Wheat in the Developing World

Wheat is the most widely grown cereal grain, occupying 17% (220 million hectares in 1994) of the total cultivated land in the world. Wheat is planted on about 100 million hectares in the developing world, excluding the countries of Central Asia and the Caucasus. It is the staple food for 35% of the world's population and provides more calories and protein in the world's diet than any other crop. The uniqueness of wheat in contrast to other cereals is that its kernel contains a gluten protein that makes it possible to produce a wide array of end products. The two most common kinds of wheat are bread wheat and durum wheat.

Bread Wheat

Most of the wheat sown in the countries of the developing world is bread wheat. Bread wheat dominates the wheat area of South Asia, eastern and southern Africa, the Southern Cone of South America, Central Asia, and Mexico/Guatemala. The most important developing world producers are China, India, and Turkey. Forty percent of the bread wheat in developing countries is produced in irrigated environments. In South Asia, wheat is produced in the irrigated rice-wheat rotation system covering an estimated 12 million hectares, though it is also grown in dryland areas on residual moisture from the monsoon rains. Bread wheat is consumed in a wide variety of ways, depending on the region: raised bread in loaves or buns, flatbreads such as chapatis and tortillas, and many kinds of crackers, cookies, and cakes. The different types of preparations demand wheat with different grain qualities. Grain quality is important for producers growing wheat as a subsistence crop (it influences the grain's suitability for domestic food preparations) and also for producers who grow wheat for cash (wheat with suitable quality for certain products is purchased at a premium, so producers want to grow better quality wheat). For these reasons, quality is taking on increasing importance in wheat breeding programs.

Durum Wheat

Durum wheat is cultivated on approximately 17 million hectares worldwide. About half of that area is in developing countries; its production is concentrated in the Middle East, Central India, and the Mediterranean region of West Asia and North Africa (WANA), where 80% of the durum area is found. Other production areas include Ethiopia, Argentina, Chile, Russia, and Kazakhstan, as well as Mexico, the United States, Italy, Spain, and Canada. Durum wheat production in developing countries is generally low because durum wheat is grown using low levels of inputs (e.g., fertilizer, water) in semi-arid regions and other marginal areas characterized by sharp annual fluctuations in cropping conditions. In addition, yields may be reduced by insects, poor crop management, and deficient weed control. In irrigated environments where moisture and other resources are not limiting, high yields are obtained, but these sorts of favorable environments represent a relatively small portion (28.2%) of the total durum wheat area. Durum wheat is used to prepare a broad range of products in different parts of the world, from pasta to couscous and burghul (i.e., bulghur wheat). The acceptability of a new durum variety is greatly influenced by its grain quality, since high quality durum brings in premium prices. Quality characteristics are thus an important breeding consideration.

Wheat Yields in Favorable and Marginal Production Environments

At present the average wheat yield in developing countries is 2.5 tons per hectar (t/ha), but in marginal environments yields may not even reach 1 t/ha, mostly because farmers still grow old, disease-susceptible wheats. Modern varieties that use nutrients more efficiently and tolerate drought and other stresses better yield at least as much as local varieties when conditions are poor, and more when conditions improve. Consequently, they can lower the risk that farmers face because of yield variability from year to year. CIMMYT's latest data on the impacts of wheat breeding research show that farmers in marginal areas are increasingly using modern wheat varieties. In marginal environments, improvements in crop and soil management practices will often precede changes in variety. Also essential to raising and stabilizing yields in marginal environments are improvements in water availability, such as increasing the water supply through irrigation, improving moisture conservation, and utilizing moisture more efficiently. Given that the first option (irrigation) is possible only in some areas, and that its long-run sustainability is uncertain, the two remaining strategies are critical to generating future productivity gains in marginal environments. Although marginal environments account for a significant proportion of the total cereal area, their share in total cereal production is much lower. In the developing world, 84% of bread wheat is produced in favored environments, where farmers may produce as much as 5 t/ha. However, some highly productive irrigated environments, such as the intensely cropped areas of South Asia where farmers apply close to the optimum levels of inputs, are experiencing yield stagnation or declines. To reverse this trend and raise yields globally, breeders are focusing on developing wheats with a higher yielding capacity than current wheats. One strategy they are pursuing is to create a new plant type with bigger spikes and twice as many grains as a "normal" wheat plant. Another strategy is the development of hybrid wheat. If breeders are successful, these new kinds of wheat will offer the possibility of increasing yields by 10-15% above yields of currently planted commercial varieties.

Wheat Production Constraints in Developing Countries

Abiotic stresses

Plants can suffer from many kinds of abiotic (i.e., "non-living") stress, including drought, heat, waterlogged soils, acidic soils, zinc-deficient soil, and soils with toxic levels of boron. All of these stresses can pose serious problems for wheat farmers, especially in the less-favored growing environments. Researchers are working to solve these problems via a combination of well-adapted tolerant varieties and appropriate crop management practices.

Approximately 32% of the wheat growing regions in developing countries experience some type of **drought stress** during the growing season. Drought-stressed regions are defined as those where the amount of water available, mainly through rainfall, is under 500 mm.

Many studies have looked at the yield losses associated with drought at different stages of plant development. Crown root initiation and anthesis are two stages at which yield losses from drought stress can be most critical to wheat. Current research is aimed at identifying different plant traits that would allow wheat varieties to withstand the different types of drought that occur in the developing world.

Drought occurs in different patterns. It can come early or late in the cropping cycle. Drought can also occur when wheat is planted in soil that has some residual moisture left after the rainy season has ended—for example, after the monsoons in central and southern India. In early drought conditions, later maturing varieties do better, since they slow their development sufficiently to benefit from the late rains. In late drought conditions, earlier maturity is a mechanism that allows the wheat crop to escape stress late in the crop cycle.

Wheat is grown as the "winter" crop in the subtropics. Temperatures during the growth cycle are relatively high. It is estimated that more than 7 million hectares of wheat are cropped under continual **heat stress** in approximately 50 countries, in environments with mean daily temperatures greater than 17.5°C in the coolest month. Terminal heat can be a problem in up to 40% of the irrigated wheat growing area in the developing world.

Modern wheat varieties generally do not tolerate high temperatures well. When wheat is planted late, high temperatures are an important yield limiting factor, especially in the Indian Subcontinent, the Yangtze River Basin of China, and in other warm regions where wheat is grown.

Genetic heat tolerance is the most effective insurance against losing wheat to heat stress. One research effort aimed at developing heat tolerance involves the use of an infrared thermometer to take the temperature of the crop canopy. Varieties that keep their canopies cooler have been found to yield better under heat conditions. Use of this physiological trait in selecting for tolerance may accelerate progress towards this goal.

Drought and heat can reduce wheat yields, but so can excess water—or **waterlogging.** In the rice-wheat cropping systems of South Asia, wheat crops follow rice crops in the same field, but the ideal production conditions for both crops are not the same. For rice cropping, farmers "puddle" soils, creating a moist environment into which rice seedlings may be transplanted. As a result, soils have several limitations for the subsequent wheat crop: poor aggregate size, formation of a plow pan, and reduced water percolation. Care must be taken to minimize waterlogging, or the wheat crop will suffer. For example, Chinese farmers in the Yangtze region use intricate in-field drainage ditches to avoid yield loss during wet winters, when waterlogging is a problem. Agronomists are focusing on crop management strategies in rice as well as wheat production to limit the effects of waterlogging on wheat sown after rice.

Breeders are working on developing waterlogging tolerant wheats, and have found that "synthetic" wheats, bred from grass species that are the wild relatives of wheat, are exceptionally good sources of tolerance.

Soil acidity is a major growth-limiting factor for plants in many parts of the world. About 1 billion hectares in the tropics and subtropics are acidic. These areas include large parts of Brazil and other parts of South America, especially within the Amazon Basin, vast areas in the *llanos* (plains) of the Orinoco, and substantial portions of the Andes. China, the Himalayas, the Deccan Plateau of the Indian Subcontinent, and vast areas of Central Africa also have acidic soils.

In many acid soils of the world, **aluminum toxicity** is an important factor limiting crop growth. Aluminum toxicity is particularly severe below pH 5.0. At this level, it inhibits root growth by preventing cell division in the root apical meristem. The restricted root system makes the plant vulnerable to drought and unable to utilize normal levels of available essential plant nutrients.

Current approaches to solving the aluminum toxicity problem are raising the pH by adding lime and/or gypsum to the soil, improving management practices, and, most importantly, breeding plant varieties that are tolerant to the mineral. As a result of successful breeding efforts initiated in the 1970s, good acid tolerance has been achieved, and most of the wheats currently grown in problem areas of Brazil, India, and China tolerate acidic soils.

Zinc deficiency. Soils that are deficient in certain micronutrients can produce grain that is also deficient. Zinc deficiency is recognized as a worldwide nutritional constraint, particularly in calcareous soils of arid and semiarid regions. It is estimated that zinc deficiency is the most widespread micronutrient deficiency in cereals, especially in wheat. In Turkey, 50% of the arable soils were found to be zinc deficient. The deficiency also occurs in Afghanistan, Egypt, Iran, Iraq, Kyrgyzstan, Syria, and South Australia.

Zinc deficiency reduces grain yield and the nutritional quality of wheat grain. Zinc deficiency is a common nutritional problem in humans, especially where there is high consumption of cereal-based foods with low levels of zinc.

Distinct differences in tolerance to zinc deficiency have been found between bread and durum wheats, and also among varieties of bread wheat. The reasons why different wheat varieties are better at using the zinc that is available in the soil are still not well understood, but enhanced root growth, better release of zinc-mobilizing phytosiderophores from roots, and improved zinc uptake capacity of roots may be responsible. Researchers continue to work on determining these mechanisms to breed varieties that are better at growing in zinc-deficient soils and at producing more zinc in the grain. Zinc plays such an important role in plant and human nutrition, that only positive effects can be expected from breeding zinc-efficient wheats.

Boron toxicity has long been recognized as a problem around the world. It occurs in South Australia, the WANA Region, South Asia, China, Japan, the Philippines, and parts of South America.

Excessive amounts of soil boron have a detrimental effect on the yields of many crops, including wheat. The effects of boron toxicity on wheat growth can be manifested as reduced height and shoot growth, delayed plant development, and reduced root growth. Since it is not possible to leach out excess boron from the soil, genetic tolerance seems to be the only practical solution to the problem. Although possible mechanisms of tolerance to boron toxicity have studied by many researchers, further research is needed to determine its exact nature.

Biotic stresses

Many biotic or "living" stresses, such as diseases, insects, and weeds, can reduce wheat yields. Agricultural intensification in general and continuous cropping of cereals in particular may increase the incidence of disease, weed, and insect problems.

Farmers' front line of defense against **diseases** is genetic resistance. Genetic disease resistance has many advantages. It is inexpensive, because it is incorporated into the seed, and it is safe for farmers and the environment, because it reduces the amount of potentially harmful chemicals applied to the crop. Many modern wheats have effective resistance to diseases such as stem, leaf, and stripe (yellow) rust, septoria leaf blotch, Karnal bunt, and barley yellow dwarf.

A key strategy in developing durable, effective genetic disease resistance has been to transfer a large number of resistance genes from different sources into different wheat varieties. This broadens the genetic base of the resistance, which is essential for keeping epidemics from devastating wheat crops over extensive areas.

Breeders are constantly looking for new sources of useful genetic diversity. Species that grow in the wild and are closely related to wheat are a novel source of new genetic diversity for many traits associated with disease resistance and high yield. By crossing durum wheat with some of these wild relatives, researchers have created synthetic wheats that carry the desirable genes present in wild species. Synthetic wheats have been found to possess resistance to many diseases (e.g., Karnal bunt, fusarium head scab, helminthosporium spot blotch) as well as tolerance to environmental stresses such as heat, drought, and lodging. Though not adequate for farm production, synthetics can be crossed readily with high-yielding wheats, thereby acting as a "genetic bridge" that allows useful traits to be transferred to improved wheat.

Weeds are a major farming constraint in many regions of South Asia. The most common weed, *Phalaris minor*, poses an especially serious problem for wheat, particularly in cooler areas of South Asia. Phalaris competes strongly with the wheat crop and reduces yields. If left unchecked, it can cause the total loss of a crop. In areas where Phalaris has become resistant to herbicides, crop management practices such as bed planting with zero tillage offer a way to control this weed.

Adequate tillage and proper seedbed preparation are important for minimizing weed infestation, reducing the need to resort to expensive manual or chemical control methods once the crop emerges. Hand weeding is sometimes preferred to other methods because of the high economic value of weeds as green fodder for livestock. Farmers in many areas supplement manual weed control with the use of chemical herbicides, particularly in higher rainfall areas where fallowing has been eliminated and weed infestation can be severe. However, greater attention must be given to ensuring that chemicals are used properly to reduce health risks and environmental damage.

Although **insects** are not usually a serious problem for wheat cultivation, certain areas are plagued by these pests. For example, in the WANA region and in Central Asia, insects such as Hessian fly, sunni pest, and sawfly may cause wheat farmers serious losses. Widespread outbreaks of Hessian fly may occur in North Africa, where the pest recurs annually. Wheats having solid stems are much less susceptible to attack by Hessian fly and sawfly, and wheats adapted to this area are being improved for this trait.

Supplying the Nutrient Needs of Wheat Plants

Supplying the nutrient needs of the wheat plant is essential to increasing grain production. This can be done through the use of organic fertilizers—for example, by applying animal manure, incorporating crop residues, and using legume rotations. Unfortunately, the supply of organic fertilizer is declining in many parts of the world. In some areas, manure is needed fuel; in others, farmers can no longer afford to keep many animals (especially in areas where farm size is shrinking). In still other areas, farmers need to use crop residues for purposes other than mulching (for example, they need it to feed their livestock).

Chemical fertilizers are also used to increase grain production and fulfill the crop's nutrient needs. As production levels rise over the coming decades, nitrogen applications are expected to increase greatly, with two-thirds of the increment taking place in the developing world.

Chemical fertilizer is used more extensively in irrigated and well-watered areas where modern varieties are concentrated and crop response is highest. In these areas, fertilizer application rates often exceed 100 kilograms (kg) of nutrient per hectare. In rainfed conditions, the application of nitrogenous and phosphorous fertilizers could considerably improve wheat yields. However, response to fertilizer in dryland environments—environments where farmers depend on rainfall alone to produce their crops—is influenced by a large set of interacting agroclimatic, soil, and management factors, many of which are beyond the control of the farmer. The amount and temporal distribution of rainfall are the dominant influence on the crop's response to fertilizer, especially to nitrogen. Given the strength of this relationship, rainfall variability greatly increases the risk of using fertilizer in dryland environments, and fertilizer use in those areas remains low (40-50 kg nutrient/ha).

Estimates from farmers' fields and experiment stations indicate that the wheat crop usually recovers only 30-50% of the nitrogen that farmers apply. The rest is wasted, either going up into the atmosphere or escaping into the soil and water. More nitrogen can be recovered by the crop if its nitrogen demand is better matched to the supply—for example, through bed planting systems that enable farmers to apply fertilizer when and where it is most accessible to the crop. In certain situations, nitrogen-use efficiency can be improved by delaying or splitting nitrogen applications. Delayed applications may also raise yield and improve grain quality.

Nitrogen-use efficiency is affected by late planting. In the intensive, irrigated cropping systems of South Asia, late harvest of the previous crop (often a rice crop) and the long turnaround time between rice harvest and wheat planting may delay wheat planting. One solution to this problem is to introduce reduced and zero-tillage options to farmers, with the objective of reducing turnaround time and planting wheat closer to the optimum date.

Sustainability and Environmental Problems

Sustainable agriculture requires striking a balance between reaching productivity goals and reducing the impact of farming on soil, water, and air quality. Long-term productivity can be ensured only through conservation of the natural resources upon which agriculture depends. Problems of deteriorating soil fertility and declining productivity—for instance, in the intensive rice-wheat system of South Asia—and sustainable drought management—for example, in wheat systems of WANA—have to be addressed to enhance productivity without eroding the natural resource base over the long term.

The expected increase in fertilizer applications in the developing world will come at a cost, for it will engender higher losses of contaminating nitrate from soils into freshwater and marine systems and of nitrogen-containing gases into the atmosphere. Fertilized agriculture is the biggest source of human-generated greenhouse gases such as nitrous oxide (N_2O) and also produces high emissions of nitric oxide (NO), a precursor to acid rain. This process, if left unchecked, could seriously damage the ecosystems where farming is practiced and, ultimately, the whole planet.

The use of nitrogen- and phosphorus-efficient cultivars can prevent the application of excessive amounts of fertilizers. Also, a greater knowledge about the efficient use of nitrogen allows farmers to fine-tune fertilizer applications through appropriate agronomic practices. At CIMMYT, studies are underway to develop agronomically feasible management practices that would reduce nitrogen gas emissions and nitrate contamination and yet remain economically attractive to farmers. It is important that technologies that lessen the impact of fertilizer on the environment maintain yield levels and make economic sense to farmers. Otherwise, they will not be adopted.

As an example of research aimed at making more sensible use of fertilizer, CIMMYT and Stanford University (California) researchers in the Yaqui Valley of Mexico have found that decreasing the amount of nitrogen applied and changing the timing of its application may significantly reduce the amount of nitrogen pollution and waste without affecting yields. They monitored changes in soil nutrients and gas emissions before and after fertilization over a period of two years.

They found that the farmers' practice, which included applying two-thirds of the nitrogen fertilizer one month before planting and then irrigating, resulted in very large emissions of N_2O and NO, largely resulting from denitrification under waterlogged conditions. The best alternative practice tested (one-third of nitrogen applied at planting and two-thirds six weeks later) applied nearly 30% less fertilizer and reduced total N_2O and NO emissions to 0.74 kg N/ha, compared to 5.61 kg N/ha with the farmers' practice. The best alternative also produced a savings of US$ 55-76/ha, which is equivalent to 12-17% in after-tax profits. Attracted by the technology's potential to reduce fertilization, their highest production cost, farmers in the Yaqui Valley are beginning to adopt the new practice.

Future Challenges

An estimated one billion tons of grain will be needed annually by 2020 to feed a world population that is rising by at least one hundred million people every year. At the same time, the amount of farmland per capita is decreasing the world over due to soil erosion, encroaching human settlement, and industrialization. In addition, loss or degradation of arable land and environmental deterioration brought about largely by improper agronomic practices is acutely affecting many poor, populous countries. As a result, they have low and unstable wheat production, poor food security, and the need to import grain.

It is estimated that people in developing countries now consume half of the world's wheat and that within ten years they will consume 60% of all wheat produced. Since the 1960s, wheat consumption has risen almost 5% a year in developing countries, partly due to rising population and partly because, as standards of living rise, people tend to eat more wheat in the form of convenience foods (for example, sandwiches). As a result, it is estimated that by 2020 the demand for wheat will be 40% greater than it is today.

Global wheat productivity must improve by at least 2.5% per year to 2020 to satisfy such high levels of demand. Less land will be available to expand wheat production, so yields must increase. Yet the overall rate of yield increases in developing countries from 1986 to 1995 (1.8% per year) was lower than in the previous two decades. This slowdown compounds the problem of producing enough wheat to meet future demands.

The complexity of this problem requires looking for solutions in more than one direction. Researchers are thus implementing different strategies to raise productivity. Some strategies focus on raising the grain yielding capacity of the wheat plant by developing hybrid wheats and constructing a new plant type, as explained earlier. Other research efforts are aimed at developing management practices that provide modem varieties with the environment they need to perform well, and at the same time minimize the effects of farming on the ecosystem. A good example is the bed planting system, which combines bed planting with reduced tillage to enhance the physical, chemical, and microbiological properties of the soil. It holds great promise for improving the irrigated and high rainfall wheat-cropping systems where most wheat in the developing world is produced by making them less resource intensive and more sustainable.

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