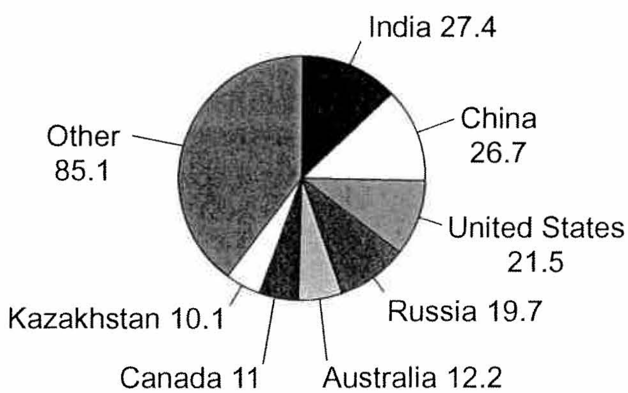
Wheat *Triticum* species

Production	
Area Under Cultivation	213.7 million ha
Global Production	585.0 million MT
Average Productivity	2,737 kg/ha
Producer Price	$140 per MT
Producer Production Value	$81,900 million
International Trade	
Share of World Production	22%
Exports	129.0 million MT
Average Price	$123 per MT
Value	$15,897 million
Principal Producing Countries/Blocs (by weight)	China, India, United States, Russia, Canada, Australia, Argentina
Principal Exporting Countries/Blocs	United States, France, Canada, Australia, Argentina
Principal Importing Countries/Blocs	Brazil, Italy, Iran, Japan, Algeria, Egypt, Indonesia, Belgium, Morocco
Major Environmental Impacts	Habitat conversion Soil erosion and degradation Water and agrochemical use and pollution Burning of crop residue
Potential to Improve	Fair Breeding programs may take pressure off land when the wheat genome is better understood Inputs are higher per metric ton of production than many other crops Scale of production makes the adoption of many BMPs difficult Subsidies drive production and impacts in the U.S. and E.U., and globally as well

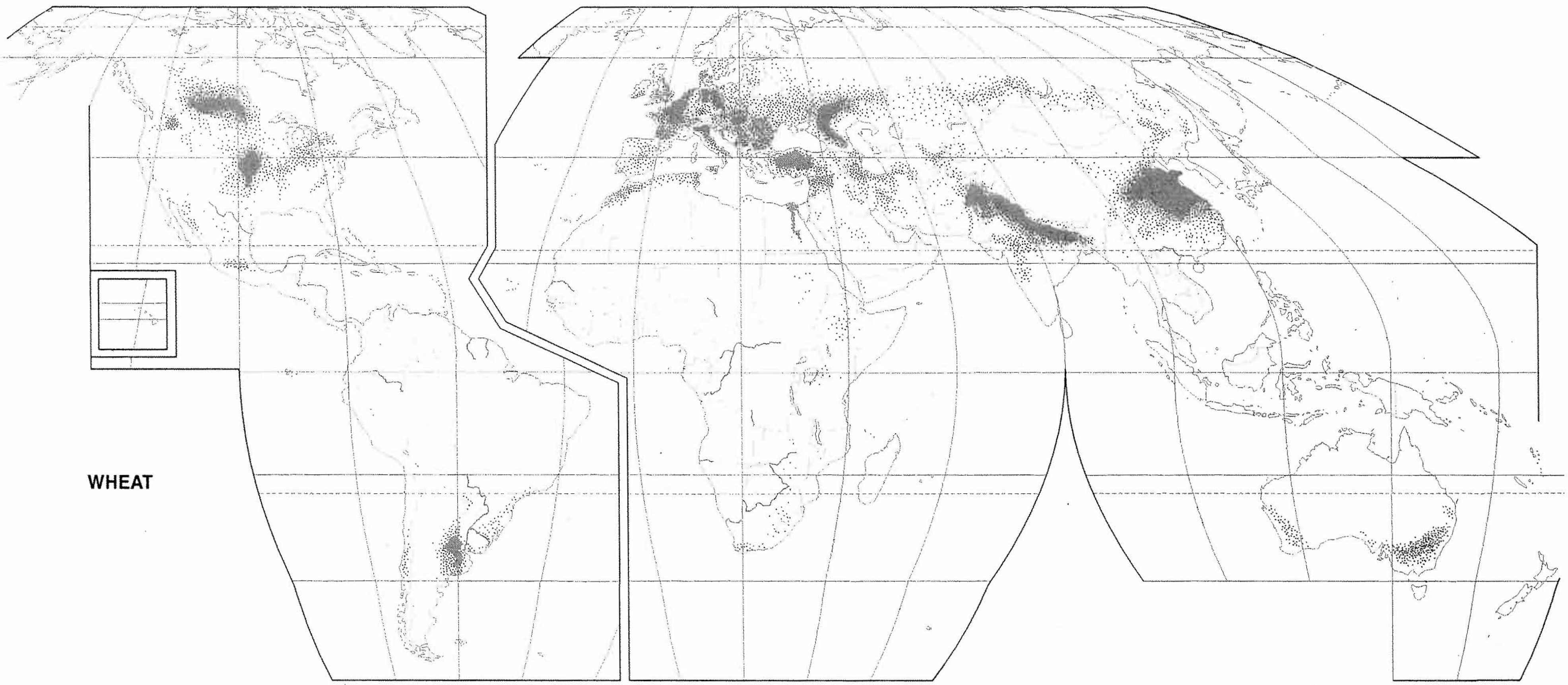
Source: FAO 2002. All data for 2000.

Wheat

Area in Production (MMha)



WHEAT



Each dot represents 54,400 MT per year

Chapter 16

Wheat

Overview

Wild wheat, and its close relative barley, originated in Asia's Fertile Crescent. The archeological record suggests that people were collecting and eating wild wheat and barley as early as 17,000 B.C. Both bear their seeds on the tops of stalks that shatter when ripe, dropping the seeds to the ground where they germinate (Diamond 2002). This trait helps wild plants to reproduce, but makes it difficult for humans to gather the seeds. Though in the wild a mutation that causes the seeds not to drop can be lethal, this is attractive to human gatherers. Initially, it was unconsciously selected; stalks that did not drop their seeds were the only ones that could be harvested by humans after they ripened. After these seeds were gathered, they were probably dropped accidentally and later planted on purpose. In both ways the seeds became more dominant relative to their ancestors. It appears that wheat may have first been consciously planted as early as 8500 B.C. (Hopf 2001; Lev-Yadun, Gopher and Abbo 2000). Recognizable agriculture followed by at least 6000 B.C. The earliest evidence of people using bread wheat (the spelta variety, commonly known as spelt) is from 4700 B.C. in the Caucasus region between the Black and Caspian Seas (Zohary 2001).

Those who first domesticated foods such as wheat had a clear advantage over all but their closest neighbors. The surpluses agriculture produced freed parts of the population from hunting and gathering, which enabled them to develop the world's first metal tools, writing, armies, and eventually empires that allowed them to spread their food-producing technologies, among other things (Diamond 2002). As a result of these activities and subsequent domestication programs, wheat is now probably the most common plant on the planet, with rice a close second.

Early agriculturalists in Mesopotamia quickly found the production of cereals such as wheat to be unsustainable due to low and inconsistent rainfall, the soil erosion and degradation that followed deforestation, and salinization from irrigation (Diamond 2002). As the Mesopotamians destroyed their resource base, agriculture spread west into present-day Egypt and Israel and northwest into Europe. As farming shifted, so did political power. Three important precedents were established. First, agriculture was the basis not only of economic but also political power. Second, agriculture allowed and even encouraged population growth. With the reliable food supplies and even surpluses, birth spacing could be reduced to one to two years. The fastest population growth rates presently occur in agricultural areas. And third, agriculture outstrips the ability of a region to regenerate nutrients that are the basis of productive and profitable agriculture, creating moving agricultural frontiers.

At least 5,000 years ago wheat had spread to North Africa (especially Egypt), Asia, and parts of Europe, areas where it has been in continuous cultivation ever since. The term ancient Egyptians used for wheat is thought to be *kamut*, which meant "soul of the Earth." Varieties of these traditional wheats are still in cultivation today in the United States.

Producing Countries

The Food and Agriculture Organization of the United Nations (FAO) lists 122 wheat-producing countries. Globally, 213.7 million hectares of land were devoted to the cultivation of wheat in 2000. India (27.4 million hectares), China (26.7 million hectares), the United States (21.5 million hectares), and Russia (19.7 million hectares) dominate (FAO 2002). The four countries that have the most land in wheat production account for 45 percent of all land planted to wheat. The next nine countries with the largest amount of land devoted to wheat account for 34 percent of the global area devoted to wheat. Other significant producers with more than 5 million hectares under cultivation include Australia (12.2 million hectares hectares), Canada (11.0 million hectares), Kazakhstan (10.1 million hectares), Turkey (8.7 million hectares), Pakistan (8.5 million hectares), Argentina (6.5 million hectares), France (5.3 million hectares), Ukraine (5.2 million hectares), and Iran (5.1 million hectares). Globally, more land is used to produce wheat than any other commodity. Many countries devote a quarter to half of all agricultural land (FAO 1996) to the production of this basic commodity, as shown in Table 16.1.

Table 16.1 Percentage of Agricultural Land Devoted to Wheat, 1995

25–49 Percent		10–24 Percent	
Azerbaijan	Mongolia	Afghanistan	Macedonia
Belgium-Luxembourg	Morocco	Albania	Moldova
China	Nepal	Algeria	Netherlands
Czech Republic	Pakistan	Argentina	Paraguay
Denmark	Romania	Armenia	Poland
Egypt	Slovakia	Australia	Portugal
France	Switzerland	Austria	Russia
Greece	Syria	Bulgaria	Saudi Arabia
Iran	Tunisia	Canada	Slovenia
Iraq	Turkey	Georgia	South Africa
Israel	Turkmenistan	Germany	Spain
Italy	United Kingdom	Hungary	Tajikistan
Kazakhstan	Uzbekistan	India	Ukraine
		Jordan	United States
		Kyrgyzstan	Uruguay
		Lebanon	Yugoslavia

Source: FAO 1996.

India, China, and Russia devote a tremendous amount of land to wheat but do not export significant quantities. The United States, France, Canada, Australia, and Argentina, by contrast, dominate wheat exports, accounting for 90 percent of all exports. Exports, however, account for only 10 to 20 percent of global production depending on the year (FAO 2002). Most countries attempt to produce enough wheat to meet internal demand, to be self-sufficient in the world's most basic foodstuff.

Global yields are low by comparison to rice because only one wheat crop can be grown each year. (In many areas other crops such as soybeans or hay are grown sequentially after the wheat is harvested.) Globally, average yields are about 2,737 kilograms per hectare per year. Several countries (Belgium, Denmark, Egypt, France, Germany, Ireland, Namibia, the Netherlands, New Zealand, Sweden, Switzerland, the United Kingdom, Zambia, and Zimbabwe) produce at levels that are more than double the global average. Of the largest producers, China has the highest average yields with 3,990 kilograms per hectare. Russia has the lowest with 1,350 kilograms per hectare (FAO 2002).

Global wheat production stands at about 585 million metric tons per year. This would be enough wheat to fill the cars of a train stretching 2.5 times around the Earth. The top four producers account for 47.8 percent of all production by volume (FAO 2002).

Consuming Countries

Foods that are made with wheat account for a major part of the diet for more than a third of the people on Earth. Given that most wheat is not exported, the main consumers of wheat are also the main producers. The main importers of wheat are Japan, Brazil, the countries of the former USSR, China, and Indonesia. Wheat imports are spread over most of the globe, however. The five leading importers account for only 28 percent of all wheat imports (FAO 2002).

Demand for wheat is increasing faster than population growth. According to Baenziger and Gill (2001) some two-thirds of the increased demand is based on population growth and one-third is due to increased income. What these statistics do not show is that wheat is increasingly used for animal feed rather than for direct human consumption. The direct consumption of wheat tends to provide a smaller portion of calories in the diet as incomes rise. For each 1 percent increase in real income, the demand for wheat increases by only 0.5 percent. Wheat's main attraction is that it can be used to make convenience foods that are ready-to-eat or quickly cooked for human consumption. These include a wide range of already-baked products and pasta, which is easily and quickly cooked.

Production Systems

Wheat grows in a wide variety of climates and soils. However, good soil and moderate climate are both critical to good yields and healthy wheat crops. Wheat prefers fairly dry, mild climates. High-quality, disease-free seeds are also important, and of course wheat must be planted and harvested at the proper time if yields are to be optimal. Some longer-growing varieties of wheat are planted in the fall to give them a head start on the growing season, while others can only be planted in the spring.

Production systems changed very little in the first 6,000 years that wheat was cultivated. Wheat was originally sown, tended, harvested, threshed, and processed by hand. It was first irrigated some 6,000 years ago in the Tigris and Euphrates River areas. In that region Sumerians first used animals to prepare fields and thresh the grain by walking on it. This was how wheat was produced until recently.

Changes in production began when mills were developed for processing, with wind or water power driving the millstones to grind the grain. Subsequently, animal-drawn and eventually self-propelled machines were introduced to plant, harvest, and thresh the grain in the field. Even so, in much of the world wheat is still planted and harvested by hand, with animals used only to plow the fields.

The mechanization of wheat farming seems to have driven the mechanization of agriculture in general. In 1834 McCormick invented the reaper, a horse-drawn machine that increased the harvest rate of wheat fourfold, from 0.8 hectares per day by hand to 3.2 by machine. Some fifty years later the Case steam-powered threshing machine revolutionized the ability of farmers to thresh grain in the field, even though all the grain still had to be shocked and hauled to the stationary threshing machines. Subsequently, self-propelled machines were developed that cut and threshed as they moved through the field; they retained the grain while depositing the straw back on the field.

For nearly five millennia, increases in wheat production were accomplished by increasing the acreage planted to wheat. In many parts of the world this was accomplished by plowing huge expanses of prairies, steppes, and pampas and turning under the native vegetation. This process destroyed the habitat of animals and literally turned upside down the soil structure where most of the biodiversity and biomass resided.

Today, wheat is the most widely grown crop in the world, but the area devoted to its cultivation has been fairly constant since the 1960s. Productivity has more than doubled since the mid-1960s. But per-hectare increases in yields through breeding programs for wheat have not kept pace with productivity gains in soybeans, corn, or rice. As a consequence, the area devoted to wheat has remained relatively stable while the area devoted to the other crops has increased because farmers find it more rewarding to grow other crops that give higher financial returns. New varieties of other crops (corn and sorghum, in particular) have been developed that are more drought-resistant, so these crops can now be grown in areas where wheat, barley, rye, or oats were grown in the past. Finally, wheat is mostly consumed by humans. But while demand is increasing faster than population growth, yield increases have exceeded demand for human consumption. Unless wheat becomes a major source of animal feed (and there are some indications of that trend, with 30 percent of wheat production now used for animal feed in the United States), the amount of land devoted to wheat is not likely to change. In fact, increases in yields may actually reduce the total amount of land devoted to the crop.

Between 1966 and 2000 wheat yields increased in the United States (from 1,890 to 2,780 kilograms per hectare) and Australia (from 1050 to 1820 kilograms per hectare). Yields in France started higher than other producers in 1966 and continued to climb at higher rates, from 3,260 kilograms per hectare to 7,490 kilograms per hectare). However, the most significant increases in yield have occurred in developing countries. China and India, for example, have shown some of the most significant improvements in yields over the same period. In China, per-hectare yields have increased more than fourfold in the same period, from 850 to 4,130 kilograms per hectare. China has by far the highest average yields of any major wheat producer, yields that are nearly half again higher than those in the United States. In India, while the increased yields have not been so great, they have still increased threefold (900 to 2,700 kilograms per hectare). India's yields are now nearly equal to those in the United States (Baenziger and Gill 2001).

Wheat is grown on some 4 percent of all the land area of the continental United States. About 17 percent of the 45,000 farmers who cultivate wheat produce two-thirds of the total crop. Wheat production in the United States is very chemical-intensive. According to the U.S. Department of Agriculture, wheat producers apply more than 7.4 billion kilograms of pesticides to their fields every year, at an average rate of more than 340 kilograms per hectare. About half of winter wheat fields in the United States are sprayed with herbicides, while some 95 percent of fields of the spring and durum wheat varieties are sprayed. The most common pesticides applied include the herbicides 2,4-D, dicamba, MCPA (4-chloro-2-methylphenoxyacetic acid), metsulfuron, tribenuron, and chlorsulfuron (USDA 2000 as cited in Kimbrell 2002).

Nitrogen is the nutrient most frequently applied in fertilizer for wheat production in the United States. About 85 percent of the U.S. winter wheat crop receives nitrogen applications and about 10 percent requires potassium as well. Similar application levels apply to spring and durum wheat, but a larger proportion of those crops also receive applications of phosphate (Kimbrell 2002). Nitrogen, potassium, and phosphate are the three nutrients found in most fertilizers, as they are the ones most likely to be needed by growing plants.

Another major input for wheat production is fossil fuels. Wheat requires greater use of fossil fuels than corn, sorghum, or soybeans per metric tons of production because productivity is lower and there are few methods of conservation tillage that work for wheat. As a consequence, more machinery is used per ton of production than for other cereals or grains.

Wheat production can generally be categorized as intensive or extensive based on the use of machinery, agrochemicals, and water per hectare and per metric ton of product. Intensive systems require more inputs and generally result in higher production per hectare. Higher levels of production are found in more humid environments. In more arid areas wheat is produced at the margins of other agro-pastoral production systems and production is generally less intensive. As a rule of thumb, the more intensive the use of inputs the greater the environmental impact per area (but not necessarily per metric ton of production) for areas already in production. Once wheat production systems have been established, the overall environmental impact of production depends primarily on the inherent characteristics of the land, soils, and climate where the wheat is grown as well as the intensity, methods, and seasonality with which inputs are used (Runge 1994).

Table 16.2 compares the impacts of three different production systems—intensive in high income countries, extensive in high income countries, and intensive in low income countries. The table describes and compares the inputs used, crop rotations employed, environmental impacts, and BMPs (Runge 1994).

Table 16-2 Comparison of Different Wheat Production Systems

	Intensive in High-Income Countries	Extensive on High-Income Countries	Intensive in Low-Income Countries
Examples	Paris Basin	Western Canada, Australia	India
Inputs used	Machinery Higher fertilizer use Higher pesticide use Some irrgation	Machinery Lower fertilizer use Lower pesticide use	New varieties Fertilizers Pesticides Irrigation
Crop rotations	Sugar beets/wheat/barley or corn/wheat/barley	Clover (in Australia)	
Environmental Impacts	Leaching of nitrogen Nitrate and pesticide residues	Soil erosion (wind and rain) Land degradation	Degradation Soil erosion (wind and rain) Salinization Alkalinization Deforestation Shifting cultivation
Improved practices	Better rotations Reduced fertilizer and pesticide use	Conservation tillage	Reduced fertilizer and pesticide use

Source: Adapted from Runge 1994.

Like other agricultural crops, wheat suffers from pests. Rust is the most destructive wheat disease. Caused by fungi, it attacks the leaves and stems and can significantly reduce yields. Grasshoppers and locusts are two of the more common insect pests. They contribute to annual losses of some 10 percent per year in the United States and sometimes much more in other producing countries. Weeds, too, are a common problem, robbing wheat of both moisture and nutrients.

Increased wheat yields in many developing countries have come largely as a result of public-sector investments, either from governments or through bilateral or multilateral agencies. In the United States, 41.4 percent of investments in wheat have come through the private sector (Frey 1996, as cited in Baenziger and Gill 2001). In Europe, due to highly flexible rotations and strong seed organizations, wheat breeding is done primarily by the private sector. Seed companies protect these markets by providing a full line of seeds, including wheat (Baenziger and Gill 2001).

Globally, there are more than 30,000 known varieties of wheat. These fall into six main classifications—hard red winter wheat, soft red winter wheat, hard red spring wheat, hard white winter wheat, soft white wheat, and durum wheat. Of the 30,000 known varieties, only 1,500 or so bred for commercial production dominate what is grown today. Most of these varieties (80 percent or so) were developed by companies, universities, or research laboratories in the United States. Pioneer HiBred International alone produces more than 3,000 new genetic combinations annually, which are field-tested on 40,000 trial plots (Kimbrell 2002). While most of these varieties are not commercially viable, wheat development is still largely an American business. The other creators of commercial wheat varieties include Canada (with seventy-nine varieties to date), Mexico (forty-eight), Russia (twenty-six), and Australia (fifteen). China and India, the world's leading wheat producers, have produced a combined total of only five varieties (Kimbrell 2002). Unfortunately, while it is easy to create nearly endless numbers of varieties through manipulation, very few of them are commercially viable, and farmers tend to rely on a small number of varieties that they plant for a shorter time.

Cultivated wheat is polyploid; it has more than two sets of chromosomes. Wheat used for bread is a hexaploid (has six times the original chromosome number), while the durum or hard wheat that is used for pasta is tetraploid (has four sets of chromosomes). Wheat has extensive germ-plasm resources within the cultivated and related species gene pools. Because wheat is polyploid, it tolerates chromosome loss, deletions, and additions much better than plants with only two sets of chromosomes (Baenziger and Gill 2001). The origin of wheat provides for its extensive germ-plasm resources. The hexaploid bread wheat genome, for example, is comprised of some 16,000,000,000 base pairs (chemical compounds that make up genes).

Improvements in wheat yields have come partly from technology and partly from improved genetics. Technological improvements have revolved around the use of agrochemicals, water, mechanization, and developing and communicating better information about production. Breeding efforts for wheat, including those from the green revolution, have focused on a few key traits (Baenziger and Gill 2001):

- Semidwarfing genes, which focus the plants' energy on producing more grain and shorter stalks that are more easily harvested and less susceptible to wind and storm damage;
- Day-length insensitivity, which allows for broader adaptation of wheat so that it can be produced in different parts of the world; and
- Systematic international germ-plasm exchange, which means that new varieties and traits can be experimented with and can be crossed more easily with local varieties.

In the future, many of these same traits will drive genetic advances in wheat breeding. International germ-plasm exchanges will certainly be the basis for most wheat breeding programs. However, a better understanding of wheat genomics and genetic manipulation will drive the breeding methodology because of the tools now available to plant breeders. And, finally, improvements in related technologies such as mechanization and better on-farm management practices, coupled with better information, will continue to generate yield improvements in the future (Baenziger and Gill 2001).

The most impressive gains will be made in wheat when the wheat genome and the variations are more fully understood. In particular, it will be important to understand how wheat is dispersed in the gene-rich regions where it is found in the wild and where many different varieties are cultivated. In particular, it will be important to understand which types of genes are in those regions, what particular environmental factors they are most or least adapted to, and what proportion of overall wheat genes (or genes of its relatives) are in those regions (Baenziger and Gill 2001). Finally, understanding which genes are associated with which characteristics—e.g. yields, disease resistance, drought tolerance—will also reduce the costs of and improve the performance of genetic manipulation. All of these suggestions can be done with the same technology as those used to create transgenic varieties, but without the introduction of any genetic material from unrelated species. There has been work, for example, to create a transgenic Bt wheat which would produce its own chemicals as a defense against soil-based pests.

New conditions will require adaptations in the varieties being grown. The reliance of producers on only a few varieties of wheat can have severe repercussions. In 1996, for example, a fungal disease known as Karnal bunt swept though the wheat belt of the United States, ruining more than half of the crop and leading to the quarantine of more than 116,000 hectares. As producers come to rely on a smaller and smaller number of varieties, such disease susceptibility can be expected to become more common. To date, the development of new wheat varieties has largely been seen as a legitimate government expenditure, since wheat is a basic food and thus its development can be seen as a food security issue. Certainly, the development of new varieties has benefited producers and consumers the world over. It is hard to argue that this is not a legitimate social expenditure for the global consumers of wheat. However, when the technology is developed with government funding, it is a legitimate question as to whether it should be given to seed companies who not only profit from it but can also patent the technology.

Processing

Wheat processing commences with harvesting and threshing. It includes drying the grain, removing the husks and any other foreign matter, and removing the bran, ending up with the final milling of the grain into white flour. The development of water- and wind-driven mills to grind wheat into flour changed agriculture fundamentally. Mills were expensive to build, maintain, and operate. Consequently, they were usually owned by a very large landowner, the church, or royalty. Each farmer was charged a fee (often one-sixteenth of the total grain milled) to mill the wheat into flour. Over time, smaller mills were destroyed or made illegal as a way to force people to use the royal or church-owned mills. In the end this forced families (including farmers) to buy flour rather than make it themselves (CyberSpace Farm 2002a).

Technological developments have allowed cleaner, more uniform flour to be produced using much less labor. By 1870 flour mills in the United States were far more automated and required only three workers to produce a much larger volume of flour than ever before. Over time, mills have become larger in size, fewer in number, and more specialized. For example, in 1873 there were 23,000 mills in the United States grinding wheat, corn, rye, and feed grains. By 1993 there were only 205 wheat mills, and Kansas milled almost 10 percent of all the flour in the United States (CyberSpace Farm 2002b). Most countries have their own milling operations, whether they produce wheat or not. It is easier to ship and store wheat as grain than it is as flour.

Processing wheat is energy-intensive and produces a lot of dust and organic matter as by-products. Over time each of these by-products has been captured and sold into other product lines. Most wheat is milled into white flour, which does not contain the germ or bran. When white flour is produced, the wheat germ and wheat bran are sold for other uses. Whole wheat flour contains both wheat bran and white flour. The flour milling process is normally integrated into the packaging process and the marketing of the different products. Therefore, flour-milling companies control more of the sale price than the retailer; these companies also have more control over the price paid for grain than the producer of the raw grains.

Most of the processing of the grain involves dry product. Drying improves the storage life of grains and makes them easier to process. Energy (usually natural gas or electricity) is used to dry grain, either on the farm or in nearby grain elevators, to keep the wheat from spoiling. In addition, considerable energy (in the form of gasoline and diesel) is required to transport the product.

Product Substitutes

For human food, there are many substitutes for wheat, but few of them are as well accepted around the world. Oats, barley, and rye are substitutes, but total consumption and, consequently, the areas in production of all have declined over the past 100 years. Corn, rice, or manioc flour is preferred in parts of Latin America, Asia, and Africa. As incomes increase in these areas, however, consumption tends to switch, at least in part, to wheat.

As societies have become wealthier an increasing portion of their calories has come from meat and vegetable oils. From a strictly caloric point of view, these too must be seen as product substitutes.

Wheat is used increasingly in animal feed at least in the United States, the European Union, and Australia. This is true both for terrestrial animals and increasingly for aquaculture feeding operations as well.

Market Chain

The market systems for wheat are similar to those for corn and soybeans and have changed over time in the same way. In the nineteenth century most wheat was bagged at the farm and sold in the same bag all the way to the mill that processed it into flour. With the creation of commodity markets, wheat was graded when it first entered the market and was sold to a trading company. Over time it became easier, more efficient, and more competitive to store, transport, and process fewer varieties as each had slightly different characteristics and required separate handling and storage facilities before, during, and after processing.

Wheat is given one of six grades when it is brought to central grain elevators. Grading depends on the weight and the quality of wheat. Wheat of similar grade and the same variety is stored in the same place. Thus, wheat from one area is substitutable for wheat from another.

At this time, most commercial production is sold to trading companies that have large holding elevators both in the areas of production as well as in or near large grain markets. These grain elevators dominate the landscape. Wheat is transported by truck, rail, or barge to centers where it is made into flour or exported to other countries. Wheat that is exported is independently graded and inspected by the government.

Some of the grain-trading companies also make flour. Most, however, sell their grain to flour companies. The flour mills are quite large in order to take advantage of economies of scale. If anything, the wheat market chain is even more concentrated (e.g. involves fewer companies) than that of other cereal grains as wheat processing is mostly to make flour and very little of that is sold directly to consumers. Normally, flour is held and sold, as needed, to the manufacturers who make it into food products.

Market Trends

Between 1961 and 2000 total production of wheat increased 163 percent, the amount of wheat traded internationally increased 179 percent, and the price of wheat declined by 61 percent (FAO 2002). In 1961 total global wheat consumption for all purposes was 225 million metric tons, of which 9 percent (19 million MT) was fed to livestock. Both total consumption and feed consumption rose steadily over the next three decades. By 1992, total wheat consumption had more than doubled to 562 million metric tons. In addition to increases in demand for human consumption, by 1992, wheat fed to animals had risen more than fivefold, to 107 million metric tons, accounting for 19 percent of total consumption worldwide.

Several factors have affected the world wheat market. Russia had a 40 percent drop in production in 1998 that buoyed the world market, but Russia's devaluation of its currency made imports expensive so other cereals and starches were substituted whenever possible. In addition, the price of pork has collapsed in the United States and Europe.

While this first affected corn and soybean prices, wheat prices quickly fell as well since all are used in feed (UNCTAD 1999). It is clear from this example that the price of wheat is linked more to meat prices in developed countries than to production and consumption in any single country.

When Cargill (the second-largest grain-trading company) bought Continental (the fourth-largest), the new grain-trading company had a 17.2 million metric ton (631 million bushel) capacity. That made it the single largest grain-trading company in the world. Archer Daniels Midland (ADM) had been the largest with a capacity of 16.6 million metric tons (610 million bushels). Monopolies such as this tend to lower prices paid to producers, as there are fewer buyers for producers to choose from. An increasing number of producers, for example, have only one buyer for their product. While markets may be more transparent than ever before, a lack of competition tends to allow the big grain traders to pass a lot of their costs on to the producers as well as to the buyers. And since fewer and fewer companies dominate the global grain trade, these same conditions are true internationally as well. In fact, the one thing that the large grain trading companies have in common is that they are not publicly held companies. This means that their profit margins are not public. Even if all the different producers and buyers could organize themselves, there would be less room to negotiate price either from the supply or the demand side.

Environmental Impacts of Production

The FAO has developed a qualitative assessment of the environmental impacts of various commodities (Runge 1994). This assessment includes wheat in a more general category of grains. One of the main environmental impacts of grains such as wheat is the destruction of natural habitat due to field enlargement or creating new fields following the abandonment of degraded areas. This, in turn, causes the displacement of indigenous species and biodiversity loss, due especially to the promotion of high-yielding varieties. Other major environmental problems are soil erosion, soil degradation, and water use and pollution. The increasing use of manufactured fertilizers and pesticides and creation of dust from dry milling also cause environmental problems.

Despite these problems, wheat has a fairly positive role because much of it is planted in the late fall, winter, or very early spring depending on the location and the variety. Due to its "off-season" nature it provides ground cover and reduces soil erosion. It requires less fertilizer and pesticides per hectare than many other crops (but often more per ton produced), and most wheat is not irrigated.

A broad range of pesticides is used on wheat including herbicides, soil fumigants, insecticides, and fungicides. While the quantities used per hectare are not large, because wheat is grown on so much land the total quantities of chemicals used are quite large. More importantly, these chemicals end up in runoff and freshwater systems if soil is not protected from erosion and if there is insufficient organic matter and mulch to bind and hold them.

Habitat Conversion

Given that wheat is grown on more land than any other single crop, its historical impact on the environment has been considerable. Habitat conversion for cultivation has been a very large environmental impact from wheat production in the past. The production of wheat, in fact, has created many of the current agro-pastoral landscapes that are seen as "natural" in Europe, northern Asia and the United States.

Habitat conversion continues to this day in such areas as the western United States, where subsidies make wheat production profitable in marginal areas that could not be farmed profitably otherwise. Many of the areas now under cultivation include some of the few remnants of blue-stem prairie that had never before been plowed. While globally, grasslands and savannas are not as biodiverse as many other terrestrial ecoregions, they are nonetheless unique. Furthermore, they provide essential ecosystem services (e.g. overall water retention and runoff and carbon sequestration) that biodiversity in other regions depends upon.

The expansion of wheat production into fragile ecosystems of the Northern and Southern Hemispheres would threaten remaining biodiversity. While the consumption of wheat is certainly increasing in tropical countries, most production is still in the colder temperate regions because tropical wheat remains a poor producer compared to that produced in temperate zones. Intensive breeding programs could certainly change this in the future. If that happens, it could become possible and even profitable to grow wheat on the savannas of such places as Africa.

Most of the temperate areas that are suited for wheat production are already under cultivation. The remaining areas include savannas with fewer water resources. To become productive these areas will require huge investments in irrigation infrastructure that will drastically change ecology and habitat.

Soil Erosion and Degradation

Because landscapes and subsurface geology vary widely, the impacts of grain production on land resources also vary. Soils vary tremendously within a given field as well as over broader landscapes. Soil characteristics such as depth, particle size, nutrient composition, organic matter content, and physical chemistry are all altered by wheat production. These characteristics, which determine the capacity of soil to produce grain, must be restored or rebuilt over time if an area is to remain productive.

It is clear from historical records that wheat production can dramatically affect soil conditions and nutrient cycles. Cultivation of wheat has led to converting previously fertile areas into dustbowls and deserts, as in North Africa in the first millennium and parts of North America in the early twentieth century. As populations increase, agricultural technology changes, and human-induced soil degradation increases, the land devoted to wheat production increases or at the very least shifts to new agricultural frontiers.

Continuous cropping of wheat and other grains often depletes nutrients even in the most fertile soils. Replacement can occur through fallowing, crop rotation, leaving crop residue on the surface, applying animal manure, or using manufactured chemical fertilizers. Applying too much nitrogen or any other nutrient can cause imbalances that harm plants as well as the environment, especially if other essential nutrients (such as potassium) are limiting yields or if the applied element is already in sufficient supply in the soil. There are several methods of application, but the best are those that put the nutrient in the soil rather than on top of it. Nutrients applied to the surface are easily leached away. These nutrients, if allowed to leave the field through runoff or leaching, will induce plant growth (including algal blooms) at their new location.

Water Use and Pollution

There are several impacts of wheat production on water resources. First, because many countries see wheat as a strategic food crop and want to be self-sufficient in basic food production, the crop is often grown in areas with insufficient rainfall to support it. Wheat is the second most irrigated crop cultivated globally. Irrigation always brings with it the problem of soil salinization, which at low levels reduces yields but eventually can make soils unfit for any type of cultivation. In addition, pollution of waterways with silt from soil erosion, surface water pollution due to agrochemical runoff, and subsurface contamination of aquifers due to agrochemicals are all problems that can be caused by the production of wheat.

Wheat production can also affect the amount of water available for agriculture or other uses, both indirectly through changes in hydrology and directly through diversion for irrigation. Habitat conversion for wheat cultivation often causes severe changes in the drainage and hydrology of vast areas. In natural landscapes the organic matter on the surface and within the soil acts like a sponge. Water is absorbed and released over time. After conversion to wheat, water runoff is more seasonal with severe peaks and valleys in runoff rates.

Irrigation of wheat can cause major changes in ecological structures of landscapes such as reduced water flow or even the elimination of streams, rivers, wetlands, or marshes. Changing the course and speed of water flows, along with seasonal changes in water levels, can devastate plants, animals, and fish. Underground water resources can also be depleted by pumping water for irrigation, especially when those are nonrenewable sources such as ossified aquifers. This causes tremendous problems for people who depend on those underwater reserves as their water source.

Water quality is another important issue. Runoff from grain fields pollutes surface water with nutrients such as nitrogen and phosphorous as well as particulates (silt). Phosphorus in particular tends to be a problem because it feeds algae and can cause algal populations to explode. Huge quantities of algae can deplete the oxygen in creeks, rivers, ponds and lakes, creating excessive biochemical oxygen demand (BOD) and killing fish and other aquatic life. This starts a process known as eutrophication, which can permanently alter water bodies. Organic matter carried in runoff from grain fields also increases the BOD of surface waters. Groundwater quality can also be affected through the leaching of fertilizer nutrients and other agricultural chemicals into underground water sources.

The health impacts of water quality changes from agriculture, for humans and other species, are only beginning to be investigated. Groundwater contamination from nitrates in fertilizers has been linked to methemoglobinemia or "blue baby syndrome." Groundwater contamination from pesticide residues has been linked to such human ailments as skin diseases, autoimmune diseases, and some cancers. The evidence on pesticide residues for humans is fragmentary, however, and even less research has been done on other species. Some research is beginning to indicate that pesticides have demonstrated carcinogenic and teratogenic properties (causing birth defects) in animals, even though few have been shown to be cancer-causing in humans (Cabello et al. 2001; Reif 1999). Other studies have shown a correlation between pesticide exposure and certain types of cancer in some populations of agricultural workers (Mills 1998).

Runoff from wheat fields is often funneled through a very small number of rivers, where the aggregate impact of even small quantities of chemicals over such a large area can be significant. Reports, for example, have suggested that pesticides used on wheat have been linked to frog deformities in Minnesota. However, controlled experiments found correlations between prior infections by trematodes (parasitic flatworms) in frogs and common pesticides such as atrazine (the most commonly used herbicide in North America), malathion (used to control both household and agricultural insect pests), and esfenvalerate (a synthetic pyrethroid insecticide). It is not clear that these pesticides are directly linked to wheat more than to other agricultural commodities (Associated Press 1998; Danielson 2002; Milwaukee Journal Sentinel 1999).

Better Management Practices

There are three main areas where the impacts of wheat production can be reduced. For the most part, habitat conversion is not a major issue at this time, and the elimination of subsidies would address this problem. However, the development of genetically modified wheat could greatly extend the range of wheat production into areas that had previously not been farmed. The areas where greatest improvement could take place that would make wheat production more sustainable are practices that not only reduce soil degradation and loss but actually build it over time. Similarly, practices that decrease water use and water-based pollution would reduce the impacts of wheat production and make it more viable in the long term.

Avoid Habitat Conversion

For a few thousand years, wheat cultivation expanded into areas of natural habitat. By 2000, the area under cultivation had generally stabilized. The areas of expanding wheat cultivation are generally offset by areas that are no longer used for wheat. The main cause of the expansion of wheat cultivation into natural habitat are agricultural subsidies in the United States. Subsidies make production financially attractive under circumstances and conditions when it otherwise would not be. While it is not clear if U.S. subsidies have forced other wheat producers to cultivate additional land to remain competitive, it is clear that eliminating subsidies would take pressure off the few native prairies in the United States that have managed to survive.

Another factor that may contribute to the expansion of wheat production into pristine natural habitats in the future is the creation of genetically modified wheat that would extend the range where wheat can be grown. Changes in the nutrient or water requirements or the pest tolerances of wheat could allow wheat to be produced in areas where it has not been possible in the past. Plant breeding in the past has expanded the number of wheat varieties and the range of each. However, the changes that have resulted in the past are nothing like those that could occur through the development of genetically modified wheat varieties with today's technology.

Build Soil Fertility

In the face of expanding monocrop production year after year, traditional forms of soil conservation such as using fallows, integrating livestock into cropping systems, rotating crops, and using polyculture production systems are often abandoned. This simplification of production practices tends to accelerate the degradation of the soil and the land resource base in general.

Forms of production that are more conserving or restoring of the soil can still be practiced if producers are convinced that they are economically viable. Fallowing (in which land is removed from wheat cultivation and left to pasture or growing soil-building cover crops) provides a good example. Most nutrient depletion occurs in the upper level of the soil where the roots of the wheat are concentrated. Enriched fallows of some seven years (where plantings are chosen to increase fertility) can build up soil fertility. For example, legumes grown to fix nitrogen and deep-rooted cover crops to scavenge for native or leached potassium, phosphorus and other trace elements and pull them to the surface make it easier for short rooted crops such as wheat to utilize the nutrients. In addition to reducing the need for fertilizers, such extended fallows also increase the soil's organic matter tremendously and restore soil biodiversity and soil structure. These, too, have a positive impact on future production. Thus, fallowing is both a soil conservation and rejuvenation measure that can help to return soils to their former vitality.

Fallowing also provides temporary habitats and increases foraging areas for wildlife. Many producers in developed countries have found that encouraging wildlife in such areas allows them to make money by selling hunting rights, mostly for game birds but also for some mammals. Depending on the price of wheat, such hunting fees can represent 5 to 25 percent of net income. The major problem with this strategy, at least in the United States, is that most wheat-producing areas are located far from urban areas and few accommodations for hunters are available. By contrast, in developing countries, attracted wildlife can be an important source of protein for farm families.

Another possible strategy to reduce the financial impact of an extended fallow is through government sponsored programs. In the United States, the Conservation Reserve Program

(CRP) provides financial support for ten years. Producers can sign up part of their land for CRP to fallow those areas. Undertaking this approach on a partial basis would allow land to rotate into and out of production. Even if this is not the intended use of the CRP or other subsidy programs, adapting it in this way could help restore productivity in large areas of wheat cultivation in the United States and other areas as well. In Brazil, a similar system that does not involve government support involves cropping for 3 to 5 years followed by the use of the same land for pasture for 7 to 10 years.

Unfortunately, agricultural credit and investment systems do not incorporate these features as regular measures for consideration. Fallowing and crop rotations are not seen by financial institutions as being good investments, even though they improve the resource base and reduce future costs for expensive fertilizers and pesticides. In addition, many agricultural extension agents often do not understand the value of such systems and denigrate them to local farmers. This reality is gradually shifting, however, and soil and environmental rehabilitation strategies are increasingly seen as worthwhile investments.

Avoid Burning Crop Residue

Wheat is grown in many parts of the world with relatively short growing seasons. As a consequence, the stubble and crop residues do not have much time to decompose. Even when plowed into the soil, straw can take several years to decompose, especially in climates with short dry summers and long winters. As a consequence, burning is a common practice in many parts of the world where there is an insufficient market for straw. Burning wheat stubble not only destroys valuable organic matter but also causes air pollution and releases carbon dioxide into the environment, therefore becoming an environmental problem.

It is possible, however, to use stubble to improve the soil. If slow decomposition is an issue, it can be inoculated with decomposing microorganisms before it is plowed under (Panfilo Tabora, personal communication). As the wheat stubble breaks down it is converted into organic matter in the soil, which then binds with water, fertilizers, and pesticides, reducing the runoff from all of these.

Increasingly, farmers in developed countries are selling their straw to particle and fiberboard manufacturers, who use it to make engineered timber. By the early 1990s some wheat producers were making 15 to 25 percent of their net income from the sale of straw. At that time they were lamenting the dominance of shorter wheat varieties, which, while more storm and drought resistant, produce less straw.

Improve Water Quality and Reduce Water Pollution

Wheat producers can reduce the overall impacts of production by managing their use of water more efficiently. While the major wheat producers do not irrigate, this is not the case in parts of Europe, the Middle East and Asia where irrigation is most commonly undertaken by gravity-fed flooding of fields. This is not an efficient use of water. Moreover, whether wheat's water needs are met by rainfall or irrigation, water will be used more efficiently by the plant if there is more organic matter in and on the soil to absorb it and release it more gradually. The elimination of burning would help to build up organic matter as would various forms of conservation tillage. Such practices reduce effluent runoff and pollution.

As the scale of wheat production has increased, more and larger machinery has become the norm. However, per hectare wheat production is less productive than most other cereal grains so farmers tend to farm more land to make the same or even less money. Under these circumstances, it is difficult for producers using large machinery to protect lower lying areas of fields that are most affected by runoff. For most producers, it is easier to cultivate such areas during planting than to leave them in grass which reduces erosion but requires far more precision to engage and disengage both the machinery to till the soil prior to planting as well as the planter itself. The maintenance or re-establishment of grass-covered waterways in wheat fields would reduce dramatically overall runoff and pollution issues. Similarly, terraces would reduce runoff and erosion, but depending on the amount of land moved, could make it difficult to maneuver large machinery. Also, the price of wheat may simply not be high enough to justify such earth works.

Outlook

Global consumption of wheat and wheat products is increasing only at about the rate of production increases. An increasing portion, nearly 20 percent, of all wheat is being fed to animals. Because of increased yields, the amount of land devoted to wheat production is stable to declining. These trends are not expected to change.

A major factor that could affect the overall consumption of wheat is the market for other substitutes, either cereals or starches. For example, rice production has peaked in many areas, so with populations continuing to increase, it appears that consumers may switch to wheat or other foods out of necessity. Corn, barley, sorghum, and millet are also important substitutes for wheat that, depending on shifting cultural values, may have increased or decreased levels of consumer preference in the future. Finally, potatoes and cassava are also both increasing as sources of calories in the diet globally.

Recent decisions to abandon Bt and other GMO research on wheat imply that there will not likely be major changes in production practices or overall production levels in the near future. But, this could change in the future. Another outstanding issue is whether the U.S. government in particular or other governments more generally will continue to invest in genetic research and breeding programs that could increase wheat yields to new levels or expand even further the conditions under which cultivation can be undertaken. In all likelihood, neither the production nor consumption of wheat is likely to change a great deal in the near future.

Resources

Web Resources

www.wheatworld.org/
www.ers.usda.gov/publications/SB968/
www.uswheat.org/USWpublicII.nsf/0/
a692531e359ab83985256ab7006eb766?OpenDoc ument&ExpandSection=-1000
www.oznet.ksu.edu/wheatpage/economics.htm
www.uswheat.org/USWpublicII.nsf/0/
70ab940f41b40c4185256ab7006d2072?OpenDocument

Additional resources can be obtained by searching on "wheat" on the WWF International Intranet: http://intranet.panda.org/documents/index.cfm

Contacts Within the WWF Network

No one within the WWF network has been identified as working on this commodity. Please contact Jason Clay at WWF-US (jason.clay@wwfus.org) for suggestions of contacts outside the network.

References

Associated Press. 1998. Pesticide deforming the frogs? *Channel 4000.* March 23. Available at http://www.channel4000.com/news/stories/news-980323-062043.html.

Baenziger, P. S. and K. S. Gill. 2001. *Give us this day our daily bread: The future for wheat.* Paper presented at the American Association for the Advancement of Science Annual Meeting, San Francisco, CA.

Betz, V. M. 2002. Identification of the initial site of einkorn wheat cultivation. *Athena Review.* 12(1).

Bonjean, A. and W. Angus. 2001. *The world wheat book: A history of wheat breeding.* Andover, UK: Intercept.

Cabello, G., M. Valenzuela, A. Vilaxa, V. Duran, I. Rudolph, N. Hrepic, and G. Calaf. 2001. A rate mammary tumor model induced by the organophosphorous pesticides parathion and malathion, possibly through acetylcholinesterase inhibition. *Environmental Health Perspectives.* 109 (5):471–479.

Chapman, G. P. 1992. *Grass evolution and domestication.* Cambridge, England: Cambridge University Press.

CyberSpace Farm. 2002a. *Planet wheat: A short history of wheat.* Kansas Women Involved in Farm Economics (WIFE), sponsor; High Plains Journal, host.Available at http://www.cyberspaceag.com/wheathistory.html. Accessed August 2002.

——. 2002a. *Planet wheat: a short history of flour milling.* Kansas Women Involved in Farm Economics (WIFE), sponsor; High Plains Journal, host. Available at http://www.cyberspaceag.com/flourmillinghistory.html. Accessed August 2002.

Danielson, S. 2002. Pesticides, parasite may cause frog deformities. *National Geographic News.* July 9. Available at http://news.nationalgeographic.com/news/2002/07/0709_020709_deformedfrogs.html.

Diamond, J. 2002. Evolution, consequences and future of plant and animal domestication. *Nature* 418 (8 August):707. London: Macmillan.

FAO (Food and Agriculture Organization of the United Nations). 1996. *Production yearbook 1995.* Vol. 49. FAO Statistical Series No. 130. Rome: UN Food and Agriculture Organization.

——. 2002. *FAOSTAT statistics database.* Rome: UN Food and Agriculture Organization. Available at http://apps.fao.org.

Frey, K. J. 1996. *National plant breeding study—1.* Special Report 98. Ames, Iowa: Iowa State University.

Kimbrell, A., Editor. 2002. *Fatal harvest: The tragedy of industrial agriculture.* Washington D.C.: Island Press.

Lev-Yadun, S., A. Gopher, and S. Abbo. 2000. The cradle of agriculture. *Science* 288, 1602–1603.

Mills, P. K. 1998. Correlation analysis of pesticide use data and cancer incidence rates in California counties. *Archives of Environmental Health.* 53 (6):410–413.

Milwaukee Journal Sentinel. 1999. Pesticide linked to deformed frogs, studies indicate. *Milwaukee Journal Sentinel.* October 6. Milwaukee, WI.

Reif, J. S. 1999. Companion dogs as sentinels for the carcinogenic effects of pesticides. *Pesticides, People & Nature.* 1 (1):7–14.

Robertson, H. 2002. *Triticum (wheat genus).* Cape Town, South Africa: Iziko Museums of Cape Town. Available at http://www.museums.org.za/bio/plants/poaceae/triticum.htm.

Runge, F. 1994. *The grains sector and the environment: Basic issues and implications for trade.* Draft discussion paper prepared for the Intergovernmental Group on Grains of the UN Food and Agriculture Organization.

Smil, Vaklav. 2000. *Feeding the world: A challenge for the twenty-first century.* Cambridge, Mass: MIT Press.

UNCTAD (United Nations Commission on Trade and Development). 1999. *World commodity survey, 1999–2000.* Geneva, Switzerland: UNCTAD.

USDA (United States Department of Agriculture). 2000. *Agricultural chemical usage field crops summary 2000.* Washington, D.C.: USDA.

Wilford, J. N. 1997. New clues show where people made the great leap to agriculture. *The New York Times.* November 18.

Zohary, D., and M. Hopf. 2001. *Domestication of plants in the old world (3rd edn).* Oxford: Oxford University Press.