CHAPTER 13

Food and Soil Resources

CHAPTER OBJECTIVES

After reading this chapter, you should be able to do the following:

- Identify the major categories of human food sources on a global scale.
- Explain the concept of hunger.
- Describe current patterns and future projections of agricultural food production.
- Explain the differences between "traditional" and "modern" agriculture (including the Green Revolution).
- Outline the pros and cons of genetically modified foods.
- Describe the benefits and hazards of aquaculture.
- Explain the nature and importance of soil.

Chapter Opener Image: More than 1 million workers, mainly women, harvest tea leaves in Sri Lanka for multimillion-dollar international companies. Recently, educated consumers around the world have made increasing demands on businesses to increase their social, environmental, or financial performance levels by putting pressure on them to increase corporate integrity, responsibly handle global resources, and positively affect the international communities in which they operate. Through increased global awareness and the intelligent social media campaigns of students and others, the lives of workers on large tea plantations like this one are slowly improving. With consumer pressure leading the way, Sri Lanka now has 17 fair trade tea producers. Using consumer power to shift corporate practices is having a positive effect on the lives of workers in many developing nations; however, more involvement is needed to sustain this positive momentum.

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We are part of the global biosphere, and as such, we are ultimately dependent on other living organisms for virtually all aspects of our lives. Many of the ways we depend on other organisms are obvious. Trees shade us. Green plants and other photosynthetic organisms produce the oxygen (O_2) that we breathe and absorb carbon dioxide. Worms and microorganisms prepare the soil for us and recycle necessary nutrients, and insects pollinate our crops. We do not fully understand all of the complex interrelationships among bacterial and other microorganisms, plant, fungal, and animal species that make up the biosphere, and we have no way of knowing what roles certain seemingly insignificant species perform now or will play in the future. One thing is certain, though. Without a healthy biosphere the supporting conditions necessary for life, including human life, would not be possible—the human experience is interconnected with and possible because of the global environment.

Humans of course utilize many resources for the formation/advancement of markets, and governments use and seek out resources for a number of national projects. Modern industry and medical technology, for instance, are dependent on animals and plants for a plethora of important drugs and other substances. All of our fossil fuels were formed by organisms over millions of years, as were many commercially important rock and ore deposits (such as limestone and phosphate deposits). Biological resources provide a large percentage of the raw materials that we use (e.g., wood, natural rubber, and leather).

Perhaps most important, we are totally dependent on other organisms as a source of nutrition. We raise plants and animals to eat; we harvest wild plants and animals as food (e.g., fishes). In this chapter, the focus is on people's most fundamental use of biological resources—as food. Because the majority of the world's food needs are met today by the cultivation of crops, a discussion of the soil resources that form the basis of **agriculture** is also provided.

13.1 Food as a Biological Resource

Virtually all of the food that people depend on is derived from other organisms. Although we eat many different types of plants and animals, actually only a very small number of species provide the majority of our food. Only 20 different species of plants supply 80% of the world's food supply, and just three kinds of plants constitute 65% of the food supply—rice, wheat, and maize (corn). It is also important to understand how we view and treat food. Consider a turkey sandwich—turkey breast, Swiss cheese, lettuce, tomato, whole wheat bread, and mustard. This is a standard sandwich that can be purchased almost anywhere. When this sandwich is purchased, do you consider it a natural resource? You should. Turkey is an animal cultivated for human consumption; cheese is produced from cow's milk and bacterial cultures. Lettuce, tomato, and the whole grains used to make bread are also naturally occurring substances that are cultivated for humans. The plants that produce the seeds that are used to create the mustard are also cultivated. Every part of a standard sandwich is derived from natural resources, thus the sandwich is a natural resource.

Hunger

The numbers are daunting. According to a recent survey conducted by the Food and Agriculture Organization of the United Nations, of the world's population of 7.3 billion people, about 795 million people—one in nine—suffer from chronic undernourishment. Almost all the hungry people—780 million—live in developing countries, representing 12.9% of the population of those countries, or one in eight people. Undernourishment is less prevalent in developed countries, affecting 11 million people.

Terms such as **hunger** and **malnutrition** can be hard to define, although their meaning can be painfully obvious when one sees a starving human. To maintain good health, a person must have adequate nutrition—proper amounts of protein and various vitamins, minerals, and other nutrients—and an adequate supply of kilocalories as an energy source (in popular usage, kilocalories are often referred to simply as "calories," but a kilocalorie or Calorie is actually equal to 1,000 calories). The amount of kilocalories (a deficit results in hunger) and nutrients (one is malnourished without enough macro-molecules, vitamins, and minerals) that individuals require also depends on their age, gender, and other characteristics. Statistics of global hunger are often based on the number of kilocalories available or ingested per person per day. According to the United Nations, the recommended daily intake per person is 2,350 to 2,500 kilocalories. The U.S. National Research Council recommends a daily intake of 2,700 and 2,000 kilocalories for the average adult male and adult female, respectively.

From a simple caloric point of view, globally, many people do not consume enough to live and work actively. It is estimated that as many as 1.2 billion people are undernourished and underweight (recall that 795 million are chronically undernourished, meaning at heightend risk to serious health problems, even death). In some countries, especially in Saharan Africa and Asia, the average daily kilocalorie intake is less than required for people to carry out productive work. Studies have demonstrated that in many countries malnutrition is correlated with high death rates, particularly among children. Children with malnutrition are characterized by stunted growth, reduced mental functions and learning capacities, and lowered general activity levels. Damage caused by severe malnutrition may be irreversible, but one study found that increasing the per capita consumption of food from slightly under 2,000 kilocalories to 2,700 to 3,200 kilocalories could cut the death rate in half (**FIGURE 13.1**).

In addition to an adequate intake of kilocalories, a healthy person requires proper amounts of vitamins and minerals. Vitamin and mineral deficiencies can cause many symptoms, including general poor health; blindness (vitamin A deficiency); mental handicaps; learning disabilities; decreased work capacity; decreased resistance to illnesses, diseases, and infections; and premature death. More than one billion people, primarily in developing countries, currently have vitamin and mineral deficiencies, whereas another one billion are at risk.

Feeding the World Today

Why are so many people in need of food, especially when some countries have grain surpluses? In part, the large inequities in food distribution are related to political and social problems; all too often, food is withheld as a weapon (**FIGURE 13.2**), especially in internal struggles in developing nations. However, political considerations are only part of the problem. Around the world, arable land is being lost to construction (i.e., building more subdivisions and shopping malls), and cultivated land is being degraded through **erosion**. Furthermore, global climate change is displacing weather patterns, causing localized droughts and floods. This is particularly acute today in California. The state is one of the largest agricultural producers for the United States, and rising food costs around the country have been linked to the drought gripping the state. Warming of temperatures also fosters insect infestations, and rising sea levels can flood low-lying coastal areas and cause saltwater contamination of groundwater supplies in coastal regions.

FIGURE 13.1 Severely undernourished children are more likely to die of childhood illnesses.

Courtesy of Master Sgt. Keith Brown/U.S. Air Force.

FIGURE 13.2 Syrian Red Crescent aid convoys carrying food, medicine, and blankets leave the capital Damascus as they head to the besieged town of Madaya on January 11, 2015.

© SANA/AP Photo.

A remarkable amount of food is being produced annually, but it is barely enough (**TABLE 13.1**). Perfect management of the world's current food production might just barely feed the global population, but this would be only a temporary measure, for soon the global population will outrun food supplies.

Per capita **grain production** peaked in 1985 at 343 kilograms (756 pounds) per person, and since then the population has grown faster than grain production. Lower global grain production and more people to feed brought this number to 299 kilograms (659 pounds) per person in 2001. Based on a peak total grain harvest of approximately 1.9 to 2.4 billion metric tons (seen in 1997, 2001, 2004, and 2010), researchers

TABLE 13.1 Global Food Production in 2016

Food Source	Metric Tons per Year
Grain	2.5 billion
Meat	262.8 million
Wild fish	105 million
Aquaculture	74 million

Data from Statista.

have calculated the percentage of the world's population that could be fed using various diet models. In the United States, the typical person consumes about 25% to 30% of his or her kilocalories from animal products, such as meat and cheese—a notoriously inefficient way of deriving energy from foodstuffs. If the entire world followed the American dietary example, less than half of the current global population could be fed adequately. Typical Latin Americans consume about 10% of their kilocalories from animal sources. Using the Latin American diet as a model, approximately 4 billion people could be fed based on the harvest of 2010. Only with everyone maintaining a strictly vegetarian diet and assuming perfect food distribution systems (which is unrealistic given current political and transportation problems) could the current population of 7.4 billion be adequately fed. If we could considerably decrease the waste factor (e.g., as much as 40% of all food typically spoils or is eaten by insects, rats, or other pests, and much food is thrown away as "leftovers," made into food for nonessential house pets, and so forth), perhaps as many as 8 billion people worldwide could be fed a subsistence diet.

Such food conservation measures would be of little consequence to the extra mouths that would need to be fed if the world's population reached 8 to 10 billion. Few options seem to be available for dealing with this situation. One possibility is to increase global food production dramatically and to ensure that the food is equitably distributed; however, whether major gains in global food production will be possible is a point of heated debate. By 2050, it is estimated that the world population will top 9 billion people. To meet the basic dietary requirements of every person on the planet at that time, current food production would have to increase by 70%. Some analysts argue that innovative agricultural techniques, combined with advances in biotechnology, will allow us to significantly increase food production. Other researchers believe that global food production has already peaked (see the following discussion) and that even maintaining current levels will be difficult. Analysts suggest the only way out of the predicament is to reduce world population growth significantly.

Food for the Future

If the world population continues to grow, then more food will be needed in the future. World food production could be increased through two basic, but certainly not mutually exclusive, strategies: (1) increase the amount of land under cultivation or (2) increase the yield per unit of land under cultivation. Today, slightly more than 1.5 billion hectares (3.7 billion acres) of land worldwide are under some form of cultivation—an average of approximately one-quarter hectare per person. According to various theoretical estimates, the Earth has between 2 and 4 billion hectares (average of 7.4 billion acres) of **cultivable land** (much of the variation in the estimates is attributable to the use of different criteria for defining "cultivable land"—how fertile the soil must be, how much water must be available, and so forth). However, much of the theoretically cultivable land realistically will never be cultivated, and doing so would either irrevocably damage natural ecosystems on which we depend or irrevocably disrupt human society. Cultivable land includes vast expanses of forests and grasslands, some of which are designated as national parks or national forests. In addition, much cultivable land has been paved over as highways, roads, parking lots, and shopping malls. Cities and suburbs are built on cultivable land.

Differing scenarios involving various combinations of land cultivation and yields on a global scale have been proposed (see **FIGURE 13.3**). If the population increases at the exponential rate seen in the 1990s and current average yields continue (i.e., they do not increase), before the year 2050, all of the theoretical 4 billion hectares (0.88 billion acres) of cultivable land will have to be put into production, and by the end of the 21st century the population will quickly outstrip its food supply. This scenario unrealistically assumes that the current high crop yields of prime land can be maintained, even on marginally arable land. However, it also assumes a higher population growth rate than is currently expected for the first half of this century. It also assumes that no cultivable land is lost during the next 100 years, which is also unrealistic because, as explained later, the absolute amount of cultivable land on Earth is declining for a number of reasons.

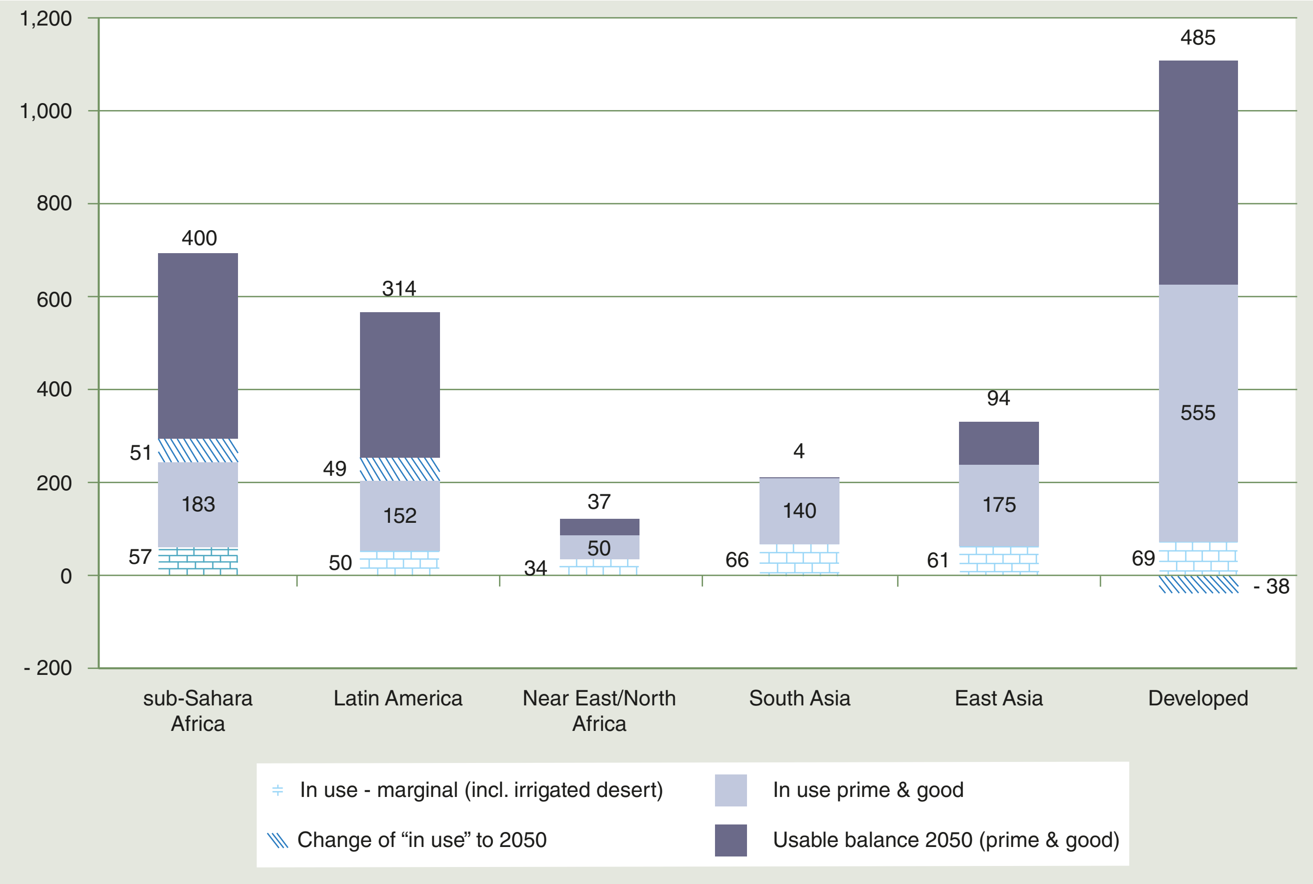


FIGURE 13.3 Possible land futures, with projections out to 2050. Seen here is land available for food production in areas of the world experiencing fast population growth along with the developed world. With current population models, one can see that by 2050 most areas will have plenty of land to utilize for food production. This gives an air of keeping pace with food demands, but due to poor infrastructure, difficulty of terrain, or distance from markets, not all of this is economical for agriculture.

© FAO 2012 Alexandratos, N., & Bruinsma, J. World agriculture towards 2030/2050: The 2012 revision. ESA working paper no. 12-03. http://www.fao.org/docrep/016/ap106e/ap106e.pdf.

If the population increases, according to various World Bank projections, Earth's population can be sustained through the 21st century within the range of estimates of land available for cultivation. However, unless crop yields can be significantly increased or food losses and wastage significantly decreased, an additional 1 billion or more hectares (2.5 billion acres) may have to be placed under cultivation by the end of the century to feed all the globe's people. Such a dramatic increase in cropland will severely strain natural ecosystems and may be quite difficult pragmatically and politically.

Some optimistic studies have concluded that if we really wanted to we could grow enough food to support a global population of 50 billion people. However, such estimates are based on totally unrealistic assumptions. For one thing, they assume that all potentially arable land would be cultivated, including land occupied by forests and land that is of marginal fertility or is so arid that massive irrigation would be necessary. The human population would have to live in areas, such as the Polar Regions, where agriculture is totally impossible, whereas the potentially arable land beneath our current cities and towns would be put under the plow. In addition, these studies assume the yields on all this land would either match or (with advances in agricultural technologies) surpass those that have been attained under ideal conditions on the most fertile land in the past. Such super-high yields are only a pipe dream. Finally, these projections ignore the detrimental and nonsustainable aspects of modern agriculture (discussed in a later section) and the consequences (climatic and otherwise) of destroying the world's remaining forests. The question of where the massive quantities of energy, **fertilizers**, **pesticides**, **herbicides**, and freshwater necessary for modern, intensive, high-yield agriculture will come from is not addressed, nor are the attendant problems of pollution caused by chemical use, **topsoil** (a mixture of mineral matter and humus, alive with microscopic and macroscopic organisms) loss and exhaustion, soil salinization, and waterlogging addressed. To suggest that we could feed close to 50 billion people is irresponsible—indeed, it is a lie.

A more conservative estimate is that we could potentially feed about 8 billion people, but even this estimate assumes better yields than occur today in many agricultural areas and also assumes essentially a subsistence diet. Although some increase in yields may be possible (e.g., the best farmers in Iowa can produce four times the world's average corn yield per acre), in recent years global yields have shown signs of leveling, and additional large increases in the future cannot be counted upon.

Taking all of these factors into account, some experts insist that we are just about at the limit of the number of people we can realistically expect to feed. They note that even now, with 11% or more of the world's population underfed, we do not do a very good job of feeding a mere 7.4 billion, and as mentioned, per capita grain production has declined. Still, it must be pointed out that this is a very controversial topic. New crop varieties continue to be developed, and new methods of farming and more efficient equipment have yet to be used around the world. Even if crop yields have leveled in the past few years, this does not necessarily mean that they will remain at these levels for all time. They may begin to increase once again as successful new cultivation techniques spread around the world. Also important to note are various socioeconomic issues. Vertical farming, artificial fertilizers, low-tech local farming, urban farms, and permaculture are all completely viable. Even today, the developed world produces (and wastes) enough food to feed everyone. Globally, it is typically disadvantaged populations—women and children—that cannot be fed. Poverty is arguably the greatest hunger hurdle.

Agricultural Food Production and Supplies

Grain (rice, wheat, maize, sorghum, barley, oats, rye, millet, and so forth) forms the backbone of the world's food supply, so global annual grain production is of utmost importance. Total world grain production nearly tripled between 1950 and the end of the 20th century (**FIGURE 13.4**), in large part because of the "Green Revolution," which is discussed later.

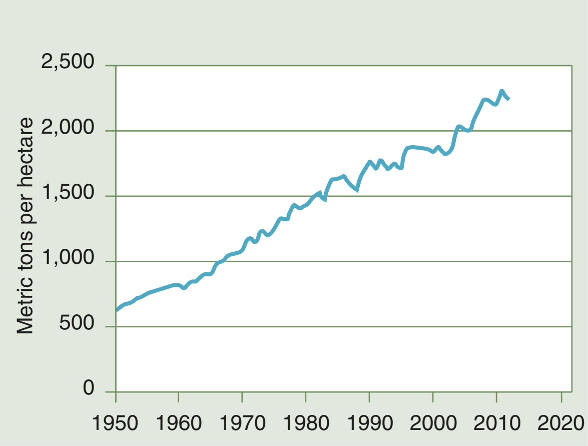


FIGURE 13.4 World grain production, 1950 to 2016.

Courtesy of U.S. Department of Agriculture.

Not all grain grown is used for human consumption. Since 1960, about one-third to more than two-fifths of the world's grain supply each year has been used to feed livestock and poultry. To raise livestock and poultry on grains, farmers must routinely include a protein supplement in the animals' diet. The most important such supplement is the protein-rich soybean, which is also a valuable source of oil and protein for people.

It is far more efficient to consume grains and other plants directly than to feed them to animals and then consume the animals. This is because plants (including grains) form the base of the food web. As producers, they directly use energy from the sun to manufacture sugars. Ninety percent of the energy from the sun used in photosynthesis is lost to the universe as heat, leaving just 10% of the energy reserve in the plant. When consumers ingest plants, the processing of plant material causes 90% of the stored plant energy to be lost to the universe as heat, thus the animal gains a net 10% of the energy available by the plant, which is just 1% from the sun. This is known as the **rule of 10s**, whereby 90% of energy is lost as heat with each transaction, increasing entropy in the universe. This is why there are far more producers than consumers in the world.

As the world population continues to increase and grain production remains stable or declines, it may become necessary to allocate less grain to animals if we want to ensure that all people are fed adequately.

Not all grain produced in a given year is necessarily consumed in that year. An important concept is that of **carryover grain stocks** from one year to the next. The size of the world's grain carryover stock is often used as an indicator of global food security. Often, if the stocks drop too low, as they did in the early 1970s, grain prices may fluctuate widely. In such cases, it becomes even more difficult for the poor to obtain adequate food until a good harvest is restored.

Some observers point out that historically there has always been grain to buy—as expressed in stockpiles of grain around the world. They contend that the primary reason hunger exists in the world today is because poor nations cannot afford to buy food. Some researchers maintain that the best way to ensure that all people are adequately fed is to expand food production in temperate regions (such as the United States) where advanced agricultural technologies and transportation systems are in place. In addition, a global free trade policy for food must be established. A worldwide free market system for food would discourage inefficient, often government-subsidized, food production in marginal areas. For instance, in India, overpumping of groundwater supplies using free government-provided electricity has resulted in lowered water tables, salinization, and waterlogged soils. In the name of "self-sufficiency," Indonesia has cleared 607,000 hectares (1.5 million acres) of tropical rain forest to grow soybeans for use as chicken feed. The problem is that the cost of Indonesian soybeans is higher than the price for soybeans on the world market. Likewise, India produces milk at a cost above world market prices.

Even those who espouse a "free market solution" to world hunger must acknowledge that the problems of debt (particularly on the part of developing countries), trade imbalances, and restrictions on free market policies are complex and not easily solved. Politically, it would be very difficult to have a genuine global free market system for food products. Even if free trade/free market policies could accomplish the equitable distribution of food around the world, enough food must be available to go around. Currently, the food supply appears to be adequate, but as has been discussed, if the global population continues to grow, it is far from certain that there will be enough food to feed everyone in the future.

Land, Fertilizers, and Water Devoted to Agricultural Production

An enormous amount of land is devoted to agricultural use. Globally, 3.3 billion hectares (8.15 billion acres) of land is used for grazing animals (roughly 60% of agricultural land) and slightly more than 1.5 billion hectares (3.7 billion acres) is devoted to cropland. Not all agriculture is devoted to food production—for instance, cotton and other crops are grown to manufacture textiles and animals are raised for leather products. An estimated 275 million hectares (680 million acres) are artificially irrigated to grow crops.

Every year, new land is put under cultivation as forests are cut and dry areas are irrigated, but other land is removed from cultivation because of such factors as soil exhaustion, degradation, and the building of residences and shopping malls. Currently, a rough balance exists between land newly put under cultivation each year and land removed from cultivation, but some observers fear that within a few decades, the amount of cropland may begin to diminish substantially.

More important, because of global population growth and the dependence on grain crops, the amount per capita of land used to grow grain has steadily declined. For now, this decrease has been offset by an increase in yield. This has been accomplished through intensive, often mechanized, farming techniques using specially bred varieties of crops and massive doses of artificial fertilizers, pesticides, herbicides, and in some cases artificial irrigation (the Green Revolution is discussed later). In many regions, **irrigation** is essential to grow crops that would not otherwise survive (**FIGURE 13.5**).

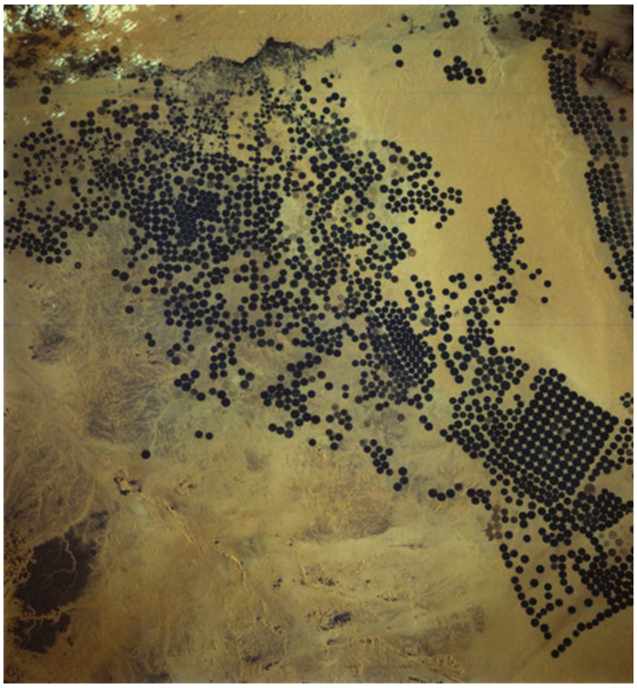


FIGURE 13.5 Genuine crop circles. Each of these circular features is an irrigated crop field in the desert southwest of Riyadh, Saudi Arabia.

Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center. http://eol.jsc.nasa.gov.

13.2 The Effects of Agriculture

Most agriculture alters and manipulates natural ecosystems, transforming them into artificial ecosystems that are inherently unstable and can survive only with constant human attention. Maximum food production is the only goal.

In nature, during the process of **ecological succession**, successive groups of plants and animals will colonize a clear patch of land. The first settlers generally will be smaller, fast-growing, pioneer plants. Then larger, slower-growing, and longer-lasting plants will progressively replace the original colonists. The final stage of succession is the **climax community**, which in many terrestrial areas consists of mature forest composed of large trees interspersed with younger trees and other plants and animals.

In clearing land for agricultural use, farmers essentially begin the cycle of succession anew (**FIGURE 13.6**). However, the farmer does not allow succession to follow its natural course and reach a climax stage. Instead, the land is artificially maintained at the pioneer stage. The pioneer plants that are allowed to grow on the land are carefully picked, maintained, and managed. Corn (maize), wheat, or rice may be planted as the pioneer plant; other weeds are eliminated (many major food crops are essentially cultivated weeds). When the crop has matured, it is harvested; the next season the land is cleared, and the system begins again. Most agricultural systems emphasize the **pioneer stage of succession** because this is when an ecosystem is most productive (although not most efficient in energy use). In this stage, virtually all of the energy and nutrients that the plants use go into growth. In contrast, in the climax stage, much of the energy and most of the nutrients go into maintaining the system; the only new growth that occurs replaces plants that die. The long-term arrestment of ecosystems at the pioneer stage leads to major problems.

Pioneer ecosystems are inherently unstable, and this instability is exacerbated by the human habit of planting only one variety of plant per field at a time (**monoculture**). In a mature, climax ecosystem, the complex relationships and interactions among many species of plants and animals promote long-term stability. In the climax community, natural checks and balances act on predator–prey relationships (including insect attacks on vulnerable plants), disease, population explosions of particular species, and so forth. Climax communities are also less susceptible to the ravages of climatic fluctuations such as droughts or floods. In the artificial environment of a crop field, human interventions must mitigate to a greater extent the pests, disease, and the vagaries of climate. Although there are more natural alternatives, pests might be controlled by applying poisonous chemicals to a field. Watering or irrigation may compensate for a lack of rain.

Pioneer stages also extract a heavy toll of nutrients from the soil without replenishing them. Replenishment occurs naturally during later stages of ecological succession, but when people harvest and remove their pioneer crops, the nutrients are lost from the land, and artificial fertilization must restore them. In contrast, complementary, even symbiotic, relationships between organisms characterize the climax community. The nutrients that one organism extracted are eventually passed on to and restored by another organism. The cycle of growth, death, decay, and regrowth—all on the same parcel of land—ensures continued recycling of raw materials.


(a)

(b)

FIGURE 13.6 **(a)** Pioneers cut down climax stage forests to build their homes, grow crops, and generally "tame" the wilderness. **(b)** Strip cropping and woodlots in Leelanau County, Michigan.

(a) © Photos.com. (b) Courtesy of Lynn Betts/USDA ARS.

The characteristics of pioneer communities that make modern monoculture farming so productive and successful on a short-term basis cause continued environmental degradation in the long term. Rapid nutrient uptake (absorption) without recycling destroys the soil's fertility. A lack of a balanced vegetation—or no vegetation at all between harvesting and the next planting season—to hold the soil in place and absorb moisture can lead to massive erosion of valuable topsoil, flash floods, dust storms, and droughts. Monocultures are notoriously susceptible to attack by disease and pests uncontrolled by natural predators or other mitigating agents.

The Effects of Irrigation

In areas where irrigation is necessary, a whole new set of problems is encountered, particularly **salinization** and **waterlogging**. All soils contain various mineral salts. Under natural conditions, in areas that are characterized by relatively high rainfall and good drainage, these salts are washed out of the soil and travel, through water flow, to the sea. This is why the sea is salty—it is where salts from the land surface accumulate. In contrast, arid regions tend to have higher natural concentrations of salts in the soil and in any groundwater or standing bodies of water simply because there is not a constant flow of water to remove the salt. Irrigating arid land dissolves the salts in the soil, and as the water evaporates, the salts are drawn toward the surface. Many artificially irrigated lands are poorly drained, and as a result, the salts simply remain in the upper levels of the soil, rather than being flushed out and carried to the sea. Furthermore, the poorly drained land and soils themselves can become waterlogged, and the water table can rise over time, as the groundwater and soils become progressively saltier. Accumulated mineral salts are toxic to most plant life, and as land becomes increasingly salinized, it may reach a point where it can no longer support most crops or other plants (**FIGURE 13.7**).

FIGURE 13.7 Salt-affected agricultural land near Katanning, Western Australia.

Courtesy of Department of Primary Industries and Regional Development, Western Australian Agriculture Authority.

Modern Agriculture's "Solutions": Fertilizers, Pesticides, and Herbicides

The "modern" agricultural industry of the late 19th through to the present has shunned many traditional farming methods as inefficient and unsuited to mass production. This has resulted in a "quick fix" of bumper crops at the expense of the land, nonrenewable mineral and energy resources, and long-term sustainability.

Much modern agriculture is synonymous with the circumvention of biological agents in the restoration of depleted soil fertility; crop diversity, crop rotation, and even manure use are abandoned. Instead, minerals and chemicals are mined, processed, and applied directly to croplands in the form of fertilizers; simultaneously, irrigation efforts are intensified. This has been referred to as "force-feeding" the land.

The main nutrients applied to the soil are phosphorus, potassium, and nitrogen. Phosphorus and potassium are mined from mineral deposits; phosphorus in particular is potentially in short supply as high-grade, naturally formed phosphate deposits are exploited faster than new deposits are discovered (like the fossil fuels, there is only a finite supply of geologically formed high-grade phosphate deposits, many of which are the result of accumulations of ancient animal bones millions of years ago). Nitrogen was initially supplied from manure or from bird droppings known as "guano." Some isolated islands contain huge mountains of bird droppings, and these were once mined for their nitrogen content. Today, artificial nitrogen-bearing fertilizers can be manufactured using the abundant nitrogen of the atmosphere.

An increasing emphasis on monoculture (planting huge fields with a single variety of a single crop) has accompanied the heavy use of fertilizers. Monoculture allows the farmer to tailor the fertilizers to the specific needs of the particular crop and increases efficiency in mechanical harvesting and processing of the crop. But monoculture brings with it increasing problems from pests and diseases that find a happy point of attack in the huge, ecologically unstable fields. This means that such pests and diseases needed to be controlled. The preferred way to control them has been through the use of more chemicals—synthetic pesticides and herbicides that can be designed to kill everything except the crop being cultivated. In the United States, pesticide use

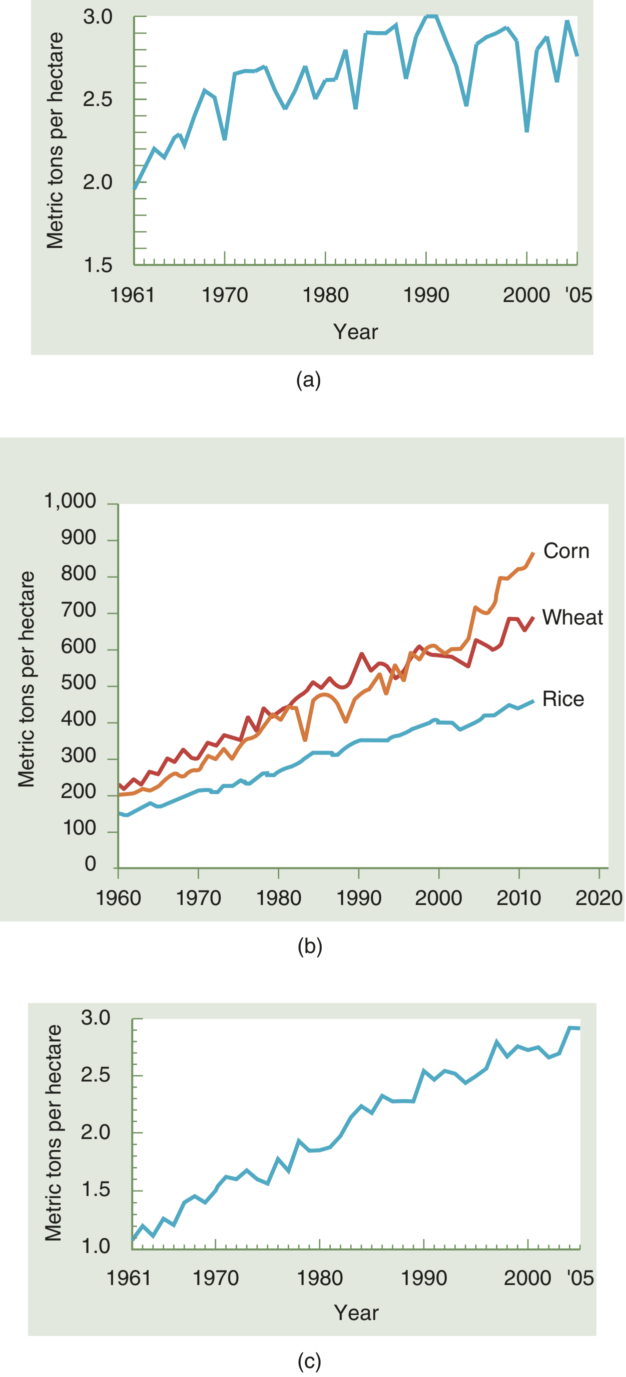
FIGURE 13.8 Spraying pesticide on leaf lettuce in Yuma, Arizona.

Photo by Jeff Vanuga , USDA Natural Resources Conservation Service.

in agriculture rose from about 154 million kilograms (340 million pounds) per year in 1965 to about 404 million kilograms (890 million pounds) in the early 1980s. U.S. pesticide consumption has dropped slightly; it is currently 398 million kilograms (877 million pounds) per year. Globally, pesticide use has increased, with the average amount applied to agricultural land more than tripling—from about 0.5 kilogram per hectare in 1961 to between 1.5 and 2.0 kilograms per hectare at the end of the twentieth century. But such techniques have led to obvious problems. Despite the massive addition of fertilizers, soils are slowly becoming exhausted. The major nutrients extracted by the plants are being temporarily restored, but many trace elements necessary for the ultimate sustainability of agriculture are not; examples of such trace elements include zinc, iron, boron, copper, molybdenum, and manganese. In addition, good healthy soil is more than just a handful of dry minerals and fertilizers. It is full of organic debris, humus, and living organisms, including worms, beneficial insects, fungi, and bacteria. These organisms help mix and aerate the nutrients. The texture, structure, and quality of the soil are necessary for the roots of plants to take hold and the soil to retain water, which helps minimize both droughts and waterlogging of the earth below. Dumping massive amounts of toxic substances (in the form of pesticides and herbicides) literally kills the soil (**FIGURE 13.8**). Dead soil loses its structure and no longer functions properly. An unstable, dead soil may quickly erode away, perhaps further spreading the noxious chemicals that killed it.

The Green Revolution

Shortly after the end of World War II, modern, chemically based agriculture began to be used on a large scale in industrialized countries. In the 1960s, the Food and Agriculture Organization of the United Nations began a massive program to increase world food production, especially in developing countries. This effort was based on the use of modern agricultural techniques applied to high-yielding, Western-designed crops. The resulting food production gains of the 1950s through 1980s (**FIGURE 13.9**) are often termed the **Green Revolution**.



(a)

(b)

(c)

FIGURE 13.9 **(a)** World mixed grain yields, 1961 to 2005. **(b)** World corn, wheat, and rice production, 1960 to 2016. **(c)** World wheat yields, 1961–2005. All yields are in terms of metric tons per hectare.

(a) Data from United Nations Food and Agriculture Organization. (b) Courtesy of U.S. Department of Agriculture. (c) Data from United Nations Food and Agriculture Organization.

The immediate, short-term gains of the Green Revolution were truly impressive. For instance, between 1950 and 1986, annual world grain production rose from approximately 631 to 1,664 million metric tons. This growth rate in grain production was greater than the rate of human population growth across the planet, with the net result that per capita grain production rose from 250 to 338 kilograms (551 to 745 pounds) per person during the same period (see Figure 13.4). Given the increase in the Earth's population from just slightly more than 3 billion in 1960 to the current 7.4 billion, the Green Revolution may have staved off immediate starvation for billions, but this has come at a price. The massive application of "modern" agricultural techniques has resulted in numerous problems, and it is unclear whether current food production levels will be maintainable for much longer. The peak per capita annual production of grain in 1984 (343 kilograms, or 343 pounds) has thus far (through 2016) not been duplicated. In many areas, **soil fertility** is declining rapidly as nutrients are extracted from the soil but not returned in kind. Massive irrigation, even in countries where forms of traditional irrigation have been successfully carried out for millennia, is causing waterlogging and salinization at unprecedented rates. Ironically, in arid and semiarid regions, this often leads to **desertification** (**FIGURE 13.10**), the spread of desert-like conditions that human exploitation and misuse of the land have caused. In China, perhaps more than 1 million hectares (2.5 million acres) of agricultural land have had to be abandoned since 1980 because of problems with salinization and waterlogging. Similarly, 2.9 million hectares (7 million acres) were removed from use in the Soviet Union between 1971 and 1985, and in India the newly irrigated land that is put into production each year is counterbalanced by damaged land that must be removed from production. In Egypt, irrigation has been a necessity since ancient times, yet traditionally the fields were not used continuously; the fields were allowed to lie fallow, and thus the accumulating salts could be naturally washed out and the land rejuvenated. Since about 1960, intensive modern irrigation has caused salinization of about one-third of Egypt's cultivated land, and an estimated 90% is experiencing the effects of waterlogging.

Just as serious as nutrient depletion, salinization, and waterlogging are the effects of toxins (in the form of pesticides and herbicides) and soil erosion. Pollution from herbicides and pesticides is a global problem: it destroys not only the living organisms in the soil, but also other wildlife and vegetation and is directly harmful to the human population. Denuded soils quickly erode, and topsoil loss is a serious global problem (discussed later). A study in Tanzania found that land with natural vegetation cover experienced virtually no topsoil loss and absorbed almost all the rainfall compared with land that was either artificially cultivated or left bare. It has been estimated that currently about 26 billion metric tons of topsoil are lost worldwide from erosion every year. It can take as long

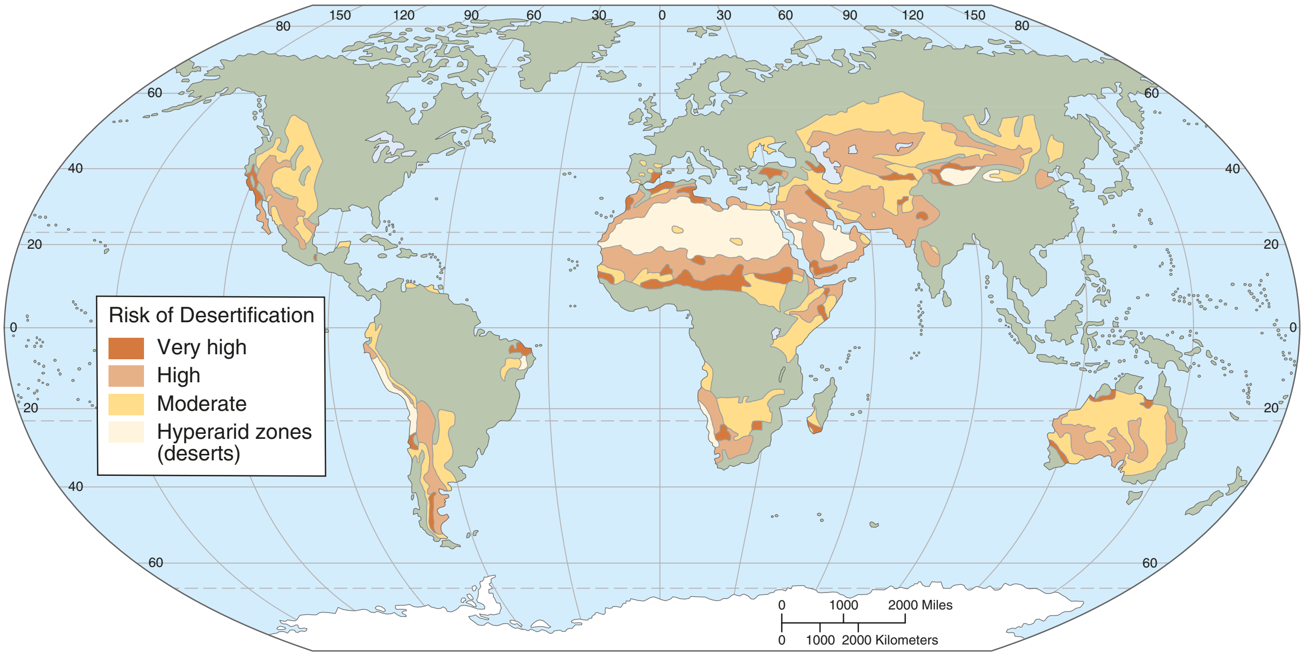


FIGURE 13.10 Deserts and areas at risk of desertification.

Based on United Nations data.

as 1,000 years to form a layer of soil 1 centimeter (0.4 inch) thick, yet it can be lost in just a few years from poor agricultural management. Some researchers estimate that, at current rates of erosion, the once-fertile land of the U.S. Corn Belt could be nearly depleted of topsoil before the middle of the 21st century.

The Green Revolution has also been held responsible for the contamination and depletion of groundwater supplies in many parts of the world. Agrochemicals—artificial fertilizers, pesticides, herbicides, nitrates (derived from fertilizers), and other chemicals (many of which are highly toxic and carcinogenic)—applied in abundance to fields have penetrated and polluted groundwater supplies. An estimated 50 million people in the United States are potentially exposed to pesticide-contaminated groundwater used for drinking. Contaminated groundwater often is virtually impossible to clean. Underground aquifers are cool, dark, and well protected; they have poor water circulation, contain little in the way of life forms, and thus form an ideal place for contaminants to be stored and remain stable (and toxic) for centuries or millennia. Deep in the aquifer there are no natural mechanisms to break down or neutralize contaminating toxins, so they remain indefinitely. Many authorities think that in most cases, a badly contaminated groundwater supply must be dismissed as a future source of freshwater.

The Green Revolution has also greatly stressed the supplies of freshwater. Many of the miracle crops of the Green Revolution were hybrid varieties that, although they may have been more productive, required much more water than traditional varieties of wheat and rice. In addition, in some areas crops for export were introduced that required even greater amounts of water; a case in point is sugarcane, which can require 10 times as much water as wheat. In addition, arid land was put under artificial irrigation using modern wells that tapped deep underground aquifers. In the past few decades, many areas have routinely withdrawn water from aquifers much faster than the aquifers are recharged by rain. The net result of these practices is that water tables are declining around the world.

Beyond the Green Revolution: Higher Yields Through Sustainable Agriculture

The acme of the Green Revolution, with its heavy dependence on synthetic chemical compounds—fertilizers, pesticides, and herbicides—and its use of water-consuming, genetically identical monocultures grown with the help of heavy equipment powered by fossil fuels, has now passed. The gains of the Green Revolution were impressive, but they were achieved unsustainably. The downside of the Green Revolution has been environmental damage to an extent previously unknown in recorded history. Fortunately, an increasing number of farmers around the world are using "new" (in fact, based on traditional practices), ecologically sound, and sustainable methods of growing food (see **CASE STUDY 13.1**).

Traditional and Sustainable Methods of Coping with Agriculture's Effects

A traditional and time-honored way of circumventing the problems inherent in agriculture is to occupy the land for a year or two, often using slash and burn or **swidden techniques** (cutting and burning the natural vegetation to clear the land and release the nutrients into the soil), and then moving on to another plot of land. In this way, the natural ecological cycle of succession can occur once again; the land is allowed to regenerate and replenish itself. This method is feasible as long as the human population in any one area is relatively small and they are willing to pick up and move on a regular basis.

A variation on this theme is to maintain a permanent place of residence but use alternating fields in different years. In late ancient and medieval Europe, many farmers used a "two-field system" in which only half of their land was planted with crops in any particular year; the other half lay fallow. Native wild plants would colonize the fallow land, and farm animals were allowed to graze there; their manure helped to restore fertility to the soil. Fallow fields could also serve as a home for wildlife, such as birds, that could help keep insects and other pests in check. Each year, the crops would be planted on the previous year's fallow land. A related method is **crop rotation**, rotating crops from field to field and season to season. With proper rotation, the next crop can restore nutrients that a previous crop used. For instance, periodically planting a field with legumes (members of the pea and bean family) will restore nitrogen to the soil. These plants' roots attract soil bacteria that have the ability to remove nitrogen from the air and produce nitrogen compounds on which other forms of life are dependent. Crop rotation also tends to decrease the threat of pests and disease. If the same crop is planted in the same field year after year, a colony of a harmful pest or disease agent (be it a rodent, insect, fungus, or other life-form) can take up permanent residence in or near the field. Such a colony has less chance of establishing itself if crops are rotated from year to year.

Another traditional way to avoid the problems inherent in some agricultural practices is to promote

CASE STUDY 13.1 SUBSISTENCE GROWERS AND SUSTAINABLE AGRICULTURAL PRACTICES

For much of agricultural history, all farming was carried out on a subsistence level. That is, a subsistence farmer produced only enough food to feed himself or herself, his or her immediate family, and perhaps some of the farmer's close neighbors. A number of subsistence farmers might have supported a local village that included artisans and other workers who themselves did not farm. With local subsistence farming, farm produce did not travel far; all markets were nearby, local tastes were accommodated, and there was little issue of produce losses during transport or storage. Furthermore, wastes and refuse tended to be returned to the local ecosystem, and the cycling of nutrients formed a relatively closed loop with little seepage or net loss from the immediate area. Under traditional subsistence farming, occasional surpluses might be sold outside of the local community, but that was not a primary goal.

In modern times, and especially during the past century and a half, the trend has been strongly away from subsistence farming and toward commercialization of agricultural activities and the expansion of markets. Modern technology, including fertilizer and pesticide use, fast-growing and high-production strains of crops, mechanization, and modern transport systems, means that on a local, national, and global scale more food and other agricultural products (such as fibers for cloth production or energy crops) can be produced with reduced human labor demands—fewer and fewer people are directly, or even indirectly, involved with farms and agriculture. Thus, an American consumer today may think nothing of sitting down to a meal that includes kiwis from New Zealand, apricots from Turkey, and mangoes from Peru. Decorating the table may be a bouquet of flowers from Colombia.

A farmer today may grow crops or raise fowl and livestock exclusively for a market that is on the other side of the world with little consideration for local needs. The farming activities become purely a commercial enterprise embedded in the national or global market economy, and this often leads to mass production, economies of scale (cheaper to specialize and grow one product in bulk), and the movement toward large agribusiness at the expense of the small-scale subsistence grower. Certainly, modern agribusiness is in large part responsible for the development of modern civilization as we know it. For instance, huge cities would hardly be possible otherwise. However, if not carefully managed, modern agricultural developments disrupt fragile local societies and economies, as well as adversely affect local ecosystems. Sustainable and self-perpetuating subsistence farming may give way to unsustainable practices that maximize short-term gains (whether the "short term" is measured in years or decades).

Problems associated with large-scale agriculture include damage to local ecosystems with loss or extinction of indigenous organisms and biodiversity, topsoil depletion, surface water and groundwater depletion and contamination, loss of indigenous human cultures and ethnographic diversity, and disruption and breakdown of local time-tested social and economic systems, which may result in increasing poverty, crime, and other societal evils.

Many analysts argue that, if we as a species are to survive at anything better than a marginal level well beyond the 21st century, we must reinstitute sustainable agricultural practices. A key factor is that sustainable agriculture, unlike at least some concepts of large-scale mechanized agribusiness, is not a one-size-fits-all solution. Rather, it is extremely important, if sustainable agriculture is to be successful, that crops and techniques be carefully fitted to local environmental and cultural conditions. Indigenous resources, knowledge, conditions, and customs must be honored.

Some basic principles and themes of sustainable agricultural practices can be enumerated as follows:

1. The needs of the present must be met without compromising the ability of future generations to meet their needs and fulfill their potential.
2. Crops suitable to a particular setting, which are often local indigenous forms, are emphasized and fostered. Tolerance of local climatic and soil conditions, resistance to local pests, and similar factors are taken into account. Local biodiversity is maintained.
3. Careful stewardship of all resources (material, energy, organismal, land, ecosystems, and people and human institutions) is necessary. Nonrenewable resources must not be exploited unsustainably (thus reuse and recycling must be implemented), and ecosystems must not be degraded. Inputs to the system (such as water and nutrients) must be managed efficiently; low or no input of any synthetic fertilizers and pesticides is fostered. Practices such as rotation of crops, planting crops that will restore nutrients to the soil, and so forth are used. Local peoples and their cultures, lifestyles, and societal values must be treated with respect and dignity. Laborers are not a resource to be exploited or taken advantage of.
4. All participants in the system are important and deserve a decent standard of living and a fair share of the profits earned. The roles and value of laborers, farmers, managers, consumers, governing bodies, and policy makers must all be acknowledged. All participants, from a local to a global level, share in both the responsibilities and

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CASE STUDY 13.1 (continued)

the benefits for making sustainability work. Social and economic equity is a necessary component of long-term sustainability.

5. Sustainability in agriculture and farming encompasses an interdisciplinary systems approach (a review of environmental science provides additional information). All components of the system are interdependent and affect all other components, from the smallest to the largest. Thus, for example, fertilizers or pesticides must not be applied indiscriminately; rather, they must be used judiciously with a clear understanding of their implications for long-term soil fertility, ecosystem health, and so forth. A chemical application, while increasing agricultural production, may cause damage to the health of the local citizenry. To give another example, it must be acknowledged that high-level global policy decisions, such as those concerning import tariffs, can have major ramifications for local growers.

Even as we move from subsistence farming to national and global economies integrated with sustainable agricultural practices, age-old subsistence techniques can continue to be used to advantage and, in some cases, rediscovered. An example of the latter is the use of *albarradas* (Spanish for "earthworks") of the Santa Elena Peninsula of western Ecuador. This region, like other parts of Central and South America, is highly dependent on the fluctuations of El Niño to bring rains; periods of drought are interspersed with deluges brought by El Niño. In pre-Columbian times, for thousands of years, the indigenous peoples built horseshoe-shaped *albarradas* to capture and store the rainwater brought by El Niño so that it could be used during dry times. Similar ancient stone and earthwork structures are known in Peru, where they were also used to collect water during the wet season (**FIGURE 1**).

In some *albarradas,* crops were grown in the moist soil at one end, even as the structures served to recharge the local aquifers. In modern times, structures to trap rainwater are widely built, but many of these modern structures have been damaged by the ferocity of the strongest El Niño storms, whereas the ancient structures survive and continue to do their job. Modern researchers are studying the ancient structures to learn how to apply their successful design and construction techniques to modern local farming. Furthermore, ancient *albarradas* have yielded evidence of the plants that once formed the ancient Ecuadorian ecosystem but have been displaced or destroyed in modern times. In some cases, the *albarradas* have served as a living refuge for ancient genetic varieties that are not found anywhere else. By studying the ancient *albarradas,* progress is being made toward understanding and ultimately restoring the local biodiversity and fragile indigenous dry tropical forest ecosystems of western Ecuador. Here indigenous ancient knowledge, subsistence growing and wider markets (i.e., surpluses can be marketed beyond the local area), and sustainable agricultural practices can come together to ensure a bright and self-perpetuating future for the region.

FIGURE 1 Ancient earth and stonework structure in the Peruvian Andes used to collect water during the wet season.

Photo by Robert Schoch, August 2005.

Critical Thinking

1. Environmental science is a broad area of study dependent on numerous fields in both the social and natural sciences. With regard to subsistence agriculture, how can sociology, biology, and geology contribute to our understanding of these techniques?
2. How could sustainable farming techniques be used in urban neighborhoods to increase the supply of inexpensive fruits and vegetables, and thus address the issue of food deserts in these areas? How can these techniques be applied to large-scale industrial agriculture?

FIGURE 13.11 Planting two or more crops in alternating strips is referred to as *strip cropping*. Here, alternating strips of alfalfa with corn protect this field in Iowa from soil erosion.

Photo by Tim McCabe, USDA Natural Resources Conservation Service.

diversity. This can take many forms and is not unrelated to the concept of crop rotation. In many traditional aboriginal agricultures, numerous varieties of many different crops are planted each season; for instance, the aboriginals of Amazonia used at least 70 varieties of manioc (a group of tropical plants with edible roots, also known as cassava or tapioca). In some cases, many different types of plants are cultivated within a small area, even planted together in the same space—mimicking some of the characteristics of a climax community. In Central America, the farmers traditionally have interplanted maize (corn), beans, and squash. The three crops benefit one another, and the system leads to greater long-term productivity and sustainability than planting a single crop at a time. The more varied diet such interplanting promotes is also nutritionally preferable for people. In addition, using a variety of crops is a form of insurance—one does not put all of one's eggs in a single basket. Different crops and varieties have different tolerances for adverse pest, soil, disease, and climatic conditions (**FIGURE 13.11**). Even if unexpected rains or droughts occur or an abnormal fungus or insect plague strikes, it is less likely to destroy the entire harvest if a variety of plants have been cultivated.

Integrated Pest Management and Biological Controls and Organic Farming

The basic philosophy behind **integrated pest management (IPM)** and **biological control** is that the farmer does not try to eliminate pests, as was often the idea behind using massive amounts of poisons as part of the Green Revolution, but simply attempts to control pests so that they do not cause serious damage. IPM advocates "natural" controls, such as the use of the pests' biological predators. IPM systems also use cultural practices such as crop rotation, allowing fields to lie fallow periodically and interplanting to help control various pests and weeds.

To an increasing extent, farmers are returning to the use of natural fertilizers such as crop wastes that are plowed back into the soil or left to rot on top of the soil, natural compost, animal manures, and even human wastes. In some areas, farmers have taken up true **organic farming**, which avoids the use of any synthetic chemicals—fertilizers, pesticides, or herbicides.

IPM, biological control of pests, and organic farming are proving to be productive and economically feasible. In some cases, the yields have been slightly lower (although sometimes they are higher), but because the farmers did not have to purchase extra synthetic chemicals, their costs were lower and their profits the same as or higher than they would have been with the use of more conventional methods. In fact, one study of nine crops in 15 U.S. states found that the farmers using IPM systems had a collective profit of $579 million more than their projected earnings using other methods. Thus, these new techniques are economically viable; they will not drive farmers out of business or cause a dramatic drop in food production. Most important, however, they do not deteriorate the land and general environment to the extent that the techniques of the Green Revolution did. In fact, at their best, organic farming and IPM, combined with very limited use of synthetic chemicals, appear to be sustainable—a claim the Green Revolution could never approach.

Biotechnology and Genetically Modified Crops

The Green Revolution was based on many new "miracle" strains of crops that grew faster and produced higher yields. Many hope that we can continue to increase food production through **biotechnology** and **bioengineering**—the artificial use and manipulation of organisms toward human ends, including genetic manipulations that can in effect produce new types of organisms (see **CASE STUDY 13.2**). **Genetically modified (GM)**, transformed, or **transgenic crops** (transgenic varieties) are already a reality. Many people may not realize it, but sizable percentages, from one-third to one-half or more of such crops as soybeans, corn, and cotton, are composed of transgenic varieties in America. In 1994, the Flavr Savr tomato developed by Calgene, Inc. (since taken over

CASE STUDY 13.2 GENETICALLY MODIFIED FOODS AND CROPS

In less than a decade, GM crops have grown by orders of magnitude on the world stage. In 1996 (when the first edition of this book was published), a mere 1.7 million hectares were planted worldwide; however, by the turn of the century, some 50 million hectares were being planted with GM crops, and in 2016, it was estimated that more than 185 million hectares were dedicated to GM crops. The use of GM crops is concentrated largely in the United States (the leader in such operations), Argentina, Canada, and China. It is estimated that in the United States more than 70% of all food contains some GM component.

However, GM crops did not explode just in terms of dramatic increases in plantings; they also exploded in terms of worldwide controversy over the advisability of relying on such technologies. In many European countries, much of the populace is very wary of genetically modified foodstuffs. For example, it was not until early 2004 that Britain finally gave the go-ahead for the first GM crop for commercial growing. In Europe, generally there is much concern with the labeling of GM foods and regulation of their importation. In the United States, there is no requirement for food labels to print genetically modified components, though a QR code will soon be put on labels for consumers to scan.

GM organisms are plants (or in some cases animals or microorganisms) that contain genes extracted from other types of organisms (viruses, bacteria, plants, animals, and so forth) inserted artificially into the subject organism. Thus, *transgenic organisms* is a more accurate term for organisms that contain genetic material transferred from another species. People have been selectively breeding, and thus artificially modifying, the genetic makeup of domesticated organisms for thousands of years, but transgenic organisms are different. Traditional breeding involves, by necessity, the crossing of organisms that are closely enough related that they can interbreed. The engineering of transgenic organisms involves the mixing of genes from organisms that are widely separated evolutionarily, such as the inserting of bacterial genes in a plant or animal, or even animal genes in a plant or vice versa. For this reason, sometimes transgenic food crops are referred to as "Frankenfoods" (after the fictional Dr. Frankenstein's monster, which was manufactured from a combination of body parts originally belonging to different individuals).

Why engineer transgenic organisms? Direct desired benefits include increasing crop yields, developing more advantageous characteristics of crops (be it better taste, higher nutritional value, or longer shelf life), resistance to pests, and tolerance of herbicides and pesticides (so that the crop can be treated with a herbicide that will kill everything other than the desired crop). Through transgenic engineering, plants can also be developed that will yield precursors of plastics, vaccines, and other products not necessarily associated with the plants in nature. It is not only plants that are genetically engineered; a variety of "super salmon" has been genetically engineered with a growth hormone gene that causes the fish to grow extremely quickly (four to six times as fast as the original, unaltered fish) and reach very large sizes.

One early example of a genetically engineered plant is the GM soybean developed by the Monsanto Company. This variety of soybean was developed to be immune to the Monsanto herbicide known as "Roundup." The idea was that farmers could plant the genetically modified soybeans and then control weeds simply by spraying Roundup on the crop. All plants other than the soybeans with the immunity to Roundup would be eliminated. This, it was argued, would reduce the need to use other, more toxic and dangerous herbicides. Various herbicide-resistant varieties of soybeans, corn, cotton, and canola (rapeseed) are among the most common types of transgenic crops currently planted (in 2010, the latest year for which there are accurate statistics), accounting for 71% of the area worldwide planted with transgenic crops. Another major development was the insertion of bacterial genes (from the common bacterium *Bacillus thuringiensis*) that produce a toxin poisonous to various insect species into corn, cotton, and other crops. Such genetically modified Bt crops (named after the initials of the bacterium) have a "built-in" resistance to insect damage. As of 2015, Bt corn and Bt cotton accounted for more than 25% of the transgenic crop area planted globally. Plants can also be modified to both produce Bt toxins and be herbicide-resistant simultaneously, known as "trait-stacked" varieties that contain more than one genetic modification; in 1999, 7% of the transgenic crop area consisted of corn and cotton varieties that produced Bt and were herbicide-resistant. Since 1999 these numbers have increased by a staggering amount. As of 2015, according to the USDA, more than 80% of the transgenic crop area consisted of corn and cotton varieties that produced Bt and were herbicide-resistant.

GM crops such as those described have incredible potential, their proponents argue, to increase production and decrease costs (less money needs to be spent on pest control), so transgenic crops have been rapidly adopted in a few countries, led by the United States. However, critics argue that there is a darker side to GM foods. One example often pointed to is the use of so-called terminator technologies. In the late 1990s, Monsanto and other companies were worried, in part, that their investments and what they regarded as their valid intellectual property rights would be lost if genetically modified plants that they had worked hard to develop could simply be purchased once and then regrown year after year by saving some seeds from the previous year's harvest, as is done by many traditional farmers. To eliminate such a possibility, they worked to engineer sterility into the seeds—that way, each year the farmers would be forced to buy more seeds from the parent company. However, such technology came under intense public scrutiny, and under pressure from

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CASE STUDY 13.2 (continued)

the critics Monsanto decided in 1999 not to commercialize terminator technology. Instead, Monsanto decided to threaten legal action against "seed savers" or "unauthorized" farmers found with the technology on their property.

This incident did not make for good global public relations when it came to GM products. It also brings up larger philosophical and ethical issues, such as whether private individuals and companies should be allowed to patent life forms or parts of life forms. On the one side, some people believe it is wrong to "play God" and patent organisms or simply unethical to develop a beneficial strain of a crop that could help feed the poor in developing nations, yet make it available only to those willing to pay the asking price, thus potentially eliminating those who could most benefit from such a development. On the other hand, it can be argued, why shouldn't a company reap the benefits from the risk and investment involved in attempting to develop new GM products? Indeed, in 1980, the U.S. Supreme Court cleared the way for the patenting of newly developed types of organisms, which helped make investing in genetic engineering more attractive to private corporations.

Many questions have been raised, especially by environmental and consumer advocate groups in Europe, about the potential health and environmental risks of GM foods and crops. However, according to advocates of the benefits of GM foods and crops, no such "hypothetical" risks to people have yet to be definitively demonstrated for GM organisms, and what minimal risks might be involved in the usage of GM organisms are far outweighed by the benefits. Let us briefly examine both sides of the issue.

The Arguments For and Against Transgenic Foods

It has been suggested that transgenic foods may produce toxic or allergic reactions in people (although no studies to date have definitively demonstrated this to be the case), and at the least, critics argue that consumers should be allowed to choose whether they want to purchase and ingest GM foods. For instance, why should a strict vegetarian be unwittingly subjected to ingesting a GM product that might contain an animal gene? Of course, this would not only mean labeling all GM foods, but keeping separate and distinct GM crops and non-GM crops and processing so that the end products could be labeled correctly. (In the fields, non-GM crops planted too close to GM crops may become inadvertently pollinated with GM pollen, thus turning a non-GM crop into a GM crop, to the detriment of the farmer attempting to grow a GM-free product. This has already become a concern in some areas where GM crops are grown.) GM proponents argue that there are no demonstrated human health risks involved with commercially available GM foods, so such separation and labeling are unnecessary and only an added expense that will scare consumers. In opposition, GM opponents note that there have been very few studies of GM foods and their safety, and the few studies that have been carried out were aimed primarily at determining whether the GM food in question is "substantially equivalent" to its natural counterpart, and if it is "substantially equivalent" in composition to the natural form, then it is considered safe. However, "substantial equivalence" is a poorly defined concept, and potentially a very slight difference in composition could have major health or environmental ramifications.

Indeed, depending on what level of evidence one accepts, some evidence exists that GM foods may pose health risks. In a widely publicized and controversial study, Dr. Arpad Pusztai of the Rowett Research Institute in Aberdeen, Scotland, reported stunted growth, damaged internal organs, and damaged immune systems in rats after feeding them experimental varieties (not commercially grown) of GM potatoes for several years. Part of the problem, at least according to critics of GM food, is found in the very techniques that are used to engineer the organisms. Viruses are typically used to insert foreign genes into an organism, and this process can result in other, unintended insertions of genetic material with unanticipated consequences either in the short or the long term.

As a result of the disparate views toward GM foods on various continents, different parts of the world have treated GM food very differently. The United States does not require print labeling. It is suggested that Europeans in general have a different attitude toward food than do Americans. Europeans traditionally have cared more about the food they eat and have been more "purist" concerning what they ingest. In addition, the mad cow disease (bovine spongiform encephalopathy) scares eroded European public confidence in their healthcare officials, and GM food was also viewed as an imposition from America. Regardless of whether any harm could be demonstrated to be caused by GM foods, as a precautionary measure and to allay public concerns, beginning in the late 1990s, the European Union implemented the labeling of GM foods and restricted the import of GM crops. This had a severe negative effect on corn imports from the United States to Europe, given that much of American corn is composed of GM varieties. By 1999, the concerns of Europe had spread to many other large importers of American crops, including Japan and South Korea. Various food companies in Europe and Japan implemented policies of removing any GM ingredients from their products. These developments have cost U.S. agriculture hundreds of millions of dollars as exports dropped and transgenic crops became devalued because of a lack of markets.

GM organisms also raise many environmental concerns. For example, laboratory studies have suggested that the pollen produced by Bt corn can harm Monarch butterfly larvae, although these studies have been disputed and any

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CASE STUDY 13.2 (continued)

risks from Bt crops under real-life conditions may be relatively low. Other studies have suggested that the toxins Bt corn produces can accumulate in soils and may have negative ecological effects. Concerns have also been raised that using crops genetically engineered to produce their own "insecticide toxins" could, analogous to the overuse of antibiotics to treat diseases, induce the evolution of insects and other crop pests that are resistant to the toxins. Such super pests might then not only attack the crop, but also begin attacking other plants. If such toxin-resistant pests have not evolved yet, that does not mean there is no potential for their evolution; after all, GM crops have seen widespread commercial use for 20 years. Concerns have also been raised that genetically engineered herbicide resistance could be spread to wild plants, such as wild relatives of the crops (many crops are essentially cultivated weeds), or the plants may even escape into the wild and ultimately produce "super weeds" that cannot be controlled by standard herbicides. Much damage has already been caused by the introduction of exotic species from one region of the world to another; the escape of GM organisms and their genes would effectively constitute additional cases of the introduction of exotic species, in this case from the laboratory to nature.

Another concern, not distinct from the above considerations, is the basic unpredictability of the effects of genetic engineering. A recent case in point involves potatoes. When potatoes were genetically modified to repel aphids, it was found that they actually attracted other pests, including the potato leafhopper that feeds on the plant's leaves. It has also been found that the stems of herbicide-resistant Monsanto soybean plants are more prone to cracking open in hot climates than are non-GM soybean plants.

The use of GM crops might not be "all or nothing." Grafting is common in certain types of horticulture, and genetically modified root stocks that are pest and disease resistant can have non-GM stalks and fruit- or nut-bearing portions grafted onto them. This has been done, for instance, with walnuts. Such hybrid plants may combine the best of both—the advantages of GM with a final non-GM product that will cause no concern to consumers.

Passions run deep on both sides of the GM organism debate. Should farmers in Britain, France, Sweden, and India be forced to destroy their crops of rapeseed or cotton, as has been the case in some instances, because they were sowed using "illegal" or "unapproved" GM seeds? Irrational fear of GM crops can lead to nonsensical actions, contend GM proponents. Yet opponents of GM crops argue that it is better to be "safe than sorry" when we do not know the potential consequences of the widespread use and consumption of GM organisms. For example, the president of famine-stricken Zambia refused to accept GM grain from food aid organizations to feed his people. Part of his concern was that European countries would not accept grain imports from Zambia (if contaminated with GM varieties) should the country ever recover its crop production. Some proponents of GM foods and crops suggest that the opponents of GM are hurting primarily the poor farmers in developing countries who may ultimately be the ones to most benefit from the "Gene Revolution" (following a half-century after the "Green Revolution"). It has been suggested that wealthy European consumers can easily afford to indulge in non-GM products, but the poor and starving need all of the help they can get. These proponents say GM plants and technologies should be designed specifically to increase yields and decrease costs in tropical and developing countries and distributed at fair prices. In fact, over the past few years, this is exactly what has been happening in China. China currently has the second largest GM program (the United States is number one), but in China, the emphasis has been to engineer insect and disease resistance, rather than focus on herbicide resistance. As of 2012, it was reported that the Chinese had introduced more than 120 different genes into approximately 50 different species. Already either in use or in the late trial stage are Chinese GM varieties of rice, cotton, wheat, tomatoes, sweet peppers, potatoes, rapeseed, peanuts, cabbage, melons, maize, chilies, papaya, and tobacco. Literally millions of Chinese farmers benefit from GM crops, especially Bt cotton. Approximately 2 million Chinese farmers plant Bt cotton on 7,000 square kilometers of fields, and since the introduction in 1997 of the Chinese version of Bt cotton, the use of toxic pesticides on these fields has dropped by 80%. Costs have decreased by 28%, and the farmers have accordingly increased their earnings. In August 2015, the Chinese government began a sustained ad campaign promoting GM crops, stating that they are key to China's economic development (and key to feeding its population). Naysayers suggest that it is only a matter of time before resistant insect strains evolve and all of the GM gains will be lost, but so far, the Chinese are benefiting from GM technology.

Critical Thinking

1. List some of the reasons GM organisms are being developed. How are they enhancing food production?
2. If you live in the United States, you probably eat some foods that are composed, at least in part, of GM organisms. Does this bother you? Are you aware of when you are eating foods with a GM component?
3. It has been suggested that GM crops and organisms might "escape" into nature, or crossbreed, with close natural relatives and cause damage to ecosystems. What is the evidence, thus far, for such a potential threat? What precautions do you think should be taken with GM crops to avoid such problems?

by Monsanto Corporation) of Davis, California, became the first genetically engineered whole food product to hit the market. Essentially, the Flavr Savr was designed so that an altered gene blocked production of a certain enzyme that controls ripening and softening. Normally, tomatoes are harvested before they are ripe, shipped, and then artificially ripened (such as by using ethylene gas) after they reach their destination. However, flavor is lost with such procedures, and an estimated 30% of the tomato crop is still destroyed by rotting or is damaged during shipping. The idea was that the Flavr Savr could be left on the vine longer so that it would ripen naturally and develop a better flavor, resist spoiling during the shipping process, and have a longer shelf life after it arrived at a supermarket or home; however, the Flavr Savr was not a success. Within a few years, it was off the market because of reported problems with taste, damage during shipping, poor growing in soils and climates outside of California where it was developed, and the general public wariness concerning GM foods. Still, many other fruits and vegetables are plagued by the same ripening and spoilage problems as tomatoes and might benefit from similar genetic engineering.

Genetic engineering can also change the taste or other properties of plants by modifying their sugar and starch content. Peas, corn, tomatoes, and other crops can be made sweeter. The starch content of potatoes can be increased, making them more suitable for potato chips.

In the long run, genetic engineering's most important contribution may be to increase the resistance of crops to insect and disease vectors. The common bacterium *Bacillus thuringiensis* (abbreviated as Bt) naturally produces a substance that is toxic to certain types of pest caterpillars. For several decades, Bt and its derivatives have been used as a natural pesticide on crops with good results; it is relatively nontoxic to birds, mammals, and various nonpest insects. Through biotechnology, the Bt bacterial genes can be implanted into the crops themselves so that they produce the toxin. Such a transgenic organism is in effect mostly plant but also part bacterium. Spiders and other creatures also produce toxins that kill insect pests. Plants that resist various viral, bacterial, and fungal diseases can be designed by implanting genes from various viruses, bacteria, plants, and animals into crop plants.

Clearly, transgenic crops require reduced loads of standard pesticides and have an advantage in resisting diseases. However, researchers point out that genetically engineered crops must be used carefully. Many insects and diseases can evolve very rapidly. If too much reliance is placed on one or a few types of transgenic crops, natural pest populations may rapidly evolve immunities to the toxins given off by the crops. Already there are reports of insects that can tolerate fairly high levels of Bt toxins. This situation is analogous to insect populations evolving the ability to withstand the assaults of standard insecticides. To prevent immunities from developing in the pest insects or disease vectors, IPM techniques can be used in conjunction with transgenic crops. For example, different types of transgenic and standard crops might be combined in the same field. The unaltered, nonresistant stands of plants would act as a feeding and breeding ground for insects that are not immune to the toxins engineered into the transgenic crops. Thus, the more damaging individuals—those carrying natural immunities—would never be allowed to dominate the population. By not overusing the resistant strains of crops, their effectiveness will be maintained.

Efforts are under way to alter plant crops genetically so that they will have increased tolerances to stresses such as drought, cold, heat, or high soil salinities. However, less progress has been made in this area than in developing insect- and disease-resistant strains. Stress-tolerant crops could be a real boon in developing countries that have only marginally arable lands, have soil salinization, or lack adequate irrigation systems. Some observers worry that in the long run stress-tolerant crops could cause more harm than good by encouraging the continued cultivation of marginal, fragile, or already damaged lands until they are destroyed.

From a human dietary perspective, an important potential of genetic engineering is to improve the nutritional content of familiar foods. People whose staple is rice often experience vitamin A deficiency; thus, researchers engineered a rice variety containing substantial quantities of beta-carotene, a precursor of vitamin A. (However, this "Golden Rice" has come under some criticism. It is suggested that the average person would have to consume 12 times the normal intake of rice to get the necessary amount of beta-carotene, and beta-carotene is best converted into vitamin A in a healthy person, not in the undernourished individuals targeted for Golden Rice. It might be more useful to help people with vitamin A deficiencies to grow various green vegetables that are rich not only in beta-carotene but also in other nutrients that are lacking in rice, Golden or otherwise.) Likewise, levels of various proteins might be increased in crops that are eaten directly by people and in those used as feed for farm animals.

Genetic engineering is also being used to meet the specialized needs of consumers in industrial countries: coffee with a lower caffeine content and rapeseed (oilseed, canola) varieties that produce specialized oils for use as lubricants, in cosmetics, for soaps, and in cooking. A mustard family plant has been designed to produce the biodegradable plastic known as polyhydroxybutyrate, which is similar to polypropylene (derived from petroleum). One concern with this kind of research is that currently many specialty oils, waxes, and rubbers are derived from tropical forests and are among the major exports of developing countries. Successful development of "oil crops" could restrict the market for these goods. However, by growing "plastic crops," the developing countries could produce their own plastics without relying on oil or petrochemical facilities. In addition, biodegradable plastics could alleviate many of the disposal problems associated with traditional nonbiodegradable plastics.

Fisheries

It is sometimes suggested that we could feed additional billions of people by harvesting the natural, renewable biological resources that grow wild on land and in the seas. People have been hunting wildlife and collecting naturally growing edible plants for millennia, but the reserves of such sources are virtually depleted. Certainly, traditional hunting and gathering on land is not a viable option for feeding anything but an infinitesimally small proportion of the current global population.

However, the ocean is often viewed in a different light. Using modern techniques, tens of millions of tons of fish and other seafood are harvested from the sea each year. The oceans are so vast that at first glance it would seem that a dent in our food shortages (especially protein shortages, for fish is high in protein) could be made by drawing more from this resource. Sadly, this is not the case.

Many people have a mistaken impression of the magnitude and abundance of life in the seas. They may be familiar with the productive shallow-water coastal and reef areas, which are unrepresentative of the life in the oceans. Most of the open ocean is a "biological desert" that is very sparsely populated by life forms. Only certain areas where nutrients upwell and collect near the surface are highly productive. Because these fishing grounds are limited, we are approaching, and may have already surpassed, the maximum sustainable yield of fishing from the oceans of approximately 80 to 100 million metric tons of fish a year. In the past decade, the global fish catch from the oceans has been in the range of 90 to 100 million metric tons per year. The oceans are literally mined; fishes and other organisms are removed much more quickly than they can replenish themselves. Fishing on the open oceans has often been done on a massive scale using drift nets. These huge nylon nets—some are as long as 50 kilometers (30 miles) and 30 meters (100 feet) deep—indiscriminately catch everything in their path, including squid, fishes, dolphins, seals, sea turtles, and marine birds. The carcasses of these unwanted animals, or by-catch, are simply thrown overboard as waste. As a result, international pressure has been mounting to limit the use of drift nets. Since 1992, the United Nations has imposed an international moratorium on the use of drift nets more than 2.5 kilometers (1.55 miles) long, but even if drift nets are banned, some fishing fleets will continue to use them illegally on the high seas. In addition, many broken pieces of nets or damaged and abandoned nets ("ghost nets") are floating unattended through the oceans. These ghost nets continue to catch and kill sea organisms indiscriminately.

Already, people have exploited certain species of ocean organisms, some perhaps to the point of **commercial extinction**, which occurs when it is no longer economically viable to harvest them due to depleted stocks (**FIGURE 13.12**). Populations that have

FIGURE 13.12 The collapse of a commercial fish population almost always creates financial hardship for fishing communities; local fishermen lose their livelihood and their expensive boats sit idle.

© Djordje Zoric/Shutterstock.

dropped to such low levels may never fully recover; indeed, they may become extinct. Classic examples of such overexploitation include the Peruvian anchovy fishery, the Alaskan king crab fishery, and the exploitation of whales. The Peruvian anchovy industry more than tripled its catch from 1960 to 1970, peaking at about 13 million metric tons in 1970. By 1973, it had collapsed to less than 2 million metric tons, possibly because of both overexploitation and adverse climatic conditions. It has never recovered to the levels of peak production. The Alaskan king crab story presents a similar scenario: peak production in 1980 was 84,000 metric tons, but this dropped to 7,000 metric tons in 1985 and has not fully recovered. Whales have been hunted to commercial extinction over several centuries, beginning on a large scale in the 1700s and early 1800s and continuing into the 20th century.

Oceans are also being polluted at a tremendous rate. Some seafood species are being killed off altogether, and others contain such high levels of toxic chemicals that they are unfit to eat. Many coastal cities continue to dump their raw or inadequately treated sewage and waste directly into the oceans. This pollution is destroying the wildlife. In 1988, 10,000 seals died in the North Sea, apparently from a viral infection that they could not fight off because the pollutants in the water had weakened their immune systems. Beluga whales inhabiting the St. Lawrence River have been reported to contain such high levels of heavy metals, **polychlorinated biphenyls (PCBs)**, and other pollutants in their flesh that their corpses are classified as toxic waste.

The surfaces of the oceans are manifesting the symptoms of the "pollution disease." Around the world, surface algal blooms, sometimes called *red tides*, are appearing with increasing frequency. Currently, dozens of red tides occur each year in Hong Kong's harbor, where they were unknown before the mid-1970s. In a red tide, certain species of phytoplankton in the upper layers of the oceans proliferate out of control. Apparently, sewage, fertilizer runoff, and other pollutants that are released into the water are fit nutrients for the algae, which grow on the surface of the water. As the algae grow, they deplete the oxygen in the water that is necessary for the survival of other organisms. Shellfishes, crabs, shrimp, a variety of fishes, and numerous other organisms can be suffocated under the red tide (**FIGURE 13.13**). An algal bloom off the coast of Norway reportedly killed more than 609,000 kilograms (1.34 million pounds) of salmon and trout. Poisoned shellfish, if consumed, can cause food poisoning.

FIGURE 13.13 Red tide bloom near La Jolla, California.

Courtesy of P. Alejandro Díaz.

Perhaps even more pernicious than overfishing and pollution are the effects that climate change and the weakening of the ozone layer will have on marine life. Abnormally warm ocean temperatures appear to be killing coral reefs; it is estimated that 11% of the world's reefs have been lost as of 2001, with an additional 40% lost as of 2015. In the Philippines, where the destruction is the worst, more than 70% of reefs have been destroyed, and only 5% can be said to be in good condition. If the current rate of destruction continues, more than 70% of the reefs will be obliterated in the next two decades. Reefs are particularly important because an estimated 500 million people live within 100 kilometers (62 miles) of a reef and depend on the reefs and their biota for food and employment, either directly or indirectly. A 2008 comprehensive report (last year for which dependable data is available) published by **National Oceanic and Atmospheric Administration (NOAA)** indicated that one-third of all corals on the planet are threatened; more than one-half of the coral reef habitats are in poor or fair condition because of climate change and human-related causes. An estimated 25% of the fish catch in developing countries comes from coral reef areas, helping to feed 1 billion people.

In 1988, when ozone levels reportedly declined 15% because of the ozone hole over Antarctica, phytoplankton levels also decreased by 15% to 20%. Phytoplankton are small, photosynthetic organisms; they form the basis of the oceanic food chain and also help the oceans to absorb carbon dioxide (the main greenhouse gas). If increasing global heating and destruction of the ozone layer adversely affect the phytoplankton, this will have a detrimental effect on the entire ocean ecosystem. Some researchers have even suggested that life in the oceans may collapse. As phytoplankton die, the oceans will take up less carbon dioxide, which will lead to increased global warming; this, in turn, will accelerate the destruction of the ocean ecosystem. Ironically, both too much of certain phytoplankton (those producing red tide) and too few phytoplankton (destroying the base of the marine food chain) are detrimental to oceanic ecosystems.

What about the possibility of increased "fish farming" through **aquaculture** (used to refer to aquatic organism farming in general, or freshwater "seafood" farming in particular) or **mariculture** (saltwater seafood farming)? Organisms such as salmon, shrimp, and edible seaweed are being raised under controlled conditions in many countries. Aquaculture systems can be very productive and efficient at producing animal protein, and generally are more efficient than terrestrial farms (see **CASE STUDY 13.3**). The drawbacks of aquaculture are that it is very labor intensive, it can involve very intricate management of delicate ecosystems, and

CASE STUDY 13.3 AQUACULTURE

As catches from natural fisheries have stabilized or even decreased, production from fish farms (including freshwater and marine fishes, mollusks, crustaceans, and other aquatic edible animals) has skyrocketed over the past 2 decades (**FIGURE 1**). Today, aquaculture continues to be the fastest-growing form of food production in the world; 30% of the world's food fish is produced by aquaculture, and this is bound to increase in years to come. China is the leader in fish farming, producing an estimated 70% of the world's output. In terms of volume, but not value of final product, the next largest producer is India, followed by Japan, Indonesia, and Bangladesh. Overall, nearly 90% of all aquaculture is done in Asia.

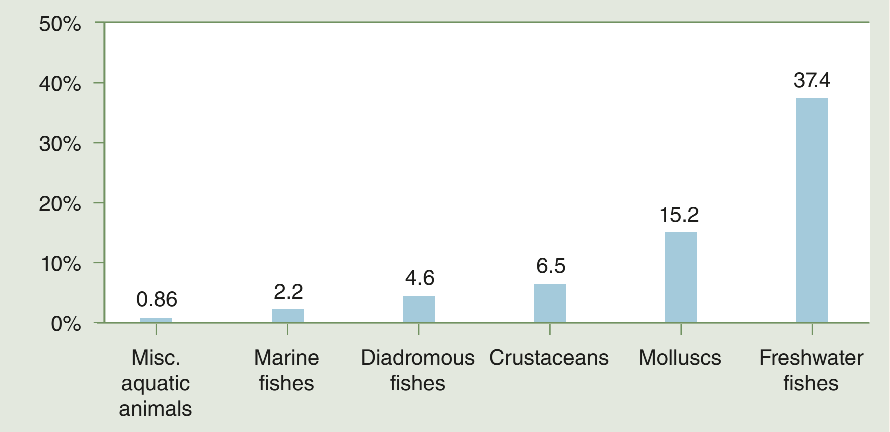

FIGURE 1 Global aquaculture production in 2012 in millions of metric tons.

Data from FAO Global Aquaculture Production database. Retrieved from June 2017 at https://salmonfarmscience.files.wordpress.com/2014/04/world-aquaculture-production-2012.png.

Fish farms produce not only fishes, such as flounder, salmon, trout, carp, tilapia, and catfishes, but also oysters, clams, shrimp, prawns, and many other aquatic organisms (**FIGURE 2**). More than 200 species are farmed using aquaculture, although the majority of production is only a dozen or so species. More than half of world production consists of relatively low-value freshwater fishes, such as carp and tilapia, which are primarily raised for local consumption. High-value species, such as salmon, shrimp, and certain mollusks, are grown primarily for export. About two-thirds of fish farming activities take place along inland rivers and in lakes, ponds, and artificial tanks, whereas the remainder are located along the coasts, in bays, and sometimes even in the open ocean.

An important reason for the steady expansion of aquaculture is that fishes and other aquatic organisms typically are very efficient at turning feed from plants into animal meat. Fishes, crustaceans, and mollusks are cold-blooded, so they do not burn excess calories to keep warm. The water they live in helps support their body weight, so they expend less energy than do comparable terrestrial animals. As a result, only 2 pounds (or less) of feed is typically required to produce a pound of fish, far less than is needed to produce an equivalent amount of beef or pork.

However, fish farming has numerous drawbacks. Aquatic farming naturally requires tremendous quantities of clean water, a substance in increasingly short supply. Of course, the water is not consumed in the same way that water is when crop plants are irrigated, but fouling of the water environment can be a real problem. Excess organic wastes may pollute the water to the extent that all aquatic organisms suffer; for instance, excess wastes may induce algae blooms, resulting in oxygen depletion and suffocation of fishes, mollusks, and

FIGURE 2 An aquaculture facility in Louisiana raises catfish. The color differences between ponds are due to the number and type of algae in each pond.

Courtesy of Scott Bauer/Agricultural Research Service/USDA.

(continues)

CASE STUDY 13.3 (continued)

crustaceans. Like any animal farmer, fish farmers generally must purchase grain products to feed their stock. This, on a global scale, means that less grain is available for other purposes (such as feeding terrestrial livestock or even people). Furthermore, some aquatic species, such as shrimp or salmon, are carnivorous or omnivorous. In aquaculture, such species typically are fed pellets with a high-protein content. But where does the protein come from? In some cases, it comes from plant-based proteins, but in many cases, the feed pellets used in aquaculture are made, at least in part, from fishmeal derived from relatively low-value fish caught in the wild, such as anchovies and herrings. In such cases, aquaculture is not supplementing and adding to the wild fish catch, but actually consuming part of the wild catch. In contrast to carnivorous species that must be artificially fed a rich diet, marine mollusks (such as oysters and clams) raised in pens along coasts and in bays can feed on nutrients that naturally occur in the water and thus require little in the way of artificial inputs.

Specialized and expensive equipment may be necessary in aquaculture operations, especially if the stock is being raised in artificial tanks, ponds, or holding areas. Hormones, antibodies, vaccines, and other medical supplies may be required. The dense populations of fish that are typical of modern fish farms are vulnerable to infectious diseases. Disease outbreaks among farmed aquatic species, especially in monoculture situations (where a single species is being raised in a small, confined area), are a constant threat. For instance, in 1999, farmed shrimp in Ecuador experienced an outbreak of white spot virus that resulted in a loss of nearly $500 million of product. Inbreeding, resulting in genetically weakened strains, can also be a problem, particularly if cultivated organisms escape and interbreed with a wild population.

Another controversy that has developed in recent years is the use, or potential use, of transgenic (bioengineered or genetically modified) species in aquaculture. For instance, transgenic Atlantic salmon (sometimes colloquially referred to as "super salmon") that have been genetically engineered with growth hormones reportedly can grow four to six times as quickly as the wild variety, reach larger sizes, and are more efficient at turning feed into fish flesh. As of this writing, the transgenic salmon have yet to be introduced to the countries where their use has been proposed, including Canada, Chile, New Zealand, and the United States. While governing authorities in these countries continue to debate the practice, the United States will allow transgenic "Aqua-Advantage" fish in 2018—U.S. consumers will have access to genetically modified animal meat for the first time. Concerns raised relative to the transgenic salmon are comparable to the concerns expressed more generally relative to genetically modified organisms: Are they totally safe for human consumption? Is there a possibility that the modified fish could have a negative impact on natural fish populations and ecosystems? If, or when, transgenic fish escape into the wild, will they outcompete their nonmodified relatives? Will they destroy natural prey populations? (Many critics suggest that it is inevitable that some will escape—farmed salmon have been known to escape into the wild, sometimes in large numbers. In December 2000, as many as 100,000 farmed salmon held in pens off the coast of Maine escaped when a storm damaged their cages.) Will transgenic fishes interbreed with nonmodified populations and essentially genetically destroy the wild populations? These are all issues that will increasingly come to the fore in future years. Currently, major efforts are underway to derive the benefits of transgenic salmon and other fishes while protecting wild varieties. Examples include raising and keeping transgenic species in secure, self-contained, land-based facilities so that there is no possibility of escape into the wild, or developing strains where the final adults raised for food purposes are sterile so that even if they inadvertently escape into the wild they will not reproduce or mate with wild varieties.

Another major problem with fish farming is the space it requires. The best settings for fish farms are along coasts, rivers, and lakes, but these same areas are considered prime waterfront property, and land values are often very high. Furthermore, in some areas, coastal mangrove forests and other wetland areas have been cleared to build fish farms. These coastal wetlands are the breeding grounds for wild fishes, so clearing such areas often causes natural (wild) fish populations to decline.

Still, fish farming continues to expand and with good reason. It is one of the most efficient means of turning plant products into animal meat. With proper management, fish farming can have a very low impact on the environment. As the human population increases, we can expect that more and more of the animal protein in our diet will come from the cultivated aquatic realm.

Critical Thinking

1. How can aquaculture serve to protect wild populations of aquatic organisms?
2. What are some potential ways that fish farming can harm wild populations?
3. Do you believe that "super salmon" and other genetically modified fish varieties should be farmed? If so, under what conditions? If not, why are you opposed to the raising of such varieties?
4. List the advantages and disadvantages of aquaculture. Do you think that the advantages outweigh the disadvantages? Explain.
5. Do you believe that aquaculture operations should be promoted in the United States? Explain.

it is not suited to all locations. One must have adequate water of the right purity, salinity, and so forth, and temperatures need to be maintained within close tolerances. The startup and maintenance costs of aquaculture can be relatively high. Some of the best locations for aquaculture are coastal areas that are being destroyed by pollution and development. For these sorts of reasons, many experts have little hope that aquaculture will ever significantly relieve the world's hunger.

13.3 The Soil of the Earth

Soil is one of our most precious commodities: It is vital for the health and well-being not only of human civilization, but also of most terrestrial ecosystems. Without soil, we could not grow food, our single most important activity.

We are quickly squandering our natural inheritance of soils. Various estimates suggest that we are losing soil to erosion at a rate of 25 to 75 billion metric tons a year globally. When land is cleared for agriculture, very little plant material is left to reinforce the soil when it rains. The soil washes away. The annual loss of topsoil from agricultural lands averages about 17 metric tons (almost 19 tons) per hectare (2.5 acres) in the United States and Europe and as much as 30 to 40 metric tons per hectare in parts of Asia, Africa, and South America. In contrast, erosion rates in undisturbed natural forests are on the order of 0.004 to 0.05 metric ton per hectare per year; in nature, soil loss generally is more than offset by soil formation. It has been estimated that soil erosion costs the United States some $44 billion a year in direct damage to agricultural lands and indirect damage to infrastructures, waterways, and health (**FIGURE 13.14**). Globally, the direct and indirect costs of soil erosion may be close to $400 billion a year.

FIGURE 13.14 Lack of growth (the light areas) for this field of new wheat in Palouse, Washington, indicates topsoil loss.

Photo by Tim McCabe, USDA Natural Resources Conservation Service.

As soils are depleted on prime agricultural lands, crop yields decrease. For every 2.5 centimeters (1 inch) of topsoil lost, average corn and wheat yields drop by about 6%. Generally, at least 15 centimeters (6 inches) of topsoil are needed to grow crops. After the layer of topsoil has become too thin, the land is no longer useful for agricultural production.

Some soil loss can be sustained, because soil is continually produced on the surface of the Earth. The generation and maintenance of soils are functions that healthy natural ecosystems perform for "free." However, under the best of conditions, soil formation is a very slow process. Some scientists have estimated that soil is forming in the United States at an average rate of only about 2.5 centimeters (about 1 inch) per century, which is equivalent to about 3.7 metric tons per hectare per year; other researchers suggest that the average rate may be closer to 1 metric ton per hectare per year. Around the world, some studies indicate that average rates of topsoil formation may be as little as 2.5 centimeters (about 1 inch) in 500 or 1,000 years. The inescapable conclusion is that we are losing our soils more quickly than they are forming.

Currently, modern civilization is living off—and eroding into—the capital of the past (the soils accumulated over many thousands of years), rather than using the soils in a sustainable manner. We need to learn to live off income; that is, to deplete the soils no faster than they are forming under natural conditions.

What Is Soil?

Soil is a combination of weathered, disintegrated, decomposed rocks and minerals (technically known as *regolith*) plus the decayed remains of plants and animals (organic matter or humus); small living animals, plants, fungi, bacteria, and other microscopic organisms; water; and air. For all purposes, soil is alive. Typical soil is about 50% mineral and organic matter by volume and about 50% water and air. Literally thousands of different types of soils are found around the world, but they all serve the same vital functions in the ecosystems in which they are found. Soils hold nutrients and water in place such that surface fauna and flora can grow and thrive. Without healthy, porous soils, most rainwater quickly runs off the surface of the land instead of soaking in. Soils supply the vital nutrients, such as usable nitrogen, phosphorus, sulfur, carbon, hydrogen, oxygen, and various trace elements and important compounds, to the plants that grow in the soil. As organisms die and are decomposed in the top layer of the soil, the nutrients are recycled back to the above-ground organisms.

Healthy soil is alive, a complex ecosystem unto itself. Without its living components, soil lacks its characteristic properties: texture, fertility, and the ability to dispose of wastes and recycle nutrients. An amazing number of organisms can live in a handful of soil. Larger animals that live in soils include earthworms, mites (relatives of spiders and ticks), millipedes, and insects. In a little more than three-quarters of square meter (1 square yard) of pasture in Denmark, researchers found 40,000 small earthworms and related organisms, almost 10 million roundworms, and more than 40,000 mites and insects. This is not even taking truly microscopic organisms into account. One ounce (approximately 28 grams) of good forest soil can contain:

- More than 28 million bacteria
- Approximately 3 million yeast cells
- 1.4 million individual fungi

The same amount of good agricultural soil can contain:

- Billions of bacteria
- 11 million fungi
- 1.4 million algae 850,000 protozoa

A typical well-developed soil is not a homogeneous mass. It consists of layers, or **soil horizons**, that are approximately parallel to the surface of the Earth (**FIGURE 13.15**). The horizons have different biological, physical, and chemical attributes, such as the amount of living and dead organisms and organic matter they contain, water and air content, texture, structure, color, and mineral content. In any particular part of the world, the soil horizons develop characteristics based on the underlying bedrock and the influence of the climate, flora, and fauna over time. In some places, many horizons develop, whereas elsewhere only one or two horizons are distinguishable. From top to bottom, a typical soil profile (a vertical section through the soil at a particular locality) may exhibit the following basic soil horizons: the uppermost organic matter and humus (heavily decomposed organic matter), the topsoil, the subsoil (composed mainly of minerals), a layer of partially disintegrated rock, and the underlying bedrock.

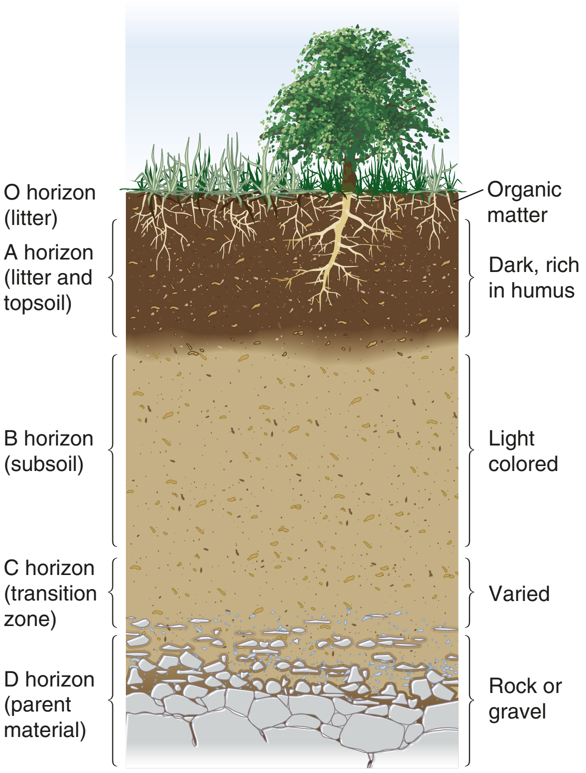

FIGURE 13.15 A typical soil is composed of five horizons.

Global Assessment of Soil Degradation

For many years, the amount and degree of **soil degradation**, leading to land degradation, has been a topic of intense controversy. For several decades, certain environmentalists have enumerated cases of **deforestation**, overgrazing, desertification, and clear destruction of once-fertile lands. At the same time, other experts pointed out that crop yields and livestock production have increased significantly since World War II and concluded that land degradation is not a major global problem. This dispute was essentially unresolvable without a global database on soil degradation.

A major study, the Global Assessment of Soil Degradation, was sponsored by the United Nations Environment Programme and coordinated by the International Soil Reference and Information Centre in the Netherlands. The Global Assessment of Soil Degradation, unlike many earlier studies, looked only at soil/land degradation that has occurred because of human intervention since World War II, specifically, from 1945 to 1990. Hundreds of soil scientists measured the degree, area, and causes of land degradation since 1945, and the results were compiled by continental regions and globally. The findings were alarming. Globally, approximately 2 billion hectares (4.8 billion acres), or 17%, of the vegetated land surface of Earth has been degraded by people to some extent in less than half a century.

On a worldwide basis, livestock overgrazing, deforestation, and agricultural activities account for more than 90% of the soil degradation since 1945. Overgrazing is responsible for 35% of land degradation, deforestation for 30%, and agricultural activities for 28%. Of course, these percentages vary greatly by continent, but the damage from soil and land degradation is still

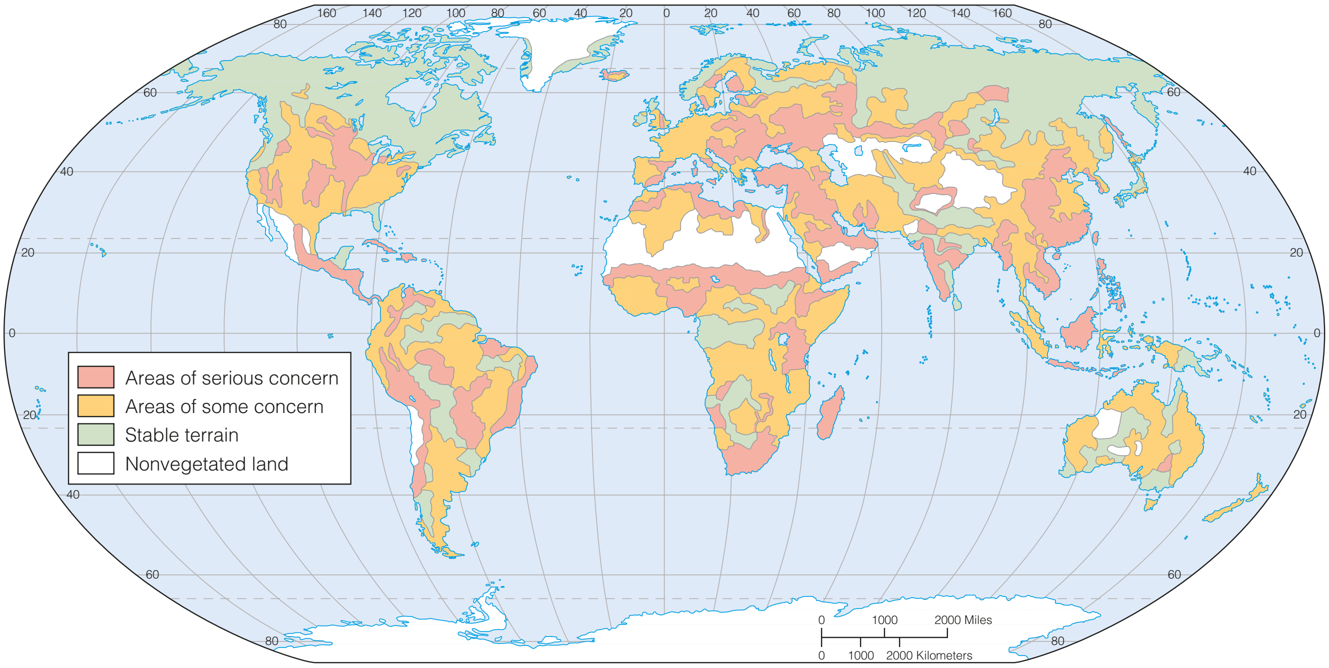

FIGURE 13.16 Areas of concern for soil degradation.

Modified from World Resources Institute. (1992). *World Resources 1992–1993*. New York, NY: Oxford University Press.

occurring. As **FIGURE 13.16** shows, every inhabited continent has areas that are at serious risk.

The U.S. Midwest and Great Plains, the America's breadbasket, have experienced various degrees of soil degradation. The Soil Conservation Service has determined that approximately one-fourth of all U.S. cropland is eroding faster than is sustainable. Central America is experiencing extreme soil degradation and is an area of serious concern for the future. Most of this damage is a result of deforestation, overgrazing, and mining, but improper agricultural practices are also an important factor. In South America, areas of intensive deforestation are particularly in danger of continued soil degradation, as is the mountainous region on the west coast.

Europe, particularly the middle and eastern portions, is experiencing extreme soil degradation that is predicted to continue into the future. Much of this is attributable to pollutants, including industrial and urban wastes and pesticides that have damaged the soil. Asia is also experiencing severe and continuing soil degradation, especially in India, China, and Southeast Asia. Deforestation, agriculture, and overgrazing primarily cause Asian soil degradation. Africa has continued soil degradation and desertification, especially along the north coast, in the sub-Saharan Sahel region, and in South Africa. Overgrazing, wind erosion, and poor agricultural practices are to blame for much of Africa's problems. Compared with the rest of the world, Australia is an area of only moderate soil degradation. Most of Australia's problems with soil deterioration result from overgrazing.

Stopping Soil Degradation

As the world population continues to increase, stabilization and restoration of soil resources will become increasingly important. Since World War II, modern agricultural technologies have masked the soil deterioration by increasing yields even as the soil has become degraded. Crop yields would have been even higher with healthier soils. If unsustainable agricultural practices continue, the soil will become so degraded that despite the use of fertilizers, pesticides, and high-yield crop varieties it will not be possible to produce a good harvest. After the soil is dead or eroded, the land becomes barren.

Techniques, such as no-till sowing of crops, drip irrigation, crop rotation, and leaving land fallow, can mitigate or prevent soil degradation, but many farmers often do not practice them for simple economic reasons (**FIGURE 13.17**). The farmers find that it does not make short-term economic sense to invest very heavily (if at all) in soil conservation, preservation, or restoration efforts. Of course, in emphasizing the maximization of short-term profits, the farmer is destroying the capital upon which the business depends, but in a fertile area, the soil may take half

(a) (b)

FIGURE 13.17 **(a)** No-till planting in the residue of the previous crop reduces erosion and returns nutrients to the soil. This field is in northwest Iowa. **(b)** Drip irrigation delivers water directly to plants (like the grapes shown here) and helps prevent erosion by reducing water runoff.

(a) Photo by Gene Alexander, USDA Natural Resources Conservation Service. (b) Courtesy of Lynn Betts/USDA ARS.

a century to become severely degraded—longer than the individual farmer may stay in business. In the past, the next generation would move on to new land, but the world is now running out of new land to place under the plow.

Aside from economic considerations, even if an isolated farmer wants to practice soil conservation techniques, often this is impossible because the action required to stop soil degradation may go beyond the scale of a single farm. Many factors are causing soils to degrade around the world. Soil conservation measures, such as watershed management and river and catchment basin maintenance, may be required on a regional or national level. Only governmental authorities on a local, national, or even international level can implement such projects. An isolated farmer may be virtually helpless if the government does not support and implement sound conservation policies.

Ultimately, the problem of global soil degradation can be solved, but it must happen through a variety of actions addressing a multitude of causes on every level from the individual to the international community. The long-term needs of society, which essentially means sustainability, must take precedence over all other concerns, be they personal short-term economic gains, debt payment on the part of a poor government, or political jockeying in the international arena. Without healthy soil, civilization as we know it cannot survive.

Study Guide

Summary

- Virtually all food for humankind comes from other organisms, with just three kinds of plants—rice, wheat, maize (corn)—constituting 65% of the global food supply.
- Depending on estimates, globally at least 795 million people are chronically hungry and more than 1 billion are undernourished and underweight.
- Globally, the number of people who can be fed adequately depends on the components of the diet (grain vs. animal products, for instance).
- An important topic of debate is how many people will be able to be fed in the future.
- "Modern agriculture," including the "Green Revolution," is heavily dependent on monocultures, mechanization, irrigation (where needed), and the use of fertilizers, pesticides, and herbicides.
- Newer, ecologically sound, and environmentally friendly farming methods are now increasingly being used, such as integrated pest management (IPM) and crop rotation.

- Genetically modified foods and crops potentially hold great promise for the future but are also surrounded by controversy.
- Aquatic organisms (both wild and farmed) are an important component of the human diet, and aquaculture (aquatic organism farming) is increasing at a fast pace.
- Soil is vital for terrestrial food production and also for the well-being of most terrestrial ecosystems.
- Globally, primarily because of the intervention of people, soil is being lost at an alarming rate—much faster than it is being produced by natural processes.

Key Terms

agriculture
aquaculture
bioengineering
biological control
biotechnology
carryover grain stocks
climax community
commercial extinction
crop rotation
cultivable land
deforestation
desertification
ecological succession
erosion
fertilizers
genetically modified (GM) crops
grain production
Green Revolution
herbicides
hunger
integrated pest management (IPM)
irrigation
malnutrition
mariculture
monoculture
National Oceanic and Atmospheric Administration (NOAA)
organic farming
polychlorinated biphenyls (PCBs)
pesticides
pioneer stage of succession
rule of 10s
salinization
soil
soil degradation
soil fertility
soil horizons
swidden techniques
topsoil
transgenic crops
waterlogging

Study Questions

1. Describe the current global food situation. Is everyone fed adequately?
2. What is hunger? Approximately how many hungry people are there in the world?
3. What three plant species supply most of the world's food?
4. What was the "Green Revolution"?
5. Describe the effects of modern intensive agriculture.
6. Given that the world population continues to grow, more food will be needed in the future. What are two basic strategies that can be pursued to increase world food production?
7. Do you believe that the world could adequately feed a population of 10 billion? Justify your answer.
8. What are the high and low estimates of the number of people that could be fed in the future? What types of assumptions are these estimates based on?
9. What is the major nonagricultural food source? Is it being used sustainably?
10. How can biotechnology, bioengineering, and the increasing use of genetically modified organisms help us deal with increasing food scarcity?
11. What are some of the criticisms of GM organisms?
12. How does integrated pest management (IPM) attempt to control crop pests?
13. What is soil?
14. Discuss the types and extent of soil degradation that are occurring globally.
15. Why are soil and potential soil degradation such important issues?
16. What is being done to help stop global soil degradation?

What's the Evidence?

1. The authors state that perfect management of the world's current food supply could adequately feed the world's population. Do you agree? What is the evidence for this statement? Is "perfect management" realistic or possible?
2. The authors contend that global soil loss and depleted soil fertility, in part the result of modern agricultural techniques, are vital issues that must be addressed in this century. Are you convinced they are as important as the authors suggest? Cite evidence to support your answer.

Calculations

1. Currently, about 1.5 billion hectares (3.7 billion acres) of land worldwide is under cultivation. Assuming that currently just enough food is produced to feed everyone on Earth, if the world population increases from 7 billion to 8 billion and yields per unit area of land remain constant, approximately how much more land will need to be cultivated to feed everyone?
2. Using the same assumptions as in Question 1, how much more land will need to be cultivated if the world population increases from 7.4 billion to 10 billion?

Illustration and Table Review

1. Study carefully the projections shown in Figure 13.3 (possible land futures). If current crop yields per area of land remain the same and the world population grows according to World Bank estimates, approximately how much land will need to be cultivated in 2050 to feed the world's population? What percentage increase is this over the amount of land currently under cultivation?
2. If current crop yields per area of land double and the world population grows according to World Bank estimates, approximately how much land will need to be cultivated in 2050 to feed the world's population? How does this compare with the amount of land currently under cultivation?
3. Referring to Figure 13.9a (world grain yields), beginning in 1960, approximately how many years did it take to increase average world grain yields by 25%?
4. Referring to Figure 13.16 (areas of concern for soil degradation), a continuous band of desert and areas at moderate to very high risk of desertification stretches from the coast of Western Africa east into the Asian heartland. About how many thousands of miles long is this continuous band?