Development, Productivity, and Sustainability of Crop Production

Maarten J. Chrispeels
University of California San Diego
David Sadava
The Claremont Colleges

In the previous chapter we discussed some of the broad outlines of agricultural progress in the 20th century: the remarkable increase in food production, the role of agricultural technologies and agricultural science, and the need for the public and private sectors to invest in such research. In this chapter, we look at some of these themes again in greater detail and consider not only the achievements, but also the problems that are looming on the horizon.

People are very much a part of Earth's ecosystems, and every ecosystem has both producers and consumers. The producers are the plants: They convert solar energy into chemical energy stored in food (see Chapter 10) that is available to the consumers. The consumers are the animals—from the smallest to the largest—and the microorganisms that break down organic matter and recycle nutrients. Humans are therefore consumers who directly or indirectly depend on plants for their food.

Before humans first practiced agriculture, ancient hunter-gatherers had evolved a complex relationship with their environment (see Chapter 13). They had an intimate knowledge of the plants and animals in their surroundings and used a wide variety of plant and animal foods. Aboriginal peoples relied largely on plants, but most had diets that included animal products. With the development of agriculture some 10,000 years ago, people narrowed their food selections. Instead of the many plant species once gathered in the wild, 24 cultivated plants now account for much of the food people eat. Three of them—the cereals: wheat, rice, and maize—make up about two thirds of the human diet (**Table 3.1**).

Various cultures rely on different plants as their main food crop, or staple. The major food plants evolved at the same time as the societies that use them (see Chapter 13). Thus the Japanese have many different soybean-based foods and sauces, and Westerners eat wheat under many guises. Many Latin-Americans and Africans eat cassava, a tuber crop that is virtually unknown in North America and Europe.

CHAPTER

3

3.1 Directly or indirectly, plants provide all of humanity's food.

A look at food sources in various regions of the world reveals another interesting feature: Some societies eat almost entirely plants, whereas others use a substantial amount of animal-derived foods. For example, in India plants supply 80% of dietary protein (cereals and legumes), but in the United States plants provide only 25% of dietary protein. The rest comes from animals and animal products (**Table 3.2**).

There are also differences among regions, social classes, and people of various religions. In developing countries, city dwellers typically eat more meat—historically regarded as a sign of affluence—than do farmers. For political reasons, governments often encourage meat consumption by providing agricultural price supports for feed grains, tax incentives for feedlot operators, guaranteed minimum prices, or government storage of surpluses.

Researchers estimate that 85% of the calories and 80% of the protein in the human diet now come directly from plants. However, this situation

Table 3.1 Humanity's most important food crops

Category	Crop Name	Amount Produced, 2000 (millions of metric tons)
Cereals	Maize	596
	Rice	593
	Wheat	582
	Barley	136
	Sorghum	60
	Millet	27
Rootcrop	Potatoes	302
	Cassava	170
	Sweet potatoes	138
Legumes	Beans, dry	20
	All others combined	40
Vegetables	Tomatoes	100
	Cabbage	50
	Onions	50
Oll crops	Soybeans	162
	Oil palm fruit	98
	Coconuts	48
	Rapeseed (canola)	40
Starchy fruits	Bananas	58
	Plantains	30
Fruits	Oranges	66
	Apples	60
	Grapes	60

Notes: In addition to these, some 3,000 million tons of animal feed crops are harvested yearly.

Source: Data from Food and Agriculture Organization (FAO) of the United Nations.

Table 3.2 Comparison of diets in India and United States

	Source of Calories		Source of Protein	
Food	**India**	**United States**	**India**	**United States**
Cereals, starchy foods	61%	23%	60%	21%
Sugars	6	12	—	—
Beans, lentils	11	4	18	4
Fruits, vegetables	2	6	1	4
Fats, oils	4	19	—	—
Milk, milk products	7	14	12	24
Meat, poultry, eggs, fish	9	22	9	47

Source: 1998 data from the Food and Agriculture Organization and U.S. Department of Agriculture.

is changing as people become more affluent. Rising affluence therefore puts additional pressures on the food system.

We have already noted, in Chapter 2, that urbanization and economic development, and the rise in income and expectations associated with them, make increasing demands on the food production system. People want to eat a more varied diet, and they want and can afford to eat more animal products. Global meat production has increased dramatically in the last 50 years, quadrupling since 1950 (**Figure 3.1**). Until about 1950 in the industrialized countries, and even today in many parts of the developing world, farmers who practiced a sustainable mode of farming integrated livestock rearing with food crop production. They rotated food crops (wheat, potatoes, and sugar beets) with feed crops (hay, clover, and alfalfa). People ate the former; farm animals ate the latter. Farmers spread animal waste (manure) over the soil as fertilizer, and leguminous feed crops (clover and alfalfa) added nitrogen to the soil (see Chapter 12).

Unfortunately, this integrated system is hard to sustain when demand for meat is high. Specialized animal production facilities, often located close to the population centers, feed animals soybeans and grains such as maize and sorghum. This system requires large areas of land just to raise food for animals. To understand why eating animal products puts additional demands on the food production system, also consider how matter and energy transfer from one organism to another in the ecosystem. In the food chain, plants are called *primary producers*. When an animal eats the plants, only about 10% of the plant matter and energy ends up as part of the growing animal's body. The other 90% is "lost": The animal uses a lot as energy to fuel its digestion and to refashion plant material into animal material. So if humans eat plants directly, the transfer efficiency is about 10%. Now consider what happens if an extra step occurs between plant and human: Let's say a cow eats grain, and then a human eats the cow. The efficiency from plant to human via cow is 10% ÷ 10%, or 1%. So people must grow 10 times the amount of grain to supply a meat-eating human with the same energy and matter as would be needed if the person ate the grain directly.

Actually, in some cases modern methods have improved the efficiency of transfer from grain to animal. Efficiency is higher in feedlots and chicken farms, where animals are confined and fed optimal diets. Still, it takes about 7 kg of grain to produce 1 kg of pork

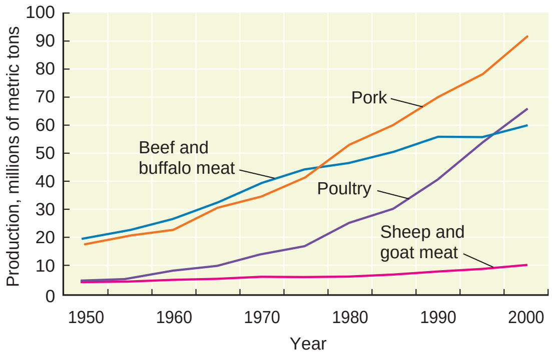

Figure 3.1 Increase in world meat production, 1950–2000. The fastest-growing meat source in the United States is poultry, whereas in eastern Europe it is pork. *Source:* Data from Food and Agriculture Organization.

(15% efficiency), 5 kg of grain to produce 1 kg of beef (20%), and 2 to 3 kg of grain to produce 1 kg of egg, cheese, or poultry (33–50%).

Some people have argued that eating animal products wastes precious agricultural resources, but there is at present not enough economic demand for food grains (rice and wheat) to expand their production. Despite ecological inefficiencies, meat production is rising rapidly. The existence of several successful farming systems based on animal husbandry (for example, nomadic sheep, cattle, and goat herding as well as cattle and sheep ranching) confirms that under certain conditions the inefficient conversion of energy and protein is also a positive aspect of the food production system. For example, some 30 to 40 million pastoralists living in the world's driest lands produce animal products (milk, meat, and wool) in areas that are essentially unsuitable for crop agriculture. Nevertheless, meat consumption can sometimes have unintended negative consequences as well (see **Box 3.1**).

3.2 Land use patterns in agriculture show increased intensity of resource use on arable land.

With suitable temperature and rainfall, people can successfully use land to grow crops and produce foods. But where is the arable land (cropland) located, and how much exists? Certainly not all of Earth's land is used for crops. Of the total land area of Earth, people use about 11% for crops (arable land) and use another 24% for pastures; 31% is forested. The arable land is heavily concentrated in Canada, the United States, Europe (including Russia and the Ukraine), India, China, and Southeast Asia (**Figure 3.2a**). The rest of the land surface—about one third—is too cold, too dry, or too steep for plant growth. The unequal distribution of agricultural resources over the globe is shown clearly if we express the amount of cropland per inhabitant and the available freshwater per inhabitant for each continent (**Figure 3.2b**). Asia, which already has the most people, has the least agricultural land and freshwater per person.

Box 3.1

Meat, Manure, and Subsidies

Some choices are difficult. In the Netherlands, a small country in northwestern Europe, the meat and dairy industries produce 85 million tons of manure each year. Feeding animals is inefficient, and about 80% of the protein (and larger percentages of other nutrients) fed to animals shows up in manure in various forms (protein, urea). People could dispose of about 50 million tons of this manure in an environmentally acceptable way, but the other 35 million tons clearly are surplus. Export is not feasible because transport is expensive and the amount of manure is so great. A 25-mile-long manure train would have to leave the country every single day. So the nutrients (100,000 tons of phosphate each year, for example) continue to pollute the ecosystems.

Where does all the animal feed come from? In the past, cows ate grass and chickens ate grain. Until recently, the livestock, poultry, and dairy industries depended on locally produced animal feeds. The most recent rise in consumption of meat and animal products in Europe is driven by feed imports from abroad. Although Europe produces plenty of wheat and other grains (the countries of the European Union annually produce 165 million tons) and actually has a grain surplus of 35 million tons, the animal industries prefer to buy cheaper substitutes. The substitutes are cheaper, in part, because various governments heavily subsidize grain production (to the chagrin of other countries—such as Australia—that also have enormous grain surpluses). The grain substitutes that Europe buys—powdered cassava roots, maize gluten, soybean press cakes, and citrus pulp—are produced in the United States (40%) and in various developing countries (60%) and enter western Europe primarily through the giant harbor of Rotterdam. Much of the animal feed remains in the Netherlands and is used by the local meat and poultry industries. The rest is dispersed all over Europe by rail and boat. The livelihoods of many farmers and workers in the developing countries now depend on this export of animal feed, which arrives in Rotterdam in giant ships at the rate of 100,000 tons each day.

How can such a problem be solved? Consumers want cheap cheese and steak. Environmentalists want to reduce the manure output. European farmers want subsidies. The traders and those who promote "development" in the developing nations want to continue the trade, which earns hard currency for developing countries. Neither the United States nor the farmers of the developing nations want import taxes that would make European grain more competitive with their products.

Several principles should underlie the search for a solution. First, perhaps too much land is being cultivated in the developed countries. If subsidies are really necessary to give such farmers a decent standard of living, they should be maintained, but pinned to a lower total output. Land could then be taken out of production and be used for other purposes. Second, the price of steak or eggs should include the cost of disposing of the manure in an environmentally acceptable way. Third, policies in the developed nations should be examined for their effects on developing countries. This will involve value judgments. Who benefits if European pork is produced with cheap cassava from Thailand or with soybean press cake from the United States? Do policies in developing countries that promote the production and export of these new cash crops imperil the ability of these countries to produce food for their own people? Would it be better to take land out of production in the United States, rather than supply the Europeans with grain substitutes so they can have cheaper cheese, eggs, and meats?

The location of arable land is itself a function of climate, soil type, and type of vegetation that grew in the area before people cleared the land. Climate, soil type, and vegetation all interacted during the soil formation process and the most productive soils formed in areas of permanent grassland (such as the prairies of the midwestern United States) or hardwood forests (most of Europe and India). Grasslands produce rich soils with abundant organic matter that can remain productive for many decades after farmers convert them to cropland. These soils are quite suitable for annual row crops (maize, wheat, beans, and so on).

The process of converting natural ecosystems into pastures or cropland is now being repeated most dramatically in the tropical rainforests of South America. However, converting a tropical rainforest into an agricultural field can be very difficult. Most rainforests grow on relatively infertile and highly weathered soil (see Chapter 11). When people clear such land and burn the vegetation, they expose bare earth to the sun, soil temperatures rise, and the soil organic matter quickly decays, because the vegetation does not replenish it. Because of the high rainfall, the soil erodes easily.

Asia, Latin America, and Africa contain many examples of massive soil degradation caused by clearing away tropical forests and imposing agricultural practices on soils that are totally unsuitable for row cropping. People need new approaches for these soils (see Chapter 5).

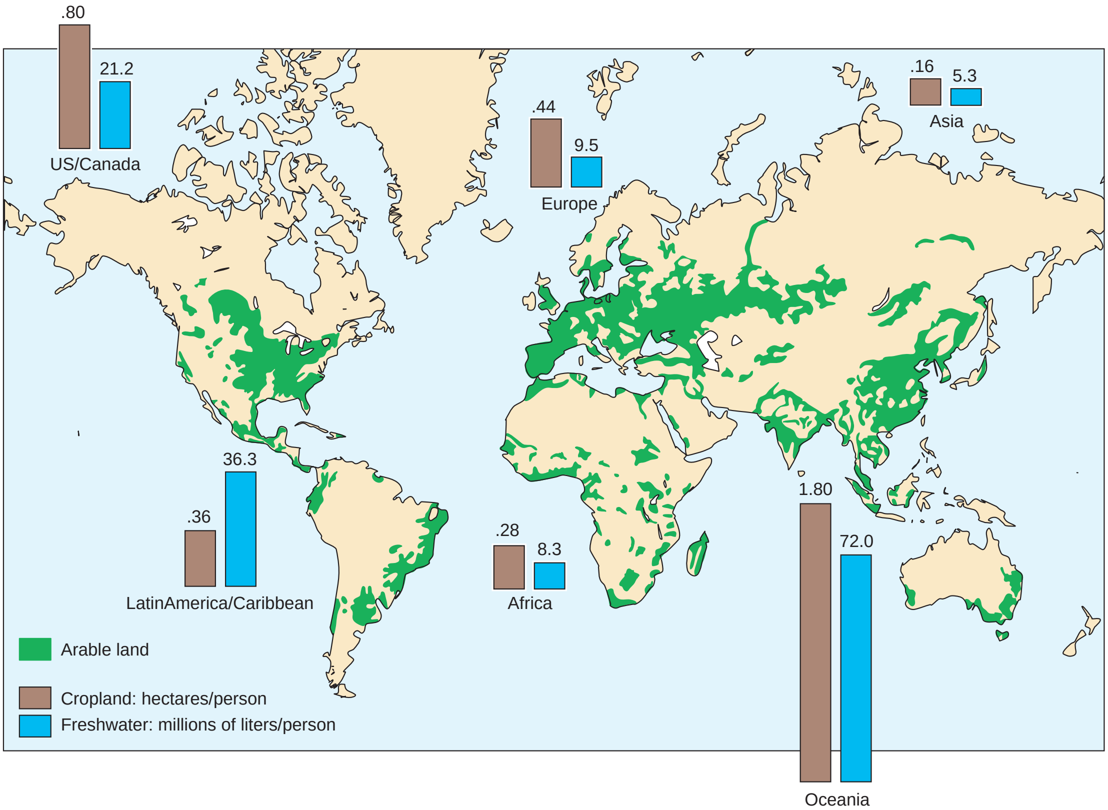

Figure 3.2 The world distribution of arable land and fresh water. Notice that most of the arable land is in Canada, the United States, Brazil, Argentina, Europe, Russia, western Asia, India, and China. Cropland and available freshwater are expressed on a per capita basis for each continent. Oceania includes sparsely populated Australia, New Zealand, and a number of small Pacific island states (total population about the same as one large Asian city).

Plowing more land may not achieve a greater total of cropland than the 1.5 billion ha presently used. The FAO estimates that 5 to 7 million ha are being lost each year to land degradation. One problem is that the areas with the greatest population pressures, such as the east coast of China and most of India, have the least land reserves that could be cleared for crops. Other areas—in the former Soviet Union, for example—have good arable land but not enough rainfall. Improved agricultural technologies could greatly expand food production in these regions (see Section 3.3).

The development of agriculture in different regions of the world has intensified land use. Each stage of intensity has its own characteristics and productivity (**Table 3.3**):

1. *Forest fallow.* Cutting and burning parts of a forest release nutrients contained in the plants; this fertilizes the land, allowing it to support crops. But this fertility lasts only until crops deplete the soil of its nutrients, and the farmers then move on to another part of the forest, repeating the cycle. In the meantime, they leave the original land fallow for up to 20 years, to restore its fertility.
2. *Short fallow.* As human population density grows, grassland replaces the forest and farmers shorten the fallow period to one or two years. This is not long enough to fully restore the soil, to let it support crops, so added fertilizer—often animal manure—is required. Farmers often plant special legumes to accelerate restoration of soil fertility. In addition, they achieve higher yields by manual pest control (for example, weeding).
3. *Annual cultivation.* With a still-increasing population, now coupled with market demand, farmers drop the fallow period and grow a crop every year. Now they need constant fertilization and pest control to keep up the yield. Crop rotations increase the sustainability of the system.
4. *Multiple cropping.* This is the most intensive use of the land. Not only do farmers grow several crops on the same land sequentially in one year, but also they grow two or more crops at the same time. Farmers often follow this latter pattern, called *intercropping,* for the same reason as they rotate crops: One species removes one type of nutrients, and the intercrop removes other nutrients.

Chapter 5 discusses the reality of these land use patterns in sub-Saharan Africa.

Table 3.3 Farming operations in different systems

Operation	Forest Fallow	Short Fallow	Annual Cultivation	Multiple Cropping
1. Land clearing	Fire	None	None	None
2. Land preparation	None	Plow	Plow, tractor	Plow, tractor
3. Fertilization, compost	Ash	Manure, compost	Manure, compost, chemicals	Manure, chemicals
4. Weeding	Low	Intensive	Intensive	Intensive
5. Animals or machines, transport	None	Plowing, transport	Plowing, transport, irrigation	Plowing, irrigation
6. Percentage of world cropland	2%	28%	45%	25%
7. Grain yield (kg/ha)	250	800	2,000	5,000

Sources: Adapted from H. Binswanger and P. Pingali (1988), Technological priorities for farming in sub-Saharan Africa, *World Bank Research Observer* 3:83. Data on yields and areas from P. Buringh (1989), Availability of agricultural land, in D. Pimentel, ed., *Food and Natural Resources* (New York: Academic Press).

3.3 Modern agriculture depends on purchased inputs.

Historically, the transition from stages 1 to 3 in the preceding schema has been gradual, as populations grew slowly and the necessary technologies evolved over time. We discussed in Chapter 2 how purchased inputs gradually replaced farm-produced inputs such as hay or manure. Farmers now purchase the following inputs:

Farm Machinery. The process of mechanization started in the mid-19th century. New farming techniques depended on scientific advances and the industrial production of inputs. Manual labor and animal power were replaced by steam power and later by the internal combustion engine. Farmers used tractors to pull plows or the reaper-binder, which they later replaced with the combine harvester. Milking machines, cotton gins, cotton pickers, sugar beet and potato harvesters, and tomato-harvesting machines all have greatly reduced the need for manual labor. In developing countries small tractors have revolutionized agricultural production and greatly reduced the input of labor.

New and Improved Varieties. Initially, farmers selected suitable varieties of crops for planting the next year. These selected strains were the mainstay of agriculture until the science of genetics emerged in the 20th century. Then it became possible to deliberately interbreed different strains of a crop to consolidate desirable characteristics in a single strain. The first step is always to evaluate the field performance of known varieties. Scientists have systematically applied plant-breeding principles to improving rice and wheat, and have widely introduced new varieties in Latin America and Asia, displacing local varieties. This process, often called the Green Revolution, has significantly raised crop yields in an era when the amount of land cultivated has remained more or less constant. The introduction of hybrid rice in China and Southeast Asia is raising rice yields even further (**Figure 3.3**). About roughly 40% of all increases in crop productivity during the past 50 years stemmed from breeding new varieties. The other 60% improvement has come from managing the crop environment by inputs such as energy, fertilizer, and pesticides.

Figure 3.3 The availability of hybrid rice will increase rice yields beyond those experienced with the Green Revolution varieties. The bag on the right identifies the brand Proagro in different languages of India. *Source:* Courtesy of Eugene Hettel, IRRI.

Inorganic Fertilizers. Originally European farmers relied on manure and crop rotation to maintain fertility. Later they found that ground bones and rock phosphate enhanced crop production, as well as nitrates (long imported from Chile, in the form of fossil guano). The invention of a chemical process that combines nitrogen gas with hydrogen gas to form ammonia, allowed the widespread production of nitrogen fertilizers. This led to a tremendous increase in nitrogen fertilizer use worldwide. Fertilizer applications have been slowly decreasing in developed countries, but in developing countries they are still rising.

Herbicides and Pesticides. Herbicides replaced manual labor for weeding (**Figure 3.4**), and farmers used insecticides and fungicides to minimize crop losses. These changes in food production had a great impact on commercial grain farming (for example, in the United States, Canada, and Australia), on mixed crop and livestock farming (in Europe), and on intensive wetland rice farming in Asia and Africa. More complex approaches to weed control and pest control are now replacing heavy use of chemicals in agriculture.

Irrigation Technology. Irrigation has become a very important agricultural input in the past 40 years and accounts for much success in raising food production. Indeed, although only 18% of the world's arable land is irrigated, this land produces 40% of our food. Irrigated land is highly productive. However, this trend cannot be maintained: There simply is not enough water in many areas. Experts now see that water is the resource that will be most limiting for food production in the 21st century.

Information Technology. New innovations in agriculture that use information technology are often called *precision agriculture.* To obtain maximal yields, farmers of very large farms use remote sensing of their land and their crops by satellite or airplanes to adjust irrigation water, fertilizer application, and genetic varieties. Large tractors equipped with computers can now control row spacing and crop planting densities.

Inputs do not exist in isolation, but interact. Scientists often breed improved varieties to fit other production-enhancing inputs. For example, after scientists introduced hybrid

Figure 3.4 Woman farmers weed a communal field of groundnuts in Kashipa, Zambia. Hand weeding is a major agricultural activity in developing countries and is often done by women and children. Without weeding, the weeds will out compete the crop seedlings. Care must be taken not to disturb the root system of the crop seedlings.

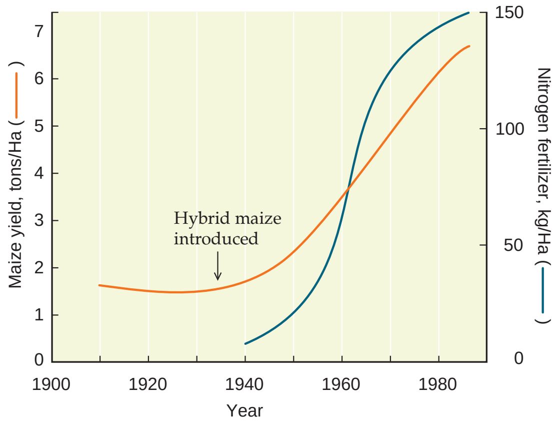

Figure 3.5 Interaction of inputs in crop production: Maize yields and the use of nitrogen fertilizers in the United States. The arrow points to the introduction of hybrid maize. By the time the planting of hybrid maize was complete (1950–1955), yields had increased significantly. The big yield increase parallels the use of nitrogen fertilizers and is caused by breeding strains that respond to nitrogen fertilizers. *Source:* Data from U.S. Department of Agriculture.

maize in the United States in the 1930s and nitrogen fertilizers became widely available, agronomists bred maize to respond to nitrogen fertilizers (**Figure 3.5**). After the invention of the automatic tomato harvester, tomatoes were bred to withstand the rougher handling to which such machines subject these fruit.

These technological advances have led to a style of agriculture that depends on purchased inputs. A survey of U.S. production methods for maize from 1910 to the present clearly shows this dependence (**Table 3.4**). The technological advances resulted from government-

Table 3.4 The technological basis of modern agriculture (inputs per hectare of corn in the United States)

Input	Hand Produced	1910	1980
Labor (hr)	1,200	120	12
Machinery (kg)	1	15	55
Animal use (hr)	0	120	0
Fuel (L)	0	0	125
Manure (kg)	0	4,000	1,000
NPK fertilizer (kg)	0	0	316
Lime (kg)	0	10	426
Seeds (kg)	11	11	21
Insecticides (kg)	0	0	2
Herbicides (kg)	0	0	2
Irrigation (%)	0	0	17
Drying (kg)	0	0	3,200
Electricity (10^3 kcal)	0	0	100
Transport (kg)	0	25	326
Yield (kg)	1,880	1,880	6,500

Source: Data summarized by D. Pimentel, from USDA and estimates, in D. Pimentel, ed. (1989), *Food and Natural Resources* (New York: Academic Press).

sponsored and industrial research, the main thrust of which has always been to develop technological inputs that let farmers minimize per unit production costs. Many of these advances diminished work opportunities on the farm in favor of jobs in towns and cities where the inputs are manufactured. The benefits of the lower production costs (cheaper food) accrued to the consumers and to agribusiness, whereas society as a whole had to bear the penalties (pollution and land degradation).

3.4 Applying science and technology to crop production in developing countries between 1955 and 1985 resulted in the "Green Revolution."

Worldwide food production has been rising by 2.3% annually as a result of the development of high-input agriculture, which in turn results from applying agricultural research and technology. This use of scientific knowledge started about 150 years ago in the developed countries and has resulted in yields taking off spectacularly, as can be charted quite accurately for individual crops (see Figure 2.2 in Chapter 2).

Japan is a classic case of a country turning to high-yield agriculture. By 1900, this island nation was growing crops, mostly rice, on all its arable lands. But the population was still growing. The government was reluctant to become dependent on foreign food imports lest a hostile nation cut off food from Japan during an international crisis. Short of lowering the people's nutritional standard, the only thing to do was to increase the yield of the rice crop. The government mobilized the country's political, social, and scientific resources, and as a result the yield per hectare tripled between 1900 and 1965. One characteristic of the new crop varieties that raised Japanese rice yields and U.S. wheat yields was that they were short-stemmed (semidwarf) and responsive to nitrogen fertilizer. But as with most varieties, scientists had selected and then bred them specifically to grow in the soils and climate of developed regions. That is, a variety that thrived in the U.S. Northwest had the genetic makeup to do well there, but not necessarily in the drier, hotter regions of the less developed world. There, crop production still relied on local varieties (landraces).

The genetically improved varieties of wheat and rice that drove the Green Revolution resulted from a targeted crop improvement program at two CGIAR institutes: the International Rice Research Institute (IRRI) in the Philippines and the International Center for the Improvement of Maize and Wheat (CIMMYT) near Mexico City. Farmers adopted the new varieties over a period of about 10 years, repeating a phenomenon that had occurred in the United States some 30 years earlier, when farmers adopted hybrid maize.

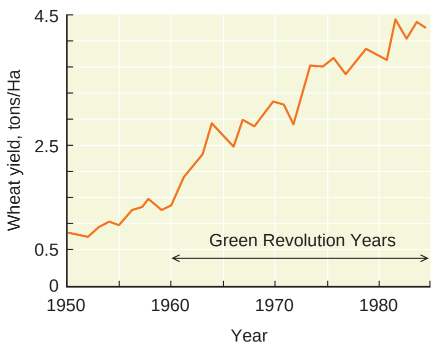

Figure 3.6 Growth of wheat yields in Mexico after adoption of Green Revolution varieties. *Source:* Food and Agriculture Organization.

In the case of high-yielding varieties of wheat and rice, the farmers had to adopt not only the new seeds, but an entire technology package, including fertilizers, insecticides, weed killers, equipment for irrigation, and tractors to till the land. Indeed, the new varieties let farmers grow two or even three crops per year, potentially increasing the demand for labor. Thus labor-saving technologies (tractors and herbicides) had to accompany the new strains. Furthermore, farmers needed nitrogen fertilizer so the new varieties would yield up to their potential (without fertilizer, they produced the same yields or less, than the landraces they replaced). Adopting these new varieties of wheat doubled and tripled production in Mexico (**Figure 3.6**), India, and other countries in Asia. Rice production increased similarly.

But the yield increases on farms were never as great as those at research stations. Scientists at IRRI showed that the new varieties could outproduce the old ones by a factor of 3 or 4, yet most farmers in Asia realized increases of only 1.5. This discrepancy in production is not surprising and also occurs in developed countries, where farms seldom match yields obtained in experiment stations. Surveys of farmers who were using the new technology showed that the constraints on higher productivity were poor water control, inadequate nitrogen fertilizers, and diseases. Put another way, the major constraint was inadequate capital to purchase the input package needed to obtain the high productivity of which the seeds are capable. The fundamental fact of the Green Revolution is that the farmers must manipulate the environment to get the most out of the plants, and too often they have not been able to afford it.

Nevertheless, the Green Revolution allowed many developing countries to raise food production and even become food exporters. International agricultural experts saw breeding the high-yielding varieties and applying the industrial inputs as the quickest way to increase production. As a result, agriculture in developing countries came to resemble agriculture in developed countries: more heavily dependent on purchased outside inputs, more capital intensive, and less dependent on labor (**Figure 3.7**). Earlier, we noted that families needed the money generated from labor to buy food. Merely raising production is not enough to eliminate hunger. (But raising production is intended to create profits, not to eliminate hunger, as noted earlier.) Because the need for farm laborers decreases as agriculture becomes more technological, the displaced laborers must find other employment.

Figure 3.7 Agriculture in developing countries has come to resemble agriculture in developed countries. To get high productivity, farmers must use purchased inputs that include tractors, fertilizers, and pesticides. In this photo, a Filipino farmer is shown preparing the soil of his rice field. *Source:* Courtesy of Eugene Hettel, IRRI.

When farmers first apply a new technology—for example, fertilizer or pest control—yield immediately increases as the amount of input rises. A little bit is good, and more seems better! During this phase, the money spent on the technology results in a substantial return. Once the plant's inherent capacity to respond to the input is reached, however, the yield increase slows drastically. Adding fertilizer and other inputs follows the law of diminishing returns: less output for a given amount of input.

In the United States, farmers now apply 90–100 kg of fertilizer per ha of cropland, and it is not easy to raise the yield further by adding more. This figure is 65 kg/Ha for India, so there is still hope for improvement, but fertilizer use is only 4 kg/Ha in Ethiopia and 12 kg/Ha for Costa Rica. Gains in crop productivity should be possible in these countries if researchers can find the proper cropping systems and crop varieties that can take advantage of additional fertilizer. When all technologies are maximal, agriculture may reach a yield plateau. Some crop physiologists argue that people will always be able to find new crop varieties to escape the yield plateau and take advantage of new and existing technologies. Biotechnology has the potential to allow continual crop production increases. For example, scientists at IRRI and elsewhere are now producing hybrid rice varieties to raise rice yields even further (see Figure 3.3).

3.5 The CGIAR institutes are catalysts for agricultural research in developing countries.

The success of the Green Revolution, and the perceived need for more research on tropical and subtropical food crops, led to the establishment of other research institutes in different countries of the developing World (see also Chapter 2 for a listing). These institutes have a triple mandate: (1) to improve the crops assigned to them, (2) to study farming systems for these crops, and (3) to create gene banks in which the landraces of the crops under study can be preserved (in the form of seeds stored under conditions that ensure their longevity). Initially the institutes focused on the approach that was successful with high-yielding wheat and rice varieties in the 1960s and 1970s. That is, they concentrated on monoculture and on improving crop production by a package of improved varieties and associated technologies to modify the environment. More recently, this focus has begun to change, showing a greater concern for integrating agriculture more with the natural environment.

For example, scientists at ICRISAT in India have identified strains of groundnut (a drought-resistant legume) that produce more than 1,000 kg grain per hectare, even when stressed by drought, compared to the 500–800 kg per hectare the normal varieties produce. Similarly, they have found strains of sorghum that produce two to three times more grain than the present commercial types. One of their goals is to select drought-resistant crop plants to use not only in Asia, but also in the Sahel region of Africa.

Scientists at CIAT in Colombia have identified genes in wild varieties of beans that let them resist attack by bruchid beetles. These beetles do enormous damage to the seeds after harvest because they multiply in the dry, stored beans. By crossing a wild bean variety with a cultivated variety, CIAT scientists were able to introduce the bruchid-resistance genes into the cultivated variety.

When the CGIAR system of research institutes was first established, people saw biological and technological research problems as separable from political and social issues. The research institutes generated the necessary innovations and offered these as packages to various national and regional extension services or development authorities. Fine-tuning these packages to local conditions, and solving social and political problems that resulted from implementing new technologies, were the responsibilities of the implementing agencies or the governments of the countries in question. In this system, people saw agricultural development as an activity that came from the top (the CGIAR institutes) and trickled down to the bottom (the farmers).

This approach has worked reasonably well in some countries or areas, and poorly in others. Agricultural development has not often been a high priority for many governments of developing nations, except for developing cash crops that earn foreign exchange. In many African countries, national agricultural research efforts have been weak, in part because governments mistakenly assumed the CGIAR institutes would solve all their agricultural problems, and also because these high-profile institutes attracted all the international funds and the best scientists.

The Green Revolution has done more than raise overall food production. It has also caused the rapid disappearance of the landraces (see Chapters 13 and 14) and of indigenous farming systems that may have had much to offer to agricultural researchers. The top-down approach of development implies that agricultural researchers can learn little of value from subsistence farmers. For example, although the institutes have often stressed monoculture, many farmers have been growing more than one crop on the land (either by crop rotation or by intercropping) for centuries. These practices led to a more sustainable agricultural system than did monoculture.

Scientists at the CGIAR institutes know they must do more than create new strains to hand over to extension agents. They need to become involved in understanding the tropical agroecosystems at the farm level and to evaluate with the farmers the local varieties (genotypes) (**Figure 3.8**) and breed varieties for different environments. For example, IRRI is located at a place where rainfall is reliable and adequate—in the Philippines. But much rice in Asia is grown on land where rainfall is intermittent and unreliable. So how can a technology developed at IRRI be useful to a farmer who has very different needs? This type of problem led to the formulation of a second mandate for these institutes: to study local farming and make sure that proposed development uses the strengths of those systems (see Chapter 5). Biotechnology is an important tool, but only one of many, to raise crop productivity in the less developed countries.

Figure 3.8 Scientists from the Centro Internacional de Agricultura Tropical in Colombia, evaluating local varieties. These scientists and farmers are walking through an experimental bean field in which different varieties are grown. *Source:* Courtesy of CIAT.

3.6 Biotechnology will contribute to the continued rise of crop yields in the 21st century.

Between 1960 and 1985 the yield of the major cereals (wheat and rice) rose dramatically in many developing countries, resulting in a 25% rise in the per capita food availability. However, in more recent years (1985–2000) this trend has leveled off. As noted in Chapter 1, the rate of population growth is slowing, so it is hard to predict whether world crop production is on track to meet the needs of the future human population. But two relatively new factors have arisen to challenge crop producers. First, increased demand for feed grains has followed increased demand for meat. Second, people realize that high-input agriculture can degrade the environment, so that plants must be even better adapted to the natural system. Although people still need ever better genetically improved varieties in combination with new technologies, they also need to more thoroughly understand the sustainability of crop production. Researchers need to devise different strategies for the highly productive regions that are already intensely cropped and where yields have risen dramatically and for the more marginal soils where, as in sub-Saharan Africa, productivity has stagnated and per capita food availability has declined (see Chapter 5).

Classical plant breeding, more fully discussed in Chapter 14, has been a very important factor in the past successes. A new set of tools has become available in the past 20 years, that—combined with plant breeding—will allow people to produce the genetically improved varieties of the future. This set of tools, which comes under the general title of *biotechnology*, encompasses a variety of laboratory methods that include

- Cell, tissue, and embryo culture (**Figure 3.9**)
- Clonal propagation of disease-free plants
- Identification of chromosome regions (quantitative trait loci) that carry important multigenic traits
- Gene identification and isolation
- Genetic engineering for agronomic traits such as pest and disease resistance or better adaptation to environmental stresses (such as salinity, or water deficit)
- Genetic engineering for greater nutritive value (such as vitamin A, minerals, and better amino acid balance)
- Genetic engineering to reduce postharvest losses (**Figure 3.10**)
- Genetically engineered male sterility to facilitate hybrid seed production

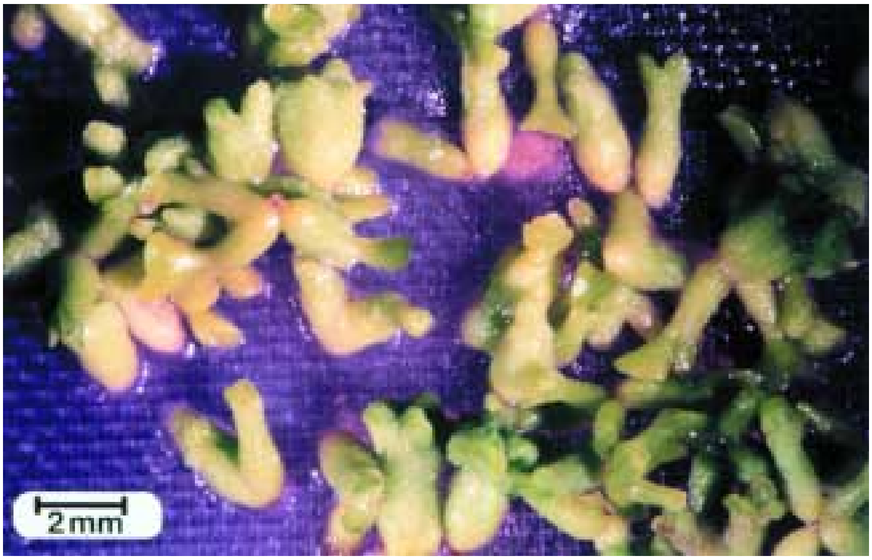

Figure 3.9 Cultured somatic embryos of alfalfa (*Medicago sativa*). Somatic embryos are embryos derived from ordinary vegetative cells of the plant body rather than from fertilized egg cells. The embryos shown are at the stage of development 18 days after scientists transferred vegetative cells to an embryo-inducing medium. The cells were originally derived from the stemlike portion of the leaf. Alfalfa is a cross-pollinating plant, and cross-pollination between plants from certified elite lines of alfalfa results in loss of yield and other important agronomic traits when the seeds of such crosses are planted. The quality of an elite line can be maintained by mass production of somatic embryos, which are genetically uniform because they derive from a uniform population of vegetative cells. *Source:* Courtesy of Derek Bewley, University of Guelph, Ontario, Canada.

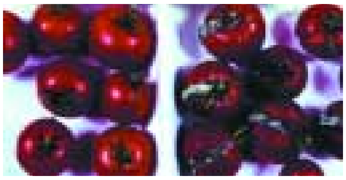

Figure 3.10 Genetic engineering for reduced postharvest losses in tomatoes. The photograph shows the effect of down-regulating ethylene synthesis using gene technology. The GM tomatoes on the left produce about 5% of the normal level of ethylene. The tomatoes were harvested and kept for three weeks at room temperature. The control tomatoes on the right are spoiled, the GM tomatoes on the left are ripe and marketable.

Embryo culture is used to rescue the embryos produced when plants of different species are crossed. For example, a cross between the wild rice *Oryza nivara* and domesticated rice *Oryza sativa* is not normally viable. Researchers at IRRI used embryo rescue to introduce a trait for resistance to the grassy stunt virus present in this wild rice into domesticated rice. The horticulture industry routinely uses meristem culture and plant regeneration from small parts of the meristem to propagate virus-free planting materials.

The discoveries that the genetic material (DNA) of all organisms basically has the same structure and that genes from one organism can function normally after transfer to another organism have opened up the field of genetic engineering. In plants, gene transfer is made possible by a natural process discovered in a soil-dwelling plant pathogen that transfers a few of its genes to plant cells. Molecular plant biologists have manipulated this process so that the pathogen will transfer one or more genes of the scientist's choosing (see Chapter 6). This technique opens up unlimited possibilities for modifying crop traits. Plant breeders were previously limited to using the genes of the crop's closest relatives, but with genetic engineering they can now use any gene from any organism. It is important to emphasize repeatedly that the genetic engineering and biotechnology can make important

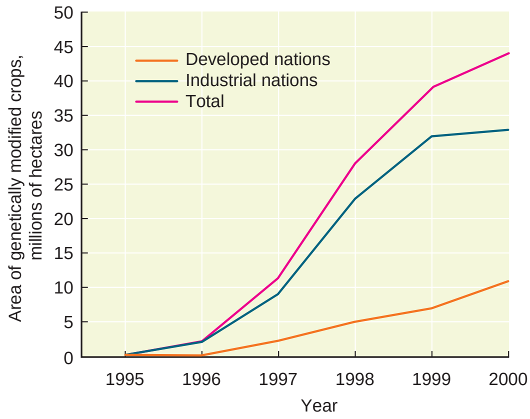

Figure 3.11 Worldwide adoption of GM crops. The data do not include China.

contributions but are not the silver bullet that will solve all food production problems. It is but one of the many technologies that people need.

Genetically engineered plants that resist certain insect pests or can tolerate herbicides so that farmers can destroy weeds more efficiently, are being grown in more than half a dozen countries already (Argentina, Australia, Canada, China, India, Mexico, and the United States). The rapid adoption of these new varieties (**Figure 3.11**) has pleased the biotechnology companies that produce them and the farmers who adopt them because it lowers their production costs, but has aroused some anxiety in the general public. Some countries in western Europe and a few localities in the United States have banned genetically engineered (or manipulated, GM) crops. The four major GM crops being grown are rapeseed (canola), cotton, maize, and soybean. Molecular techniques will also greatly facilitate chromosome mapping of important agronomic traits. This will make it easier to follow these traits in the progeny of crosses when the traits have no easily discernible phenotype (characteristic) in the field. It will also greatly speed up classical breeding, which is a rather slow and cumbersome process. Gene replacement (gene therapy) is not yet a reality, but is on the drawing board. It eventually will be possible to take a small chromosomal region that encompasses a whole set of genes, and simply replace it with another region from a plant that is more distantly related.

3.7 The effects of intensive agriculture on the ecosystems are causing concern about its sustainability.

Growing populations and increasing affluence demand ever-increased output from agricultural systems. This is true whether we are talking about the high-input agriculture of the United States and Western Europe, about nomadic herds in Africa, or about intensive rice cultivation in Asia. Concerns are now being raised about the sustainability of this ever intensifying productivity.

The World Commission on Environment and Development defined sustainable development as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs." To understand sustainability, we must first look at the rate at which people are losing productive soils as a result of present agricultural practices. The FAO of the United Nations has estimated that salinization, soil erosion, and desertification have degraded a quarter of the world's arable land. Second, there may not be enough energy resources to maintain high-input agriculture. Third, the increasing use of pesticides is arousing concern that people are polluting ecosystems with synthetic chemicals. Fourth, the trend toward genetically uniform crops increases the potential for serious disasters by eliminating the many different strains of a given crop that farmers previously used. Fifth, government policies perpetuate conventional agriculture and discourage farming practices that could make agriculture more sustainable.

Land Degradation. The term *land degradation* denotes the physical and chemical changes that reduce long-term soil productivity. Such changes are sometimes very obvious but are often difficult to measure because they occur over long periods of time. Other improvements, such as more fertilizer or new genetic strains, often compensated for them, so the effects of land degradation do not always show up as decreased yield—at least, not in the short run.

Physical degradation takes the form of erosion, the carrying away of soil particles by wind and water. In an annual cropping system, the soil is alternately covered with plants, and then almost totally bare. When the soil is bare, it is exposed to higher wind velocities and to the force of raindrops, which destroy the structure of the uppermost layer of topsoil. The net result is muddy runoff and/or dust storms.

Chemical degradation can take several forms, including (1) acidification from acid rain, (2) alkalinization and salinization (buildup of salts) as a result of irrigation or the intrusion of saline groundwater into topsoil (**Figure 3.12**), (3) exhaustion of mineral nutrients when farmers don't use enough fertilizer to replace minerals removed with the crop, and (4) leaching of excess mineral fertilizers into streams, lakes, and groundwater.

Pesticides and Herbicides. Agriculture uses pesticides and herbicides extensively in the developed countries, and their use in developing countries has also increased rapidly. Many problems accompany their use, including the emergence of pesticide-resistant pests, adverse health effects on farm workers, pesticide residues on crops, and pollution of lakes, streams, and groundwater with pesticides and herbicides. Furthermore, the realization that pesticides have not diminished the proportion of the crop lost to pests is prompting many people to try alternate pest control methods. There is renewed emphasis on pest-resistant varieties and biological pest control (discussed in Chapters 16 and 17).

Loss of Crop Biodiversity Because of Genetically Uniform Crops. A main feature of the high-input system of agriculture is genetically uniform crops. These reliably produce high yields if used with appropriate inputs. But their use has several drawbacks. First, when farmers start planting seeds furnished by seed companies or state agencies, they stop using and usually discard their own varieties, which were well adapted to the microenvironment on their farm. Local varieties contain valuable genes that are thus lost to plant breeders. Second, genetic uniformity means crops are more susceptible to sudden outbreaks of disease. When a pathogen mutates and overcomes the plant's resistance, the entire crop over a wide geographic area can be ravaged. An excellent example is the potato blight that ravaged the Irish potato crop in the 1840s (see Chapter 13).

Government Policies. Sometimes government policies actively promote high-input agriculture and discourage sustainable practices and technologies. Such policies are difficult to change because large and powerful lobbies, including farm organizations and industry advocates, have vested interests in such policies.

Figure 3.12 Extensive salinity damage in abandoned cropland in California's Coachella valley. The land shown here was previously desert, converted to cropland through irrigation. Salts already in the soil dissolved and rose to the top via high evaporation/transpiration. The farmer has abandoned the large block in the foreground. Economics permitting, such land can be reclaimed by leaching off the salts with excess irrigation water.

To protect their resource base—the soil—and to decrease costs, farmers have begun to adopt alternative practices. Taken together, these practices constitute sustainable agriculture, which differs from conventional agriculture not so much by the practices it *rejects* (for example, heavy use of inorganic fertilizers), but by the practices it *incorporates* into the farming system. The more widely used term *organic farming* (or *biological farming,* in Europe) describes two major aspects of alternative agriculture: (1) substituting manures and other organic matter for inorganic fertilizers and (2) using biological pest control instead of chemical pest control. The objective of sustainable agriculture is to sustain and enhance, rather than to reduce and simplify the biological interactions on which production agriculture depends. Alternative agriculture is not a single system of farm practices, but encompasses many farming systems variously called *organic, biological, low-input, regenerative*, or *sustainable* systems. Such systems emphasize management practices as well as biological relationships between organisms; in addition, they take advantage of naturally occurring processes such as nitrogen fixation.

Alternative or sustainable agriculture is any food or fiber production system that systematically pursues the following goals:

- More thorough use of natural processes such as nutrient cycles, nitrogen fixation, and pest-predator relationships in agricultural production

- Reduced use of off-farm inputs with the greatest potential to harm the environment or the health of farmers and consumers
- Greater productive use of the biological and genetic potentials of plant and animal species
- Improved match between cropping patterns and the productive potential and physical limitations of agricultural lands, to ensure long-term sustainability of current production levels
- Profitable and efficient production, with emphasis on improving farm management and conserving soil, water, energy, and biochemical resources

Studies of alternative agriculture show that the farms derive sustained economic benefits and are not necessarily at a disadvantage. Although yields are often lower, costs are also considerably lower.

3.8 Weather and climate profoundly affect crop production.

The weather is the one factor with which people are familiar that profoundly affects the growth of plants. Everyone knows that to grow plants need sunlight and rain and that both are quite variable around the world. Weather—defined as short-term (less than a few weeks) variations in the atmosphere—affects the year-to-year yield of crops. The longer-term variations that comprise climate determine the geographic conditions where crops can grow at all.

Short-term variations caused by the weather that affect crop yields occur even in the modern era of technology-based agriculture:

1. *Moisture stress* is caused by insufficient, too much, or ill-timed rainfall. Plants often have precise water requirements, in terms of both amount and time. If these requirements are not met, yields and/or quality suffer.
2. *Temperature stress* occurs commonly when the temperature is either too low or too high for optimal growth. A short period of stress can severely depress growth later. Sudden cold snaps injure plants because they do not have enough time to become acclimatized to the cold weather. Moisture stress often accompanies high-temperature stress.
3. *Natural disasters* occur, such as cyclones, hurricanes, and hailstorms. Although these are more common in such Asian countries as Sri Lanka and Bangladesh, they can also cause severe damage in developed countries by physically harming crops and the soil that supports them.

Yields of many crops vary considerably year to year in many locations. The probability of a staple crop yielding the same year after year can be quite low. Over much of North Africa and the Middle East, for example, yields fall significantly below expectations in half of the crop years. A similar situation exists in the countries of the former Soviet Union. Complex statistical models, proposed to explain crop yield variability in other situations, show that in many cases climate is the major factor. When things go well (the yield trend is a smooth upward or constant curve), it is because the weather is unusually benign.

Different regions of the world are affected differently by climatic variation. Some of these effects are as follows:

1. *Temperate regions.* The north and south temperate regions produce 75% of the world's wheat and maize. The most prominent climatic factors affecting yield are

moisture stress and temperature extremes. Wheat and soybeans are more drought resistant than maize.

2. *Humid tropics.* Ranging from fertile valleys to jungles to floodplains, these regions are heterogeneous and show great variability of year-to-year yields. The major determining factor here is rainfall. There are pronounced wet and dry seasons, with the wet season often being in the form of a monsoon, with very heavy, sustained rainfall. But the unpredictability of the intensity of the monsoon, combined with poor water-holding capacity of soils and high rate of evaporation, lead to unstable water supplies for agriculture. In addition, torrential rains on lowland areas, such as river deltas, inundate the crops.
3. *Semiarid tropics.* These regions (for example, the Sahel south of the Sahara, in Africa, and much of India) have a long history of periodic crop failures and resulting famines. The major problem here is rainfall or, more precisely, the lack of it. Most of the rain falls in a two- to five-month period (April–October in the Northern Hemisphere, October–April in the Southern Hemisphere), when temperatures are at their yearly peak. This leads to extensive evaporation and less water availability. The sequence of events in growing a crop here is exquisitely sensitive to the annual rainfall cycle. Farmers time the growth of the crop to coincide with the maximum available water. If this period is very short, so is the growing season. In these areas farmers often plant two crops: one that will yield some food if the rains fail to come, and one that will yield abundantly if they do come (**Figure 3.13**).

This relationship of agricultural practices to climate is an ancient one. Every culture has its deities and stories relating the cycle of the seasons to food production. Chapter 5 describes how Africans have adapted their agricultural practices to a variety of climatic zones.

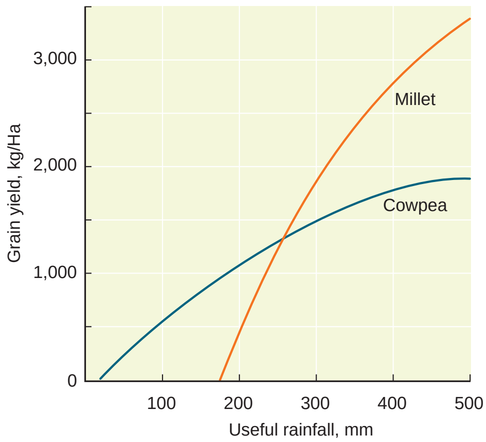

Figure 3.13 Grain yields of cowpea and millet respond differently to rainfall. In the Sahel region of Africa, farmers plant both cowpea and millet. Cowpea always produces some food, even when the rains fail completely; when the rains are abundant, millet easily outproduces cowpea. Planting both is a type of crop failure insurance. *Source:* Adapted from M. Ndoye, C. Dancette, M. Ndiaye, T. Diouf, and N. Cisse (1984), L' amelioration du niebe pour la zone sahelienne: Cas du programme national Senegalais. International Society for Research in Agriculture Publication. World Cowpea Research Conference, International Institute of Tropical Agriculture, Ibadan, Nigeria, November 1984.

3.9 Global climate change and global pollution will limit agricultural production in the future.

Human activities can substantially alter the global environment and thereby negatively impact our ability to grow crops. The public is now keenly aware of the effects of pollution on society, and generally considers industry to be the main source of pollutants. However, in the past 30 years agriculture has also become an important environmental polluter.

The book *Silent Spring*, written by biologist and science writer Rachel Carson in 1962, first awakened public opinion to unintended effects that pesticides can have on the environment. Although organochlorine insecticides then used have since been phased out, they did considerable damage both in developed and developing countries. These pesticides prevented crop damage by insects, but in Asian rice paddies pesticides kill fish, shrimp, and crabs, important sources of protein for poor people. (However, it is good to remember that these pesticides, used for mosquito control, also saved millions of people from contracting malaria.)

Burning vegetation to clear forestland or to encourage grass growth in savannas is an important source of global air pollution (**Figure 3.14**). When vegetation burns, some

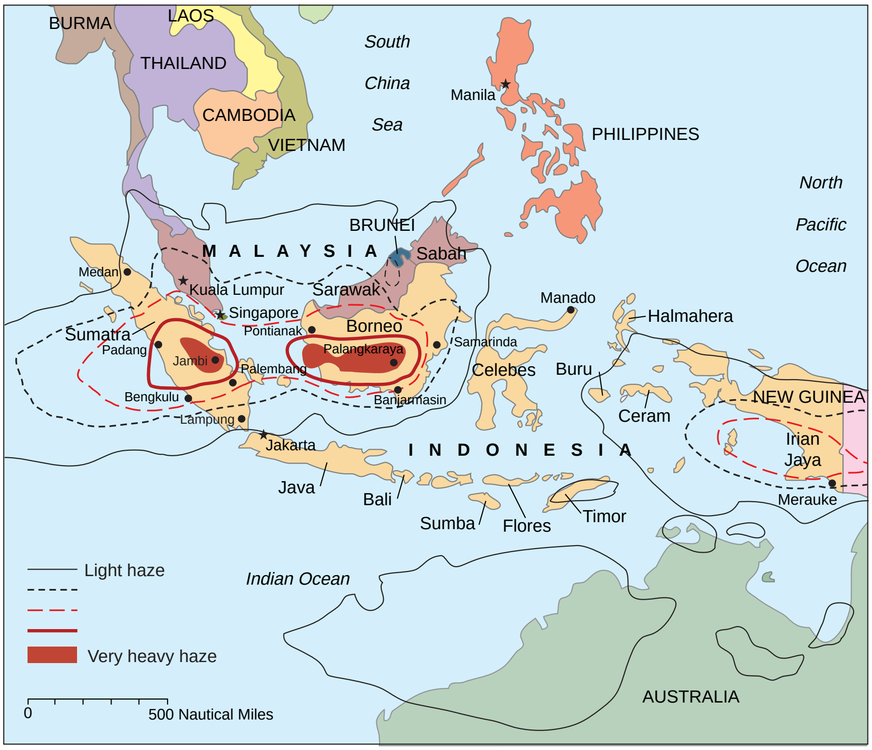

Figure 3.14 Burning of vegetation to clear land contributes to global air pollution and releases greenhouse gases. In 1997, excessive burning of forests in Indonesia led to an intense haze that spread over a huge area. Among other dramatic effects, agricultural production declined. *Source:* World Resources Institute; made by Y. M. Hardiono, Telepak, Indonesia, with data from NASA.

nutrients (potassium, phosphate, and calcium) return to the soil, but nitrogen, sulfur, and carbon disappear into the atmosphere as gases. In addition, burning releases particulates into the air. The sulfur dioxide and nitrogen oxides, in combination with those same two gases released from the burning of fossil fuels, help acidify soil via acid rain. In Europe and North America acid rain is killing some forests, and in China it has shrunk rice and wheat harvests, with most of the damage occurring at the beginning of the rainy season.

Burning biomass (vegetation) annually releases about 1 to 2 billion tons of carbon into the atmosphere as carbon dioxide. This amount adds to the 2 billion tons of carbon released by burning fossil fuels. Carbon dioxide is a greenhouse gas, which means it contributes to warming of Earth. Anaerobic decay of organic matter in marshes produces methane, another greenhouse gas. Rice paddies are an important source of methane worldwide, and increased rice cultivation in Southeast Asia has much increased methane production. These gases are responsible for the greenhouse effect, which warms the surface of Earth. If greenhouse gases were completely absent from the atmosphere, Earth's surface would be a chilly –18°C. Their presence maintains Earth at a higher temperature, making human life possible. The temperature of the planet has been rising slowly—about 0.3 to 0.6°C during the past 100 years, and is expected to rise another 0.4 degrees C by 2020. A 2°-C rise by the end of the 21st century is possible. Although this slow global warming could be a natural phenomenon, most experts believe it is the direct consequence of the rise in emissions of greenhouse gases. A likely result of global warming is greater variability in the weather and more extreme weather conditions (droughts, floods, typhoons, frosts, heat waves, and so on). Rainfall may be more variable, making crop production even more variable than it is now.

Other gases, especially nitrous oxides and the now banned chlorofluorocarbons formerly used as refrigerator coolant, destroy the protective ozone layer in the upper atmosphere. Ozone shields Earth from destructive ultraviolet solar radiation. Closer to Earth, nitrous oxides emitted from cars or released by burning vegetation help create photochemical smog, of which ozone is a significant component. Even at quite low concentrations, ozone inhibits plant growth and recent experiments suggest that the ozone levels around cities and in some rural areas are now high enough to impair crop yields. Scientists may need to take this into account when breeding new crop varieties.

CHAPTER SUMMARY

In Earth's ecosystem, humans are consumers and consume primarily plants, although as their standard of living rises, they consume more animals and animal products. This lifestyle is "expensive" because it requires setting aside pastureland and arable land for producing feed crops. Some small human populations depend on animals that consume only plants grown in areas unsuitable for crop production.

During the past 10,000 years agricultural production has become gradually more intense. In the 20th century agriculturists have started applying scientific principles and technology to crop breeding and farming. This has resulted in yields taking off for the major staples (maize, rice, and wheat).

Since 1960, international research centers have been breeding crop varieties specifically for the climates and soils of developing countries. This activity generated the Green

Revolution, which dramatically increased staple production in Asia and Latin America. A network of international agricultural research institutions has been established to carry on with this task.

Modern agriculture depends heavily on purchased inputs. These include new genetic varieties, pest and disease control programs, irrigation technology, fertilizers, mechanical equipment, and even computers to access public databases containing relevant information.

During the past 40 years, scientists have used laboratory techniques (biotechnology) more and more as part of genetic crop improvement. This trend has developed into genetic engineering of crops. Genetic engineering involves transferring genes between unrelated organisms. So far, genetic engineering combines with traditional breeding practices to produce elite varieties adapted to local climate and soil conditions.

The practices of high-input agriculture are causing concerns about the sustainability of crop production. There are many negative effects on the environment, including pollution by pesticides, emission of greenhouse gases, soil degradation, air pollution by dust, and loss of landraces and other biodiversity. People need to develop new techniques that will keep agriculture both profitable for the farmer and make it sustainable for the future.

Discussion Questions

1. Discuss the economic demand for food versus the availability of food. How do they differ?
2. Discuss the use of resources to produce animal products. What would be gained by eliminating animal products from the human diet? How would this cause economic dislocation?
3. Discuss climate change (commonly called *global warming*), and its likely causes and effects on Earth and its food production capacity.
4. How should the political process treat farming? Should there be subsidies, and to whom should they go? How is farming subsidized in your country?
5. Discuss GM technology in relation to biotechnology in general and plant breeding. How has plant breeding been modified over the years?
6. How should the CGIAR system be funded? Explain your answer.
7. Discuss the relationship between agricultural and economic development in the developing countries and the security of your own country. How is your security tied to development elsewhere?
8. Discuss the differences between purchased inputs and inputs produced on the farm.
9. Plants can be “stressed out” just like people. Discuss plant stresses and what the response of the plants is.

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