technology flow.[28]

During the 1960s, the agricultural research program in USAID was held back by Congressional concern that it might lead to increased competition. Thus, work on basic food crops such as wheat and rice was constrained until 1968.[29] During this period, there also were increased benefits of growth; the arguments and evidence were summarized in a speech prepared for the 1970 National Agricultural Outlook Conference.[30] This and similar efforts did not immediately turn the situation around but did help lead to a substantial change in view over time.[31]

It also began to become apparent during the 1970s that the United States was starting to accrue substantial benefits from the development of the semi-dwarf high-yielding varieties of wheat and rice. This led me to develop a detailed bulletin on the subject in 1980.[32] I continued to follow this matter in some subsequent reports on the high-yielding varieties.[33] The very significant economic impact was evaluated more formally in an IFPRI report in 1996.[34]

While mutual benefit can be demonstrated for both the IARCs and the CRSPs, it perhaps has worked more to the advantage of the CRSPs (Table 3). The CRSP program was established with a direct eye to mutual benefit, and the location of project leadership in the U.S. has led to a strong support from the local Congressional representatives. The CGIAR IARCs, being located overseas (except for IFPRI, which is in Washington), do not have this advantage; but occasional Congressional contacts reported to us suggest there is strong interest in the benefits of center work to the U.S.

One might bemoan the relative decline of humanitarianism as a motive, but the mutual interest concept probably provides a stronger domestic basis of support for international research—as long as the benefits to developing countries continue to remain a key point of focus.

6. Major Constraints in International Public Research

The constraints on international agricultural research are much the same as those facing public agricultural research around the world and agricultural development more generally. They are primarily financial and can be traced to a number of causes. In addition, Mother Nature continues to throw up challenges of a biological nature. And man has worsened the situation through overuse and abuse of natural resources.

A. Overall Funding Patterns and Some Comparisons

Funding for international agricultural development, both by multilateral and bilateral assistance organizations and by developing countries themselves, has been shown by IFPRI to have declined from the early 1970s to 1990.[35] The pattern undoubtedly has persisted since. Agricultural research has not been hit so sharply, but its rate of growth for public research has been reduced in both developed and developing countries, as is shown in the following data recently reported by IFPRI.[36]

Region	1971-81	1981-91
Developed	+2.7%	+1.7%
Developing	+6.4%	+3.9%

The overall decline in rate of growth was about the same for both regions; it probably has continued. The authors noted that "Some countries (especially in Africa but also in Asia and Latin America) have seen a contraction in real public support for agricultural R&D."

The situation for agricultural research in the United States in recent years has been more mixed. At the federal level in 1999—which turned out to be an exceptionally good year for research—the overall research budget will rise by $4.1 billion to $80.2 billion. Defense R&D accounts for 52 percent (or $41.8 billion) of this total, and non-defense R&D 48 percent (or $38.3 billion). Non-defense R&D will rise by $2.7 billion or 74 percent; much of the increase is in the health area, which will grow 14 percent. USDA, which accounts for 4.3 percent of the non-defense area, will rise by $103 million or 6.6 percent. However, $23 million, or 22 percent, of this total is emergency funding to develop ways to destroy crops of illegal drugs. Also, Congress blocked funding for a new competitively awarded agricultural research program that was authorized in June 1998 ("...when it came time to pay for these initiatives, Congress balked"[37]). USAID funding for all research remains at a relatively minuscule $150 million.[38]

Even these levels are dwarfed by more general public expenditures on the military in both developed and developing nations. These have been estimated by one source to total more than $700 billion in 1994, or 3.0 percent of GNP.[39] In the U.S., larger military and intelligence budgets may be on the way. The Pentagon has requested a $12 billion increase in next year's budget and a $110 billion increase over the following 6 years.[40] The CIA, after stating that it "will no longer be relevant" without an infusion of money and talent, recently received a supplemental appropriation of $1.8 billion and "will seek billions more" in future budget requests.[41]

Military expenditures may, of course, cut close to the bone in the poorer nations. India spends twice as much on its military as it does on education and health programs, while Pakistan spends four times as much; expenditures on nuclear weapons research recently have been noted to be in sharp contrast with widespread poverty and social needs.[42] In Ethiopia, according to one recent account titled "Food Frees Money for Arms," the country received food aid worth $90.2 million from Russia while spending $150 million for military equipment from Russia.[43]

Obviously, agriculture—despite its basic importance—does not begin to compare with the appeal of other forms of public research or other forms of public expenditure (some of which, one might argue, have relatively little to offer in terms of meeting basic human needs). The money is there for some things, but relatively little of it is finding its way into agriculture, even in some of the neediest nations. This probably is not a new story in historical terms, but it is a disquieting one as we start to think in terms of future food needs.

B. Institutional Constraints

The total level of funding available for social programs is not the whole story. There also are the questions of how much is available for agriculture and, within that amount, how much is allocated for research.

In terms of development assistance agencies, the problems can be illustrated by USAID (a bilateral agency) and the World Bank (a multilateral institution). Both face problems of maintaining a development focus in the face of a seeming eruption of natural and civil disruptions and crises.[44] Both face a problem of fitting a long-term program such as research into an increasingly tight development budget. Both organizations have relatively few officials or other staff members with agricultural backgrounds or scientific training. And both must give considerable attention to the wishes of their funders or boards, which may lie in other areas.

USAID has been involved in sponsoring agricultural research since the 1960s. Even in days when agriculture was of great importance in the agency, agricultural research had some difficulties in getting established. The situation was described well by Moseman, who was in charge of agricultural research in USAID from 1965 to 1967, in 1970:

> There is still uncertainty...about the feasibility of building and maintaining an effective support base for research and other long-range research activities within an organization so strongly oriented to general assistance, so concerned with highly visible and short-range operational projects, and so subject to frequent reorganizations.[45]

USAID also was, as noted, initially constrained because of Congressional concern about possible competition in export markets.[46] This concern eventually was overcome but re-emerged in the part of farm groups in the mid-1980s, by which time agricultural research had reached its high point in terms of funding and acceptance in the agency.[47] Thereafter, it began a gradual decline as overall funding for agriculture dropped. Many reasons have been mentioned, including decreased development funding in general, increased earmarking by Congress, and a shift in Agency attention to other areas and problems.

The World Bank's involvement in agricultural research also dates back to the 1960s, and expanded in the 1970s through an extensive program of loans for developing agricultural research programs in developing countries and its grant support for the CGIAR.[48] The loan program has expanded steadily and is limited only by the number of well-developed projects proposed for funding. Grants are a different story: they represent a small proportion of the Bank's portfolio. Grant funding—which comes from Bank earnings—has become tighter, and the competition for grants has expanded. Hence, they have come under increasing scrutiny, especially by those in the Bank who are oriented to loans and who perhaps are less interested in technical aspects of development.

The pattern, as seen at the CGIAR level, is mixed for other multilateral groups. UNDP and the Interamerican Development Bank have reduced their funding. But the European Community has come on strongly.

The developing countries themselves have a large stake in the process, but as noted many of them are facing difficulties in funding their national programs.

7. Looking Ahead

The challenges for public international agricultural research will expand rather than diminish in the future. Some exciting new research tools are coming to hand, but it is uncertain whether they will be harnessed adequately for the needs of the poorer developing countries.

A. Broad Challenges

The principal challenge will come, as always, from population growth. Even though United Nations estimates of future growth rates recently have been scaled back, it still remains that nearly all of the growth will be in developing countries. Compared to 1995, the population in these areas is expected to increase by 51 percent in 2025 and 81 percent by 2050. In some countries, particularly in Africa and the Near East, growth rates will be higher, and total populations will double in 30 years or less. And the rate of growth of population in urban areas, reflecting in part migration from rural areas, will be particularly high.[49] The result is likely to be widening food gaps as measured in terms of meeting per-capita food consumption or minimum nutritional requirements, especially in Sub-Saharan Africa, over the coming decade.[50]

This growth will, of course, call for a corresponding increase in food supply in these regions. The more affluent countries will be able to import food commercially. And, though it has declined in recent years, some food aid doubtless will be available for the more extreme—the near famine—cases of food shortage. But most of the poorer populations will have to rely largely on domestically produced food. Since relatively little suitable land is available to expand production (outside of a few countries in South America), most of the increase, as has been said many times, will have to come from increased yields. Yield expansion—which will not be as simple as many people think[51]—is heavily dependent on the development and delivery of improved technologies and policies; technologies are heavily based on research, and policies may be improved as a result of research.

But more than production expansion is needed; marketing processes also will have to be improved to meet the needs of the expanding urban population. And special efforts will be needed to get adequate food in the hands of the poor and malnourished, wherever they are. All of this will have to be done at a time when environmental issues and natural resources (especially water) will be even more of a constraint than they are now.

B. Research Prospects and Constraints

We recently have seen, and doubtless will continue to see, striking advances in biological science, especially as it relates to DNA-centered biotechnology, and information technology. Thus, significant opportunities may open up for coping with some of our major scientific and technical problems. A few are beginning to play a notable role in production.[52] The big question is the degree to which it will be possible to transfer the fruits of these efforts to the developing countries, especially the poorer ones.

The private sector, which is responsible for many of the advances, may show some interest in the larger and/or more affluent developing countries, if suitable intellectual property rights (IPR) processes are in place. But it is quite uncertain how much interest they will show toward the basic food crops of the poorest nations, which are largely self-pollinated and which benefit little from IPR regulations even if they exist. [A recent FAO report indicates that in the least developed countries, cereals comprised 62 percent of the daily dietary energy supply, compared to 27 percent in developed countries.[53]]

Public sector research is urgently needed in both developed and developing countries to provide both more basic research and applied research that will not be provided by the private sector.[54] Agriculture is, as Gallup and Sachs of Harvard have noted, part of a larger public goods issue:

> There is no doubt that many of the core issues in tropical health and agriculture are prime examples of international public goods that require a concerted scientific and financial commitment far beyond the means of any individual government. The coordinated agricultural research aid effort is seriously under funded; the situation in tropical public health is even more desperate.[55]

D. Gale Johnson of the University of Chicago, certainly not an alarmist about the world food situation, recently concluded that "If there are to be continuing improvements in the adequacy of food supplies in the developing countries, the world's commitment to agricultural research must not be reduced."[56]

C. Need for Change in Public Attitude

To confront these issues, we urgently need a change in public attitude—by the public at large, their elected representatives, and their government officials—toward development assistance in general and toward agriculture more specifically.[57] In the developed countries, food supply is taken for granted, and in some at the moment the biggest domestic concern is with surpluses. In developing countries, many governments seem to show greater concern for their military establishments than for the welfare of their populations.

In such a setting, public agricultural research tends to be neglected or taken for granted. Many who forecast future production assume that past levels of public investment will continue; we have seen that this is not presently the case. Others assume that the private sector will do the job; we have seen that this is only partially the case, especially for developing countries. Moreover, in some cases where research is making some striking advances, it faces negative reactions on the grounds of food safety or other concerns.

All of this suggests that one of our biggest constraints in achieving food security in future years will be social—the attitude of society. This is one constraint that could, through appropriate educational actions, be alleviated.

8. Concluding Remarks

To invoke an often-used phrase of Charles Dickens in *Tale of Two Cities*, these are the best of times and the worst of times. On one hand, much is now possible in terms of improving global food supplies, but we also face many problems—especially in developing countries. One of the biggest constraints is very limited public resources for meeting this most basic human need.

Malthus recognized part of the problem 200 years ago but, as is well known, underestimated prospects for increasing production. "Malthus' critics, especially the utopians of his time, have argued that man's ingenuity will always keep pace with population growth by finding improved ways to produce food."[58] Probably so for the developed nations, but there is a big question mark in the case of many developing countries and hundreds of millions of the poorer occupants of the earth. It is hard to understand why this situation doesn't elicit more concern. Perhaps part of the answer is to be found in the recent words of an anthropologist: "We are a species that doesn't respond to threats until it's too late."[59]

Duvick recently has cogently summarized the situation as it relates to agricultural research in these words:

> If we hope to implement the advances in food production that are technically possible, we must nurture societal acceptance of agricultural research and muster the political will to support it. Technical innovation will thrive only if it is supported and led forward by the public at large. In the end, society, not science, holds the key to our future food supply.[60]

This aspect of our future may not be beyond our reach, but may be beyond our will.

9. Notes and References

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1. This figure, which is not generally known or published, was derived from data provided by O. Tampieri of the Statistics Division of FAO, May 1998. In the case of the 28 largest developing countries, the food proportion ranged from a high of 99.7 percent (Ukraine) to a low of 70.4 percent (Uzbekistan). In all but two of the countries, the food proportion was over 90 percent. The comparable figure for the U.S. was 96.0 percent.

2. Based on the *State of Food and Agriculture 1988*, as reported in a November 29, 1998 AFP press account from Rome received on e-mail (the report itself was not available in the U.S. as of this writing).

3. *Ibid.* (drawn from a BBC report on the WWW, December 10, 1998 and also received on e-mail.)

4. See, for example: Seth Mydans, "A Village at Rock Bottom in a Rock Bottom Land," *New York Times*, December 3, 1998; "Child Malnutrition Plagues Cambodia" (World in Brief), *Washington Post*, November 25, 1998, p. A-18; Elizabeth Rosenthal, "In North Korean Hunger, Legacy is Stunted Children," *New York Times*, December 10, 1998, p. A-1; John Pomfret, "Portrait of a Famine," *Washington Post*, February 12, 1999, pp. A1, A30, A31; Karl Vick, "An Anarchic Somalia Lumbers Toward Another Famine," *Washington Post*, December 27, 1998, p. A-23. Iraq shows some of the same characteristics ("Iraq Vows to End Ties to U.N. Food Program," *Washington Post*, December 12, 1998, p. A-19).

5. John M. Goshko, "UNICEF Targets Malnutrition in Yearly Report," *Washington Post*, December 16, 1997.

6. Peter C. Doherty, *Harnessing Science to Solve Global Poverty and Hunger*, World Bank, CGIAR Secretariat, Sir John Crawford Memorial Lecture, October 29, 1998, p. 4.

7. Improved technology also may have other effects, such as improving qualitative aspects (such as flavor) which are prized by consumers and result in higher prices. This appears to have been the case in the Philippines with the third and most recent generation of rice varieties produced by IRRI (*Program Report for 1997*, IRRI, 1998, pp. 90-92).

8. Julian M. Alston and Philip G. Pardey, "International Approaches to Agricultural R & D: The CGIAR," International Food Policy Research Institute (IFPRI), Environment and Production Technology Division (EPTD), February 1999, pp. 33-35, Table 3.1. (Based on J.M. Alston, M.C. Marra, P.G. Pardey, and T.J. Wyatt, "Research Returns Redux: A Meta-Analysis of the Returns to Agriculture R&D," IFPRI, EPTD Discussion Paper No. 38, November 1988.) The highest and lowest 2.5 percent of the rates of return were excluded.

9. The division of agricultural research workers in the public sector in Africa in 1991, for instance, was broken down as follows: government agencies 86.5 percent, universities 10.0 percent, and semi-public entities 3.5 percent (J. Roseboom, P.G. Pardey, and N.M. Beintema, "The Changing Organizational Basis of African Agricultural Research," IFPRI, EPTD Discussion Paper No. 37, November 1998, pp. 23-24, 61).

10. These changes are summarized nicely in a series of articles in a special section on "Evolution of National Agriculture Research Systems" (ed. by Derek Byerlee), *World Development*, June 1998 (Vol. 26, No. 6), pp. 1103-1148.

11. P.G. Pardey, J.M. Alston, and V.H. Smith, "Financing Science for Global Food Security," *IFPRI Report 1997*, 1998, p. 11.

12. I have benefited from discussions with Dr. Josette Lewis of USAID/G/EGAD/AFS in the preparation of this and the next section. She provided several of the citations that follow. Considerable background information on the role of the private sector in agricultural research is provided in: Dina L. Umali, *Public and Private Sector Roles in Agricultural Research; Theory and Experience*, World Bank, Discussion Papers, No. 176, August 1992, 102 pp.; Carl E. Pray and Dina Umali-Deninger, "The Private Sector in Agricultural Research Systems: Will it Fill the Gap?", *World Development*, June 1998 (Vol. 26, No. 6), pp. 1127-1148.

13. During the summer of 1998, two large firms were reported ready to announce plans for significant investments: Monsanto the creation of a $146 million center in St. Louis devoted to basic plant science and sustainable agriculture and Novartis a $250 million plant genomics institute to be built outside San Diego (Jocelyn Kaiser, "Plant Biologists Score Two New Major Facilities," *Science*, Vol. 281, 17 July 1998, p. 317).

14. Robert W. Herdt, "Reflections on Keeping Asia's Food Baskets Full," *American Journal of Agricultural Economics*, 1998 (Vol. 80, No. 5), p. 970.

15. This has been common practice at state colleges of agriculture in the U.S.: "In 1994, nearly 20% of agricultural research at State institutions was funded by private industry, product sales or other private donations, up from 14% in 1978." (Keith Fuglie, *et al.*, *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*, USDA, Agricultural Economic Report No. 735, May 1996, p.iii).

16. For example, Novartis announced in November 1998 that it will provide at least $25 million to fund research at the Department of Plant and Microbial Biology at the University of California at Berkeley and may provide an equal amount for a new laboratory building. Novartis will not direct the research, saying, "It is our belief that [UCB] knows better than [Novartis] where the best research should be done." ("Novartis Pours Cash into UCB," *Nature Biotechnology*, Vol. 16, December 1998, p. 1298).

17. The Monsanto facility noted above was to be a "public-private consortium." In the UCB case, the "...university was looking for a partner to help fund its research and also wanted to see research impact on society." Zeneca Plant Science (Wilmington, DE) is reported about to "invest $82.5 million into a 10-year wheat genetics research program in an alliance with the John Innes Center and Sainsbury Laboratory in Norwich, U.K." ("News: Collaborations," *Genetic Engineering News*, October 15, 1998, p. 38). An example of an earlier and somewhat different approach is provided by the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) established in 1991 (see Pray and Umali-Denninger, *op. cit.* (see fn. 12), p. 1143, and Clive James, *Agricultural Research Partnerships*, World Bank, CGIAR, Issues in Agriculture 9, December 1996, pp. 31-38.

18. The Ford and Rockefeller foundations established the first international agricultural centers and have remained involved in the international agricultural research arena. Their ranks have grown slightly but not in proportion to needs. The possibilities for further engagement have recently been raised by massive philanthropic grants—not directly to agriculture—by two affluent businessmen: Ted Turner ($1 billion to the U.N.) and William Gates ($100 million for childhood diseases in developing countries and $4 billion more generally for the William H. Gates Foundation, which focuses on world health and population issues) (Geraldine Fabrikant, "Turner Begins Delivering on U.N. Pledge," *New York Times*, December 7, 1998, p. C8; Lawrence K. Altman, "Gates Giving $100 million to Fight Childhood Disease," *New York Times*, December 2, 1998; Katie Hafner, "Bill Gates and His Wife Give Away $3.3 Billion," *New York Times*, February 6, 1999, p. A7).

19. Further recent information and perspectives on U.S. engagement are provided in "Report to Congress on Title XII: Famine Prevention and Freedom from Hunger," USAID, December 1998, 54 pp.; and *Proceedings AIARD (Association for International Agriculture and Rural Development) 34th Annual Meeting, June 1998*, Office of Associate Provost for International Affairs, University of Illinois, 114 pp.

20. Details are provided in *Cooperating to Enrich Earth's Capacity: The Agricultural Biotechnology for Sustainable Productivity Project*, Michigan State University, ABSP Project Office, August 1998, 44 pp.

21. See Wanda W. Collins, *US University Collaboration with International Research Centers, 1990-1995*, World Bank, ESDAR, Special Report (1997), 23 pp.

22. *Ibid.*, pp. 3-4. The formal title was "Collaborative Research on Special Constraints for International Agricultural Research Centers."

23. See Roseboom, Pardey, and Beintema, *op. cit.*, pp. 49-53 (see fn. 9).

24. Curt Suplee, "Rescue Effort Ships 'Seeds of Hope' in Bid to Fight Famine in Rwanda," *Washington Post*, December 12, 1994, p. A33. Further detail and analysis are found in Louise Sperling, "Executive Summary and Reflections of Seeds of Hope Socio-Economic Analysis in Rwanda: The Impact of War on Agricultural Production," CIAT, SOH Assessment Document 10, August 1996.

25. "International Effort Launched to Sustainably Restore Food Production in Honduras and Nicaragua Following Hurricane Mitch," World Bank, CGIAR, Future Harvest, news release, January 18, 1999.

26. "A Deluge of Information," *The Economist*, November 28, 1998, p. 86.

27. Dana G. Dalrymple, "The Demand for Agricultural Research: A Colombian Illustration: Comment," *American Journal of Agricultural Economics*, August 1980 (Vol. 62, No. 3), pp. 594-596. While the Cold War played a major role in stimulating overall support for USAID programs, it did not–as far as I could see at the time–have any particular influence on the allocation of funds for agriculture or the operation of these programs (background on this issue is provided in Vernon W. Ruttan, *United States Development Assistance Policy: The Domestic Politics of Foreign Economic Aid,* Johns Hopkins University Press, Baltimore, Md., 1996, pp. 441, 474).

28. Ralph W. Cummings, Jr., "Reverse Technology Flow as a Key to Future World and US Agriculture," *BioScience*, December 1991 (Vol. 41, No. 11), pp. 775-778.

29. This period is discussed in [Dana G. Dalrymple], "Global Agricultural Research Organization," *Supporting Papers: World Food and Nutrition Study,* National Academy of Sciences, Washington, D.C., Vol. V, Study Team 14 ("Agricultural Research Organization"), 1997, pp. 94-97.

30. Quentin M. West [and Dana G. Dalrymple], "The Developing Countries and U.S. Agricultural Trade," 1970 National Agricultural Outlook Conference, February 16, 1970. Subsequently reprinted in *Foreign Agriculture*, USDA, April 5, 1970, pp. 2-6 and *War on Hunger*, USAID, May 1970, pp. 13-17.

31. Ralph W. Cummings Jr. and Dana G. Dalrymple, "Development Assistance and Exports: the Case of the United States," *Agricultural Economics*, Vol. 3 (1989), pp. 293-307. The case is summarized nicely in P. Pinstrup-Anderson, M. Lundberg, and J.L. Garrett, *Foreign Assistance to Agriculture: A Win-Win Proposition*, IFPRI, Food Policy Report, June 1995; and P. Pinstrup-Anderson and M.J. Cohen, "Aid to Developing Country Agriculture: Investing in Poverty Reduction and New Export Opportunities," IFPRI, 2020 Brief 56, October 1998.

32. Dana G. Dalrymple, *Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States: An International Perspective*, USDA, Agricultural Economic Report 455, June 1980, 150 pp.

33. Dana G. Dalrymple, *Development and Spread of High-Yielding Rice Varieties in Developing Countries*, USAID, 1996, pp. 113-116; *Development and Spread of High-Yielding Wheat Varieties in Developing Countries*, USAID, 1996, pp. 91-97; "Changes in Wheat Varieties and Yields in the United States, 1919-1984," *Agricultural History*, Fall 1998 (Vol. 62, No. 4) pp. 20-36.

34. P.G. Pardey, J.M. Alston, J.E. Christian, S. Fan, *Hidden Harvest: U.S. Benefits from International Research Aid*, IFPRI, Food Policy Report, September 1996. (An expanded version of this work is expected to be published soon as a technical report.)

35. J. von Braun, R.F. Hopkins, D. Puetz, and R. Pandya-Lorch, *AID to Agriculture: Reversing the Decline*, IFPRI, Food Policy Report, October 1993.

36. Pardey, Alston, and Smith, *op. cit.*, p. 11 (see fn. 11).

37. Elizabeth Pennisi, "Agriculture Research: 1999 Budget: One Step Forward, Two Back," *Science*, Vol. 282, 16 October 1998, pp. 392-393.

38. "R&D is Big Winner in 1999 Federal Budget," *Issues in Science and Technology*, Winter 1998-99 (Vol. XV, No. 2), pp. 25-27. Further insights are provided in: David Malakoff, "U.S. R&D Budget: Three Spending Bills Bolster Research," *Science*, Vol. 282, 9 October 1998, pp. 209-210, and David Malakoff and Eliot Marshall, "1999 Budget Finale, NIH Wins Big as Congress Lumps Together Eight Bills," *Science*, Vol. 282, 23 October 1998, pp. 598-599. Administration budget proposals for 2000 are reviewed in David Malakoff, "2000 Budget Plays Favorites," *Science*, Vol. 283, 5 February 1999, pp. 778-780.

39. Ruth Leger Sivard, *World Military and Social Expenditures 1996*, World Priorities, Washington, D.C. 1996, pp. 11, 45. Of this total, 73.4 percent was in developed countries (where it represented 2.8 percent of GNP), 19.3 percent in developing nations (3.0 percent), and 7.3 percent in transition states (6.3 percent). The proportions of GNP spent on the military were particularly high in the Near East and North Africa, but also were high in other countries such as Botswana (5.6 percent), Myanmar (4.1percent), and Ethiopia (3.7 percent) (*World Bank Development Indicators 1997*, World Bank, 1997, pp. 182-200).

40. Stephen Lee Myers, "Clinton Proposes a Budget Increase for the Military," *New York Times*, January 2, 1999, p. A1.

41. Tim Weiner, "Big Cash Infusion Aims to Rebuild Anemic C.I.A.," *New York Times*, October 22, 1998. Total appropriations for all intelligence agencies in FY 1998 were $26.7 billion (Vernon Loeb, "CIA Won't Disclose Total Intelligence Appropriation for Fiscal Year," *Washington Post*, December 25, 1998, p. A10).

42. Kenneth J. Cooper, "Grinding Poverty Persists in Newest Nuclear Powers," *The Washington Post*, January 2, 1999, p. A13. In the perhaps extreme case of Cambodia, about 50 percent of the national budget reportedly goes to the military while only 10 percent goes to health care, and 6 percent to education (Mydans, *op. cit.* (see fn. 4)).

43. In "World Briefing," *New York Times*, December 4, 1998.

44. See, for example: Paul Lewis, "World Bank Worried by Pressure for Quick Fix Fiscal Action," *New York Times*, October 5, 1998; Paul Blustein, "World Bank to Expand Crisis Role," *Washington Post*, October 6, 1998, p. C3; Jim Hoagland, "Listen to Little Norway," *Washington Post*, January 24, 1999, p. B7 (refers to U.S. assistance). The conflict side of this issue is outlined in: E. Messer, M.J. Cohen, and J. D'Costa, "Food from Peace: Breaking the Links Between Conflict and Hunger," IFPRI, 2020 Brief 50, June 1998; and I. de Soysa and N.P. Gleditsch, *To Cultivate Peace: Agriculture in a World of Conflict*, International Peace Research Institute, Oslo, Report No. 1, 1999, 98 pp. (sponsored by Future Harvest).

45. A.H. Moseman, *Building Agricultural Research Systems in the Developing Nations*, New York, 1970 (summarized in [Dalrymple], *op. cit.*, 1977 pp. 94-95; see fn. 26 above). Not a lot has changed since this was written, except that the pace of reorganization has slowed. The more general problems at the national level are summarized by J. Thomas Ratchford in "Put Science and Technology Back Into Foreign Policy," *Science*, Vol. 282, 27 November 1998, p. 1650.

46. [Dalrymple], *op. cit.* (see fn. 29 above).

47. Cummings and Dalrymple, *op. cit.* (see fn. 31 above).

48. A summary of the World Bank's activities is provided in Jock R. Anderson and Dana G. Dalrymple, *The World Bank, the Grants Program, and the CGIAR: A Retrospective Review*, World Bank, Operations Evaluation Department, Working Paper Series No. 1, February 1999, 99 pp. (in press).

49. John Bongaarts, "Demographic Consequences of Declining Fertility," *Science*, Vol. 282, 16 October 1998, pp. 419-420; John Bongaarts and Judith Brice, "Population Growth and Policy Options in the Developing World," IFPRI, 2020 Brief 53, October 1998; "Population Tidal Wave," *Washington Post*, January 3, 1997; L. Haddad, M.T. Ruel, and J.L. Garrett, "Growing Urban Poverty and Undernutrition: Implications for Research and Policy," IFPRI, December 15, 1998; and *The State of Food and Agriculture 1998*, *op. cit.* (see fns. 2 & 3).

50. *Food Security Assessment*, USDA, Economic Research Service, GFA-10, December 1998, p. 3.

51. See, for example, Charles C. Mann, "Crop Scientists Seek a New Revolution," *Science*, Vol. 283, 15 January 1999, pp. 310-314.

52. See, for example, Ann Simon Moffat, "Toting Up the Early Harvest of Transgenic Plants," *Science*, Vol. 282, 18 December 1998, pp. 2176-2178.

53. FAO, *op. cit.* (as reported in fn. 3).

54. This point is made more fully in Pray and Umali-Denninger, *op. cit.* (see fn. 12), especially pp. 1143-1144, and in four papers on "Keeping Asia's Food Basket Full" in the *American Journal of Agricultural Economics*, 1998 (Vol. 80, No. 5), pp. 948-972 (see particularly the summary paper by Robert Herdt, pp. 969-972).

55. J.L. Gallup and J.D. Sachs, with A.D. Mellinger, "Geography and Economic Development," Harvard Institute for International Development, December 1998, p. 34. (These conclusions were summarized in the *World Bank Policy and Research Bulletin*, April-June 1998 (Vol. 9, No. 2), p. 3, and in *Der Standard*, Austria, January 1, 1999, p. 35.)

56. D. Gale Johnson, "The Growth of Demand Will Limit Output Growth for Food Over the Next Quarter Century," University of Chicago, Office of Agricultural Economics Research, Paper No. 98: 09, August 22, 1998, p. 23. Also see Charles Mann, "Reseeding the Green Revolution," *Science*, Vol. 277, 27 August 1997, pp. 1038-1042.

57. The general case recently has been summarized in the U.S. context by Hoagland, *op. cit.* (see fn. 44).

58. Malcolm W. Browne, "Will Humans Overwhelm the Earth? The Debate Continues," *New York Times*, December 8, 1998.

59. *Ibid.* (fn. 58).

60. Donald N. Duvick, "Reaping the Fruits of Research," *Forum for Applied Research and Public Policy*, Summer 1998 (Vol. 13, No. 2), p. 81. (Duvick formerly was director of research at Pioneer Hybrid.)

International Agricultural Development Role of Private Industry

Bruce Maunder

Introduction

Seed, currently a $55 billion market worldwide, has evolved since 13,000 BC through several phases. These changes, while well documented in developed countries, provide likely projections for the future role of private industry in international agricultural development:

- In *phase* 1, farmers save their own seed or obtain it from nearby farmers with the low rate of varietal development limited to farmer selection within landraces. Adoption of new types is low.
- During *phase* 2, varieties developed by the public sector begin, although slowly, to replace traditional seeds; and inputs such as fertilizer, while limited, are increasing, with the likelihood of an emerging indigenous private sector involved in multiplication and distribution of public varieties.
- With *phase* 3, the private sector becomes active with research and development, particularly in developing hybrids as well as seeds for specialized crops such as vegetables. Commercial seed production and marketing are common, effective seed laws are in place, and the use of improved seed is high.

Parastatal seed systems, while supplying only 10 percent of total seed annually in Africa, occupy a position late in *phase* 2 or early in *phase* 3. The public sector may specialize in basic research and applied research on subsistence crops, while the private sector increasingly focuses on research, production, and marketing of improved seed having a high multiplication factor and a relatively low seeding rate. NGOs conversely, concentrate on multiplication and distribution of seed not targeted by the private sector. Hybrids in essence widened the agricultural evolutionary gap between developed and developing countries.

The private sector became a major player in seed in Europe after the Second World War. Agroceres, a Brazilian national company, began in 1947; the private sector became active in Argentina and Mexico in the late 1950s and 1960s; and Thailand with Suwan-1 in the 1970s. Often, the private sector got its start with public varieties or hybrids and depended on a consistent supply of high-quality seed to develop a market. Also, the first hybrids, 4-way doublecrosses, as in the U.S., were better adapted to low-input agriculture. These were followed by 3-way and then single crosses, which required adequate inputs for maximum yield expression. Morphologically, they were of shorter plant stature, with better standability, and often responded to increasingly higher plant populations. Whereas *phase* 3 seems essential for a green revolution in maize comparable to that in rice or wheat, public organizations will and must continue to play an important role in training, basic research, and technology transfer. Crop improvement for specific markets, including subsistence farming, and germplasm development for smaller, indigenous seed firms also requires a strong public component. The current U.S. evolution from public to private seed improvement suggests an advanced stage of *phase* 3.

U.S. Private Sector in Plant Breeding
% of Breeders and Number of Companies

Crop	Breeders (%)	Companies (No.)
Corn	94	91
Soybeans	64	38
Sorghum	74	19
Sunflowers	89	14
Wheat	42	27
Cotton	77	35

Current figures suggest an annual gain of 32 breeders per year for industry and a loss of 2.5 for the public sector, with the private plant breeding effort approaching two-thirds of the total monetary input. Many developing countries, in comparison to the U.S. seed industry evolution, range from 50 to more than 75 years behind.

Contribution of Private Sector

A commonly recognized logo is "first the seed," yet we've seen the private sector as "last to enter." Krull et. al. Indicate seed to be the single-most important catalyst for achieving significant increases in agricultural productivity. Sanders et. al., working in Sudan, found from farmer interviews that the principal constraint to a more rapid introduction of the first sorghum hybrid, Hageen-Dura-1, was the inability of input suppliers to produce adequate quantities of high-quality seed and to provide sufficient fertilizer. Current world agricultural statistics alarmingly tell us that grain consumption per person has dropped 7 percent since 1984; grain harvested area per person dropped 48 percent since 1950; irrigated area since 1978 by 6 percent; and of perhaps most concern, annual yield gains during the 1990's only increased by 1.1 percent compared to 2.1 percent from 1950 to 1990. With little more than one-third of the world's crop area in improved planting seed, an obvious need of developing country agriculture is technology transfer. To encourage development of the private seed industry, governments first should survey the state of agriculture, by crop and by socio-economic region, to determine which crops and areas of their country can benefit from a private seed industry.

Success of the private seed industry depends on its ability to provide: (1) a dependable supply, (2) acceptable quality and purity, and (3) hopefully, but not necessarily, an improved level of performance. Any of these advantages would provide for profit to farmers, allowing a higher price for good quality seed. In brief, commercial seeds are best suited to profitable crops in favorable farming regions. The private sector companies must concentrate on activities they do best, considering funding limits. Their infrastructures support applied breeding of lines and hybrids with increasing introgression of biotechnology, followed by extensive testing over wide environmental/geographical areas. Private industry can best accomplish these activities by:

- Being more efficient and flexible
- Better understanding market requirements
- Interacting with new agronomic practices

- Concentrating on a holistic approach
- Working large numbers in selection and testing
- Being able to assume a level of risk
- Applying seed cost economics to potential pedigrees
- Emphasizing short- or medium-term breeding programs
- Reducing crop vulnerability

The government of India, for example, has recognized the capabilities of the private sector to breed, produce, and market proprietary and publicly bred materials more efficiently. With control of 60 percent of the coarse grain market now, the Indian private sector unanimously suggests things will be better business-wise. Note that the 1998 recipient of the World Food Prize, Mr. B.R. Barwale, and his Mahyco Seed Company contributed to the Green Revolution in India by establishing mechanisms of production and distribution of quality seeds of major cereals and vegetables plus generated job opportunities in seed production for women belonging to the socially and economically underprivileged sections of the society.

Multinationals characteristically depend on in-country personnel, preferring to minimize ex-patriots in overseas assignments. This is not to minimize the considerable interaction between the base location and any other participating country. Certainly the private sector offers a logical place for short-term training of those desiring to establish a seed business. Another opportunity rests with experienced seedsmen who may be retired but willing to impart their expertise in an advisory capacity. Not to be under-emphasized, marketing and distribution play a vital role in determining the success or failure of any hybrid seed organization, whether public or private. Finally, the absence or ineffectiveness of the seed industry can pose a major problem in the spread of new crop cultivars (Pray and Ramaswami).

Business Consideration of Private Sector

The obvious business requirement before investing in a private sector seed venture, whether by a national or international effort, relates to an expected return on investment. This concern will be affected, however, by a host of other criteria such as strength and stability of the economy; freedom from disincentives resulting in a level playing field; seed price to grain ratio; intellectual property rights; need for product; an infrastructure, particularly transportation, adequate for delivery of goods and services to the farming community; and certainly political stability. Since private companies seldom are subsidized or given incentives, their entrance into a seed venture must be concerned with generating a return on shareholder equity. They therefore choose an environment where demand is likely to be strong. Public seed organizations, on the contrary, often are motivated by noneconomic considerations such as a mandate to serve all farmers. Also, vertical integration is common in the private sector but uncommon in the public sector.

Improved technologies, which are readily available in developed countries but have not reached the farm level in the developing world, will be needed for the full expression of the genetic potential. Nevertheless, ample evidence exists for the superiority of high-tech seeds over conventional landraces even under less-than-favorable growing conditions. A common suggestion on crop yield relates to a 50 percent yield increase for consideration of improved seed compared to traditional landraces. Relate this, however, to developing country yields, often less than a ton per hectare, where such an increase becomes somewhat less significant related to seed and other input costs. In the transition to hybrids from varieties, increases commonly have been expected to range from 20-40 percent from heterosis, with other inputs additionally significant. In developing countries, management practices and certainly availability of water often may be more critical for increased productivity.

With maize, adaptation allowed temperate hybrids of the private sector to move into Europe in the late 1940s, and in fact 90 percent of industrialized countries are temperate. Only 25 percent of developing countries, however, can use temperate germplasm. Therefore, most of the high-tech seed developed for the U.S., Europe, and thus the vast majority of hybrids developed by private seed companies, are of little direct use to maize farmers in developing countries. With Argentina, there was a flint versus dent grain type requirement. Therefore, the multinational private sector at times found hybrid sorghum a more likely first crop to enter into markets such as Mexico and Argentina, perhaps erroneously seeing it to be more widely adapted.

In most developing countries in which hybrid seed has been widely adopted by small-scale farmers, seed-to-grain price ratios usually are less than 10:1. Later during the maturity phase of the seed industry, according to Heisey et. al., seed-to-grain price ratios rise sharply, often stabilizing in the range of 25:1 to 30:1. China, the world's largest producer and consumer of maize seed, plants 740,000 tons annually, of which 90 percent are hybrids. Price controls here keep the seed-to-grain price ratio unreasonably low at 4 compared to the rest of Asia at 24. This pricing structure brought about widespread adoption of hybrid maize but likely has discouraged investment in agricultural research. In fact, the average age of maize hybrids used by Chinese farmers in 1993 was about 20 years and of low quality, compared to 6 years and high quality in the U.S. Without controlled pricing, producers in Sudan have indicated a willingness to pay as much as double for seed from a multinational whose reputation and track record assured appropriate purity and quality even for a locally developed product. Actually, higher seed costs often are a key factor in getting the farmer to improve management practices. Better seed doesn't *cost* more, it *pays* more.

Nonhybrid crops, except for vegetables, have been less likely as products for opportunity in overseas markets. DEKALB, using CIMMYT spring wheat materials, found an acceptance of more than 50 percent in Argentina, which was good for the country but not profitable compared to the marketing of small grain varieties in Europe. Soybeans and alfalfa also may be examples, especially with transgenic traits. In September 1998, Monsanto, the world's largest supplier of genetically modified crops, announced it would invest $550 million in Brazil to produce its herbicide, Roundup. Shortly afterwards, the Brazilian government made Monsanto's Roundup-resistant soybeans that country's first legally approved, genetically engineered crop.

Whereas a return on investment and protection of germplasm seem consistent across company philosophies for overseas expansion, a more conservative an approach of much less risk may involve exports of product or a licensing arrangement with an established indigenous business. Small markets, as well as government restrictions on ownership, may lead to these approaches. Zimbabwe is an example of public seed activity going to the semi-private Seed Co-op which to survive against multinationals formed technical collaboration agreements with U.S., South African, Zambian, and Kenyan seed companies.

The promotion of private agribusiness activity in sub-Saharan Africa has not been successful even when incentives were given for private entrepreneurs. Pray and Tripp indicate the most common strategy for encouraging increased participation in the seed industry would be for governments to ensure free and open access to products of public breeding programs. In India, where a supply of trained agriculturalists to operate seed firms is not limiting, an absence of breeders rights legislation caused reluctance to develop full-fledged breeding programs or introduce proprietary inbred lines, denying producers access to the best germplasm and technology. Certainly, open market policies between countries and fair and uniform seed regulations are additional and significant business considerations.

Benefits for Private Investment

Examples of successful seed ventures by the private sector are numerous, such as maize in Argentina, Brazil, Mexico, Thailand, and Europe; sorghum in Mexico, South Africa, and Argentina; sunflowers in Argentina and Europe; and wheat in Europe and Argentina. Pioneer's 1998 annual report shows 27 percent of their corn income was outside North America whereas DEKALB shows 34 percent of earnings from international seed operations in fiscal '97 with '98 an aberration at 83 percent.

Often public agricultural funding is sacrificed when monetary constraints of government shift funds to alternate investments. The private sector then will be more encouraged to increase its investment. Such occurred as both Mexico and Argentina moved out of the developing country category. Argentina provides a good example of changes brought about by a heavy commercial emphasis with hybrids of maize, sorghum, and sunflowers.

Evolution of Yield of the Principal Cereals
and Oil Crops in Argentina, 1910-1994

Cultivar	Years and Type	Kg/Ha/Year
Maize	1910-50 varieties	9.00
	1951-94 hybrids	57.92
Sorghum	1954-65 varieties	-7.52
	1966-94 hybrids	58.43
Sunflower	1929-80 varieties	-0.36
	1981-94 hybrids	43.00

Data from Argentine Secretary of Agriculture

Such results greatly enhance private sector relations with the producer and most often lead to greater private sector support by the government. In Thailand, Michael Morris of CIMMYT points out that seed prices, as in Europe and North America, increase with the yield potential, leading to single-cross hybrids having a seed-to-grain price ratio of 27-30 compared to open pollinated varieties of 4-5.

Numerous secondary advantages for foreign investment include extra generations such as with the southern hemisphere; early screening; germplasm exchange; grain quality differences; plant pest screening; temperature, moisture, and soil toxicity stress tolerance. A significant benefit, perhaps utilized more frequently with the rapid introduction of transgenically modified hybrids, relates to seed multiplication of a foundation or commercial nature by use of the opposite hemisphere.

Also, expanding multinationals generally operate in a growing market. For example, Brazil has moved maize from a food to feed crop, but only 50 percent of the area is in hybrids. A similar trend is occurring in Africa with sorghum, and very little is in hybrid. In fact, in Ethiopia, where the crop is thought to have originated, only 5 percent of the planted area even is in improved varieties. Naturally, the larger seed concerns can better justify their costs of biotechnology by applying this science to appropriate benefits in the developing countries as well.

Limitations/Restrictions/Concerns Affecting the Private Sector

The unpredictable climatic characteristics of many developing countries have discouraged investment in yield-enhancing technology. Farmers purchasing improved seed and fertilizer risk losing their investment, causing growth in agricultural production to depend more on land expansion than on yield increase, even then lagging in comparison to population. Also, the private sector, while able to operate more efficiently, faces lower competitive pricing since public seed organizations can include some type of direct or indirect subsidy. Pronase of Mexico sets prices to cover only its operating costs and does not have to recover research, packaging, or promotional costs as it attempts to provide seed for low-income farmers.

Since multinationals require a minimum time frame of 8-10 years to develop adapted cultivars to a new-entry market, they must be prepared to give a new venture a reasonably long-term trial for success. The availability of public breeding material during this phase of establishment becomes all the more critical. With either public or private improved seed, cultural preference can become significant to product acceptance. Hageen Dura-1 grain price dropped to 35-50 percent of the local varieties three years after its release in part due to farmers' and millers' complaints about the smaller, harder seed and a blander kisra. By 1990, the price differential disappeared, and 90 percent of farmers interviewed reported that HD-1 kisra was equal to or better than traditional sorghums. Sanders et. al. conclude that the narrowing of price over time may indicate tastes to be dynamic, responding to higher yield potential (lower costs) of the new cultivar. In Latin America and sub-Saharan Africa, consumers strongly prefer white maize, but there is no scientific support associated with digestibility or nutritional quality. Thus, the introduction of improved seed must overcome farmer preference for traditional varieties, especially if they command a premium in the market.

Pray and Tripp point out that during the early stages of seed industry development, regulatory policies may be designed to restrict participation. When decisions about which varieties may be released are made by government plant breeders, the result can be an effective government monopoly of new varieties and virtually no private sector involvement in plant breeding. Regulation should address breeders' requirements for variety protection and adequate rewards; seed producers' concerns about bureaucratic interference and unfair competition; and farmers' expectations of *access* to a wide range of varieties from good *quality* seed.

Finally, the private sector must operate in a partnership with public sector R&D, both worthy of recognition and support, not regarded as competition to be met with suspicion. Plant genetic resources can be exploited best if they remain fully accessible to all users and if passport information and technology on their use is widely disseminated. Not only must the seed industry educate farmers about the advantages of adopting improved germplasm and the benefits of using purchased seed, but all parties, which include scientists and policy makers, need an appreciation of intellectual property rights, including plant variety protection.

The emerging private sector must be prepared to face real concerns as they add a new dimension to a previously less complex agriculture. The movement, mainly in developed countries, toward

The emerging private sector must be prepared to face real concerns as they add a new dimension to a previously less complex agriculture. The movement, mainly in developed countries, toward stricter protection of commercial plant varieties, has been accompanied by a parallel initiative by the developing countries to protect local varieties and landraces, requiring payment for their use. Another concern, as well stated by Morris, suggests that the drive for increased efficiency leads to an increasing concentration and vertical integration in the private seed industry. Such trends may prove undesirable if a small number of very large companies dominate the global seed industry. An example of the current impact of one such company, Monsanto, only in relation to the Western Hemisphere:

1998 Monsanto Global Seed
Market Share (SOM)

Country	SOM %	Country	SOM %
U.S.		Mexico	
Corn	15/50	Corn	60
Soybeans	33	Sorghum	64
Sorghum	29	Argentina	
Cotton	84	Corn	65
Brazil		Sorghum	60
Corn	60	Sunflowers	30

Another example could very well have been Empresas La Moderna SA, a Mexican vegetable seed company whose seed accounts for 40 percent of all vegetables sold in U.S. supermarkets. ELM recently acquired some 11 companies that sell vegetable seed.

Predictions heard in many developing and industrialized countries that profit-motivated seed companies inevitably will engage in socially undesirable behavior in the absence of strict government controls have proved largely unfounded. Optimistically, such a consolidation as shown by Monsanto, with large market share, will in fact stimulate the larger player to increasingly search out new markets and in so doing bring the much-needed contribution of the private sector to countries ready for such a transition. With the excessive costs associated with products of biotechnology, the larger multinationals offer the best opportunity to provide this science in problem solving or improved products. As developing countries' seed systems evolve, so will their agricultural productivity, a mission of urgent importance.

The Role of Graduate Training in International Development

Arthur Klatt

It is a privilege to participate in this Symposium honoring Warren Kronstad and the contributions he has made to agriculture in Oregon, the Pacific Northwest, and throughout the world. The varieties and germplasm he has developed have had a significant impact on agricultural productivity and production in Oregon and throughout the northwestern region of the U.S. Maybe more importantly, the agricultural research scientists he has trained (and there are many) will continue his work. Many of these scientists are leaders of research programs throughout the U.S., as well as around the world. Quite certainly, they will continue to play a key role in agricultural research and education in the future.

Let me begin with some numbers to set the stage. In the 1997/98 academic year, there were 481,000 international students studying at U.S. colleges and universities. Additionally, there were 65,600 foreign scholars at our universities for teaching and/or research purposes, as well as 54,000 students enrolled in intensive English courses. This total represents 30 percent of all students who study outside of their home country; obviously U.S. higher education enjoys an excellent reputation. However, international students comprise only 3 percent of the total enrollment at U.S. colleges and universities. Yet, these students contribute $7.5 billion to the U.S. economy annually (a very conservative estimate), and education of international students has become the fifth largest service sector export of our economy.

Forty-three percent of all international students are studying at the graduate level. The 207,000 students represent 10 percent of all graduate enrollment at U.S. universities. Without a doubt, U.S. universities' graduate programs are recognized for their high quality by international students. What are some of the perceived strengths of U.S. graduate programs? The factors listed by international students include the following[1]:

1. Nearly all faculty are knowledgeable in their field and up-to-date with scientific advances.
2. Students achieve intellectual growth during their studies in the U.S.
3. Advanced degree requirements are clear and reasonable.
4. Good library resources exist at most research universities.
5. Universities have good facilities and good computer labs.
6. The campuses are safe and secure.

In addition, international students prefer graduate programs that combine advanced coursework with research. The courses give them the opportunity to obtain the latest research results and up-to-date scientific information. Time-in-seat credit hours also are popular with American and international graduate students. The American university model also brings together a range of

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[1] Open Doors 1996/97: Report on International Educational Exchange, 1997. Todd M. Davis, Ed. New York: Institute of International Education.

academic disciplines within one institution. This allows students to gain wider exposure and to learn the interrelatedness of disciplines. This knowledge and experience is invaluable for the researcher and especially for agricultural research scientists.

The required research project associated with most U.S. graduate programs teaches the student how to do effective research. Before undertaking the research, the student has to identify a problem and devise a research methodology that hopefully will give a solution to the problem. In addition, the student must plan the research, obtain the necessary inputs (supplies and labor), develop a budget, and manage the experiment. If done properly, the research portion of the graduate program teaches the student to think independently in a scientific manner and gives him/her the basics of research management. These are important tools for the future research scientist regardless of country of origin.

In order to adequately address the theme of this presentation in the time allocated, let us discuss the role of graduate training in regard to the development of the world's agricultural sector. However, we should realize that in most sectors of the economy, the importance and dividends realized from graduate training would be comparable to those obtained in agriculture.

Today, there is general consensus that the agricultural sector is vital to the economic well-being of any nation's economy, and yes, even to the U.S. economy. In many (and maybe most) developing countries, the agricultural sector is considered the "engine of growth." This phrase implies that growth in the agricultural sector will stimulate overall economic growth for the country. It is important to remember that in most developing countries, 50-60 percent of the population obtains its livelihood from agriculture. Therefore, any growth in the agricultural sector has a dramatic effect on investments and growth of the other sectors, which in turn stimulates economic growth and development of the country.

The key element for improvement in the agricultural sector is new technology. The term "new technology" does not have to mean sophisticated technology. Any change in technique or any innovation or altered production practice that results in increased productivity and total production can stimulate economic growth in the agricultural sector. A simple example is to change to a higher yielding variety. Other examples of an agronomic or management nature include the utilization of a more appropriate seeding date (earlier or later), the application of more plant nutrients, the better control of weeds (maybe through the use of herbicides), etc. More complex technologies might include the utilization of "Roundup" resistant soybean varieties to simplify weed control or the use of the bovine growth hormone to increase milk and meat production.

These technologies are most commonly developed by agricultural research scientists who have completed a post-graduate degree (a M.S. or a Ph.D.). The graduate training gave them the tools to conduct relevant research for their constituents, i.e., the farmers and ranchers of their country. The training combined with experience gave them the ability to identify the production constraints, design and manage appropriate experiments to resolve the problems, and deliver the new technology(ies) to the producer. In today's world, new technologies most frequently are developed by a team of scientists working together with a common objective–higher production with greater efficiency while maintaining sustainability.

Let me cite a few examples of how well-trained research scientists and new technologies have brought about greater agricultural productivity, and as a result, overall development.

Let's begin at home. The U.S. has enjoyed steady and sustained growth in its agricultural sector over the past 100 years. New technologies have played and continue to play a critical role. These technologies have been developed by highly trained scientists at the land-grant universities (such as Oregon State University) or by scientists working in the private sector that originally were trained at the land-grant universities. Continued training of excellent agricultural research scientists will be crucial for future growth in the agricultural sector. Our honoree today, Dr. Kronstad, has trained many of the leading wheat research scientists in the U.S., as well as other scientists who currently are working in different research areas.

In India and Pakistan, the agricultural or Green Revolution started in the mid-1960s with the introduction of the semidwarf wheat and rice varieties. These technologies were developed by teams of scientists with post-graduate degrees (many of them from U.S. universities). The initial success of the semidwarfs was due to the adaptability of the varieties (new technologies), plus some courageous decisions by politicians relevant to the amount of applied fertilizer and demonstration strategy. However, India and Pakistan have continued to have dramatic growth in their agricultural sector over the past 30 years, as well as overall economic growth (agriculture served as the "engine of growth"). Well-trained Indian and Pakistani scientists have continued to develop new technologies to "fuel" this growth. Most of these scientists have advanced degrees from Indian and Pakistani universities, but some have received their graduate training from U.S. universities.

Bangladesh recently has experienced substantial growth in its agricultural sector. Well-trained scientists doing good research were a key element. In the early 1980s, Bangladesh made the decision to grow wheat. Many agricultural scientists said wheat could not be grown successfully. However, a small cadre of well-trained agricultural scientists accepted the challenge, and today Bangladesh grows more than 1,000,000 hectares of wheat with acceptable yield levels. More food is being produced, and the economic benefits are significant. Obviously, dedicated and well-trained scientists contributed extensively to this development.

Turkey has undergone a significant agricultural revolution in the past 30 years. Productivity of the major food and fiber crops has increased dramatically during this period. Much of this success is due to the training of agricultural scientists. Let me give an example. In the 1960s, wheat production had stagnated, and the Government of Turkey sought assistance from USAID and the Rockefeller Foundation to improve wheat research and total production. Oregon State University (and W.E. Kronstad) played an important role in this effort. USAID and Oregon State University started in the mid-1960s and the RF, in cooperation with CIMMYT, initiated a program in 1970. By 1975, more than 35 Turkish scientists had been trained at the Master's level (mostly at U.S. institutions, and many of them were students of Dr. Kronstad). By the early 1980s, average wheat yields had increased more than 50 percent and total wheat production had increased 7 million tons. This interdisciplinary team of scientists had a dramatic impact on agricultural productivity and on the development of the country. Many of these scientists later assumed high-level governmental positions, and others became research leaders. Their contributions to agricultural research and to the development of Turkey have been truly significant.

China has enjoyed huge increases in agricultural production in the past 18 years. The initial increases were due to dramatic changes in governmental policies, which encouraged farmers to produce more. Obviously, the necessary technologies were available to increase productivity. Today productivity and total production continue to increase but at a slower pace. However, China is preparing for the future by training a large number of agricultural scientists. This training is being accomplished at Chinese universities and at universities around the world. Most of the overseas training is at the graduate level, and many of these students have studied at Oregon State University as well as other U.S. universities. These scientists will develop the technologies of the future for the agricultural sector of China.

In Latin America, Brazil has made great strides in agricultural development. Today it is the world's largest producer of coffee, the leading exporter of orange juice concentrate, and the second largest exporter of soybeans. It is a significant producer of sugar cane, beef, wheat, rice, and many other crops. The Government of Brazil was cognizant of the agricultural potential of the country and its potential impact for development, and in the 1970s and 1980s undertook a bold and very costly initiative, namely to train thousands of agricultural scientists and mainly at the graduate level. The majority of the training was done overseas, much of it in U.S. institutions. The decision was wise because these scientists have developed the technologies that have revolutionized agricultural production in Brazil and greatly enhanced the development of the country.

These are a few examples of the contributions that graduate training has made to the economic development of selected countries. There are many others that could be cited, although maybe not as dramatic. Proper training is the key ingredient to agricultural development and plays a crucial role in the overall economic development of any country. Changes are initiated by people, and properly trained individuals are more likely to identify the changes that lead to advancements, which result in improved economic circumstances for the people of this world.

In closing, let me say that I am proud to have worked with Warren. He has been a colleague, and we have shared failures and successes–fortunately there were more successes. His efforts in wheat research and in higher education have had a positive impact on many researchers throughout the world. I think it is safe to say that agricultural scientists from many nations have benefited dramatically from having Dr. Kronstad as their graduate advisor. Without a doubt, Warren has made the world a "better place" to live, and his students will serve as his legacy as they continue the crusade for effective research and excellence in teaching in the years ahead. Congratulations, Warren!!

International Wheat Breeding: Past and Present Achievements and Future Directions

S. Rajaram

I am immensely honored to have been invited to address CIMMYT's wheat research at the Warren E. Kronstad Symposium. I have been personally inspired by Warren's achievement. CIMMYT's association with OSU began in the early 1970s with the spring x winter wheat breeding program. Our wheat program has benefited tremendously through this association and constructive counseling of Dr. Kronstad. I salute him for his generosity in sharing of germplasm, a principle he has held throughout his entire career. Dr. Kronstad, Dr. Borlaug, and I are fortunate to steer and guide an international spring and winter wheat breeding program whose effects on global wheat improvement have been phenomenal. I take the liberty of presenting to you some of the successes and impacts of the CIMMYT international wheat breeding program based in Mexico. In doing so, I also express my gratitude to the many CIMMYT staff members whose collaboration I have enjoyed for the past 30 years.

Wheat is the most widely grown and consumed food crop. It is the staple food of nearly 35 percent of the world population, and demand for wheat will grow faster than for any other major crop. The forecasted global demand for wheat in the year 2020 varies between 840 (Rosegrant *et al.*, 1995) and 1,050 million tons (Kronstad, 1998). To reach this target, global production will need to increase 1.6 to 2.6 percent annually from the present production level of 560 million tons. Increases in realized grain yield have provided about 90 percent of the growth in world cereal production since 1950 (Mitchell *et al.*, 1997), and by the first decade of the next century most of the increase needed in world food production must come from higher absolute yields (Ruttan, 1993). For wheat, the global average grain yield must increase from the current 2.5 t/ha^{-1} to 3.8 t/ha^{-1}. In 1995, only 18 countries worldwide had average wheat grain yields of more than 3.8 t/ha^{-1}, the majority located in northern Europe (CIMMYT, 1996).

The formidable challenge to meet this demand is not new to agricultural scientists who have been involved in the development of improved wheat production technologies for the past half century. For all developing countries, wheat yields have grown at an average annual rate of over 2 percent between 1961 and 1994 (CIMMYT, 1996). In western Europe and North America, the annual rate of growth for wheat yield was 2.7 percent from 1977 to 1985, falling to 1.5 percent from 1986 to 1995. Recent data have indicated a decrease in the productivity gains being achieved by major wheat-producing countries (Brown, 1997). In western Europe, where the highest average wheat grain yield is obtained in the Netherlands (8.6 t/ha^{-1}), yield increased from 5 to 6 $t\ ha^{-1}$ in 5 years, but it took more than a decade to raise yields from 6 to 7 t/ha^{-1}. Worldwide, annual wheat grain yield growth decreased from 3.0 percent between 1977-1985, to 1.6 percent from 1986-1995, excluding the USSR (CIMMYT, 1996). Degradation of the land resource base, together with a slackening of research investment and infrastructure, have contributed to this decrease (Pingali and Heisey, 1997). Production constraints affected by physiological or genetic limits are hotly debated; however future increases in food productivity will require substantial research and development investment to improve the profitability of wheat production systems through enhancing input efficiencies. Due to a continuing necessity for multidisciplinary team efforts in plant breeding, and the rapidly changing development of technologies, three overlapping avenues can be considered for raising the yield frontier in wheat: continued investments in "conventional breeding" methods; use of current and expanded genetic diversity; and investigation and implementation of biotechnology-assisted plant breeding.

Conventional Wheat Breeding

It is likely that gains to be achieved from conventional breeding will continue to be significant for the next 2 decades or more (Duvick, 1996), but there are likely to come at a higher research than in the past. In recent surveys of wheat breeders (Braun *et al.*, 1998; Rejesus *et al.*, 1996), more than 80 percent of respondents expressed concern that plant cultivar protection (PVP) and plant or gene patents will restrict access to germplasm. This may have deleterious consequences for future breeding success, since Rasmusson (1996) stated that nearly half of the progress made by breeders in the past can be attributed to germplasm exchange. Regional and international nurseries have been an efficient means of gathering data from varied environments and exposing germplasm to diverse pathogen selection pressures, while providing access and exchange of germplasm. Breeders utilize these cooperative nurseries extensively in their crossing programs (Braun *et al.*, 1998). However, the number of cooperatively distributed wheat yield and screening nurseries has been greatly reduced during the past decade.

Investments needed for breeding efforts increase with increasing yield levels. Further progress to develop higher yielding cultivars is reduced with every objective added to a breeding program. Though the list of important traits may get longer and longer, little if any assistance has been provided by economists to prioritize breeding objectives. Considering that a wheat-breeding program like CIMMYT allocates around 60 percent of its resources on "Durable Resistance Breeding," the need for research in this field is obvious. Due to high cost, we see durable resistance breeding as one of the first fields where transformation should be applied by breeders through introgression of one or more genes controlling disease resistance.

Adoption of CIMMYT-based Germplasm

CIMMYT's breeding methodology is tailored to develop widely adapted, disease-resistant germplasm with high and stable yield across a wide range of environments. The impact of this approach has been significant. The total spring bread wheat *(Triticum aestivum L.)* area in developing countries, excluding China, is around 63 million ha, of which 36 million ha or 58 percent are planted to cultivars derived from CIMMYT germplasm (Table 2) (Byerlee and Moya, 1993; Rajaram, 1995). During the period of 1966 to 1990, 1,317 bread wheat cultivars were released by developing countries, of which 70 percent were either direct releases from CIMMYT advanced lines or had at least one CIMMYT parent (Byerlee and Moya, 1993). For the period from 1986 to 1990, 84 percent of all bread wheat cultivars released in developing countries had CIMMYT germplasm in the pedigree. Simultaneously, the use of dwarfing genes has continued to increase over time and today, regardless of the type of wheat, more than 90 percent of all wheat cultivars released in developing countries are semi-dwarfs, which covered by the end of 1990 70 percent of the total wheat area in developing countries (Byerlee and Moya, 1993). The continuous adoption of semi-dwarf spring wheat cultivars in the post-Green Revolution period from 1977-1990 resulted in about 15.5 million tons of additional wheat production in 1990, valued at about 3 billion US$, of which 50 percent or 1.5 billion US$ are attributed to the adoption of new Mexican semi-dwarf wheat cultivars (Byerlee and Moya, 1993). In 1990, an estimated 93 percent of the total spring bread wheat production in developing countries, excluding China, comes from semi dwarf spring wheats, which cover about 83 percent of the total spring bread wheat area in developing countries (Byerlee and Moya, 1993).

The cornerstone of CIMMYT's breeding methodology are targeted breeding for MES (Mega Environments), the use of a diverse gene pool for crossing, shuttle breeding, selection for yield under optimum conditions, and multi-locational testing to identify superior germplasm with good disease resistance. In this paper we would like to present some of the recent developments at CIMMYT's wheat program.

Targeted Breeding–the Mega-environment Concept

To address the needs of diverse wheat-growing areas, CIMMYT introduced the concept of mega-environments (ME) in 1988 (Rajaram et al, 1994). A ME is defined as a broad, not necessarily contiguous area, occurring in more than one country and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping system requirements, consumer preferences, and, for convenience, volume of production. Germplasm generated for a given ME is useful throughout it, accommodating major stresses, but perhaps not all the significant secondary stresses. Within a ME, millions of ha are addressed with a certain degree of homogeneity as it relates to wheat. By 1993, 12 ME were defined, 6 for spring wheats (ME1-ME6), 3 for facultative wheats (ME7-ME9) and 3 for winter wheats (ME9-ME12).

Use of a Diverse Gene Pool for Crossing to Maintain Genetic Diversity

A recent survey conducted by the CIMMYT Economic Program showed that 58 percent of all wheat cultivars in developing countries were derived from CIMMYT's breeding germplasm and that this percentage was more than 80 if cultivars with parents of CIMMYT origin are included (table 2). This spectacular success is unparalleled in the history of crop breeding; nonetheless, it puts an enormous burden on CIMMYT to continually diversify its germplasm base for resistance and stability parameters.

Broad-based plant germplasm resources are imperative for a sound and successful breeding program. Utmost attention is given to the genetic diversity within the CIMMYT germplasm to minimize the risk of genetic vulnerability since it is grown on large areas and is widely used by NARS. I also believe that the use of genetically diverse material is mandatory for future increase of yield potential and yield stability. The parental group of lines used in crossing in any year consists of 500-800 lines. Twice a year, around 30 percent of the parental stocks are replaced with new outstanding introductions. About 2,000 out of 8,000 crosses/year are made to these introductions. In addition, commercial cultivars from NARS, nonconventional sources such as durum wheat, and alien species are used to incorporate desired traits by recombination or translocation. The introductions are mostly used as female to preserve cytoplasmatic diversity.

The most recent example for the potential impact of generating new diversity is the reconstitution of bread wheat by the CIMMYT wide crossing program by crossing durum wheat (*Triticum durum*) with the D-genome donor *Triticum tauschii.* Lines derived from backcrosses to bread wheat showed substantial morpho-agronomic variation, resistance to Karnal Bunt *(Tilletia indica)* and scab *(Fusarium graminearum),* and a TKW of up to 53 g (Villareal, 1995). Yield potential is close to that of bread wheat, and grain yield of the best synthetic wheat reached 7.7 t/ha (Table 3).

Other sources exploited for new variability are:

- *Triticum dicoccoides* (Emmer wheat) as source for resistance to stripe rust, leaf rust, powdery mildew, Septoria spp., and wheat streak mosaic virus; tolerance to drought; high protein content; and higher yield potential.

- *Triticum durum.* Bread wheat is crossed with durum wheat to increase grain size. The 6 highest yielding lines derived from this program outyielded their bread wheat parent by 5 to 20 percent in yield trials in Cd. Obregon, Mexico.

Shuttle Breeding within Mexico

Young and Frey (1994) provide two factors that influence the success of a shuttle program: a) the use of a germplasm pool encompassing genotypes with broad adaptation, and b) the use of selection environments eliciting different responses from plant types. They state further that the wheat breeding program of Borlaug met these conditions. When N.E. Borlaug started the shuttle breeding approach in 1945, the only objective was to speed up breeding for stem rust resistance. Since then, segregating populations have been shuttled 100 times between the two environmentally contrasting sites in Mexico, Cd. Obregon and Toluca (Braun et al, 1992).

Some of the salient points of this shuttle breeding are as follows:

1. Cd. Obregon is situated at 28° N at 40 masl, in the sunny, fertile, and irrigated Yaqui Valley of Sonora. Wheats are planted in November, when temperatures are low, and harvested in April/May, when temperatures are high. The yield potential of location is high, (±10 t /ha); wheat diseases are limited to leaf rust, Karnal bunt, and black point.

2. The Toluca location is characterized by high humidity – ±1,000 mm of precipitation. The nursery is planted in May/June at this location, when temperatures are high, and harvested in October, when temperatures are low. The high humidity causes incidence of many diseases including rust, septorias, BYD, and fusarium.

One of the important results of this shuttle was the selection of photo-insensitive wheat genotypes. Initially, selection for photoperiodic insensitivity was unconscious, but only this trait permitted the wide spread of the Mexican semi-dwarfs (Borlaug, 1995). Today, this trait has been incorporated into basically all spring wheat cultivars grown below 48 ° latitude and is now also spreading to wheat areas above 48 ° N (Worland et al., 1994).

Multi-locational Testing and Wide Adaptation

Around 1,500 sets of yield trials and screening nurseries consisting of around 4,000 advanced bread wheat lines are annually sent to more than 200 locations. Multi-locational testing plays a key role in identifying best performing entries for crossing. Since the shuttle program (see above) permits two full breeding cycles / year, it takes around 5 to 6 years from crossing to international distribution of advanced lines to cooperators. This "recurrent selection program" ensures a continuous and fast pyramiding of desirable genes.

Ceccarelli (1989) pointed out that the widespread cultivation of some wheat cultivars should not be taken as a demonstration of wide adaptation, since a large fraction of these areas are similar or made similar by use of irrigation and/or fertilizer. Therefore, the term wide adaptation has been used mainly to describe geographical rather than environmental differences. If this is true, genotypic variation should be considerably higher than the GxE interaction in ANOVAs of CIMMYT trials. Braun et al (1992) showed that this is not the case. When subsets of locations were grouped on geographical and/or environmental similarities, the GxE interaction was mostly greater than the genotypic variance. The environmental diversity of sites where CIMMYT's 21st International Bread Wheat Screening Nursery was grown and the diversity among genotypes in this nursery was demonstrated by Bull et al (1994). They classified similarities among environments by forming subsets of genotypes from the total dataset and compared it with the classification based on the remaining genotypes. Using this procedure, they concluded that it was not possible to come to a stable grouping of environments, because little or no relationship existed among them.

Conclusions drawn from trials carried out on research stations are always open to critics who argue that these results do not necessarily reflect farmers' field conditions. However, the wide acceptance of CIMMYT germplasm by farmers in ME 1 to ME 5 does not support the view that the wide adaptation of CIMMYT germplasm is based on geographical rather than environmental differences.

Breeding for High Yield Potential and Enhanced Stability

Selection of segregating populations and consequent yield testing of advanced lines is paramount for identification of high-yielding and input-responsive wheat genotypes. The increase in yield potential of CIMMYT cultivars developed since the 1960s is shown in Fig.1. (Rees et al., 1993). The average increase per year was 0.9 percent and there is no evidence that a yield plateau is reached. This genetic progress in increasing the yield potential is closely associated with an increase in the photosynthetic activity (Rees et al, 1993.). Both photosynthetic activity and yield potential increased over the 30-year period by some 25 percent. These findings may have major implications on CIMMYT's future selection strategy, since there is evidence that wheat genotypes with a higher photosynthesis rate have a lower canopy temperature, which can be easily, rapidly, and cheaply measured using a hand-held thermometer. If verified in future trials, breeders may be able to use this trait to increase selection efficiency for yield potential. This technique may be particularly useful to select wheat genotypes adapted to environments where heat is a production constraint.

Yield per se is closely associated with input responsiveness. Increasing the input efficiency at low production levels can shift cross-over points, provided they exist, and enhance residual effects of high genetic yield potential. Furthermore, combining input efficiency with high yield potential will allow a farmer to benefit from such cultivars over a wide range of input levels. The increase in N-use-efficiency is shown in Fig 2. (Ortiz-Monastario et al, 1995).

Apart from the physiological basis of yield potential, yield gains in CIMMYT wheats can be explained by utilization of certain genetic resources. The germplasm has been paramount to increase yield in the CIMMYT program and in the Minnesota barley program (Rassmusson,1996).

Some examples are listed below.

1. The incorporation of Norin 10 x Brevar germplasm not only resulted in dwarf wheats, but also simultaneously gave high yield.

2. Spring and winter crosses involving the cultivar Kaukaz resulted in Veerys, representing high yield potential and enhanced stability (Figure 5)

3. The incorporation of Lr 19 gene and *Aegilops Squarrosa*-derived synthetic wheats has resulted in further increase in yield potential. The cultivar Super Seri has Lr 19 gene (Figure 6), and derivative of *Ae. Squarrosa* is given in Table 3.

CIMMYT's breeding strategy has resulted in the development of widely grown cultivars, such as Siete Cerros, Anza, Sonalika, and Seri 82, which at their peak were grown on several million ha's. Seri 82 was released for irrigated as well as rainfed environments. Reynolds et al (1994) reported that Seri 82 was the highest yielding entry in the 1st and 2nd International Heat Stress Genotype Experiment. Seri 82 can be considered as the first wheat genotype truly adapted to several ME, particularly to ME1, ME2, ME4, and ME5. A comparison between Seri 82 and

Pastor, a recently developed CIMMYT cultivar, demonstrates the progress made in widening adaptation during the past 10 years. Fig. 3 shows the performance of Pastor (Pfau/Seri// Bow), in the CIMMYT's 13th Elite Spring Wheat Yield Nursery. In 50 trials grown in all six ME, Pastor yielded only in 8 trials significantly (P=0.01) lower than the highest yielding entry. This figure also demonstrates that Pastor has no tendency for a crossover at any yield level. While we do not reject that such a crossover may exist for some cultivars, Pastor and Seri 82 are clear examples that it is possible to combine abiotic stress tolerance with high yield potential. Fig. 4 shows the yield difference between Seri 82 and Pastor. In only 16 out of 50 trials, Seri had a higher yield than Pastor. The latter cultivar proves that breeding for wide adaptation has not yet reached its limit.

Breeding for Durable Disease Resistance

From its beginning, incorporation of durable, nonspecific disease resistance into CIMMYT's germplasm was a high priority, since breeding of widely adapted germplasm with stable yields without adequate resistance against the major diseases would be impossible. The concept goes back to Niederhauser et al. (1954), Borlaug (1966), and Caldwell (1968), who have advocated the application of general resistance in the CIMMYT program versus the specific or hypersensitive type. Very diverse sources of resistance for rusts and other diseases are intentionally used in the crossing program. The major sources are germplasm from national programs, advanced CIMMYT lines, germplasm received from the CIMMYT or other gene banks, and CIMMYT's wide crossing program.

CIMMYT's strategy in the case of cereal rusts is to breed for general resistance (slow rusting) based on historically proven stable genes. This nonspecific resistance can be further diversified by accumulating several minor genes and then combining them with different specific genes to provide a certain degree of additional genetic diversity. This concept also is applied to other diseases such as septoria leaf blotch, helminthosporium spot blotch, fusarium head scab, etc. Following is the present situation of the CIMMYT germplasm regarding resistance to major diseases.

- Stem rust *(Puccinia graminis f.sp. tritici)* resistance has been stable after 40 years of utilization of the genes derived from the cultivar Hope, and losses due to stem rust have been negligible since the late '60s. The resistance is based on the gene complex Sr2, which actually consists of Sr2 plus 4-5 minor genes pyramided into three to four gene combinations (Rajaram et al., 1988). Sr 2 alone behaves as a slow rusting gene. Since there has been no major stem rust epidemic in areas where CIMMYT germplasm is grown, the resistance seems to be durable.

- Leaf rust *(Puccinia recondita f.sp. tritici)* resistance has been stabilized by using genes derived from many sources, in particular the Brazilian cultivar Frontana (Singh and Rajaram, 1992). No major epidemic has been observed for almost 20 years. Four partial resistance genes, including Lr 34, give a slow rusting response and have been the reason for the containment of leaf rust epidemics in the developing world during the past 15 years wherever the cultivars carry these minor genes. About 60 percent of the CIMMYT germplasm carry one to four of these partial resistance genes. Lr 34 is linked to Yr 18 as well as to a morphological marker leaf tip necrosis, which makes the gene particularly attractive for breeders (Singh, 1992a, b). CIMMYT continues to look for new sources of partial resistance.

- Stripe rust *(Puccinia striiformis)*: Slow rusting genes such as Yr 18 have been identified (Singh, 1992b); however, their interaction is less additive than for leaf and stem rust. More basic research is needed to understand the status of durable resistance in high-yielding germplasm. The breakdown of Yr 9 in West Asia and North Africa and the present yellow rust epidemics underline the need for the release of cultivars with accumulated durable resistance.

- *Septoria tritici*: Initially, all semi-dwarf cultivars developed for irrigated conditions were susceptible. Today more than eight genes have been identified in CIMMYT germplasm, and two to three genes in combination provide acceptable resistance. Future activities will concentrate on pyramiding these genes and spread them more widely in the CIMMYT germplasm (Jlibene M., 1992; Matus-Tejos, 1993).

- Karnal bunt (*Tilletia indica*): More than five genes have been identified and most of them are partially dominant. Genes providing resistance to Karnal Bunt have been incorporated into high yielding lines (Singh et al, 1995).

- Powdery Mildew (*Erysiphe graminis* f.sp. *tritici*): CIMMYT's germplasm is considered to be vulnerable to this disease. The disease is absent in Mexico, and the responsibility to transfer resistance genes has been delegated to CIMMYT's regional breeder in South America.

Breeding for Drought Tolerance

There has been a large transformation in the productivity of wheat due to the application of Green Revolution technology. This has resulted in a doubling and tripling of wheat production in many environments, but especially in irrigated areas. The high-yielding cultivars of semi-dwarf statured wheats have continuously replaced the older tall types at a rate of 2 million hectares per year since 1977 (Byerlee and Moya, 1993).

There is a growing recognition that the dissemination, application, and adoption of this technology has, however, been slower in marginal environments, especially in the semi-arid environments affected by poor distribution of water and drought. The annual gain in genetic yield potential in drought environments is only about half that obtained in irrigated, optimum conditions. Many investigators have attempted to produce wheat cultivars adapted to these semi-arid environments with limited success. Others have criticized Green Revolution technology (Ceccarelli et al., 1987) for failing to adequately address productivity constraints in semi-arid environments, although their own recommended technology has had limited impact. This criticism is in clear contrast to the actual acceptance of semi-dwarf wheat cultivars in rainfed areas. In 1990, more than 60 percent of the dryland area in developing countries is planted with semi dwarfs (Byerlee and Moya, 1993).

In this paper, we wish to give a presentation of why CIMMYT wheat germplasm has had considerable adaptive success in semi-arid environments. We also wish to draw conclusions regarding an effective methodology for a breeding program addressing drought-prone areas. While doing so, we do not intend to belittle any other methodology or approach followed elsewhere, but do wish to forward the adoption by farmers as the decisive criteria of success for any methodology.

Definition of Semi-arid Environments and Description of Distinct Drought Patterns

In Table 1, the major global drought patterns observed in wheat production are presented (Rajaram et al., 1994; Edmeades et al., 1989). Through respectively dealing with spring (ME4A), facultative (ME9), and winter wheat (ME12), these three mega-environments are characterized by sufficient rainfall prior to anthesis, followed by drought during the grain-filling period. In South America, the Southern Cone type of drought (ME4B) is characterized by moisture stress early in the crop season, with rainfall occurring during the post-anthesis phase. In the Indian Subcontinent type of drought (ME4C), the wheat crop utilizes water reserves left from monsoon rains during the previous summer season. In the Subcontinent, irrigated wheat crops (ME1) may suffer drought due to a reduced or less than optimum number of irrigations.

Traditional Methodology of Breeding for Drought Stress

The traditional methodology, which has been practiced for many years in varying forms, is typified by handling all segregating populations under target conditions of drought and recommends the use of local landraces in the breeding process (Ceccarelli et al., 1987). What is not particularly evidenced by this methodology is any impact on yield, farmers' adoption, or final national production. This traditional methodology is based on the assumption that the agro-ecological situation facing the farmer does not vary in its expression over time. It assumes that responsiveness of cultivars to improved growing conditions will not be needed. It presumes that there always is a crossover below a certain yield level under dry conditions where modern high yielding cultivars always would yield less than traditional landrace-based genotypes. Such crossovers may occur for selected genotypes, and one always should be open to the possibility that there are real "drought tolerance" traits, operating at the 1 t/ha and below yield level, that adversely affect yield potential at the 4 t/ha and higher levels. Thus far, such traits have not been identified at CIMMYT. In any case, crossover would be restricted to such harsh conditions, where farmers choose–rightfully so–not to grow wheat at all, but rather other more drought-tolerant crops such as barley or sorghum, or resort to grazing practices.

Alternative Methodology of Combining Yield Responsiveness and Adaptation to Drought

At CIMMYT, we advocate an "open-ended system" of breeding in which yield responsiveness is combined with adaptation to drought conditions. Most semi-arid environments differ significantly across years in their water availability and distribution pattern. Hence it is prudent to construct a genetic system in which plant responsiveness provides a bonus whenever environmental situations improve due to higher rainfall. With such a system, improved moisture conditions immediately translate into greater gain to the farmer. Why do we believe this can be done?

The Tale of the Veerys

In the early 1980s when the advanced lines derived from the spring x winter cross Kavkaz/Buho//KAL/BB (CM33027) were tested in 73 global environments of the 15th International Wheat Yield Nursery (15th ISWYN) (Fig. 5), their performance was quite atypical compared to any previously known high-yielding cultivars. In later tests, we found that these lines, called VEERYs, carry the 1B/1R translocation from rye. General performance of such germplasm was superior not only in high-yielding environments but particularly under drought conditions (Villareal et al., 1995, Table 4). From the Veery cross, 43 cultivars were released, excluding those released in Europe.

However, in addition to the creation of a new class of superior germplasm, there is an important lesson in breeding to be learned. The VEERYs represent a genetic system in which high yield performance in favorable environments and adaptation to drought could be combined in one genotype. The two genetic systems are apparently not always incompatible, although others have claimed that their combination would not be possible. Based on this revelation, it is possible to hypothesize a plant system in which efficient input use and responsiveness to improved levels of external inputs (in this case available water) can be combined to produce germplasm for marginal (in this case semi-arid) environments.

Evidence Supporting Promotion of this Methodology

1. By the mid 1980s CIMMYT-bred germplasm occupied 45 percent of the semi-arid wheat areas with rainfall between 300-500 mm, and 21 percent of the area with less than 300 mm (Morris et al., 1991), including large tracts in West Asia/North Africa (WANA). By 1990, 63 percent of the dryland areas, especially ME4A and ME4B, were planted with semi-dwarf wheats (Byerlee and Moya, 1993), many carrying the 1B/1R translocation. This represents clear acceptance by farmers, who widely adopted the new responsive germplasm over their traditional cultivars. The positive trend among the final users of our products cannot be ignored. Indirectly, it supports our view that the modern genotypes have adaptation to ME4A and ME4B drought areas while expressing high yields in improved conditions.

2. To support the above assumptions, an experiment was conducted (Calhoun et al., 1994; Tables 5,6) to determine how the most modern and widely (spatially) adapted germplasm compared to commercial germplasm from countries representing the Mediterranean region (ME4A), the Southern Cone of South America (ME4B) and the Indian Subcontinent (ME4C), under conditions artificially simulating these three Mega-environments. The most widely (spatially) adapted CIMMYT lines outyielded the commercial cultivars in all artificially simulated environments. The recent adoption trend of CIMMYT germplasm in these difficult, marginal environments supports the model of input efficiency/input responsiveness.

3. The story of Nesser: Nesser is an advanced line with superior performance in drought conditions bred at CIMMYT/Mexico and identified at ICARDA/Syria. The cross combines the high-yielding CIMMYT cultivar Jupateco and a drought-tolerant Australian cultivar W3918A. The performance of Nesser in WANA's ME4A environments has been widely publicized (ICARDA, 1993), and the line is considered by ICARDA to represent a uniquely drought-tolerant genotype. However, it was selected at CIMMYT/Mexico under favorable environments and carries a combination of input efficiency and high yield responsiveness. It performs similarly to the VEERY lines in the absence of rust.

Based on the above evidence, our proposed operational methodology is to actively combine input efficiency and input responsiveness.

Application

A breeding scheme we use to achieve the combination of the two genetic systems is described below. Two contrasting selection environments are alternated, allowing alternate selection for input efficiency and input responsiveness.

F1	Crosses involving spatially widely adapted germplasm representing yield stability and yield potential, with lines with proven drought tolerance in the specific setting of either ME4A, ME4B, or ME4C. Winter wheats and synthetic germplasm are emphasized.
F2	The individual plants are raised under irrigated and optimally fertilized conditions and inoculated with a wide spectrum of rust virulence. Only robust and horizontally resistant plants are selected. These may represent plants adapted to favorable environments.
F3, F4	The selected F2 plants are evaluated in modified pedigree/bulk breeding system (Rajaram and van Ginkel, 1995) under rainfed conditions or very low water availability. The selection is based on individual lines rather than on individual plants. The progenies are selected based on such criteria as spike density, biomass/vigor, grains/m^2, and other traits (Van Ginkel et al., 1995) (Table 7). This index helps identify lines that may adapt to low water situations.
F5, F6	The selected lines from F4 are further evaluated under optimum conditions.
F7, F8	Simultaneous evaluations under optimum and low water environments. Selection of those lines showing outstanding performance under both conditions. Further evaluation in international environments is carried out for purposes of verification.

The proposed breeding methodology is supported in research published in recent years by others, not only on wheat (Bramel-Cox et al., 1991; Cooper et al., 1994; Duvick, 1990, 1992; Ehdaie et al., 1988; Uddin et al., 1992; Zavala-Garcia et al., 1992). The importance of testing and selecting in a range of environments, including well-irrigated ones, has shown to identify superior genotypes for stressed conditions. The methodology aims at combining input efficiency with input responsiveness by alternating selection environments during the breeding process. This approach results in germplasm that is accepted by farmers because it translates improved environmental conditions into yield gains. The traditional methodology of only selecting under drought conditions and narrowly relying on the landrace genotypes does not move yield levels significantly beyond those traditionally obtained, and does not provide the farmer with a bonus yield in the "fat years."

Future Research Directions

1. Yield Stability and Yield Potential

Traxler et al. (1995) analyzed grain yield increases and yield stability of bread wheat cultivars released during the past 45 years. In the early period of the Green Revolution, when rapid yield increases occurred, variance for yield concomitantly increased. Since the early 1970s, yield stability has increased at the cost of increases in yield. However, steady progress was made in developing cultivars with improved stability, grain yield, or both. For the developing world, yield stability increased since the beginning of the Green Revolution (Smale and McBride, 1996). While price policy, input supplies, and environmental variation contribute more to yield stability than the genotype, the increasing yield stability reflects the emphasis given by breeders to develop germplasm with tolerance to a wider range of diseases and abiotic stresses. Sayre et al. (1997) concluded that from 1964 to 1990, yield potential in CIMMYT-derived cultivars increased at a rate of 67 kg/ha^{-1}/yr^{-1} or 0.88 percent yr^{-1}. The data did not suggest that a yield plateau had been reached, and the performance of recently released lines, such as Attilla (pb343) and Babax (Baviacora M92), indicate that yield potential has been further enhanced. Improvements made by breeding for yield stability and adaptation may be illustrated by data for the advanced line Pastor, which out-yielded the hallmark check cultivar Seri 82 in 34 out of 50 locations where the 13th Elite Spring Wheat Yield Nursery was grown (Figure 4). The grain yield of Pastor was significantly less than the highest yielding entry at only 8 locations (Braun et al., 1996). Results from CIMMYT international nurseries do not suggest that plateaus for yield or yield stability are imminent. Discussion on how to increase the yield potential of wheat often still centers around traits that contributed to the success of the Green Revolution cultivars more than 30 years ago, e.g. photoperiod and dwarfing genes (Worland et al., 1998; Sears 1998). This emphasizes the long-term commitment needed to introduce genes that may radically alter the conventional phenotype of a wheat plant. This experience may serve as a reminder for those who believe that introducing new genes through transformation, which may affect the adaptation of wheat, will allow the breeder a "quick fix."

CIMMYT had a modest investment in restructuring and creation of a new plant type characterized by robust stem, broad leaf, long spike (30 cm), and a large number of grain per spike. The new plant type still suffers due to diseases and is deficient in quality and certain agronomic characteristics. In 1994, we have launched a dynamic breeding program to correct these deficiencies.

2. *Plant Nutrition*

Selection for yield potential and yield stability under medium to high levels of nitrogen has indirectly increased efficiency for nutrient uptake. Recently released CIMMYT bread wheat cultivars require less nitrogen to produce a unit amount of grain than cultivars released in the previous decades (Ortiz Monasterio et al., 1997). Under low N levels in the soil, N use efficiency increased mainly due to a higher N uptake efficiency–the ability of plants to absorb N from the soil–whereas under high N levels, the N utilization efficiency–the capacity of plants to convert the absorbed N into grain yield–increased. In spite of the increased N-use efficiency of recently released wheat cultivars, the response to nitrogen of wheat production systems has been observed to be declining in many areas of Southeast Asia. In Turkey, where zinc-deficient soils are widespread, recently released winter bread cultivars have a higher Zn-uptake and consequently higher grain yield than local landraces (M. Kalayci, pers. comm.).

3. *Physiology*

A recent survey of wheat breeders suggested that research in plant physiology has had a limited impact on wheat improvement (Jackson et al., 1996). A strong body of evidence now, however, indicates that physiological traits may have real potential for complementing early generation phenotypic selection in wheat. One of the more promising traits identified is canopy temperature depression (CTD). CTD refers to the cooling effect exhibited by a leaf as transpiration occurs. While soil water status has a major influence on CTD, there are strong genotypic effects under well-watered, heat-stressed, or drought-stressed conditions. CTD gives an indirect estimate of stomatal conductance and is a highly integrative trait being affected by several major physiological processes, including photosynthetic metabolism, evapotranspiration, and plant nutrition. CTD and stomatal conductance, measured on sunny days during grain filling, showed a strong association with the yield of semi-dwarf wheat lines grown under irrigation, in both temperate (Fischer et al., 1998), and subtropical environments (Reynolds et al., 1994). In addition, CTD as measured on large numbers of advanced breeding lines in irrigated yield trials, was a powerful predictor of performance not only at the selection site but also for yield averaged across 15 international sites. CTD has been shown to be associated with yield differences between homozygous lines, indicating a potential for genetic gains in yield, in response to selection for CTD (Reynolds et al., 1998).

4. Germplasm is Paramount

Three-quarters of the wheat breeders recently surveyed felt that lack of genetic diversity would limit future breeding advances (Rejesus et al., 1996), though genetic diversity was not considered an immediately limiting factor in most programs. This concern was greater from breeders in developing and former USSR countries (>80 percent) than from those in higher income countries (59 percent). Furthermore, in countries where privatization of wheat breeding programs has occurred, investments in strategic germplasm development that may be risky or have importance only in the long term have declined (McGuire, 1997).

A wide range of opinion has been expressed concerning the abundance of availability of usefully exploitable genetic variability. Allard (1996) emphasized that the most readily useful genetic resource were modern elite cultivars, since these lines possessed relatively high frequencies of favorable alleles. Rasmusson and Phillips (1997) have shown that the assumption that all genetic variability is a result of the inherent exclusive contribution by two parents, *per se*, is not necessarily true considering results from molecular analysis. They discuss mechanisms by which induction of genetic variability may involve altering the expression of genes, the possible mechanisms of single allele change, intragenic recombination, unequal crossing-over, element transpositions, DNA methylation, paramutation, or gene amplification. They also stressed the possible importance of epistasis effects, which may have been underestimated in the past.

Introduction of genetic variability from distantly related wheat cultivars, or related or alien species, often has been aimed specifically at the introduction of simply inherited traits (e.g., genes for disease resistance), but has appeared to be of limited value in quantitative trait improvement. Cox et al. (1997) incorporated genes for leaf-rust-resistance from *Triticum tauschii* into *Triticum aestivum*. With two back-crosses to the recurrent wheat parent, leaf rust resistant winter wheat advanced lines with acceptable quality and equal in yield to the highest yielding commercially grown cultivars were identified. In addition, it has been postulated that since recombination between the D genomes of *T. aestivum* and *T. tauschii* occurred at a level similar to that in an intraspecific cross (Fritz et al., 1995), *T. tauschii* could be considered another primary source of genes for wheat improvement.

The wheat/rye translocations that have had a significant impact on wheat improvement actually are few in number. The majority of the 1BL.1RS translocations occurring in more than 300 cultivars worldwide can be traced to one German source, and all 1AL.1RS translocations, widely present in bread wheat cultivars grown in the Great Plains of the U.S., trace to one source, “Amigo” (Schlegel, 1997a,b; Rabinovich, 1998). Other translocations carry genes for copper efficiency (4BL.5R) and Hessian fly resistance (2RL.2BS, 6RL.6B, 6RL.4B, 6RL.4A; McIntosh, 1993). Chromosome 2R and 7R enhance zinc efficiency in wheat rye addition lines (Cakmak and Braun, unpublished). Considering the impacts that have come from the use of wheat/rye translocations, it may be warranted to further exploit these translocations.

While there have been reports indicating a positive effect of 1BL.1RS translocations on yield performance and adaptation (Rajaram et al., 1990), Singh et al. (1998) has determined that with Seri 82, replacing the translocation with 1BL from cv. Oasis resulted in a yield increase of 3.4

and 5.0 percent in irrigated and moisture stress conditions, respectively. A further increase in grain yield of about 5 percent in disease free conditions was observed in the irrigated trials through the introgression of 7DL.7Ag translocation carrying the Lr19 gene (from *Agropyron elongatum*). This yield increase was attributed to higher rate of biomass production in the 7DL.7Ag lines. However, under moisture stress condition, 7DL.7Ag lines were associated with a 16 percent yield reduction, possibly due to excessive biomass production in early growth stages. This would suggest that the effect of the 1BL.1RS translocation is genotype-specific, and 7DL.7Ag could be a useful translocation for enhancing the yield potential at least in irrigated conditions.

Recent efforts to generate newly accessible genetic diversity has involved the reconstitution of hexaploid wheat by producing "synthetic wheat" by crossing durum wheat (*Triticum turgidum),* the donor of the A and B genomes, with *Ae. tauschi,* the donor of the D genome (Mujeeb-Kazi et al., 1996). Villareal (1995) and Villareal et al. (1997) showed that lines derived after two backcrosses to *T. aestivum* showed increased morpho-agronomic variation and resistance to Karnal bunt (*Tilletia indica*) and scab (*Fusarium graminearum*). Under full irrigation in northwestern Mexico, the yield potential of this material was nearly 8 t/ha $^{-1}$. When tested under drought conditions for 2 years, nearly all of the synthetic derivatives had a significantly higher 1,000-kernel weight, with grain yield varying between 84 to 114 percent, when compared with the bread wheat checks.

It is likely that for no other crop have more crosses been made, or recombinations occurred to break linkages, than with wheat. The more focused a breeding objective may be, the more restricted a breeder may be in the choice of suitable parents. With increased understanding of the inheritance of a trait, selection strategies may be better targeted. With yield, a complex trait still not well understood genetically or physiologically, the use of genetically diverse material will continue to be a prime genetic source for increasing yield potential. As long as breeders have no other readily accessible tools, genetic diversity and the opportunity for its recombination through crossing will be important to break undesired linkages and increase the frequency of desirable alleles. Future breakthroughs in yield potential likely will come from such genetically diverse crosses.

5. Hybrid Wheat

When farmers or breeders discuss strategies for increasing wheat yields, hybrid wheat often is mentioned as an alternative. Pickett (1993) and Picket and Galwey (1997), however, evaluating 40 years of wheat hybrid development, concluded that hybrid wheat production is not economically feasible because of a) limited heterotic advantage; b) lack of advantage in terms of agronomic, quality, or disease-resistance traits; c) higher seed costs; and probably most importantly d) heterosis could be "fixed" in polyploid plants and consequently hybrids would have no advantage over inbred lines. The use of hybrid crops usually is targeted to higher yield potential environments. Results from South Africa (Jordaan, 1996), however, show that hybrids out-yield inbred lines by 15 percent at a 2 t/ha^{-1} mean production potential when narrow row spacing and low seeding rates (<25 kg/ha^{-1}) are used. Mean grain yield of hybrids tested in the Southern Regional Performance Nursery (SRPN), across locations in the southern Great Plains, were significantly higher than for inbred lines (Peterson et al., 1997). Bruns and Peterson (1998) calculated a yield advantage of hybrid wheat at between 10 to 13 percent and attributed this advantage, in part, to better temporal and spatial stability and improved tolerance to heat. In contrast, recent reports of hybrid performance in Europe indicate lower levels of heterosis (5 to 12 percent) (Eavis et al., 1996). Gallais (1989) stated that provided over-dominance is of little importance in wheat, in the long term, inbred line development will be more effective than F_1

hybrids. If biotechnological methods can identify increased expression of heterosis by more effective selection of favorable alleles, this impact likely will have equal advantage to inbred and hybrid development. Whether hybrids have a higher absolute yield potential than inbred lines has to be seen in light of inbred bread wheat cultivars with an observed grain yield of 17 t/ha^{-1} (Hewstone, 1997).

6. Biotechnology

Techniques such as doubled haploids were considered "biotechnology" 10 years ago, but have became an applied routine in many programs. The potential of biotechnology has been discussed elsewhere (Sorrells and Wilson, 1997; Snape, 1998) and will be part of many presentations at this symposium. We will look rather at the application of biotechnology in today's breeding programs. Lack of genetic polymorphism in crops such as wheat and soybeans, and the consequent problems to identify molecular markers, have been a major limitation to the impact of marker assisted selection (MAS) in wheat breeding. The identification of a high number of polymorphisms in single sequence repeats (SSR) therefore should greatly enhance the potential to find molecular markers in wheat.

Conventional plant breeders adopt breeding methods that increase their breeding efficiency but are conservative when making methodological changes. In a small survey of wheat programs having unrestricted access to new biotechnological methods, few research programs, and no main-line wheat breeding programs, routinely use MAS or quantitatively inherited trait loci (QTL). Limitation in use is due to lack of markers for traits of interest, population specificity of a given marker, or their relatively high costs when compared with conventional selection techniques. These limitations may lessen in the next decade.

Modern cultivars are the product of recombinations among the high number of landraces in their pedigrees (Smale and McBride, 1996). Direct use of landraces in contemporary breeding programs, however, often is considered only as a source for qualitatively inherited traits. Tanksley and McCouch (1997) argue that the lack of success from crosses involving landraces for the improvement of grain yield was due mainly to evaluation on a phenotypic basis, an imprecise indicator of genetic potential. Analysis of QTL as revealed that loci controlling a quantitative inherited trait do not contribute equally to the observed variation for the trait, and often few QTL explain most of the observed variation. In rice, QTL for yield were identified in a wild, low-yielding relative. After introgression into modern hybrid rice cultivars, yield increases of 17 percent compared to the original hybrid were observed. Based on the observed gains, Tanksley and McCouch (1997) identify the need to more thoroughly evaluate exotic germplasm. Those accessions most distinct from modern cultivars may contain the highest number of unexploited, potentially useful alleles.

The comparative genetic mapping of cereal genomes has identified a vast amount of conserved linearity of gene order (Devos and Gale, 1997). This observation likely will accelerate the application of QTL in wheat, as well as aid in the identification of genes required for introgression from alien species. Considering the low number of loci tagged today in wheat, the problems related to developing a high density map for wheat (Snape, 1998), and consequently the limited progress to identify QTL in wheat for yield, we believe that the impact from this linearity on wheat improvement will be significant.

Wheat has been successfully transformed for herbicide resistance and high molecular weight (HMW) glutenins, using both the ballistic and *Agrobacterium tumefaciens* systems (Cheng et al., 1997). Barro et al. (1997) inserted two additional HMW glutenin subunits, 1Ax1 and 1Dx5, and observed a stepwise improvement of dough strength. Altpeter et al. (1996) introduced 1Ax1 into Bobwhite and increased total HMW glutenin subunit protein by 71 percent over Bobwhite. However, the affects of transformation are not necessarily additive, as was shown by Blechl et al. (1998), who identified trangenics for HMW glutenins that also exhibited decreased accumulation due to transgene-mediated suppression.

Conclusion

The challenge to annually produce 1 billion tons of wheat within the next 25 years is formidable and can be met only by a concerted action of scientists involved in diverse disciplines–agronomy, pathology, physiology, biotechnology, and breeding, as well as economics and politics. I am optimistic that this target will be met. Today, funds are directed from breeding toward biotechnology, often due simply to the novelty required for publication. Eventually, transformation may be a valuable technique to alter the performance of a genotype; however, at least during the next decade, the simple decision of a breeder in the field to "keep or discard" will contribute more to yield increase than any other approach. In conclusion, I agree with Ruttan (1993), who stated that "at least for the next two decades to come, progress through conventional breeding will remain the primary source of growth in crop and animal production."

The issue of sharing genetic resources and intellectual property rights must be debated both nationally and internationally. The issue of public and private sector research in plant breeding also must get proper attention. The crucial point is that free exchange of germplasm for breeding must remain the central doctrine. A cultivar may be protected commercially to recover investment and gain for profit; nonetheless, the genes it carries should be available to all who are engaged in breeding.

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Table 1. Classification of megaenvironments (MEs) used by the CIMMYT Wheat Program

ME	Latitude (degrees)	Area (mill./ha)	Moisture regime	Temperature regime	Growth habit	Sown	Major breeding objectives	Representative locations/regions	Year breeding began at CIMMYT
SPRING WHEAT									
1	Low	32.0	Low rainfall irrigated	Temperate	Spring	A	Resistance to lodging, SR, LR, YR	Yaqui Valley, Mexico Indus Valley, Pakistan Gangetic Valley, India Nile Valley, Egypt	1945
2	Low	10.0	High rainfall	Temperate	Spring	A	As for ME1 + resistance to YR, Septoria spp., sprouting	North African Coast, Highlands of East Africa, Andes, and Mexico	1972
3	Low	1.7	High rainfall	Temperate	Spring	A	As for ME2 + acid soil tolerance	Passo Fundo, Brazil	1974
4A	Low	10.0	Low rainfall, winter dominant	Temperate	Spring	A	Resistance to drought, Septoria spp., YR	Aleppo, Syria; Settat, Morocco	1974
4B	Low	5.8	Low rainfall, summer dominant	Temperate	Spring	A	Resistance to drought, Septoria spp.,Fusarium spp., LR, SR	Marcos Juarez, Argentina	1974
4C	Low	5.8	Mostly residual moisture	Hot	Spring	A	Resistance to drought, and heat in seedling stage	Indore, India	1974
5A	Low	3.9	High rainfall/ irrigated, humid	Hot	Spring	A	Resistance to heat, Helminthosporium spp., Fusarium spp., sprouting	Joydepur, Bangladesh Londrina, Brazil	1981
5B	Low	3.2	Irrigated , low humidity	Hot	Spring	A	Resistance to heat and SR	Gezira, Sudan; Kano, Nigeria	1975
6	High	5.4	Moderate rainfall/ summer dominant	Temperate	Spring	S	Resistance to SR, LR, Helminthosporium spp., Fusarium spp., sprouting, photoperiod sensitivity	Harbin, China	1989
WINTER/FACULTATIVE WHEAT									
7	High		Irrigated	Moderate cold	Facultativ	A	Rapid grain fill, resistance to cold, YR, PM, BYD	Zhenzhou, China	1986
8A	High		High rainfall/ irrigated, long season	Moderate cold	Facultativ	A	Resistance to cold, YR, Septoria spp.	Chillan, Chile	1986
8B	High		High rainfall/ irrigated, short season	Moderate cold	Facultativ	A	Resistance to Septoria spp., YR, PM, Fusarium spp., sprouting	Edirne, Turkey	1986
9	High		Low rainfall	Moderate cold	Facultativ	A	Resistance to cold, drought	Diyarbakir, Turkey	1986
10	High		Irrigated	Severe cold	Winter	A	Resistance to winterkill, YR, LR, PM, BYD	Beijing, China	1986
11A	High		High rainfall/ irrigated, long season	Moderate Cold	Winter	A	Resistance to Septoria spp., Fusarium spp., YR, LR, PM	Temuco, Chile	1986
11B	High		High rainfall/ irrigated, short season	Severe cold	Winter	A	Resistance to LR, SR, PM, winterkill, sprouting	Lovrin, Romania	1986
12	High		Low rainfall	Severe cold	Winter	A	Resistance to winterkill, drought, YR, bunts	Ankara, Turkey	1986

Source: Adapted from Rajaram et al. (1995).

a Low = less than about 35 to 40 degrees.

b Refers to rainfall just before and during the crop cycle. High = >500 mm; low = <500 mm.

c Hot = mean temperature of the coolest month > 17.5 degrees; cold = <5.0 degrees.

d A = autumn, S = spring.

e Factors additional to yield and industrial quality. SR = stem rust, LR = leaf rust, YR = yellow (stripe) rust, PM = powdery mildew, and BYD = barley yellow dwarf.

f Further subdivided into (1) optimum growing conditions, (2) presence of Karnal bunt, (3) late planted, and (4) problems of salinity.

Table 2. Origin of spring bread wheat varieties in developing countries.

	NARS CROSS			
	CIMMYT Cross	CIMMYT Parents	CIMMYT Ancestor	NO CIMMYT
1966-90	45%	28%	3%	24%*
1991-97	58%	30%	3%	9%

* Estimated
Note: Excluding China

Table 3. Grain yield and TKW of two crosses of bread wheat with synthetic wheats in yield trials at Cd. Obregon, Mexico in 1993.

Entry	Grain yield (kg/ha)	1000 KW (g)
Chen/*T. tauschii*//BCN	7740a[1]	53a
Cndo/R143//Ente/Mexi/3/*T. tauschii*/4/Weaver	6830b	52a
Bacanora 88 (BW check)	6770b	40b

[1] Means within columns followed by different letters are significantly different at the 0.05 level of probability.

Source: Villareal, 1995

Table 4. Effect of the 1BL/1RS translocation on yield characteristics of 28 random F2-derived F6 lines from the cross Nacozari 76/Seri 82 under reduced irrigated conditions.

Plant characteristics	1BL/1RS	1B	Mean diff.
Grain yield	4945	4743	202 *
Above-ground biomass at maturity	12600	12100	500 *
Grains/m^2	14074	13922	152 NS
Grains/spike	43.5	40.6	2.9 *
1000-grain weight (g)	37.1	36.5	0.5 *

Source: Villareal et al., 1995; NS: Not Significant, *: Significant at the 0.05 level

Table 5. Wheat genotypes representing adaptation to different moisture environments

ME_1	Irrigation	Super Kauz, Pavron 76, Genaro 81, Opata 85
ME_4A	(Mediterranean)	Almansor, Nesser, Sitta, Siete Cerros
ME_4B	(Southern Cone)	Cruz Alta, Prointa Don Alberto, LAP1376, PSN/BOW CM69560
ME_4	(Subcontinent)	C306, Sonalika, Punjab 81, Barani

Source: Calhoun et al. 1994

Table 6. Grain yields of selected wheat genotypes grouped by adaptation and tested under moisture regimes in the Yaqui Valley, Mexico, 1989-90 and 1990-91.

Adaptation Group		Full irrigation[1]	Late drought[2]	Early drought[3]	Residual moisture[4]
ME_1	Irrigation	6636 a*	4198 a	4576 a	3032 a
ME_4C	Mediterranean	6342 b	3990 ab	4390 b	2883 b
ME_4B	Southern Cone	5028 c	3148 bc	4224 b	2359 c
ME_4C	Subcontinent	4778 c	3245 bc	3657 c	2704 b

Source: Calhoun et al. 1994

[1] received 5 irrigations; [2] received 2 irrigations early before heading; [3] received one irrigation for germination and two post heading; [4] received one irrigation for germination only

*: Means in the same column followed by the same letter are not significantly different at P=0.05.

Table 7: Genotypic correlation (rg) between agronomic traits and final grain yield, for optimum environment (full irrigations) and reduced water regime (late drought, Mediterranean type) in wheat.

Trait	Moisture regime	
	Full irrigation	Late drought
Days to heading	0.40	0.19
Days to maturity	0.29	0.27
Grain fill period	-0.32	0.36
Height	-0.39	0.05
Peduncle length	-0.46	0.22
Relative peduncle extrusion	-0.51*	0.25
Spike length	-0.28	-0.50*
Spike M^{-2}	-0.12	0.64**
Grains/spike	0.62*	-0.42
Grains M^{-2}	0.74**	0.68**
Yield/spike	0.55*	-0.64**
1000 grain weight	0.08	-0.45
Test weight	0.13	0.05
Harvest index (HI)	0.83**	-0.39
Biomass	0.90**	0.94**
Straw yield	0.52*	0.86**
Yield / day (planting)	0.99**	0.57*
Yield / day (heading)	0.94**	0.44
Biomass / day (planting)	0.86**	0.69**
Biomass / day (heading)	0.74**	0.63**
Vegetative growth rate	0.32	0.63**
Spike growth rate	0.62**	-0.58*
Grain growth rate	0.17	-0.44

*, ** indicate significance at the 0.05 and 0.01 probability level, respectively.
Source: van Ginkel et al., 1995.

Fig.1. Mean grain yields for the historical series of bread wheat varieties for the years 1990 - 93 at Cd. Obregon, Mexico. (Data from Rees et al, 1993)

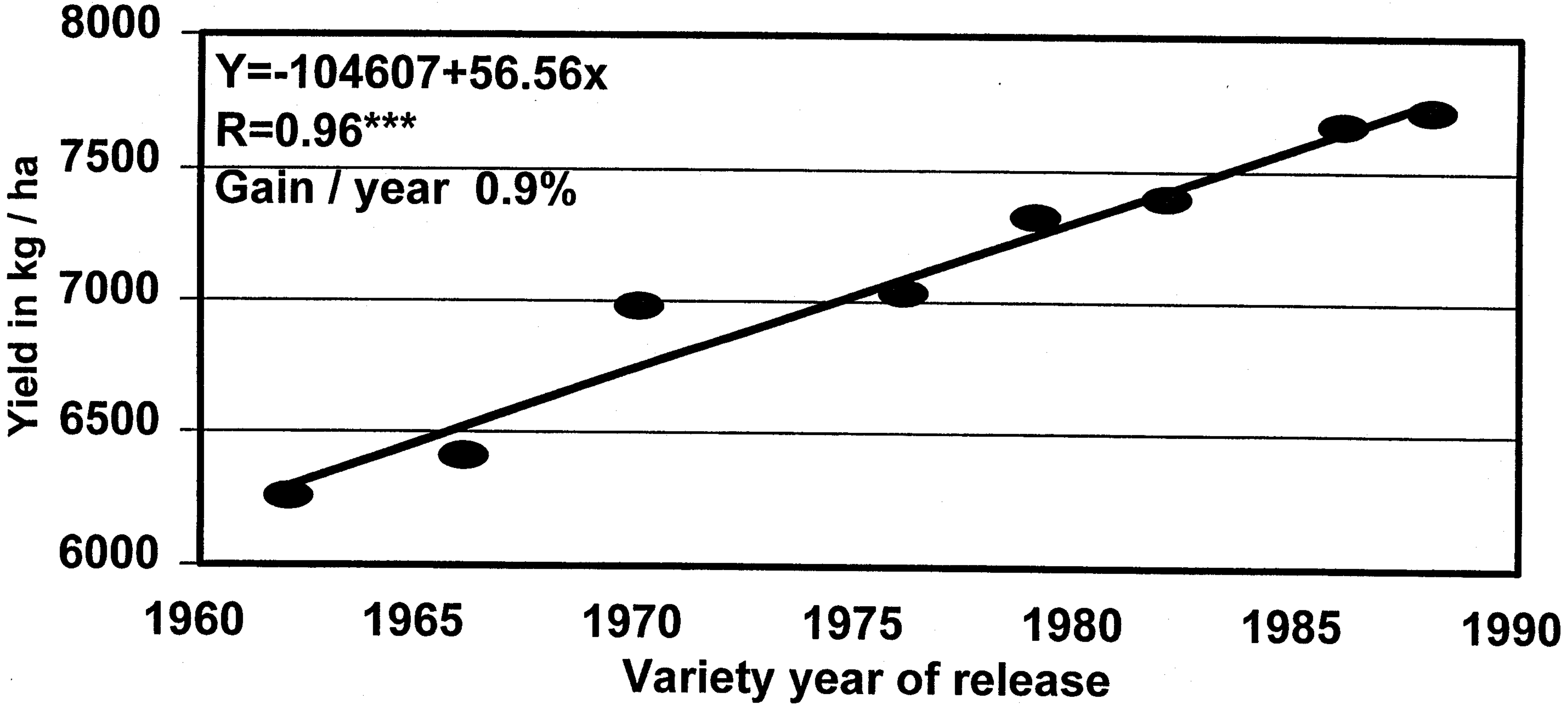


Fig. 2. Grain yield of the historical series of bread wheats at Cd. Obregon, Mexico at 0 and 300 kg/ha N application. (Data from J.I. Ortiz-Monasterio et al., 1995)

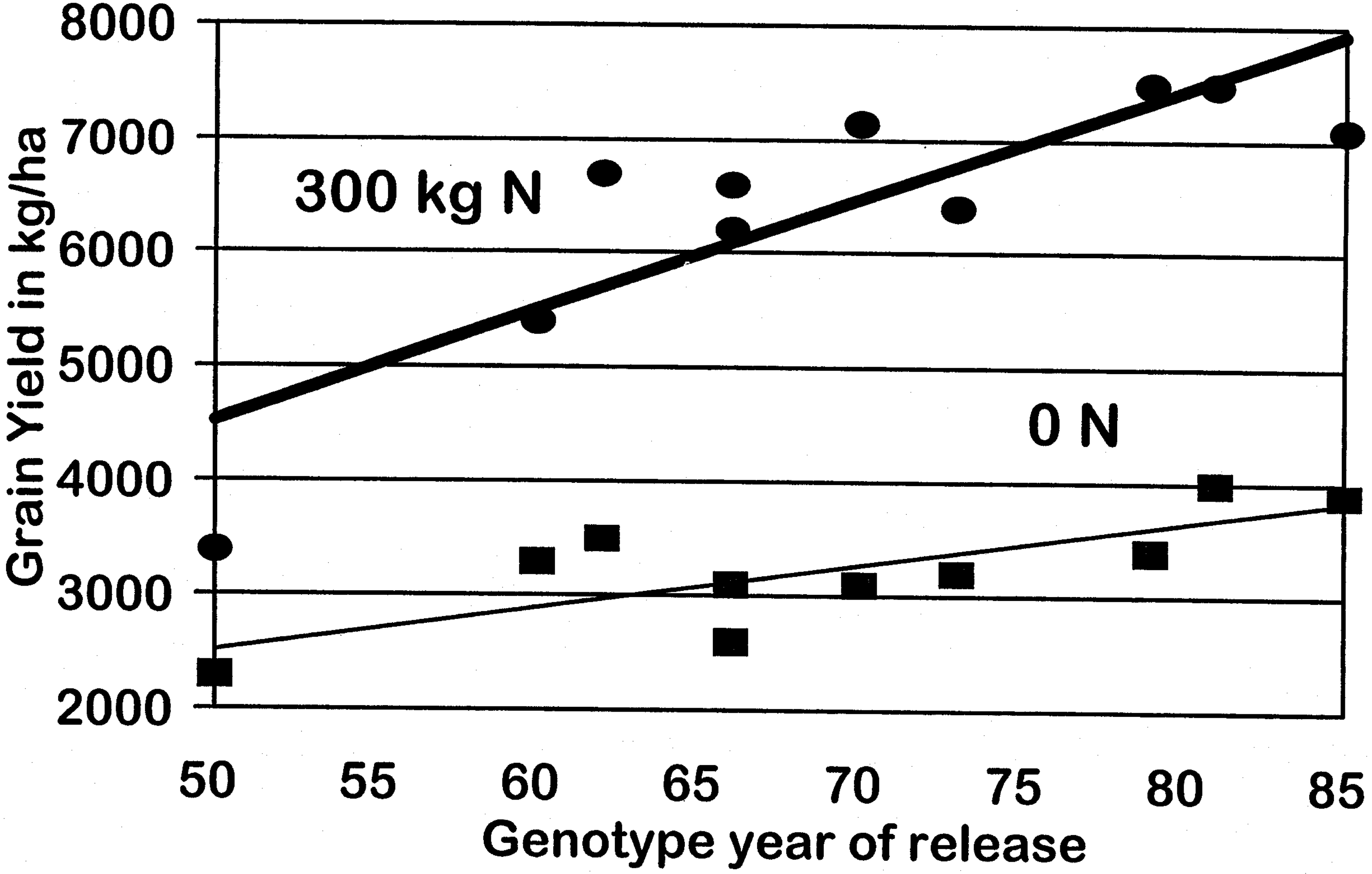


Fig. 3. Yield of Pastor at 50 locations of the 13th ESWYT

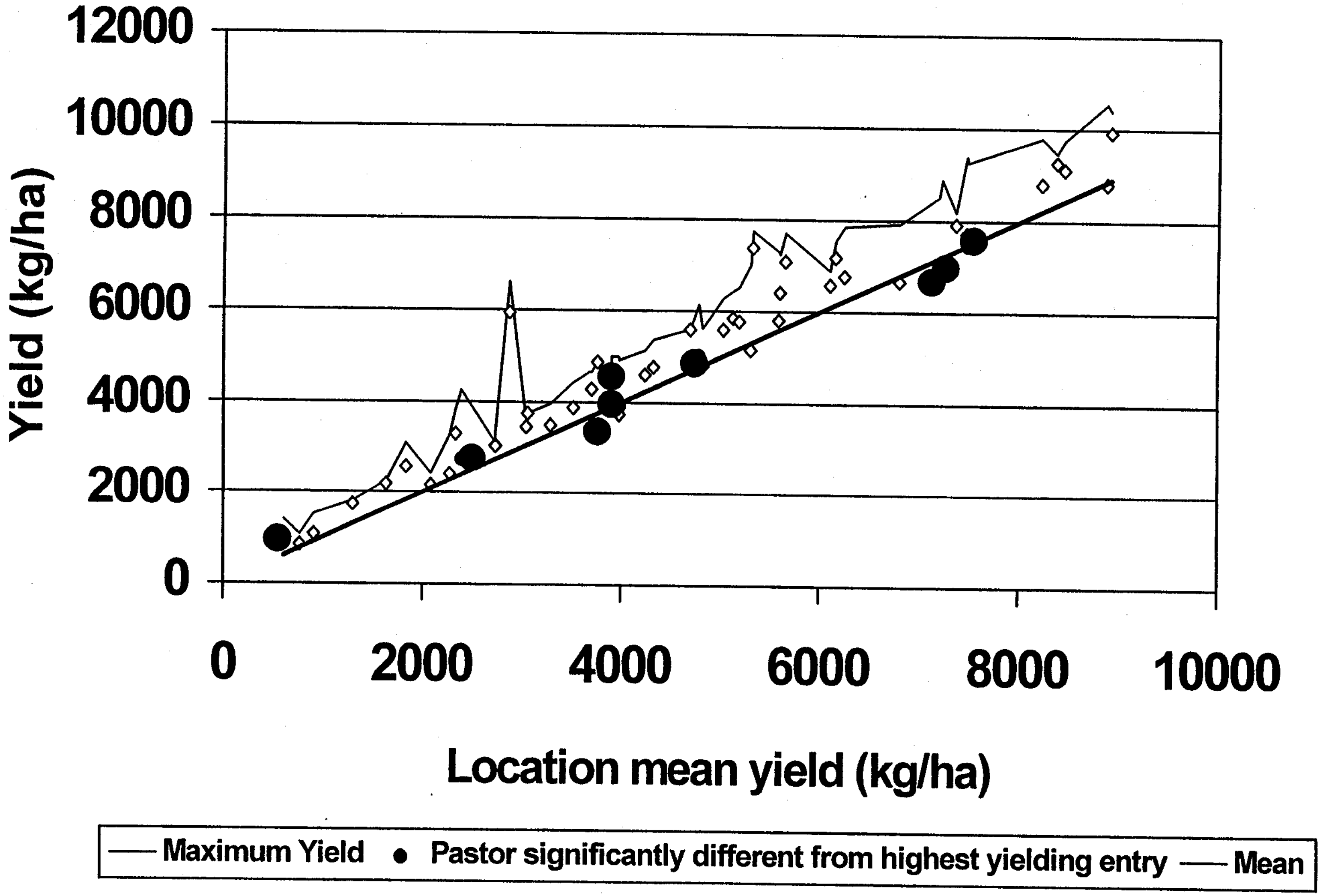
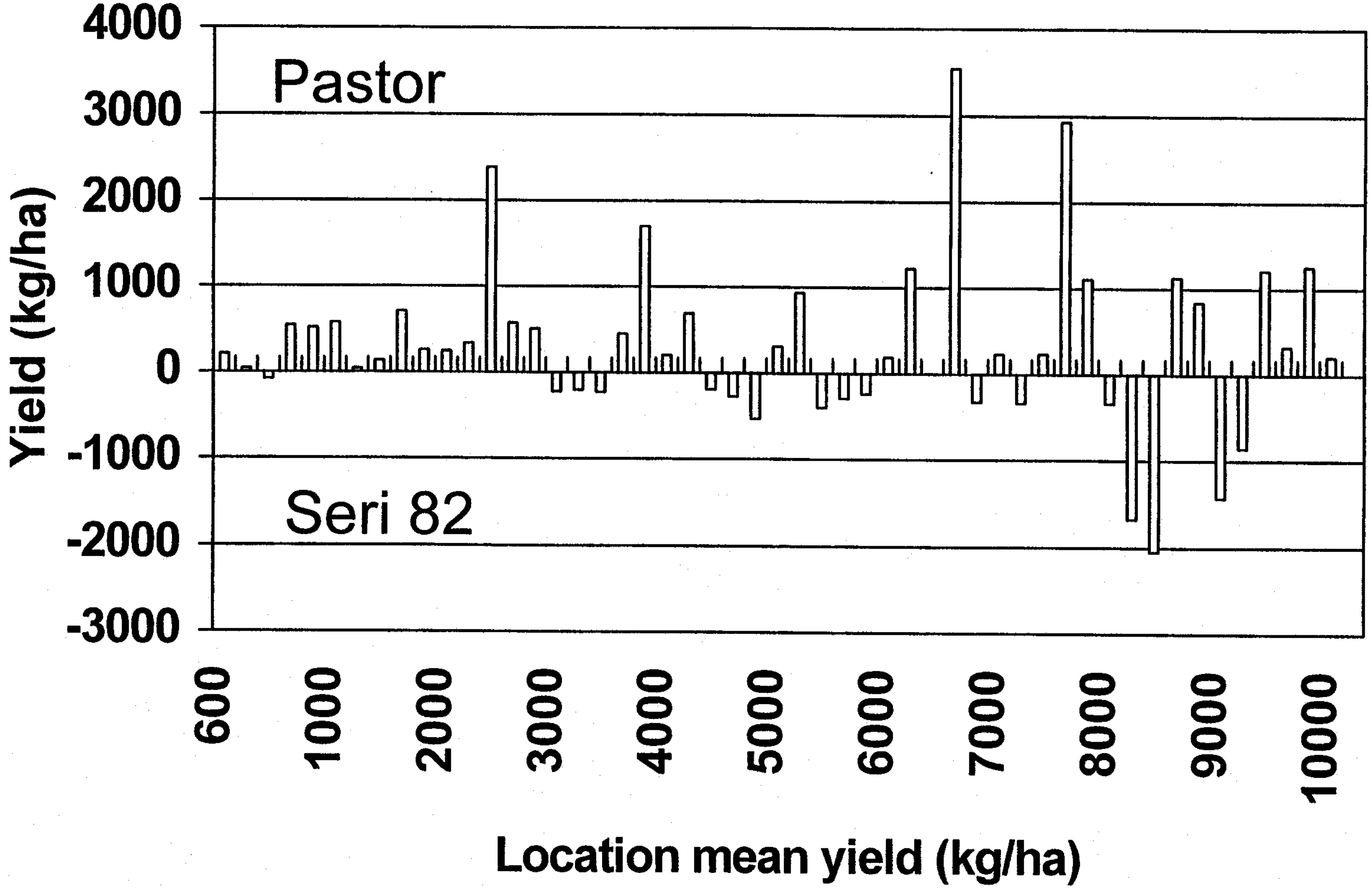


Fig. 4. Yield difference between Pastor and Seri 82 at 50 locations of the 13th ESWYT



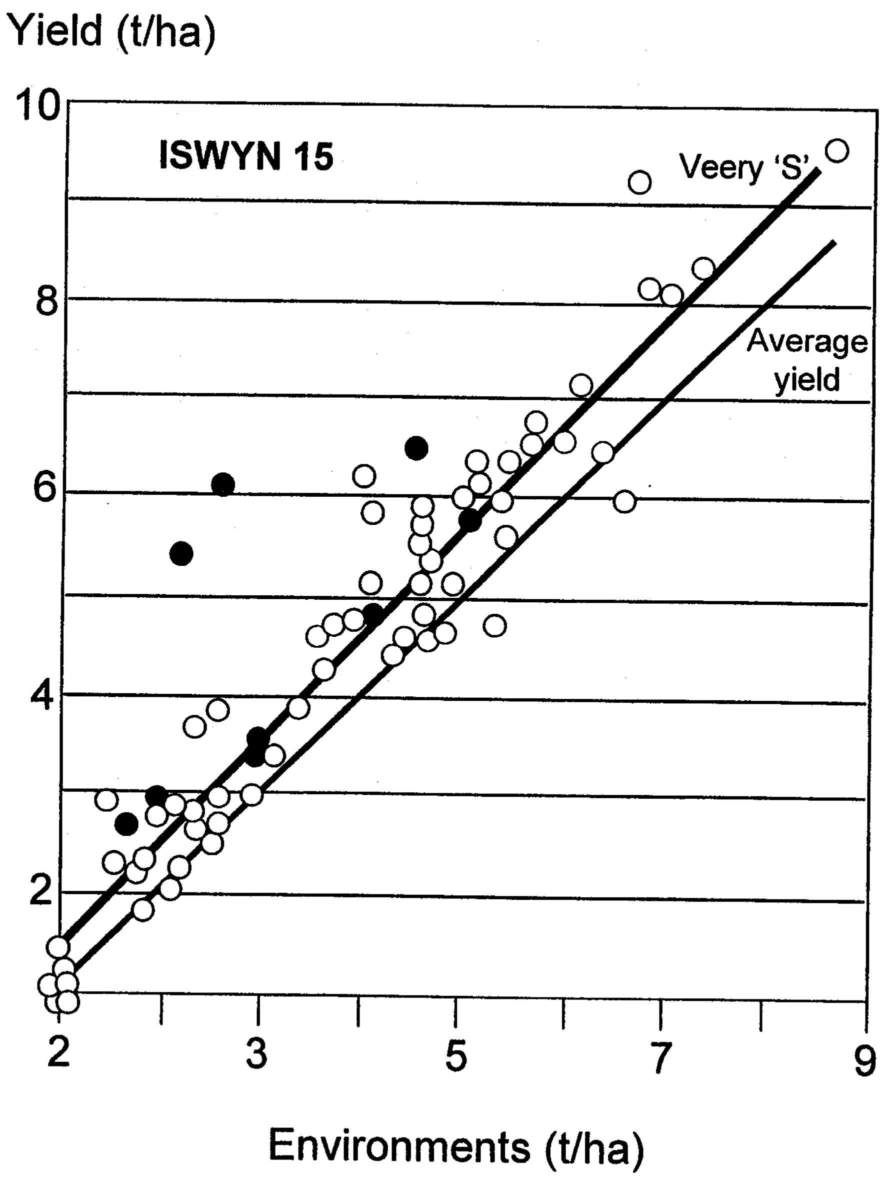
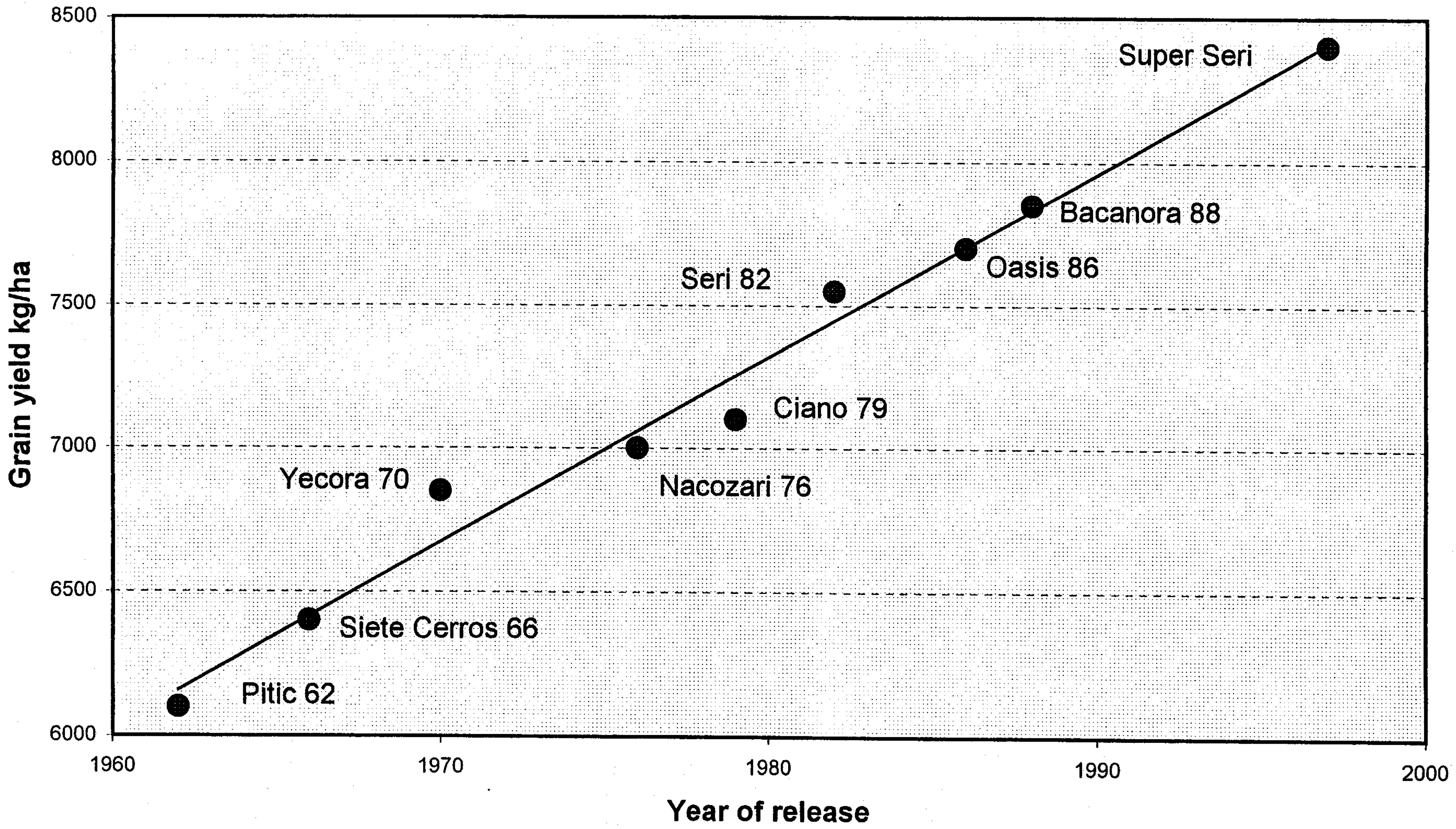


Figure 5. Performance of Veery in 73 Global environments (ISWYN 15)

Figure 6. Increase in grain yield potential of CIMMYT-derived wheats as a function of year of release



Impact of Technology on Partner Countries– The Turkish Experience

Warren E. Kronstad

In 1967, the wheat breeding and genetics program at Oregon State University (OSU) became involved in enhancing wheat production in Turkey. What initially started as a high-risk and bizarre endeavor resulted in an extremely successful example of how new technology can stimulate both the agricultural sector and the total economy of a country. The experience gained in Turkey and similar programs clearly identified those factors critical for the successful introduction of new technology while putting to rest many of the myths, especially that subsistence farmers would not accept new technology. This program was active from 1967 until 1974 with OSU's participation being funded by the United States Agency for International Development (USAID) and the Rockefeller Foundation (RF), and conducted in a close association with the International Maize and Wheat Improvement Center (CIMMYT). During the Turkey wheat program, OSU's wheat activity was expanded to include a graduate education effort and, in concert with CIMMYT, an international wheat germplasm enhancement and distribution program involving 150 countries.

Turkey is rich in history. Many of the earliest civilizations were located there. As a bridge between Europe and Asia, many armies have passed through Turkey and left evidence of their presence. Near Tarsus, on the Mediterranean coast, the well where St. Paul drew water as a child can be seen. Further west on the Aegean Sea is Ephesus, where the Virgin Mary spent her last days on earth. Today, like many countries in this region, the contrast between village life and modern cities such as Ankara and Istanbul are striking. A similar contrast can be drawn between traditional vs. modern agriculture. It was in this setting that OSU became involved in using wheat as a vehicle to stimulate and enhance food production in Turkey.

Wheat has a long history in the Near East, as its native home is in the so-called "Fertile Crescent," which encompasses southern Turkey, western Iran, northern Iraq, and the area extending along the Mediterranean basin into Israel. Carbonized wheat kernels from archaeological ruins in Turkey have been carbon dated back to 3,000 to 5,000 B.C. and appear similar to present-day kernels.

Prior to 1967, Turkey was a wheat importing country. During some years, 700,000 to one million tons of wheat had to be imported to close the gap between production and consumption. Without question wheat is the staple food of Turkey. The average person consumes nearly 500 lb of bread per year (almost 4 times as much as in the U.S.).

The wheat enhancement program will be described in two phases. The first was the introduction of wheat varieties, developed in Mexico by RF and CIMMYT scientists, into the coastal areas of Turkey. The second phase focused on enhancing wheat production on the Anatolian Plateau. Both regions share Mediterranean type climates characterized by winter rain patterns; however, the coastal area receives much more rain, and the temperatures throughout the year are much warmer there. As a consequence, spring-type wheats can be planted in the fall and do not require a large degree of winter hardiness. In contrast, winter wheats are required for the Anatolian Plateau, where limited moisture necessitates a summer fallow system. In this region, one crop of wheat can be realized every second year from a given field.

Introduction of Mexican Wheats

Turkey has 4,000 miles of coastline, with the Mediterranean Sea in the south, Aegean Sea in the west, and the Marmara and Black Seas in the northwest. Temperatures and other factors vary considerably along the extensive coastline. Crops grown range from bananas in the south to fruit trees in the north. As previously noted, Turkey is a very old country with traditional farming practices, which have evolved over a long period of time. For this program to be successful, it required major changes in attitude, organization, and procedures by the Government of Turkey (GOT). This included the very large gamble that Turkish farmers would break from tradition and accept new and largely untested varieties and management systems. Despite political opposition from the Turkish leftist group in parliament, the strong Minister of Agriculture, Bahre Dagdas, provided the necessary leadership for the program to succeed.

The program started in the summer of 1965, when a progressive farmer near Adana in the Cukurova region near the Mediterranean Sea became aware of the successful introduction of Mexican wheat varieties in Pakistan and India. Under somewhat unclear circumstances, he obtained 15 kg (33 lb.) of two Mexican wheats, one of which was the variety Sonora 64. When compared to native varieties, the Mexican wheats yielded twice as much. His success in this demonstration trial prompted 106 farmers to petition the GOT to import 60 tons of Mexican wheat seed to be planted along the coastal areas of Turkey. Recognizing the need to provide food for 32 plus million people, and based on the initial positive experience with Mexican wheats, the GOT requested USAID to provide a review team to evaluate wheat production in the country. A member of the team, the late Dr. Orville Vogel, was with the Agricultural Research Service (ARS) located at Pullman, Washington. It was Dr. Vogel who developed the first semi-dwarf wheats in the U.S. and shared his materials with Dr. Norman Borlaug, germplasm that ultimately contributed to the short, stiff-strawed Mexican wheats. Based on his evaluation, Dr. Vogel felt that Turkey could triple the yields of wheat by introducing new varieties and improved management practices. He recommended that Dr. Tom Jackson, a soil fertility specialist, and Dr. Warren Kronstad, a wheat breeder, both on the OSU faculty, spend time in Turkey developing a strategy to enhance wheat production. In 1967, they made two trips to Turkey to develop and implement the program for the importation of the wheat developed in Mexico for the coastal areas of Turkey. Unfortunately, there was little or no information available as to how such wheats would respond to the growing conditions, or even if they were susceptible to the prevailing wheat diseases. Thus, their initial effort was focused on fields previously planted by the 106 farmers along the coastal areas. In addition, Drs. Jackson and Kronstad relied on their own experience gained in Oregon and published results from the "Green Revolution" in Pakistan in developing a package of practices to reduce the potential risks of crop failure. During this same period, the GOT sent four Turkish agricultural scientists to Mexico to purchase 22,100 tons of several varieties to be planted in the fall of 1967. In addition, 400 tons of U.S. winter wheat were purchased for experimental plantings on the State Farms on the Anatolian Plateau. When it was observed that the initial variety introduced, Sonora 64, was susceptible to yellow rust, a cable was sent to the Turkish scientists in Mexico not to purchase that variety. The major spring wheat varieties introduced were Lerma Rojo, Penjamo, Nadadores, Pitic 62, Mayo, and Sonora 63. Subsequently in 1968, slightly over 1,700,000 acres were harvested. Despite adverse weather conditions and leftist political opposition, 595,000 tons of wheat were produced, which was estimated to be an additional 340,000 tons over what was expected if native varieties had been planted.

As part of the strategy in implementing the program, nine county agents and farmers from the Pacific Northwest spent 3 months in Turkey during the planting season of 1967. Additionally, three county agents were assigned to the program for 1 year, to complement USAID personnel assigned to the project.[1] These individuals, along with Turkish counterparts, were assigned to different locations throughout the coastal area. A large educational campaign was mounted, which reached 60,000 farmers through village meetings. The GOT made sure that seed and fertilizer were delivered to accessible points for the farmers, established credit for a majority of the participants, and encouraged local manufacturers to provide modified U.S. grain drills.

Detailed records were kept by GOT and USAID-OSU staff as to timing and amounts of fertilizer, dates of planting, weather, diseases, yields, etc. During the course of the program, major institutional changes were made to avoid much of the bureaucracy, which frequently plagues such programs. Not only did more Turkish extension people become involved but, as noted by the Ministry of Agriculture Bahre Dagdas, for the first time they felt useful. Vehicles and drivers were provided, paid special per diem, additional people were provided, but above all they had a message that could be reinforced by their U.S. counterparts.

The coastal wheat program in Turkey was extremely successful, though it did not receive the same publicity as the Pakistan and India programs. When reviewing the program and high risk incidence of a political dimension, one would not want to initiate a similar program with so much uncertainty.

However, when Drs. Kronstad and Jackson visited a subsistence Turkish farmer in 1967 and explained what he would have to do to take advantage of the potential yields of the Mexican wheat, one could understand his skepticism. The bottom line for the farmer meant that if these new wheats failed, his family would not have enough to eat. His concerns might be further justified by the fact that two scientists from Oregon were trying to tell him how to raise wheat developed in Mexico, when wheat had originated and had been grown in this part of the world for many generations. Visiting with the same farmer a year later in his field of Mexican wheat, which yielded more than three times what native varieties would have, was most rewarding. He had gone into debt to purchase the necessary fertilizer and other inputs. With tears in his eyes to see such yields, he noted that his family would have enough extra money to purchase a sewing machine and even a bicycle. It is this aspect that is what international work and partnerships are all about.

Wheat Production on the Anatolian Plateau

In contrast to the introduction of Mexican wheat into the coastal areas of Turkey, the Anatolian Plateau presented a much different situation. The plateau, where the majority of the wheat is produced, represents a climate similar to the dryland areas of eastern Oregon: extreme summer and winter temperatures with very limited rainfall distributed during the winter months. There a summer fallow system is used, where only one crop of wheat or barley can be obtained every 2 years from a given field. During the noncrop year, it is critical to conserve as much moisture as possible to establish a crop the second year. As a consequence, tillage practices and weed control are the key factors in establishing this goal. Also, cold winter temperatures necessitate the use of winter type wheats. To enhance wheat production on the Anatolian Plateau, a different technology than that being currently employed was needed. This included improved soil moisture conservation, control of weeds, application of fertilizer, timing of cultural practices, and introduction of high-yielding varieties that would respond to improved management practices. However, there were several social and cultural traditions that had to be addressed. For example,

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[1] A list of those who participated is provided in Appendix Table A.

during the noncrop or summer fallow year, weeds were allowed to grow as pasture for sheep. This was important since one's stature within the village frequently was based on the number of sheep owned. Likewise, an unwritten law was that, when a field was not growing wheat, it was available as pasture for everyone, including the gypsies who migrated through Turkey during certain periods of time.

Through the support of USAID, in 1969, OSU provided a staff, which included Drs. Floyd Bolton, Agronomist/Summer Fallow Advisor, Homer Hepworth, Team Leader and Leader/Weed Control Advisor, and Mr. Dale Hoecker, Extension Advisor. Subsequently, other OSU staff became involved, including Tom Zinn, Andy Anderson, Vance Pumphrey, Dale Smith, and Norm Goetze. With the establishment of the RF Wheat Research and Training Center, Dr. Bolton transferred to the Center in 1970, although he remained as an OSU staff member. He was joined by Dr. Bill Wright of the RF, who was appointed director, and Drs. Art Klatt and Mike Prescott, wheat breeder and plant pathologist, respectively, from CIMMYT, and Dr. Chip Mann, an economist from RF. The key factors to success were timeliness of tillage operations and weed control, both designed to conserve moisture. Introduction of new varieties, although important, was not as critical in enhancing production. As previously noted, in 1967, along with the Mexican varieties, 400 tons of several U.S. winter wheat varieties were introduced along with 100 tons of the variety Bezostoya from Russia. The varieties from the U.S. were later in maturity, as a consequence of late-season drought; they were not well adapted. Bezostoya, being earlier, was more suitable for the Anatolian Plateau and became a popular variety.

The program did receive some criticism in the beginning, as the initial research was conducted on Government State Farms, which were regarded as being similar to what was done in Russia. However, the state farms were more progressive, had some of the necessary equipment, including suitable land, plus they served as effective extension centers in disseminating information to surrounding villages. As results from the adaptive agronomic research became available, educational meetings were held throughout the key provinces. Slide and video educational materials were developed along with visits to experimental plots. These proved highly successful in disseminating the new technology. It also was important, in addition to research on state farms, that demonstration trials be established on farmer fields. The growers had more confidence in the technology when the improved practices and subsequent yield increases were obtained on their land.

The sharing of technology was by no means a one-way street. Having grown wheat for many hundreds of years, there were reasons why the Turkish farmers continued to use certain management practices. Thus, a lesson learned was that it is important to fully understand why certain practices evolved prior to introducing new technology. One example was a key implement for seeding wheat under dryland conditions. In the Pacific Northwest, a deep furrow drill was designed to plant wheat into moisture, which often is 6 to 7 inches below the soil surface. When discussing this concept and the use of such a drill, several Turkish farmers brought out an old wooden drill, which had been used for hundreds of years, that employed the same concept as the U.S. deep furrow drill. Also, the Turkish farmers were planting three times as much seed as is done in the Pacific Northwest. This in part was due to late seeding, often into November when most of the moisture had disappeared, resulting in poor stand establishment, but they noted that one-third was for the birds, one-third was for Allah and one-third was for the farmers. By simply avoiding the birds and employing new management practices, a large quantity of wheat could be used for human consumption without even enhancing yields.

As with the wheat program in the coastal areas, the wheat enhancement program on the Anatolian Plateau was highly successful. From 1967 until 1975, wheat yields in Turkey increased from 7 million metric tons to 17 million metric tons. Unlike the coastal areas, the key factor on the plateau was improved management, rather than new varieties. However, in both situations, the real heroes were the Turkish farmers who were willing to go into debt and take the risk of adopting new technology. Other factors were the Turkish scientists and extension personnel, and above all the highly effective and strong Minister of Agriculture, Bahre Dagdas. As previously noted, his leadership throughout the wheat campaign was instrumental to the success of the program. The scientists, extension agents, and farmers from the Pacific Northwest selected by OSU were highly respected in their disciplines, and despite some frustration and personal and professional sacrifices, they all played a significant role in what must be regarded as one of the most significant international efforts put forth by USAID. Despite the widely held belief that subsistence and traditional farmers in developing countries would not accept new technology, this program proved them wrong. Such farmers will accept new technology if: 1) it is risk reducing, 2) proper incentives are provided, 3) the technology is appropriate, and 4) the technology is sound before information is disseminated.

Establish Critical Mass of Trained People

It was apparent that to sustain the wheat enhancement program it was necessary to establish a cadre of Turkish scientists to continue the research and extension activities. Over the next 10-year period, OSU was involved in providing an educational experience at the M.S. level for 15 young scientists from Turkey. Emphasis was placed in several disciplines, including plant breeding and genetics, plant pathology, agronomy, weed control, and extension. This graduate program quickly expanded to other countries where similar expertise was required. As of 1998, the wheat breeding and genetics program had provided graduate education at the M.S. and Ph.D. levels for more than 100 scientists from 27 different countries. In addition, mid-career scientists from many different countries have participated in non-degree training in the programs to update their skills. Known as the *Oregon Mafia*, many of these former students have distinguished themselves as teachers, scientists, government decision makers, presidents of universities, etc. Perhaps out of the many areas in which the OSU wheat breeding and genetics program has been involved internationally, our major contribution will be reflected in those individuals who participated in the graduate program and subsequently their students. The graduate program focuses on three factors: 1) selection of qualified people, 2) appropriate training, and 3) establishing a positive and professional environment for germplasm enhancement and distribution.

Germplasm Enhancement and Distribution

A number of factors contributed to the phase-out of the OSU-USAID and the RF Wheat Research and Training Center in 1974-75. However, as a result of the Turkish wheat program, close ties between USAID, RF, and especially CIMMYT with OSU had been established. The importance of enhancing and distributing genetic materials along with the graduate training program remained a significant spin-off of the Turkish wheat program.

The enhancement and distribution of enhanced wheat germplasm was started by the late Dr. Joe Rupert, RF scientist working with a CIMMYT program in Chile. He had the concept that by systematically crossing winter and spring gene pools, genetic variability could be greatly enhanced for many desired traits. When it became necessary to move the program out of Chile, the first thought was to locate the program in Turkey as part of the Wheat Research and Training Center. Since the center was terminating, the so-called Winter x Spring International Wheat Germplasm Enhancement Program was moved to the University of California at Davis. The program was transferred to OSU in 1970-71 due to the need to place greater emphasis on winter and facultative wheats. As the program evolved, the initial crossings of winter with spring type wheats were done at Toluca, Mexico, where temperatures at that high elevation were cold enough to vernalize winter type wheats. The resulting F_1 populations were divided between CIMMYT, Mexico, where the improvement of spring type wheats was emphasized, and OSU for selection and evaluation of the resulting winter type germplasm. Following appropriate three-way crossing and backcrossing at the respective sites and selection, superior lines were disseminated to more than 150 countries. The concept held by Dr. Rupert proved correct. Today, many outstanding varieties have resulted from such crosses. Thus, the highly complementary relationship between OSU-CIMMYT and USAID has helped partner countries in quite a different way than the original Turkish wheat project. The result has been the establishment of a worldwide network for the free exchange of genetic materials.

Challenges to Agriculture in the Next Century

It took 10,000 years until 1975 to produce 3.27 billion metric tons of food. To just keep pace with population growth, we must achieve 6.6 billion metric tons of food in the next 60 years. As noted by Nobel Laureate Lord John Boyd Orr, "You can't build peace on empty stomachs." As noted by Dr. Norman Borlaug, "Deny the subsistence farmers of the developing world access to modern technology and the world's needed agricultural expansion to help feed future generations, humankind will be doomed, not from pollution and environmental melt-down as some say, but from starvation, social and political chaos." Lastly, when accepting the Nobel Prize for Peace, Dr. Borlaug said, "If you desire peace, cultivate justice, but at the same time cultivate the fields to produce more bread; otherwise, there will be no peace."

The wheat breeding and genetics program at OSU had the good fortune to be in the right place at the right time. The introduction of Mexican-developed varieties of wheat into the coastal areas of Turkey and the subsequent dryland program on the Anatolian Plateau, to a graduate degree and non-degree educational program, and finally the enhancement and international distribution of wheat germplasm truly has been a privilege for those involved. It has taken a team effort and the contribution of many dedicated people who have participated in the program. To have made even a small difference in helping the less fortunate people on the earth has in itself been the reward.

Appendix Table. A–Team Members

Name	Position in U.S.	Location in Turkey
John K. Frizzell	Staff Chairman, County Extension Service	Adana
Victor W. Johnson	Staff Chairman, County Extension Service	Adana
Edward A. Minnick	Area Extension Agent	Hatay
James D. Moore	Farmer	Icel
Robert E. Morrow	Farmer	Antalya
Charles A. Hindes	County Extension Agent	Izmir
Robert E. James	Farmer	Aydin
Gus W. Hokanson	County Extension Agent	Manisa
R.G. McCarty	Staff Chairman, County Extension Service	Istanbul
Daniel A. Verhagen	Farmer Fieldman Oregon A.S.C.S.	Canakkale
G. Hollis Ottaway	County Extension Agent	Balikesir
Dudley I. Sitton	Farmer	Bursa
Harvey P.H. Johnson	Deputy Food and Agriculture Officer, USAID	Ankara
Len Otto	Director of Denizli Project, USAID	Ankara

How International Involvement has Helped US Wheat Growers

Rollin G. Sears

It is truly a pleasure to be here today. I've been asked to discuss how the wheat breeding program at Oregon State University has helped U.S. wheat growers in terms of varietal and germplasm development. When we think of successful varieties, characteristics associated with that variety, acreage planted, yield, disease resistance, quality are all traits that come to mind. In reality, however, the success of a variety is only as strong as its weakest link. No matter how we categorize and describe the strengths of a variety, its success or failure generally comes down to the weakness of one particular link in the chain. It could be in agronomics (shattering or lodging), it could be in yield, it could be quality, or it could be disease and insect resistance. It's hard to predict where weaknesses will evolve. That is why germplasm, which is the foundation of any plant breeding program, is so essential, so absolutely critical. Germplasm developed here at Oregon State University through the winter by spring crossing program and through linkages with CIMMYT has been shared and utilized readily and has provided solutions to weak links. It has benefited breeding programs throughout the U.S. and the world.

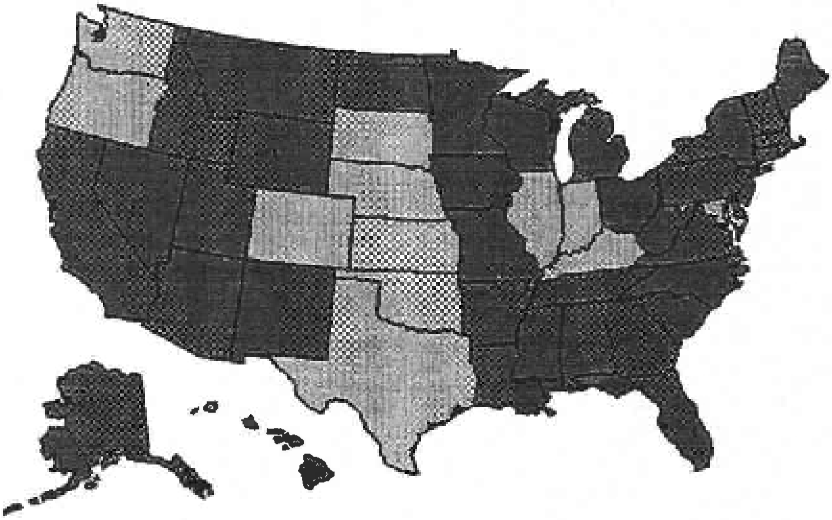
When we talk about germplasm, it's difficult to talk about the value (either in monetary terms or number of times a line is used as a parent) of that germplasm because it's unpredictable. None of us can predict how valuable a line is in the field or how it might be used in the future. It could be a new variety grown on millions of hectares or it could be a parent used in crosses in a breeding program. Someone else 15 or 20 years from today might use the line as a parent to produce an exceptional new variety. Trying to predict the value of germplasm is always dangerous because when and where that value might be expressed is really impossible to predict. For this presentation, however, I've been asked to try, and I'll use several approaches in my attempt.

First, I'll use numbers generated by agricultural economists. Economists at Purdue University estimated that every dollar invested in wheat breeding at Purdue University from 1960-1979 benefited the northern soft wheat region of the U.S. with a $26 return. In examining the Minnesota barley breeding program about 10 years ago, economists estimated that for each dollar invested there was a $32 return to Minnesota. In a similar study conducted on the Kansas wheat research program, the experiment station was spending almost $4 million a year on wheat research, and people were asking about the level of benefit. After a year-long study, of not just the breeding program but all wheat research, it was concluded that for every dollar invested there was a $12 return. A similar return on investment is true for wheat research in Oregon. Clearly, in all regions around the U.S., wheat research and improvement programs are hugely successful endeavors that bring many benefits back to the agricultural industry.

A second way to look at this issue of germplasm worth is to consider the variety 'Jagger' in the Great Plains. Jagger is the leading variety in Kansas right now with over 5 million acres planted and harvested. It's also the leading variety in Oklahoma and a popular variety in Texas, Nebraska, and South Dakota. Jagger is a cross between a breeding line from Kansas and the wheat variety 'Stephens.' Oregon producers in the audience certainly recognize what Stephens has meant to them as a variety. One of the most important components Stephens provided to Jagger was fall and early spring grazing. How many producers in Oregon graze their wheat? In all the times I've been in Oregon, I can't remember ever seeing a sheep or a cow out in a fall-planted wheat field. But grazing certainly is one of the key components to success in agricultural productivity in southern Kansas, all of Oklahoma, and Texas. The early, fast growth characteristic that is a trademark of Stephens was a major contribution to Jagger's success in the Great Plains. As we think about the kinds of traits that are important in varieties and germplasm and the exchange of germplasm, the actual benefits usually provide for many surprises. Who would ever have thought that the soft white Oregon variety Stephens would be a parent to a dominant hard red Great Plains variety and a major contribution would be improved grazing characteristics! That's why it's so dangerous to put a price on germplasm or try to predict the value of germplasm. It's unpredictable.

A third way to look at the worth of germplasm has been alluded to and discussed by others earlier today. This is the idea that germplasm exchange benefits not only the wheat breeding program directly but probably more importantly, it benefits the people associated through exchanges. Through the exchange of wheat, we exchange information. We exchange new ideas. We develop friendships that last a lifetime. Through these friendships and new ideas and information exchanges, we develop knowledge that can help us do a better job in the future.

A fourth way to look at germplasm involves education and the effect students have on germplasm. Let's look at a pedigree - a people pedigree. The map below shows the states (light grey) where wheat and barley breeders who have Warren as their "scholarly" father or grandfather are located and working. We call this group the "Oregon Mafia." Eighty percent of total wheat production in the United States is supported by breeders who have Oregon affiliations in their background (either trained directly by Warren, or indirectly by one of Warren's former students). So no matter how you look at it, either as people or wheat, germplasm and germplasm exchange is extremely valuable to the wheat producers of Oregon and around the world.



I've mentioned that Warren has been a scholarly father to many. Warren taught us the keys to success in germplasm development and plant breeding. These keys are constant over time, and I would emphasize these to the students in the audience; without them you won't be successful. First, if you are going to be a successful plant breeder you have to know and understand how the plant grows. Dr. Borlaug explains it the best: "To be a successful wheat breeder you must go to the field and go to the field and go to the field some more. When the wheat plant starts to talk to you, then you know you've made it." A similar belief was held by Dr. Barbara McClintock, who also won a Nobel Prize in medicine for her work with transposable elements. When a reporter asked her about her relationship with plants, although a geneticist and not a plant breeder, she had a similar response to that of Dr. Borlaug. She explained that she planted every seed herself and watched that seed germinate, develop, and mature. She found it a great privilege to know each individual plant in the field and to watch it grow. The key is simple: develop a relationship with the plant you are working with. Understand when it is healthy, when it is sick. Understanding how plants grow was important 10,000 years ago when we first started cultivating plants and still is critical today.

A second key involves selection of the proper testing environment. The shuttle breeding approach that has been utilized at CIMMYT and the shuttle breeding approach here at Oregon State–Moro, Pendleton, and back to Corvallis–have been instrumental to the success of these programs. They've taken material out to where it will be grown and exposed germplasm to an array of environments and looked for those that are consistent performers. You can have the best materials in the world but without the right environments in which to test them, you'll never know it. Quite literally, over the decades, Warren and his students have grown wheat in diverse environments, gone to the field and listened to what the wheat plants were telling them.

Selection of the right parents to use in a crossing program is the third key, and germplasm exchange is a critical part of this process. Breeders have historically treated germplasm as readers have treated books. A book is a story, and the words in that book are how that story is told. A plant, whether a variety or germplasm, can be thought of in the same way. The plant is the story, and its genes the words. Germplasm exchange gives breeders the opportunity to read each others books, borrow an idea or a few new words, and to write another story. We write plant books to suit our specific needs. This is exactly what plant breeders have done over many, many years. Germplasm exchange is key to new varieties. One of the other things that Warren taught his students, and something that I've always thought was critical to our success in Kansas, is a very simple concept–find a good parent and build your program around it. In the breeding program at Kansas, that was one of the first things I tried to do. I tried to find key varieties in our crossing program that combined well with other germplasm–from around the world, Oregon, from the soft red wheat region, the hard red region, Canada, and CIMMYT. I used these good parents to bring in the kinds of multiple pest resistance, agronomic characteristics, and quality traits that we needed. Every successful breeding program contains 2-3 parents that have provided the platform for future improvement. Find those parents and you'll be successful too.

The last and perhaps most difficult key to the success of a plant breeder is patience. Dr. Borlaug and Dr. Kronstad both mentioned that the breeding program in Turkey was started in the mid-1960s. Yet some of the real impacts of efforts there are just now being felt–30 years later! It takes 10 to 12 years to develop a variety through traditional methods. Sometimes it may take 20-30 years for a germplasm associated with a program to be truly appreciated. Patience is a critical key to success. A second part of the equation is stable funding. All successful breeding programs utilize the keys to success I've discussed above. In addition, these programs also have had sustained and stable funding, the importance of which can't be overstated.

When we talk about the influence the Oregon program has had on international development and especially the development of U.S. wheat breeding programs, there are several things that should be emphasized. First, if you walk into any U.S. wheat breeding program today, you'll find that either an Oregon selection is being used directly as a parent or an Oregon line is utilized somewhere in the pedigree of some of the material in that program. The OSU program has had an influence on the germplasm of every wheat breeding program in the U.S. and also has influenced breeding strategies.

Looking at the origins of winter wheat varieties grown in the southern Great Plains readily shows this idea of the value of germplasm exchange. Wheat varieties grown in the Great Plains all started with Turkey. Turkey was not native to Kansas. Russian Mennonites introduced it into central Kansas in 1874, and Turkey is a progenitor to all of the wheat varieties grown today; we estimate that 25 percent of the genes in our modern day varieties come directly from Turkey. Some of the first crosses made were with Marquis–a hard red spring from the northern wheat region. You see the names Mediterranean Hope, Norin 10, and Illinois No.1 in these pedigrees. These are varieties from around the U.S. and the world that have contributed to the successful varieties grown today. Heyne, one of the new hard white wheat varieties we just released, is a perfect example of the kinds of contributions and breeding approaches that have been talked about today. The pedigree of Heyne is KS82W422/SWM754308//KS831182/KS82W422. Heyne includes as parents a winter by spring cross from the Oregon/CIMMYT program (SWM 754308), the Colorado variety Linden and Plainsman V (KS831182), and a Kansas breeding line (KS82W422). Both public and privately developed germplasm are represented. Kenneth Goertzen and his wife Betty are the developers of Plainsman V, a privately developed variety noted for its outstanding protein concentration and excellent bread baking quality. It's a pleasure to see Kenneth in the audience today. This new variety would not have been possible without the free exchange of germplasm and ideas over long periods of time by both private and public wheat breeders.

Another important concept that this diagram points out is that plant breeding is not a project or one individual. **Plant breeding is a process**. It is a process that occurs over time. It is the contribution of many individuals and of the germplasm associated with a breeding program from the very start. It builds over time and is only as successful as the germplasm in the program and the people using it. Imagine what the picture might look like if the Mennonites hadn't shared Turkey in 1874. What if someone had taken a utility patent on this variety and prevented others from crossing with it in breeding programs. I doubt we would have made the same progress.

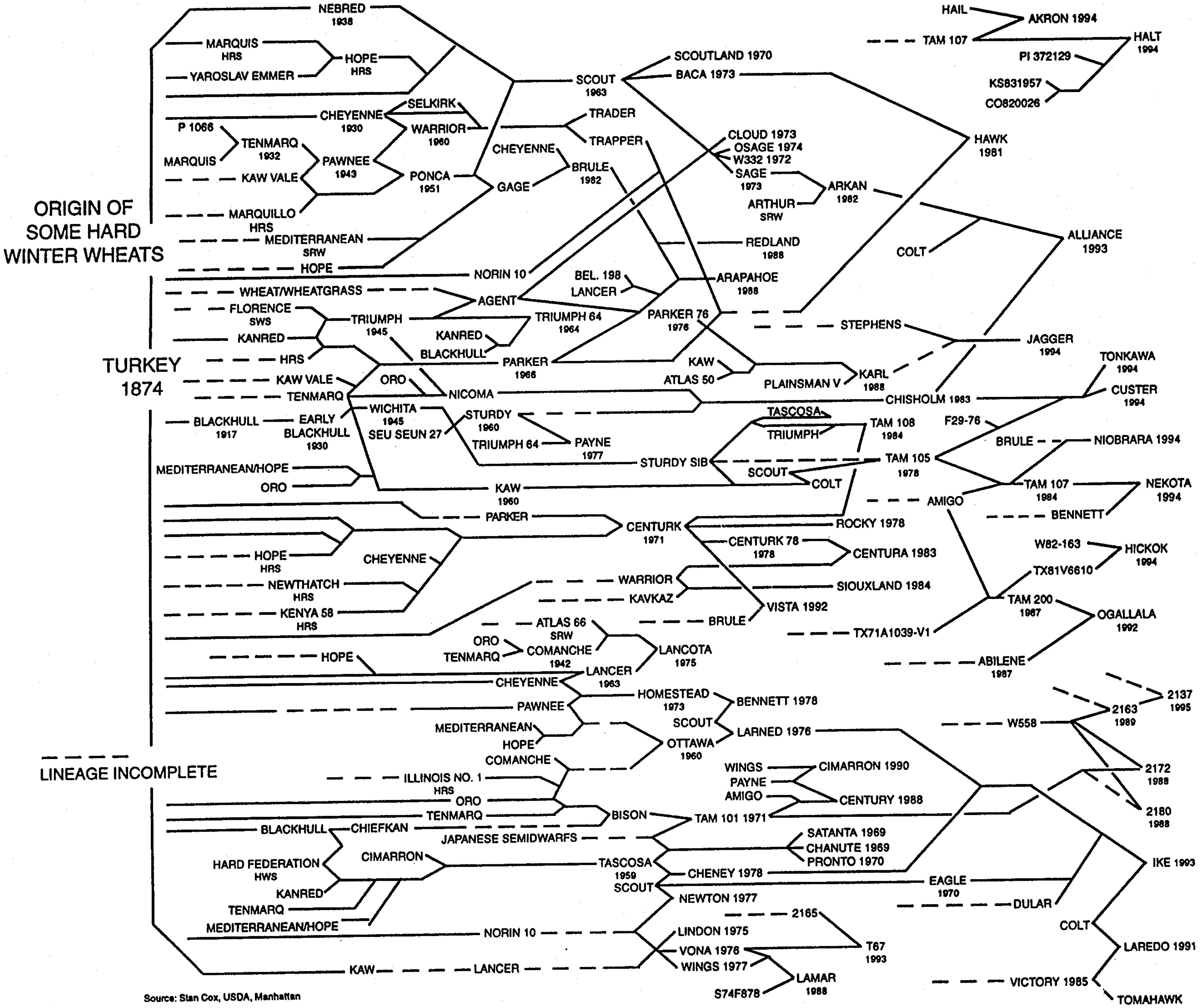
I want to talk for a few minutes about the idea of free exchange of germplasm. As several of us have stated, free exchange of germplasm has been the key to the success of wheat breeding programs around the world. But any discussion of germplasm exchange must include a discussion of intellectual property rights. Intellectual property rights are going to be one of the major challenges in the future. We must sort out the roles and missions of the public and private sectors and sort out advances in technology and how that technology will be shared and distributed around the world. I have in the past and will continue to speak out for free exchange of germplasm because it is so difficult to predict the benefits of any given germplasm. We need to continue to foster the idea that wheat germplasm should be treated exactly the way we treat books. You can copyright a book. It's okay to copyright a book and it's okay to protect a variety. But you can't copyright the words in a book, and we should not allow the wholesale protection of individual genes that make up plant varieties. Just as the words in a book can be used to create a completely different idea or a new book, the genes in varieties should be available to be scrambled and resorted to create an improved new variety for the future.

Wheat breeders have laid out some rules on germplasm exchange referred to as the Wheat Breeder's Code of Ethics. In a legal sense it is a material transfer agreement. The Code of Ethics allows for germplasm exchange. It allows for genes to be rewritten into new varieties, but it also protects intellectual property rights. If you want to test material in regional or international nurseries, you ask permission. If you want to release a variety from an early generation germplasm, you ask permission. Recognizing the rights and contribution of others is essential. In the future, intellectual property rights protection will become even more important, but we need to remember that germplasm, free germplasm exchange, and utilization of that germplasm must be maintained. The Wheat Breeder's Code of Ethics can be found in the Wheat Newsletter, published annually by the National Wheat Improvement Committee and Kansas State University.

So what have been the contributions of the Oregon wheat breeding program to U.S. agriculture? Direct use of parental material in the development of new varieties has been a big contribution. Setting an example for germplasm exchange, which has led to wheat improvement throughout the U.S., has been a larger contribution. Warren has contributed to germplasm around the world and this legacy will live on and on. And most importantly, he has trained people who will continue to develop wheat varieties and germplasm in the U.S. as well as around the world. This is his greatest legacy. As Bruce Maunder pointed out this morning, all of us are going to have to pick up the pace. People like Warren are far and few between. His level of commitment in training young people is rare. Training the next generation of plant breeders is going to be the key to our continued success.

Thank you, Warren!

ORIGIN OF SOME HARD WINTER WHEATS



Source: Stan Cox, USDA, Manhattan

A Grower's Perspective on Wheat Research–Past, Present, and Future

Robert Buchanan

It is a pleasure to join this august group today. They are notable for their intellect and their accomplishments, as you've seen through their presentations. They represent some of the brightest and most energetic minds supporting the wheat industries of this country and the world. While I didn't fully understand all the technical information that has been presented, as a producer, I do have a strong sense of the importance of this work. I sincerely appreciate this knowledge from which I draw my sustenance. Someone once said that the reward for doing a good job is the opportunity to do even better. Well if this is the case, then we'll have to change the phrase just a little. We need to change good to stellar and start astronaut training because we need to make a gigantic leap to the moon! The knowledge is there. The opportunities are at hand. But the energies that are being put into expanding new horizons are deficient.

The challenge is great. Resources are like a drum. They're very tight and difficult to come by. As a producer it's possible to ride the flow of productive gains from research without appreciating the depth of commitment and sacrifice that brought them to bear. But this can only be true if you have never negotiated a bank loan during times of depressed prices, watched TV newscasts of famine around the globe, felt the urgency of public priorities shifting under your feet, or watched plant diseases, harsh winters, drought, or embargoes strip economic value from you. These are all reality checks. They happen daily to those of us who are practitioners of a natural resource industry. International forces push and shove us routinely and continuously, but these make us stronger and more resilient. Oregon farmers, ranchers, foresters, and fishermen, and the research and extension community that supports them, see these opportunities and challenges.

Oregon services the world with its production, as does the Pacific Northwest. Eighty-five percent of what we produce must be exported. It goes to all ranks of economic strata and geographic destinations. Annual importation figures gyrate wildly and widely country by country. Exports are highly volatile, and the wheat business is very competitive. Our competitive advantage as a nation, besides having a generally benign climate and immensely fertile soils, has been the free flow of knowledge from our research institutions. This has been the case since the inception of the land grant system–the Hatch Act, the Morrell Act, and more recently Sea Grant. During the first half of this century, agricultural practitioners represented over 25 percent of the U.S. population, and the need for investment in agriculture was obvious. The population was growing, and more food was needed. But now agricultural producers are less than 2 percent of the population and this small number of producers has more than tripled output from essentially a static research base. Indeed, if you look closer, you will find that about 1 percent of the population is producing 85 percent of the agricultural goods in our nation. It doesn't take any higher math to figure out that there aren't very many of us creating an abundance of goods to feed the world. But we are on a collision course of changing public priorities in relation to natural resources and the production of food and fiber.

Food production and its availability probably have never been juxtaposed as dramatically as they are today. There are 6 billion people in the world. Growing linearly, this population will double in the next 20 to 25 years. The people of the world are drawing their sustenance from less than 3 percent of the earth's surface and this is shrinking annually. To meet population demands, we will need two to three times the food production from a shrinking land base. And if we roll back our production systems to 1940s science, as some suggest, we would need three to five times our current landmass to produce the food requirements of today.

To put this in graphic terms, to produce enough food to feed 6 billion people we would have to use all of the land area in North America, Central America, and South America, from sea to sea, from mountaintops to ocean and lake bottoms using 1940s technology. And I know that you appreciate that we can't do that. We can't feed 6 billion, or soon to be 20 billion people, off the land base that we have. We have to break some new thresholds in science, and this will take a dramatic investment of both people talent and monetary resources.

In this country, our 250 million plus people are for the most part isolated from want and hunger. Unbelievably, we are entertaining the notion and indeed in many areas of the United States, we are disassembling major sections of our production system. In Oregon alone in the past 35 years, we have witnessed the erosion of 3.6 million acres or 17 percent of our farmland. The vast majority of these lands are in the Willamette Valley. Urban sprawl, highway development, sequestering lands for parks, and the protection of biological systems all contribute to reducing productive capacity. And that is not all. There is talk of breaching dams, of limiting access to chemical tools, and of restricting cultural practices by rules. We have inadequate transportation systems for efficient movement of goods to market and, probably most significant, wholly inadequate funding levels for basic and applied research.

There are so many perspectives to consider when thinking about the impact of research. I and my fellow Oregon producers view research as a key to our competitiveness. In general, we can say that research provides our economic sustainability. Specifically, research provides the never-ending source of biological threads that, when woven together with the master's eye, provide that stability and competitiveness. There are threads that conquer plant disease and ward off insect invasions. There are threads that sustain plant life in drought. Research has provided us with short-statured grain to make harvesting more cost effective and to enhance fertilizer utilization. And we've also seen the opposite. Maryland researchers have developed plants with increased nitrogen demand to deplete excess nitrogen where this is a problem.

While all of these cultural challenges are being tackled and solved, other researchers are ensuring that the baking qualities are maintained and indeed enhanced. They are ensuring that the elasticity of the dough is consistent and repetitive. They're ensuring that cookie diameter and thickness are exactly the same so that each and every Oreo package comes out with 50 cookies in it and the machine that's stuffing that package always works. The texture and color also are unwavering, and of course the flavor always is the same for discriminating palates.

Developed world agricultural producers think about these details when they think of research and research budgets. Developed world consumers don't think of these details but take for granted their balanced diets and the stimulating variety of low-cost products available to them. They don't view foods as a necessity but as a convenience that will always be there.

But in the underdeveloped world, there is a different view. It is the face of want and starvation. It's the imploring eyes of malnourished mothers and children. Without the productivity gained since the 1940s, consumers in this world would be paying $100 billion more per year for food. The public good and the social benefits of research and development are large, but for the most part they cannot be sufficiently captured by the private sector to warrant only private investment. In some areas this works, but in many it doesn't. Here in the Northwest we don't have a large production base. In the Third World there is little if any money for investment. We need research to remain competitive and we need public investment in research.

Oregon Invests is the first quantitative and qualitative analysis of our on-going efforts toward solving these challenges and paying dividends. This database created by Dr. Thayne Dutson in the Oregon State College of Agriculture gives us confidence that we can manage our resources in ways to feed people and to maintain environmental quality, while still providing economic incentives to our natural resource practitioners to aggressively employ new and evolving technologies. A current Oregon annual investment of $50 million utilized by a relatively small number of scientists returns in excess of $200 million per year in hard currency benefits to Oregonians. Environmental benefits also are provided as is an ever-growing supply of food and shelter for the world.

Oregon producers pioneered cooperative research programs. In the late 1940s, the wheat industry initiated the country's first commodity commission to create a stable funding source to help support the public investment in research and to market research benefits to producers and the general public. This model has been replicated nationwide, and in Oregon there now are 25 additional commodity commissions. Growers annually self-assess themselves $16 to $18 million to allow partnering with the state and federal investments.

From the awareness of a needy and shrinking world after World War II, wheat industry leaders like Frank Tubbs and others brought vision to reality. Their vision was to bring consumers of the world together with producers and researchers to forge a progressive partnership to feed the needy and bring markets to Oregon producers. A few years later, Dr. Warren Kronstad brought new energies to the vision. Through collaboration with a host of scientists, specifically people like Dr. Joe Rupert, Dr. Norman Borlaug, Dr. Rajaram, Dr. Rollie Sears, and others in the Oregon Mafia, Warren has been able to scour the world for useful genetic materials. This germplasm has found its way back to Oregon producers so that we can grow fat and wealthy.

As Warren has said, with this critical mass of brain power and the access to genetic material from around the world, "10,000 years of cereal breeding started to germinate." We can share in these accomplishments but we can't rest. Much of the momentum started in the '60s and '70s flowered in the second half of the '70s and early '80s. But we've stagnated. I think we are attempting to rest on our laurels. Not we in this room, but the world and certainly the American and Oregon legislatures. The dollars invested after World War II paid huge dividends in the '70s and '80s. But the quantum leaps of progress that were made then will be hard to replicate. We've already made the easy changes. We're down now to looking at small margins of improvement in disease resistance and fertilizer use efficiency.

With 12 billion people in 2020, we're going to have to have significant new breakthroughs. And we won't get there with the resources that currently are being invested in the system. So we cannot rest on our laurels. Budget reductions, both federally and at the state level driven by tax revolt, property tax limitations, prison building, and a host of environmental initiatives, have strong-armed dollars away from research and development. It's time to kick some shins and poke fingers in the chests of people. We need to be intellectually honest about our production capabilities.

Our accomplishments have been great, and it's important to recognize what has been done. But at the same time, we've oversold our position. We've lulled the citizenry into feeling secure. They believe our past successes can be easily replicated, that we can always pull another rabbit out of the hat, and that we don't have any problems we can't solve or import our way out of. But the problems are real and at hand. We have to use the intellect that God gave us and the resources we have at hand to solve the problem of feeding the world.

The ultimate demonstration of public benefit derived from research and development is the 8.5 percent of disposable income that Americans spend to feed themselves. The next closest countries that compare in economic stature would be the Europeans. French and Germans spend somewhere between 15 and 18 percent of their disposable incomes on food. Those in Second and Third World countries are spending at least at 50 percent and usually substantially more. While providing the cheapest, most abundant, and safest food products in the world, the American farmer's share of the food dollar is less than 23 cents. The other 77 cents is going to transportation, food handling, food processing, and food preparation. In Oregon, if you add up all the food-related jobs, there are more than 230,000 people employed in the food industry. While farmers may be small in number, the food industry is huge, and we need to recognize and use that strength.

Consumers and producers of the world owe a great deal of debt to the dedicated researchers and extension people, men and women, who have allowed us to be as competitive as we have been. Science is the lead dog in my business. The Eskimo adage says that the lead dog sees new scenery and all the rest have good hindsight. I don't like hindsight. I like to be out in the lead.

I'll close with a quote. Dr. Warren Kronstad said, "I'm only one in 10,000 years of wheat breeders. They all made contributions." You have all made contributions and the wheat growers of Oregon and the world thank you.

Symposium Speakers

NORMAN BORLAUG is a wheat breeder and world traveler who is recognized for his work in breeding widely adapted, high-yielding wheat cultivars and for developing improved grain production techniques for use by the poor of the world. He received the Nobel Peace Prize in 1970 for his work. Dr. Borlaug has been involved with the International Maize and Wheat Improvement Center in Mexico (CIMMYT) for decades, as well as other agricultural programs around the world. He currently divides his time among CIMMYT, where he is involved in training young scientists from around the world; Texas A&M, where he still teaches classes; and involvement in various world food projects including Sasakawa-Global 2000 in Africa with former President Jimmy Carter. To this day, Dr. Borlaug is a spokesperson on the need to resolve issues of world population and hunger.

BOB BUCHANAN is a member of the Oregon Wheat Commission and a grower from Milton Freewater, Oregon. Bob and his wife Lynne Chamberlain-Buchanan run a farm that includes not only grains but also an assortment of higher value crops including peas and greenhouse-grown mint rootstocks. Bob served as Director of the Oregon Department of Agriculture from 1987-88 and as Director of the Oregon Department of Economic Development from 1989-90. He is a past-president of the Oregon Wheat Growers League and has served as a board member of U.S. Wheat Associates. He has traveled widely and been involved in a number of international agriculture economic development activities.

DANA G. DALRYMPLE is Research Advisor for International Agricultural Research Centers for the U.S. Agency for International Development. His training is in agricultural economics and policy and he has been involved with world food, agricultural development, and agricultural research systems activities for more than 30 years. He has worked at universities, with the Federal Extension Service, in the Office of International Cooperation and Development and USAID over this period of time. He regularly works with scientists at international research centers in more than a dozen countries around the world. He is a member of and on the Advisory Board for the Agricultural History Society.

ARTHUR R. KLATT is Director of the Office of International Programs at Oklahoma State University. He has over a decade's experience in developing and implementing exchange programs for students from around the world. He was project manager for an exchange program with Japan and has served on the Board of Directors for the MidAmerica International Agricultural Consortium. Prior to his work at OSU, Dr. Klatt was a wheat breeder, regional representative, and Associate Director of the CIMMYT Wheat Breeding Program. As part of his work with CIMMYT, he provided technical direction for CIMMYT's worldwide research activities and had responsibility for outreach programs and organization of international conferences and workshops.

BRUCE MAUNDER spent his professional career as a sorghum researcher and breeder with DEKALB Genetics. He retired in 1996 as Senior Vice President for Sorghum Research. Dr. Maunder directed DEKLAB's worldwide sorghum research effort and released more than 150 commercial sorghum hybrids during his career. These hybrids have been grown around the world on more than 4 million hectares annually. Dr. Maunder has worked in more than a dozen countries and participated in another dozen in various collaborative projects. He is a Fellow in both the American Society of Agronomy and Crop Science Society, is currently on the Board of Trustees of the Agronomic Science Foundation, is Chairman of several national committees related to sorghum research, is Adjunct Professor at Texas Tech University, and is Research Advisor to the National Grain Sorghum Producers.

S. RAJARAM is Director of the Wheat Breeding Program at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. A native of India, Rajaram received his Ph.D. in plant breeding from the University of Sydney and began work at CIMMYT as a wheat pathologist under Dr. Norman Borlaug in 1968. He has since held major leadership positions in the Wheat Breeding Program and was named Director in 1996. Dr. Rajaram has trained hundreds of young scientists from more than 40 countries and has made significant contributions to the development and release of more than 375 wheat cultivars sown on more than 30 million hectares around the world. He is recognized for his close working relationship with national programs under the CIMMYT umbrella. He is a Fellow in both Crop Science and the American Society of Agronomy and has been the recipient of numerous other awards and honors.

ROLLIE SEARS is head of the wheat breeding program at Kansas State University. He is recognized by his peers both nationally and internationally for his many innovations in breeding and for the leadership roles he plays in the wheat research community. Dr. Sears has released both hard red and hard white wheats. Since the early 1980s, his varieties have annually occupied more than 6 million acres in the Great Plains. Dr. Sears has been actively engaged in international wheat improvement activities and works in close cooperation with CIMMYT researchers. Dr. Sears has trained more than 20 graduate students, is Chair of the National Wheat Improvement Committee, is a Fellow in both the American Society of Agronomy and Crop Science Society, and has been the recipient of numerous awards and honors.

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