Food, Soil, and Pest Management

12

Golden Rice: Grains of Hope or an Illusion?

CORE CASE STUDY

Many of the world's poor do not have enough land or money to obtain foods that give them enough protein and essential vitamins and minerals to prevent malnutrition. For example, according to the World Health Organization (WHO), 120–140 million children in developing countries, mostly in Africa and Southeast Asia, do not get enough vitamin A. This makes them more susceptible to common childhood infectious diseases. Some 250,000 to 500,000 children younger than age 6 go blind each year from a lack of vitamin A, and within a year, more than half of them die.

Preschool children can get their daily requirement of vitamin A by eating a small mango or small amounts of vegetables, yellow sweet potatoes, or coriander. But these foods are too expensive for most poor people to grow or buy. Children can also be given two vitamin A capsules a year, but so far, there has been no large-scale effort to provide such supplements to the world's poor.

In 1999, scientists Ingo Potrykus and Peter Beyer decided to tackle this problem by genetically engineering a form of rice that contained beta-carotene, a substance that the body can convert to vitamin A. They transferred snippets of DNA from genes of the common daffodil (Figure 12-1, right) and from a soil bacterium into conventional rice strains to produce a strain of rice containing beta-carotene. It also contains more iron than do conventional rice strains.

Potrykus and Beyer estimate that eating 200–300 grams (about 1 to 1.5 cups) of their latest golden rice strain per day should provide enough vitamin A to prevent blindness and susceptibility to common childhood infections. They have worked out agreements for poor subsistence farmers in several developing countries to get the new strain free of charge. The International Rice Research Institute is conducting field trials of golden rice and commercial stains of this rice may be released by 2011. However, there is controversy over the new rice strain, as we discuss later in this chapter.

We face important challenges to increase food production without causing serious environmental harm. Each day, there are about 225,000 more mouths to feed. Between 2008 and 2050, the world's population is projected to increase by 2.6 billion people. To provide enough food for these individuals, we will have to sharply reduce poverty, grow and distribute more food than has been produced since agriculture began about 10,000 years ago, and reduce the harmful environmental impacts of food production. In this chapter, we consider these challenges.

age fotostock/SuperStock

Courtesy of Jongky Irawan

Figure 12-1 *Golden rice* is a new genetically engineered strain of rice containing beta-carotene (giving it its yellow color), which the body can convert to vitamin A. By 2011, some farmers in countries such as India, Bangladesh, and China may begin replacing some conventional strains of rice (left) with this new golden rice strain.

Key Questions and Concepts

12-1 **What is food security and why is it difficult to attain?**

CONCEPT 12-1A Many of the poor suffer health problems from chronic lack of food and poor nutrition, while many people in developed countries have health problems from eating too much food.

CONCEPT 12-1B The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.

12-2 **How is food produced?**

CONCEPT 12-2A We have sharply increased crop production using a mix of industrialized and traditional agriculture.

CONCEPT 12-2B We have used industrialized and traditional methods to greatly increase supplies of meat, fish, and shellfish.

12-3 **What environmental problems arise from food production?**

CONCEPT 12-3 Food production in the future may be limited by its serious environmental impacts, including soil erosion and degradation, desertification, water and air pollution, greenhouse gas emissions, and degradation and destruction of biodiversity.

12-4 **How can we protect crops from pests more sustainably?**

CONCEPT 12-4 We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).

12-5 **How can we improve food security?**

CONCEPT 12-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

12-6 **How can we produce food more sustainably?**

CONCEPT 12-6A Sustainable food production will require reducing topsoil erosion, sharply reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies for more sustainable farming, fishing, and aquaculture.

CONCEPT 12-6B Producing enough food to feed the rapidly growing human population will require growing crops in a mix of monocultures and polycultures and decreasing the enormous environmental impacts of industrialized food production.

Note: Supplements 2 (p. S4), 3 (p. S10), 4 (p. S20), 5 (p. S31), and 13 (p. 78) can be used with this chapter.

There are two spiritual dangers in not owning a farm.
One is the danger of supposing that breakfast comes from the grocery,
and the other that heat comes from the furnace.

ALDO LEOPOLD

12-1 What Is Food Security and Why Is It Difficult to Attain?

▶ **CONCEPT 12-1A Many of the poor suffer health problems from chronic lack of food and poor nutrition, while many people in developed countries have health problems from eating too much food.**

▶ **CONCEPT 12-1B The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.**

Many of the Poor Have Health Problems Because They Do Not Get Enough to Eat

Having **food security** means that every person in a given area has daily access to enough nutritious food to have an active and healthy life. Today we produce more than enough food to meet the basic nutritional needs of every person on the earth. But even with this surplus of food, one of every six people in developing countries is not getting enough to eat. These people face **food insecurity,** living with chronic hunger and

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.

poor nutrition, which threatens their ability to lead healthy and productive lives (**Concept 12-1A**).

Most agricultural experts agree that *the root cause of food insecurity is poverty,* which prevents poor people from growing or buying enough food (**Concept 12-1B**). For example, since 1990, India has produced enough grain to feed its entire population. But more than 200 million Indians—about one-fifth of the country's population—are hungry because they cannot afford to buy or grow enough food.

Other obstacles to food security are political upheaval, corruption, and war (**Concept 12-1B**). These problems interfere with food distribution and transportation systems and can result in people going hungry while stored foods spoil or are distributed unevenly in a country or region. Achieving food security on regional and global levels for both poor and affluent people also depends on greatly reducing the harmful environmental effects of agriculture, which we explore further in this chapter.

Many People Suffer from Chronic Hunger and Malnutrition

To maintain good health and resist disease, individuals need fairly large amounts of *macronutrients* (such as carbohydrates, proteins, and fats, see Table 12-1 and Figures 8, 9, and 12, pp. S42–S43, in Supplement 6), and smaller amounts of *micronutrients*—vitamins, such as A, C, and E, and minerals, such as iron, iodine, and calcium.

People who cannot grow or buy enough food to meet their basic energy needs suffer from **chronic undernutrition,** or **hunger** (**Concept 12-1A**). Most of the world's chronically undernourished children live in developing countries. They face the possibilities of suffering from mental retardation and stunted growth and dying from infectious diseases such as measles and diarrhea, which rarely kill children in developed countries.

Many of the world's poor can afford only to live on a low-protein, high-carbohydrate, vegetarian diet consisting mainly of grains such as wheat, rice, or corn. They often suffer from **chronic malnutrition**—deficiencies of protein and other key nutrients—which weakens them, makes them more susceptible to disease, and hinders the normal physical and mental development of children.

According to the U.N. Food and Agriculture Organization (FAO), the estimated number of chronically undernourished or malnourished people fell from 918 million in 1970 to 862 million in 2006. (See Figure 13, p. S17, in Supplement 3 for a map of the countries with the most undernourished people.) This is a good start, but it is still high—nearly three times the population of the United States. A 2007 study by University of Minnesota economists Ford Runge and Benjamin Senauer estimated that increased food prices from the massive diversion of corn to produce ethanol for fueling cars could increase the number of hungry and malnourished people to 1.2 billion by 2025 instead of decreasing it to 625 million as projected by the FAO.

Despite some progress, one of every six people in developing countries (including about one of every three children younger than age 5) is chronically undernourished or malnourished (Figure 1-14, p. 19). About 75% of these people live in rural areas of developing countries. In 2005, the FAO estimated that each year, nearly 6 million children die prematurely from chronic undernutrition and malnutrition and increased susceptibility to normally nonfatal infectious diseases (such as measles and diarrhea) because of their weakened condition (**Concept 12-1A**). This means that each day, an average of 16,400 children die prematurely from these mostly poverty-related causes. How many people died from such causes during your lunch hour?

Table 12-1

Key Nutrients for a Healthy Human Life

Nutrient	Food source	Function
Proteins	Animals and some plants	Help to build and repair body tissues
Carbohydrates	Wheat, corn and rice	Provide short-term energy
Lipids (oils and fats)	Animal fats, nuts, oils	Help to build membrane tissues and create hormones

Many People Do Not Get Enough Vitamins and Minerals

According to the World Health Organization (WHO), one of every three people suffers from a deficiency of one or more vitamins and minerals, most often in developing countries and involving *iron, vitamin A,* and *iodine*.

Having too little *iron*—a component of the hemoglobin that transports oxygen in the blood—causes *anemia,* which results in a general lack of vitality. According to the WHO, one of every five people in the world—mostly women and children in tropical developing countries—suffers from iron deficiency. It causes fatigue, makes infection more likely, and increases a woman's chances of dying from hemorrhage in childbirth.

New strains of golden rice (**Core Case Study**) contain more iron than conventional strains and could help to reduce the severity of iron and vitamin A deficiencies. However, some critics view these claims as mostly a public relations ploy financed by the seed industry to soften up widespread consumer opposition to genetically engineered crops. They contend that golden rice is drawing funding and attention away from a possibly quicker and cheaper option of giving

CORE CASE STUDY

John Paul Kay/Peter Arnold, Inc.

Figure 12-2 Woman with goiter in Bangladesh. A diet with insufficient iodine can cause this enlargement of the thyroid gland. Adding traces of iodine to salt has largely eliminated this problem in developed countries.

two vitamin A capsules per year to each of the millions of children suffering from vitamin A deficiency.

In addition, scientists want more evidence on how much of the beta-carotene in the golden rice will actually be converted to vitamin A in the body. And they want evidence that golden rice strains that perform well in the laboratory will perform as well in nature where many more factors come into play. Current field trials of golden rice in the Philippines may provide such information.

Elemental *iodine* is essential for proper functioning of the thyroid gland, which produces hormones that control the body's rate of metabolism. Iodine is found in seafood and in crops grown in iodine-rich soils. Chronic lack of iodine can cause stunted growth, mental retardation, and goiter—a swollen thyroid gland that can lead to deafness (Figure 12-2). According to the United Nations, some 600 million people—mostly in rural areas of south and southeast Asia—suffer from goiter, and 26 million children suffer brain damage each year from lack of iodine.

Acute Food Shortages Can Lead to Famines

A **famine** occurs when there is a severe shortage of food in an area accompanied by mass starvation, many deaths, economic chaos, and social disruption. Faced with starvation, desperate people eat the seed grain they have stored to grow crops in future years and slaughter their breeding livestock. Famines often result in mass migrations of starving people to other areas or to refugee camps in a search for food, water, and medical help. Many die during these journeys or in these camps. Famines are usually caused by crop failures from drought, flooding, war (Figure 12-3), and other catastrophic events (**Concept 12-1B**).

RESEARCH FRONTIER

Learning more about connections between food supplies, poverty, and environmental problems. See **academic.cengage.com/biology/miller**.

Harmut Schwartzbach/Peter Arnold, Inc.

Figure 12-3 *War and the environment:* starving children collecting ants to eat in famine-stricken Sudan, Africa, where a civil war has been going on since 1983.

Many People Have Health Problems from Eating Too Much

Overnutrition occurs when food energy intake exceeds energy use and causes excess body fat. Too many calories, too little exercise, or both can cause overnutrition. People who are underfed and underweight and those who are overfed and overweight face similar health problems: *lower life expectancy, greater susceptibility to disease and illness,* and *lower productivity and life quality* (**Concept 12-1A**).

We live in a world where 1 billion people have health problems because they do not get enough to eat and another 1.6 billion face health problems from eating too much. According to 2004 study by the International Obesity Task Force, one of every four people in the world is overweight (with a body mass index of 25 or more) and one of every 20 is obese (with a body mass index of 30 or more).

In the United States, a 2005 study at Boston University found that about 66% of American adults are overweight and 33% are obese (up from 15% in 1980), the highest overnutrition rate in any developed country. The more than $50 billion that Americans spend each year trying to lose weight (according to the MarketData research firm) is more than two times the $24 billion per year that the United Nations estimates is needed to eliminate undernutrition and malnutrition in the world.

12-2 How Is Food Produced?

▶ **CONCEPT 12-2A We have sharply increased crop production using a mix of industrialized and traditional agriculture.**

▶ **CONCEPT 12-2B We have used industrialized and traditional methods to greatly increase supplies of meat, fish, and shellfish.**

Food Production Has Increased Dramatically

Currently, three systems supply most of our food. *Croplands* produce mostly grains and provide about 77% of the world's food using 11% of its land area. *Rangelands, pastures,* and *feedlots* produce meat and supply about 16% of the world's food using about 29% the world's land area. *Oceanic fisheries,* and more recently *aquaculture,* supply about 7% of the world's food.

These three systems depend on a small number of plant and animal species. Of the estimated 50,000 plant species that people can eat, only 14 of them supply an estimated 90% of the world's food calories. Just three types of grain crops—*wheat, rice,* and *corn*—provide about 47% of the calories and 42% of the protein people consume. Two-thirds of the world's people survive primarily on these three grains. A small number of species also provide most of the world's meat and seafood.

Such food specialization puts us in a vulnerable position should the small number of crop strains, livestock breeds, and fish and shellfish species we depend on fail as a result of factors such as disease, environmental degradation, and climate change. This violates the biodiversity **principle of sustainability** (see back cover), which calls for depending on a variety of food sources as an ecological insurance policy for dealing with environmental change.

Despite such vulnerability, since 1960, there has been a staggering increase in global food production from all three of the major food production systems (**Concepts 12-2A** and **12-2B**). This occurred because of technological advances such as increased use of tractors and farm machinery and high-tech fishing equipment (Figure 11-7, p. 256). Other technological developments include inorganic chemical fertilizers, irrigation, pesticides, high-yield grain varieties, and raising large numbers of livestock, poultry, and fish in factory-like conditions. These developments have led to increasing reliance on industrialized production of a fairly small number of crops.

Industrialized Crop Production Relies on High-Input Monocultures

Agriculture used to grow crops can be divided roughly into two types: industrialized agriculture and subsistence agriculture. **Industrialized agriculture,** or **high-input agriculture,** uses heavy equipment and large amounts of financial capital, fossil fuel, water, commercial fertilizers, and pesticides to produce single crops, or *monocultures,* (Figure 7-13, p. 152). The major goal of industrialized agriculture for any crop has been to steadily increase its *yield*—the amount of food produced per unit of land. Industrialized agriculture is practiced on one-fourth of all cropland, mostly in developed countries, but has spread since the mid-1960s to some developing countries and now produces about 80% of the world's food (**Concept 12-2A**).

Plantation agriculture is a form of industrialized agriculture used primarily in tropical developing countries. It involves growing *cash crops,* such as bananas, soybeans (mostly to feed livestock), sugarcane (to produce sugar and ethanol fuel), coffee, palm oil (used as a cooking oil and to produce biodiesel fuel), and vegetables on large monoculture plantations, mostly for export to developed countries. Producing such monoculture crops in the tropics increases yields but decreases biodiversity when tropical forests are cleared or burned (Figure 10-16, p. 226) for crop plantations.

A new form of industrialized agriculture involves widespread use of greenhouses to raise crops. Figure 12-4 (p. 280) shows the spread of this type of agriculture along Spain's south coast. It is intended as a way to make arid lands, such as those pictured (Figure 12-4, left) productive. But it requires large inputs of water and energy to move water from one part of the country to another.

On a small scale, however, greenhouse production of crops can be water-efficient. *Hydroponics* is a method whereby plants are grown with their roots in troughs of water inside a greenhouse. Water is pumped from the troughs and sprayed on the plants as artificial rain.

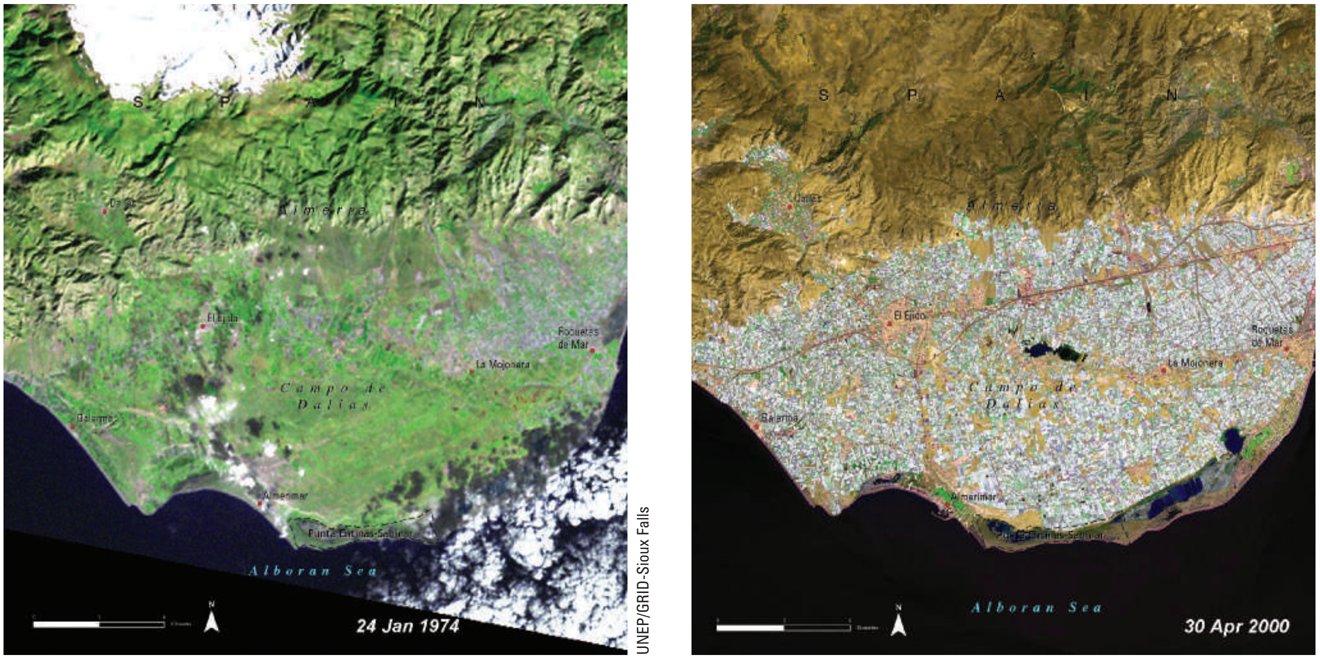


Figure 12-4 Satellite images of extensive and rapid development of greenhouse production of food crops in the Almeria province along Spain's southern coast between 1974 and 2000. Greenhouse-dominated land appears as whitish gray patches in the photo on the right. To provide the water needed to grow these crops, Spain built 118 dams and 22 water transfer projects to move water to this arid region from water-rich parts of the country.

Because the water is recycled, such an operation uses one-fifth to one-tenth less water per crop than conventional farming uses. In water-poor parts of Africa, farmers are growing tomatoes and other vegetables hydroponically in small greenhouses made of inexpensive materials.

Traditional Agriculture Often Relies on Low-Input Polycultures

Traditional agriculture consists of two main types, which together are practiced by 2.7 billion people (42% of the world's people) in developing countries, providing about one-fifth of the world's food crops on about three-fourths of its cultivated land.

Traditional subsistence agriculture uses mostly human labor and draft animals to produce only enough crops for a farm family's survival, with little left over to sell or store as a reserve in hard times. In **traditional intensive agriculture,** farmers increase their inputs of human and draft-animal labor, fertilizer, and water to obtain higher crop yields. If the weather cooperates, they produce enough food to feed their families while selling some for income.

Some traditional farmers focus on cultivating a single crop, but many grow several crops on the same plot simultaneously, a practice known as **polyculture.** Such crop diversity—an example of implementing the biodiversity **principle of sustainability** (see back cover)—reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes.

One type of polyculture is known as **slash-and-burn agriculture.** This type of subsistence agriculture involves burning and clearing small plots in tropical forests, growing a variety of crops for a few years until the soil is depleted of nutrients, and then shifting to other plots. Early users of this method learned that each abandoned patch normally had to be left fallow (unplanted) for 10–30 years before the soil became fertile enough to grow crops again. While patches were regenerating, growers used them for tree crops, medicines, fuelwood, and other purposes. In this manner, most early growers practiced *sustainable cultivation.* However, when too many people use this approach or don't understand its limitations, it can become unsustainable and lead to depletion and degradation of tropical forests, as is now taking place in parts of Africa.

In parts of South America and Africa, some traditional slash-and-burn farmers grow as many as 20 different crops together on small cleared plots in tropical forests. The crops mature at different times, provide food throughout the year, and keep the soil covered to reduce erosion from wind and water. This lessens the need for fertilizer and water, because root systems at different depths in the soil capture nutrients and moisture efficiently, and ashes from the burning provide some fertilization. Insecticides and herbicides are rarely needed because multiple habitats are created for natural predators of crop-eating insects, and weeds have trouble competing with the multitude of crop plants.

SCIENCE FOCUS

Soil Is the Base of Life on Land

Soil is a complex mixture of eroded rock, mineral nutrients, decaying organic matter, water, air, and billions of living organisms, most of them microscopic decomposers. Soil formation begins when bedrock is slowly broken down into fragments and particles by physical, chemical, and biological processes called *weathering.* Figure 12-A shows a profile of different-aged soils.

Soil, the base of life on land, is a key component of the earth's natural capital. It supplies most of the nutrients needed for plant growth (Figure 1-4, p. 9), purifies and stores water, and helps to control the earth's climate by removing carbon dioxide from the atmosphere and storing it as carbon compounds.

Most mature soils—soils that have developed over a long period of time—contain at least three horizontal layers, or *horizons,* (Figure 12-A), each with a distinct texture and composition that varies with different types of soils. Think of them as floors in the geological building of life underneath your feet.

The roots of most plants and the majority of a soil's organic matter are concentrated in a soil's two upper layers, the O horizon of leaf litter and the A horizon of topsoil. In most mature soils, these two layers teem with bacteria, fungi, earthworms, and small insects all interacting in complex ways. Bacteria and other decomposer microorganisms found by the billions in every handful of topsoil break down some of its complex organic compounds into a porous mixture of the partially decomposed bodies of dead plants and animals, called *humus.* Top soil also usually includes inorganic materials such as clay, silt, and sand. Soil moisture carrying these dissolved nutrients is drawn up by the roots of plants and transported through stems and into leaves as part of the earth's chemical cycling processes.

The *B horizon* (*subsoil*) and the *C horizon* (*parent material*) contain most of a soil's inorganic matter, mostly broken-down rock consisting of varying mixtures of sand, silt, clay, and gravel. Much of it is transported by water from the A horizon (Figure 12-A). The C horizon lies on a base of parent material, which is often *bedrock.*

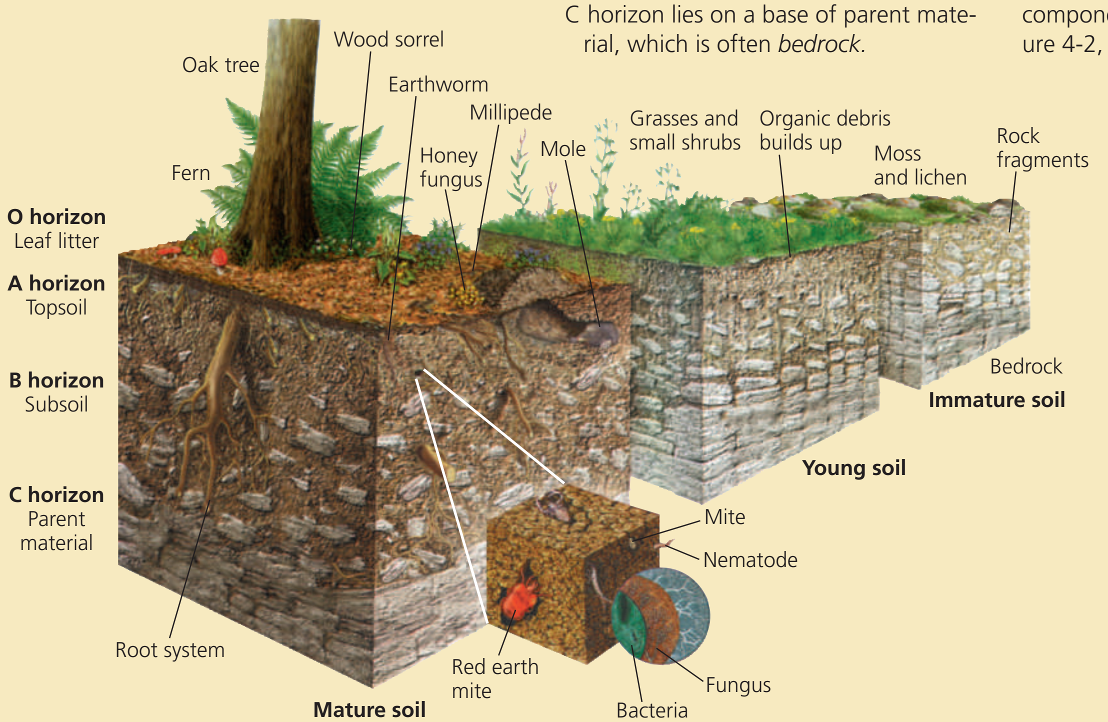
The spaces, or *pores,* between the solid organic and inorganic particles in the upper and lower soil layers contain varying amounts of air (mostly nitrogen and oxygen gas) and water. Plant roots use the oxygen for cellular respiration. As long as the O and A horizons are anchored by vegetation, the soil layers as a whole act as a sponge, storing water and releasing it in a nourishing trickle.

Although topsoil is a renewable resource, it is renewed very slowly, which means it can be depleted. Just 1 centimeter (0.4 inch) of topsoil can take hundreds of years to form, but it can be washed or blown away in a matter of weeks or months when we plow grassland or clear a forest and leave its topsoil unprotected.

Since the beginning of agriculture, human activities have accelerated natural soil erosion. We discuss erosion and ways to prevent or control it later in this chapter.

Critical Thinking

How does soil contribute to each of the four components of biodiversity described in Figure 4-2, p. 79?



CENGAGENOW™ **Active Figure 12-A** Soil formation and generalized soil profile. Horizons, or layers, vary in number, composition, and thickness, depending on the type of soil. *See an animation based on this figure at* CengageNOW™. **Questions:** What role do you think the tree in this figure plays in soil formation? How might the picture change if the tree were removed? (Used by permission of Macmillan Publishing Company from Derek Elsom, *Earth,* New York: Macmillan, 1992. Copyright © 1992 by Marshall Editions Developments Limited)

Recent research shows that, on average, low-input polyculture produces higher yields than does high-input monoculture. For example, a 2001 study by ecologists Peter Reich and David Tilman found that carefully controlled polyculture plots with 16 different species of plants consistently outproduced plots with 9, 4, or only 1 type of plant species. Therefore, some analysts argue for increasing use of polyculture, along with monocultures, to produce food more sustainably in the future. Both industrialized and conventional production of crops depend on having fertile soil (Science Focus, above).

RESEARCH FRONTIER

Investigating the design and benefits of polyculture. See **academic.cengage.com/biology/miller**.

CENGAGENOW™ Compare soil profiles from grassland, desert, and three types of forests at CengageNOW.

A Closer Look at Industrialized Crop Production

Farmers can produce more food by farming more land or by getting higher yields from existing cropland. Since 1950, about 88% of the increase in global food production has come from using high-input industrialized agriculture to increase yields in a process called the **green revolution.**

The green revolution involves three steps. *First,* develop and plant monocultures of selectively bred or genetically engineered high-yield varieties of key crops such as rice, wheat, and corn. *Second,* produce high yields by using large inputs of fertilizers, pesticides, and water. *Third,* increase the number of crops grown per year on a plot of land through *multiple cropping,* or *multicropping.* Between 1950 and 1970, this high-input approach dramatically increased crop yields in most developed countries, especially the United States (Case Study, right) in what was called the *first green revolution.*

A *second green revolution* has been taking place since 1967. Fast-growing dwarf varieties of rice and wheat, specially bred for tropical and subtropical climates, have been introduced into India and China and several developing countries in Central and South America. Producing more food on less land has the benefit of protecting biodiversity by saving large areas of forests, grasslands, wetlands, and easily eroded mountain terrain from being used to grow food crops.

Between 1950 and 1996, mostly because of the two green revolutions, world grain production tripled (Figure 12-5, left). Per capita food production increased by 31% between 1961 and 1985, but since then it has generally declined (Figure 12-5, right).

■ CASE STUDY

Industrialized Food Production in the United States

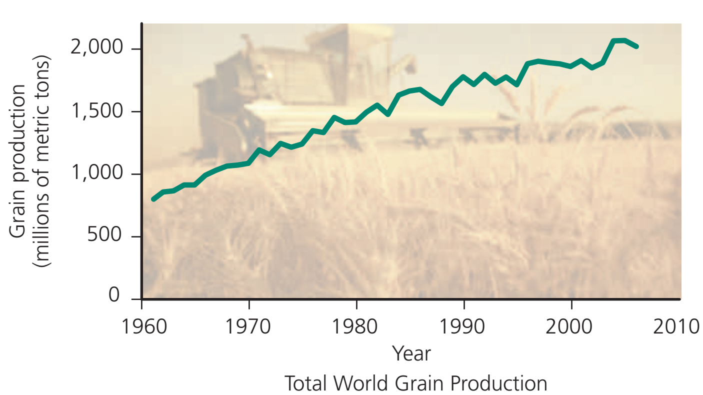
In the United States, industrialized farming has evolved into *agribusiness,* as a small number of giant multinational corporations increasingly control the growing, processing, distribution, and sale of food in the United States and in the global marketplace.

In total annual sales, agriculture is bigger than the country's automotive, steel, and housing industries combined. It generates almost one-fifth of the nation's gross domestic product. Although agriculture employs more people than any other industry, U.S. farms use industrialized agriculture to produce about 17% of the world's grain with only 0.3% of the world's farm labor force.

Since 1950, U.S. industrialized agriculture has more than doubled the yields of key crops such as wheat, corn, and soybeans without cultivating more land. Such yield increases have kept large areas of forests, grasslands, and wetlands from being converted to farmland.

U.S. food production is very efficient. While the U.S. output of crops, meat, and dairy products has been increasing steadily since 1975, the major inputs of labor and resources—with the exception of pesticides—to produce each unit of that output have fallen steadily since 1950.

U.S. consumers now spend about 2% of their disposable income on food, compared to about 11% in 1948. People in developing countries typically spend up to 40% of their income on food. And the 1.2 billion poorest people, struggling to live on less than $1 a day, typically spend about 70% of this meager income on food. Thus, to the poor any rise in the prices of wheat, rice, or corn can be disastrous.



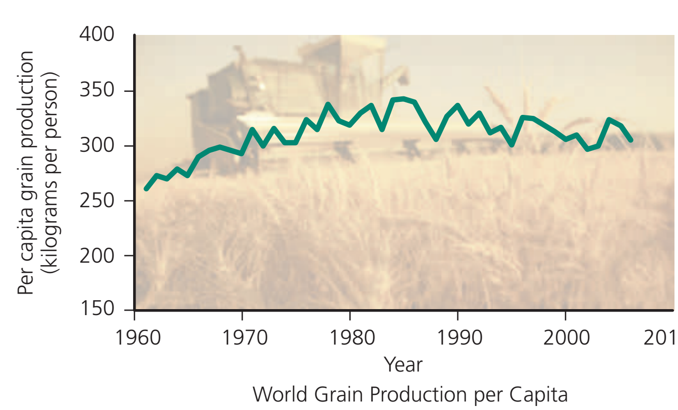


Figure 12-5 *Global outlook:* total worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right), 1961–2006. In order, the world's three largest grain-producing countries are China, the United States, and India. (Data from U.S. Department of Agriculture, Worldwatch Institute, U.N. Food and Agriculture Organization, and Earth Policy Institute) **Question:** Why do you think grain production per capita has grown less consistently than total grain production?

However, the actual food costs paid by consumers in the United States and other developed countries are much higher than the prices paid in grocery stores. In addition to the direct market prices, consumers pay taxes to give subsidies to food producers and distributors and to help deal with the massive pollution and environmental degradation caused by agriculture (discussed later in this chapter). They also face higher health and insurance bills related to the harmful environmental and health effects of agriculture. Including these harmful costs in the market prices for food would bring about a shift to more sustainable and less environmentally harmful agriculture.

Crossbreeding and Genetic Engineering Can Produce New Crop Varieties

For centuries, farmers and scientists have used *crossbreeding* through *artificial selection* to develop genetically improved varieties of crops and livestock animals. Such selective breeding in this first *gene revolution* has yielded amazing results. Ancient ears of corn were about the size of your little finger and wild tomatoes were once the size of grapes.

Traditional crossbreeding is a slow process, typically taking 15 years or more to produce a commercially valuable new crop variety, and it can combine traits only from species that are genetically similar. Resulting varieties remain useful for only 5–10 years before pests and diseases reduce their effectiveness. But important advances are still being made with this method.

Today, scientists are creating a second *gene revolution* by using *genetic engineering* to develop genetically improved strains of crops and livestock animals. It involves altering an organism's genetic material through adding, deleting, or changing segments of its DNA (Figure 10, p. S43, in Supplement 6), to produce desirable traits or to eliminate undesirable ones. It enables scientists to transfer genes between different species that would not interbreed in nature. The resulting organisms are called *genetically modified organisms* (GMOs) or *transgenic organisms.*

Figure 12-6 outlines the steps involved in developing a genetically modified plant. For example, genetic engineers used genes from ordinary daffodils (Figure 12-1, right) and a soil bacterium to produce golden rice (**Core Case Study**). Compared to traditional crossbreeding, gene splicing takes about half as long to develop a new crop variety, usually costs less, and allows for the insertion of genes from almost any other organism into crop cells.

CORE CASE STUDY

Ready or not, much of the world is entering the *age of genetic engineering.* Bioengineers are developing, or planning to develop, new varieties of crops that are resistant to heat, cold, herbicides, insect pests, parasites, viral diseases, drought, and salty or acidic soil. They also hope to develop crop plants that can grow faster and survive with little or no irrigation and with less fertilizer and pesticides.

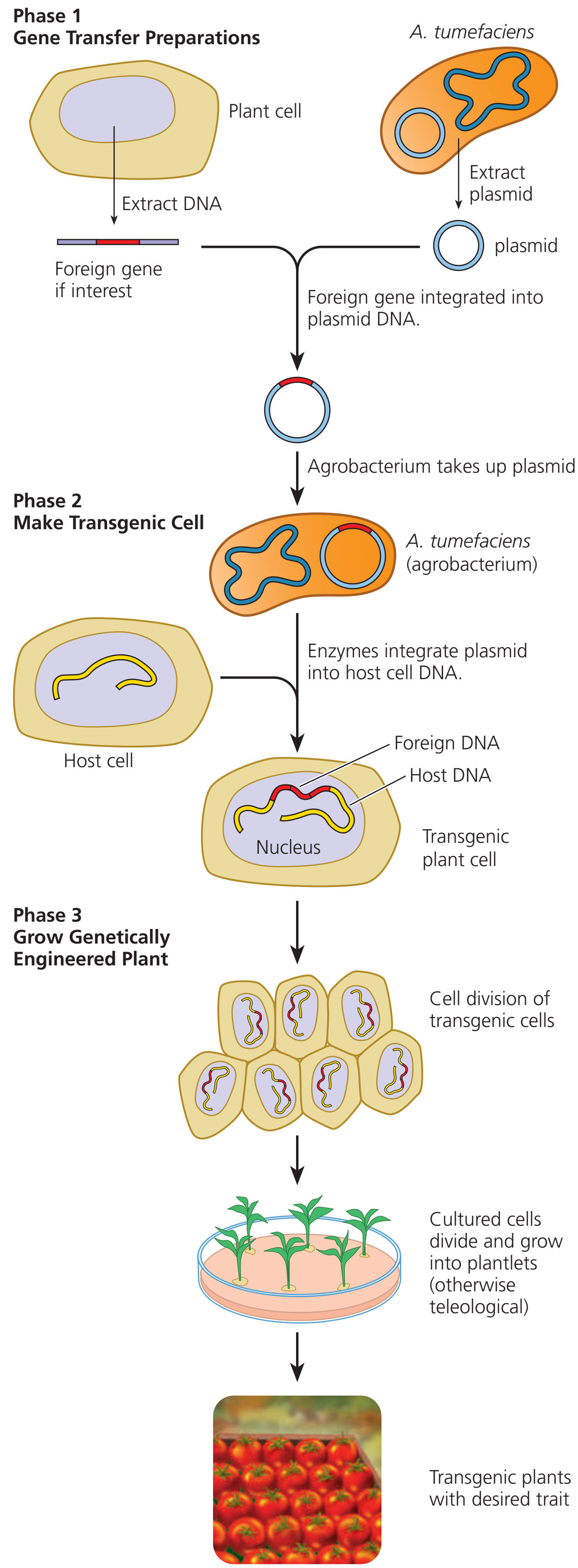


Figure 12-6 *Genetic engineering:* steps in genetically modifying a plant. **Question:** How does this process change the nature of evolution by natural selection?

Bioengineers have altered citrus trees, which normally take 6 years to produce fruit, to yield fruit in only 1 year. They also hope to use *advanced tissue culture* techniques to mass-produce only orange juice sacs, which would eliminate the need for citrus orchards.

RESEARCH FRONTIER

Genetic engineering and using cell cultures for food factory systems. See **academic.cengage.com/biology/miller**.

Many scientists believe that such innovations hold great promise for helping to improve global food security. Others warn that genetic engineering is not free of drawbacks, which we examine later in this chapter.

Meat Production and Consumption Have Grown Steadily

About half of the world's meat comes from livestock grazing on grass in unfenced rangelands and enclosed pastures. The other half is produced through an industrialized system in which animals are raised in densely packed *feedlots* and c*onfined animal feeding operations* where they are fed grain or meal produced from fish. For example, large numbers of cattle are brought to feedlots where they are fattened up for about 4 months before slaughter (Figure 12-7). Most pigs and chickens in developed countries spend their lives crowded in pens and cages, often in huge buildings where they eat mostly grain grown on cropland.

Between 1961 and 2007 world meat production—mostly pork, poultry, and beef—increased fourfold, and is likely to more than double again by 2050 as affluence rises and middle-income people begin consuming more meat and meat products in developing countries. During this same period, average meat consumption per person more than doubled.

Industrialized meat production may face certain limits in the future. For example, if we include land used to grow grain fed to livestock, the FAO estimates that 30% of the earth's ice-free land is already directly or indirectly involved in livestock production. And this percentage is likely to increase.

Furthermore, as incomes grow in a country, more of its people tend to eat more meat, with much of it produced by feeding grain to livestock. This increases the demand for grain and can lead to increased reliance on grain imports. As industrialization increases, there is also a loss of cropland to urban development. Within a few decades, a rapidly industrializing country can go from producing all the grain it needs to importing most of its grain. As a result of this process, Japan, Taiwan, and South Korea now import 70% of the grain they consume. China and India, which currently are the world's leading producers of wheat, are likely to follow this trend as they become more industrialized.

If China were to import just one-fifth of the grain it needs, this would equal the amount of grain the United States typically exports each year—roughly half the world's grain exports. The Earth Policy Institute and the U.S. Central Intelligence Agency warn that if such a scenario comes to pass, no country or combination of countries will have the ability to supply even a small fraction of China's potential food supply deficit.

Figure 12-7 *Industrialized meat production.* A cattle feedlot in Imperial Valley, California (USA), where 40,000 cattle are being fattened up on grain before being slaughtered. With only about 4.5% of the world's population, the United States grows and kills nearly 10 billion animals a year as a source of beef, pork, chicken, and other forms of meat.

Matt Meadows/Peter Arnold, Inc.

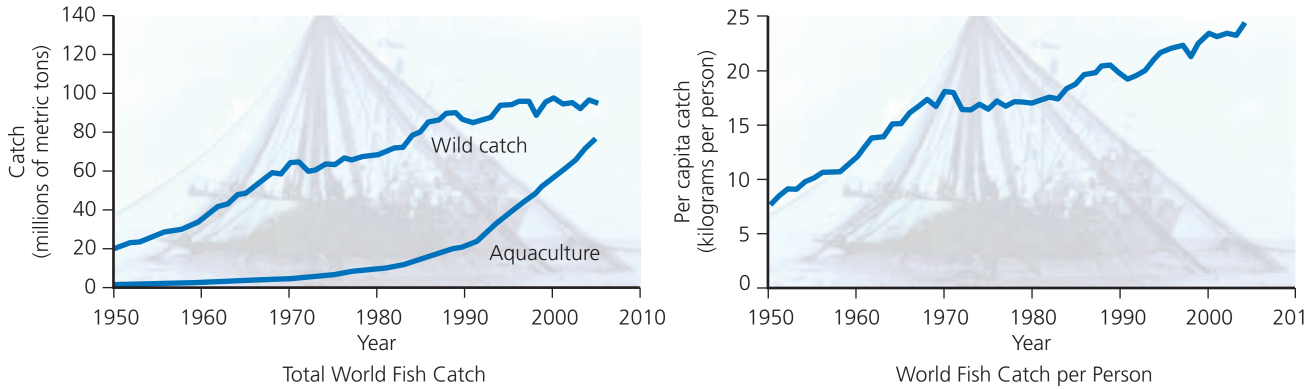


Figure 12-8 World fish catch, including both wild catch and aquaculture, 1950–2004 (**Concept 12-2B**). **Question:** What are two trends that you can see in these data? (Data from U.N. Food and Agriculture Organization, U.S. Census Bureau, and Worldwatch Institute)

This does not take into account huge grain deficits that are projected in other parts of the world by 2025, especially in Africa and India. It also does not include the possibility that climate change from global warming could decrease food production in China and in countries the world relies on for grain exports.

Fish and Shellfish Production Have Increased Dramatically

The world's third major food-producing system consists of fisheries and aquaculture. A **fishery** is a concentration of particular aquatic species suitable for commercial harvesting in a given ocean area or inland body of water. Industrial fishing fleets catch most of the world's marine fish (Case Study and Figure 11-7, p. 256). In 2006, 43% of the fish and shellfish consumed were produced through **aquaculture**—raising marine and freshwater fish in ponds and underwater cages—and this percentage has been growing steadily.

Figure 12-8 shows the effects of the global efforts to boost the seafood harvest through fishing and aquaculture (**Concept 12-2B**). Since 1950, the world fish catch (marine and freshwater harvests, excluding aquaculture) has increased almost sevenfold. Aquacultural production in the same period increased over 40-fold.

In Chapter 11, we examined the global fishing industry and its effects on aquatic biodiversity (pp. 254–257 and Case Study, p. 256). A 2007 report by the FAO found that 25% of the world's ocean fisheries are virtually depleted and 52% have been fully exploited. In other words, 77% of the world's commercially valuable fish stocks are overexploited. According to a 2006 FAO study and research by a number of fishery scientists, unless we reduce overfishing and ocean pollution and slow climate change, ocean fisheries worldwide could essentially collapse by 2050, thereby sharply decreasing food security for up to 2.6 billion people who depend on fish for protein.

Using large ships to find, catch, and freeze ocean fish consumes huge amounts of energy. According to a 2005 study by ecological economist Peter Tyedmeers and his colleagues, the energy used by the world's fishing fleets to catch and deliver the fish is 12.5 times the food energy gained by the people who eat the fish. In the process, the fishing fleets also add large amounts of greenhouse gases to the atmosphere. According to ecological economists, without government-provided fuel and other subsidies, these fleets could not afford to exist.

The other major mode of fish production is aquaculture, which involves raising fish and shellfish for food instead of hunting and gathering them. This industrialized production of fish and shellfish is the world's fastest-growing type of food production. Some call aquaculture the *blue revolution.*

Aquaculture involves cultivating fish in freshwater ponds, lakes, reservoirs, and rice paddies, or in underwater cages in coastal saltwater lagoons, estuaries, and the deep ocean (Figure 11-7, p. 256). The fish are harvested when they reach the desired size. China raises 70% of the world's farmed fish, mostly in inland ponds and rice fields.

World aquaculture is dominated by operations that raise herbivorous species—mainly carp in China and India, catfish in the United States, tilapia in several countries, and shellfish in several coastal countries. Most Chinese farmers integrate crop growing and aquaculture by using rice straw, pig and duck manure, and other agricultural wastes to fertilize farm ponds and rice paddies in order to produce phytoplankton eaten by various herbivorous species of carp—an example of *polyaquaculture.*

The continuing expansion of aquaculture faces economic and environmental challenges. For example, much of it depends on using grain and fishmeal as feed, and growing competition for these resources between food and biofuel producers could put limits on aquacultural production. The environmental impacts of aquaculture, which we examine in the next section, could also put limits on its growth.

12-3 What Environmental Problems Arise from Food Production?

▶ **CONCEPT 12-3 Food production in the future may be limited by its serious environmental impacts, including soil erosion and degradation, desertification, water and air pollution, greenhouse gas emissions, and degradation and destruction of biodiversity.**

Producing Food Has Major Environmental Impacts

According to many analysts, agriculture has a greater harmful environmental impact than any human activity and these environmental effects may limit future food production. Crop yields in some areas may decline because of environmental factors such as erosion and degradation of soil, depletion and pollution of underground and surface water supplies used for irrigation, emission of greenhouse gases that contribute to climate change, and loss of croplands (**Concept 12-3**). According to the U.S. Environmental Protection Agency (EPA), agriculture is responsible for three quarters of the water quality problems in U.S. rivers and streams.

Figure 12-9 summarizes harmful effects of agriculture on air, soil, water, and biodiversity. We do not know how close we are to environmental limits on food production, but some scientists say alarm bells are going off now. Here, we explore such effects in greater depth, starting with the problems of erosion and degradation of soils.

NATURAL CAPITAL DEGRADATION

Food Production

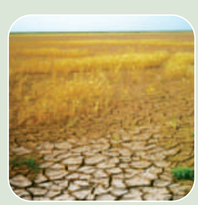
Biodiversity Loss

Loss and degradation of grasslands, forests, and wetlands

Fish kills from pesticide runoff

Killing wild predators to protect livestock

Loss of genetic diversity of wild crop strains replaced by monoculture strains



Soil

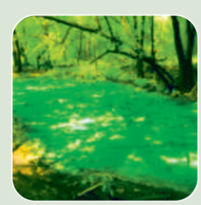
Erosion

Loss of fertility

Salinization

Waterlogging

Desertification



Water

Water waste

Aquifer depletion

Increased runoff, sediment pollution, and flooding from cleared land

Pollution from pesticides and fertilizers

Algal blooms and fish kills in lakes and rivers caused by runoff of fertilizers and agricultural wastes

Air Pollution

Greenhouse gas emissions (CO_2) from fossil fuel use

Greenhouse gas emissions (N_2O) from use of inorganic fertilizers

Greenhouse gas emissions of methane (CH_4) by cattle (mostly belching)

Other air pollutants from fossil fuel use and pesticide sprays

Human Health

Nitrates in drinking water (blue baby)

Pesticide residues in drinking water, food, and air

Contamination of drinking and swimming water from livestock wastes

Bacterial contamination of meat

Figure 12-9 Major harmful environmental effects of food production (**Concept 12-3**). According to a 2002 study by the United Nations, nearly 30% of the world's cropland has been degraded to some degree by soil erosion, salt buildup, and chemical pollution, and 17% has been seriously degraded. **Question:** Which item in each of these categories do you believe is the most harmful?

Topsoil Erosion Is a Serious Problem in Parts of the World

Soil erosion is the movement of soil components, especially surface litter and topsoil (Figure 12-A), from one place to another by the actions of wind and water. Some soil erosion is natural, and some is caused by human activities. In undisturbed, vegetated ecosystems, the roots of plants help to anchor the soil, the soil stores water and releases it in a nourishing trickle, and soil usually is not lost faster than it forms. Since the beginning of agriculture, human activities have accelerated natural soil erosion. Entire civilizations have collapsed because they mismanaged the topsoil that supported their populations (see p. S31 in Supplement 5).

Flowing water, the largest cause of erosion, carries away particles of topsoil that have been loosened by rainfall; severe erosion leads to the formation of gullies (Figure 12-10). Wind loosens and blows topsoil particles away, especially in areas with a dry climate and relatively flat and exposed land (Chapter 7 Core Case Study, Figure 7-1, p. 140). We lose natural capital in the form of fertile topsoil when we destroy soil-holding grasses through activities such as farming (Figure 7-13, p. 152), clear-cut logging (Figure 10-7, p. 219), overgrazing (Figure 10-21, left, p. 233), and off-road vehicle use (Figure 10-22, p. 234).

Accurate numbers are hard to come by, but some analysts estimate that perhaps a third or more of the world's cropland is losing soil faster than new soil is forming. In the Saharan region of Africa, dust storms that were once rare are now commonplace and have increased 10-fold since 1950. Countries in this region that face serious topsoil loss from wind erosion are Chad, Burkina Faso, Mauritania, and northern Nigeria. Many

Ron Giling/Peter Arnold, Inc.

Figure 12-10 **Natural capital degradation:** Severe gully erosion on cropland in Bolivia.

of the world's 862 million malnourished people try to survive on land suffering from severe soil erosion.

Soil erosion has two major harmful effects. One is *loss of soil fertility* through depletion of plant nutrients in topsoil. The other is *water pollution* in nearby surface waters, where eroded soil ends up as sediment. This can kill fish and shellfish and clog irrigation ditches, boat channels, reservoirs, and lakes. Additional water pollution occurs when the eroded sediment contains residues of fertilizers and pesticides (**Concept 12-3**). A joint survey by the U.N. Environment Programme (UNEP) and the World Resources Institute estimated that topsoil is eroding faster than it forms on about 38% of the world's cropland (Figure 12-11).

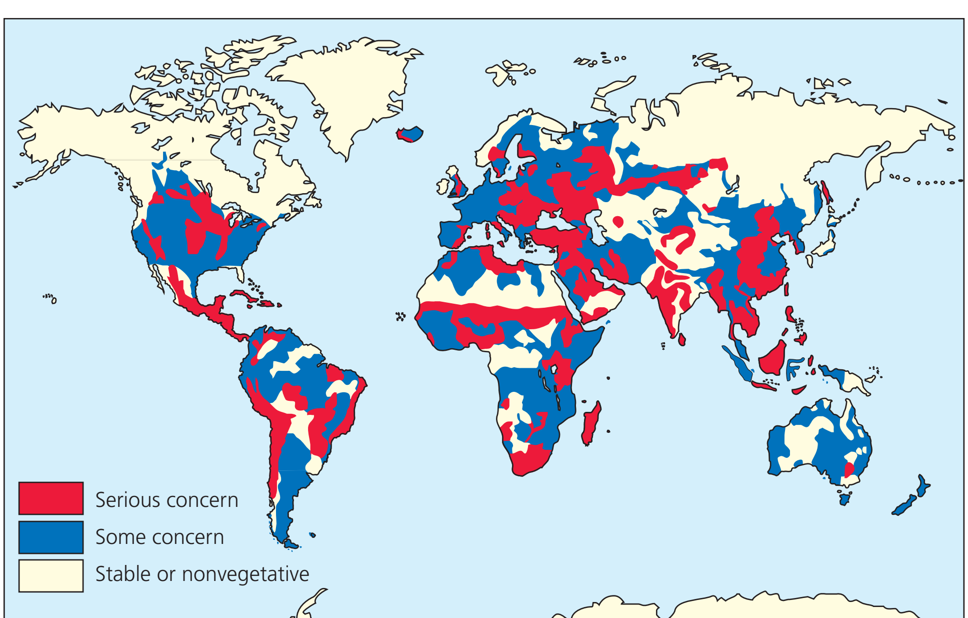


Figure 12-11 **Natural capital degradation:** global soil erosion. **Question:** Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and the World Resources Institute).

Figure 12-12 *Severe desertification.* Sand dunes threaten to engulf an oasis in the Sahel region of West Africa. Such severe desertification is the result of prolonged drought from natural climate change and destruction of natural vegetation from human activities such as farming and overgrazing.

Some analysts contend that erosion estimates are overstated because they do not account for the abilities of some local farmers to restore degraded land. The FAO also points out that eroded topsoil does not always move very far and is sometimes deposited on the same slope, valley, or plain from which it came. Consequently, in some places, the loss in crop yields in one area can be offset by increased yields elsewhere.

Drought and Human Activities Are Degrading Drylands

In arid and semiarid parts of the world, the contribution to the world's food supply from livestock and crops is being threatened by **desertification.** It occurs when the productive potential of soil, especially on arid or semiarid land, falls by 10% or more because of a combination of prolonged drought and human activities that reduce or degrade topsoil. The process can be *moderate* (a 10–25% drop in productivity), *severe* (a 25–50% drop), or *very severe* (a drop of more than 50%, usually creating huge gullies and sand dunes). Only in extreme cases does desertification lead to what we call desert. But when severe desertification occurs, it can expand existing desert area (Figure 12-12) or create new desert in areas that once were fertile land.

Over thousands of years, the earth's deserts have expanded and contracted, mostly because of natural climate change. However, human activities have accelerated desertification in some parts of the world (**Concept 12-3**) (Figure 12-13).

In its 2007 report on the *Status of the World's Forests,* the FAO estimated that some 70% of world's drylands used for agriculture are degraded and threatened by desertification. Most of these lands are in Africa and Asia, with countries including Nigeria, Iran, Afghanistan, and China suffering from serious desertification. Increasing desertification is also a threat in dryland areas of Brazil and Mexico.

According to a 2007 study by the Intergovernmental Panel on Climate Change (IPCC), projected climate change from global warming during this century (mostly the result of human activities) is expected to greatly increase severe and prolonged drought and, consequently, desertification in many arid and semiarid parts of the world. This could result in sharp drops in food production, water shortages for 1 billion–3 billion people, and huge numbers of environmental refugees.

Excessive Irrigation Has Serious Consequences

Between 1950 and 2007, the world's area of irrigated cropland tripled, with most of the growth occurring from 1950 to 1978, and little growth occurring since 1990. The 20% of the world's cropland that is irrigated produces almost 40% of the world's food.

But irrigation has a downside. Most irrigation water is a dilute solution of various salts, picked up as the water flows over or through soil and rocks. Irrigation water that has not been absorbed into the soil evaporates, leaving behind a thin crust of dissolved salts in the topsoil.

Repeated annual applications of irrigation water in dry climates lead to the gradual accumulation of salts in the upper soil layers—a soil degradation process called **salinization.** It stunts crop growth, lowers crop yields, and can eventually kill plants and ruin the land (**Con-**

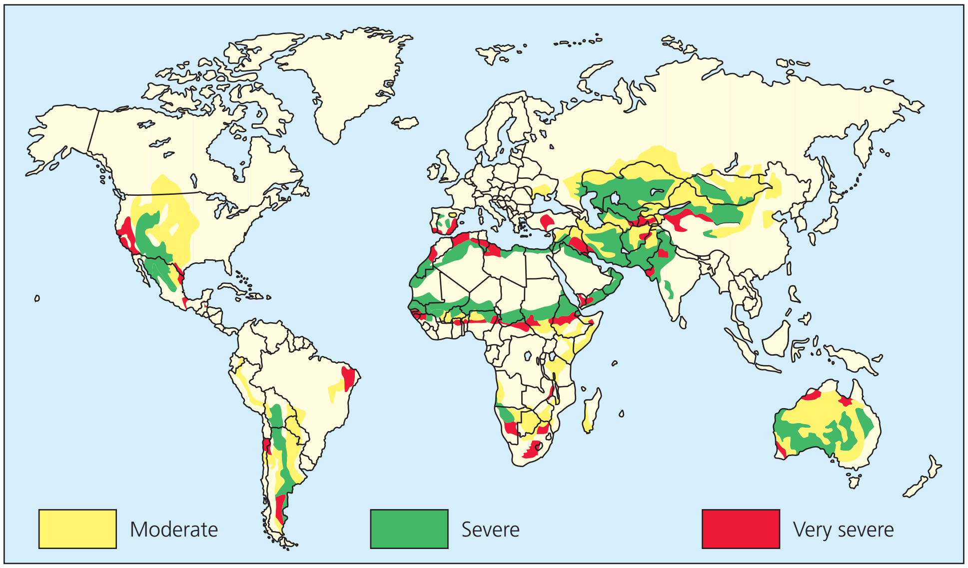


Figure 12-13 **Natural capital degradation:** desertification of arid and semiarid lands. It is caused by a combination of prolonged drought and human activities that expose soil to erosion. **Question:** Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and Harold E. Drengue)

cept 12-3). The United Nations estimates that severe salinization has reduced yields on at least one-tenth of the world's irrigated cropland, and the problem is getting worse. The most severe salinization occurs in Asia, especially in China, India, Egypt, Pakistan, and Iraq. Salinization affects almost one-fourth of irrigated cropland in the United States, especially in the western states (Figure 12-14).

Another problem with irrigation is **waterlogging,** in which water accumulates underground and gradually raises the water table. Farmers often apply large amounts of irrigation water to leach salts deeper into the soil. Without adequate drainage, waterlogging occurs and saline water then envelops the deep roots of plants, lowering their productivity and killing them after prolonged exposure. At least one-tenth of the world's irrigated land suffers from waterlogging, and the problem is getting worse (**Concept 12-3**).

There May Be Limits to Expanding the Green Revolutions

Analysts point to several factors that have limited the success of the green revolutions to date and that may limit them in the future. Without huge inputs of fertilizer, pesticides, and water, most green revolution crop varieties produce yields that are no higher (and are sometimes lower) than those from traditional strains. These high inputs cost too much for most subsistence

U.S. Natural Resources Conservation Service

Figure 12-14 **Natural capital degradation:** Because of high evaporation, poor drainage, and severe salinization, white alkaline salts have displaced crops that once grew on this heavily irrigated land in the U.S. state of Colorado.

farmers in developing countries. Scientists point out that continuing to increase these inputs eventually produces no additional increase in crop yields. This helps to explain the slowdown in the rate of global grain yields per hectare from an average increase of 2.1% a year between 1950 and 1990 to an average increase of only 1.2% annually between 1990 and 2007.

Since 1970, the sharpest drop in per capita food production has occurred in Africa, the continent that for decades has had the world's highest rate of population growth (Figure 5, p. S13, Supplement 3). Such growth, plus poor soils, water shortages, soil erosion, desertification, limited economic development, and warfare in many parts of Africa, have hindered development of the two green revolutions there.

Can we expand the green revolutions by irrigating more cropland? In 2006, the International Water Management Institute projected that between 2005 and 2050, water use for agriculture will have to increase by 80% in order for farmers to provide food for 2.6 billion more people.

However since 1978, the amount of irrigated land per person has been declining, and it is projected to fall much more between 2008 and 2050. One reason for this is that since 1978, the world's population has grown faster than has use of irrigation. Other factors are depletion of underground water supplies (aquifers), wasteful use of irrigation water, soil salinization, and climate change, which is melting mountain glaciers that provide countries such as China and India, the world's two largest producers of wheat and rice, with irrigation water. As the glaciers melt, water flowing in major rivers during the dry season, when irrigation water needs are greatest, will decrease sharply. In addition, most of the world's farmers do not have enough money to irrigate their crops.

However, we can get more crop per drop by using known methods and technologies to greatly improve the efficiency of irrigation, which accounts for 70% of the world's water use. We discuss this more fully in Chapter 13.

Is cultivating more land the answer? Theoretically, clearing tropical forests and irrigating arid land could more than double the area of the world's cropland. But much of this is *marginal land* with poor soil fertility, steep slopes, or both. Cultivation of such land is expensive, is unlikely to be sustainable, and would seriously reduce wildlife habitats and biodiversity.

In addition, during this century, fertile croplands in coastal areas are likely to be flooded by rising sea levels resulting from climate change caused by global warming. For the same reason, food production could drop sharply in some countries because of increased drought and heat waves.

However, crop yields per hectare could be increased by using conventional or genetically engineered crops that are more tolerant of drought and cold and by encouraging farmers to grow more than one crop per year on their plots (multicropping). And, there are parts of the world, especially in Africa, where additional fertilizer could boost crop yields.

Industrialized Food Production Requires Huge Inputs of Energy

The industrialization of agriculture has been made possible by the availability of cheap energy (mostly from oil) used to run farm machinery, irrigate crops, process food, and produce commercial inorganic fertilizers (mostly by burning natural gas) and pesticides. Putting food on the table consumes about 17% of all commercial energy used in the United States each year (Figure 12-15).

The input of energy needed to produce a unit of food has fallen considerably, so that most crops in the United States provide an amount of energy in the form of food that is greater than the amount of energy used to grow them. However, when we consider the energy used to grow, store, process, package, transport, refrigerate, and cook all plant and animal food, *about 10 units of nonrenewable fossil fuel energy are needed to put 1 unit of food energy on the table.* In other words, industrialized food production and consumption has a large *net energy loss.* By comparison, every unit of energy from human labor in traditional farming provides 1 to 10 units of food energy.

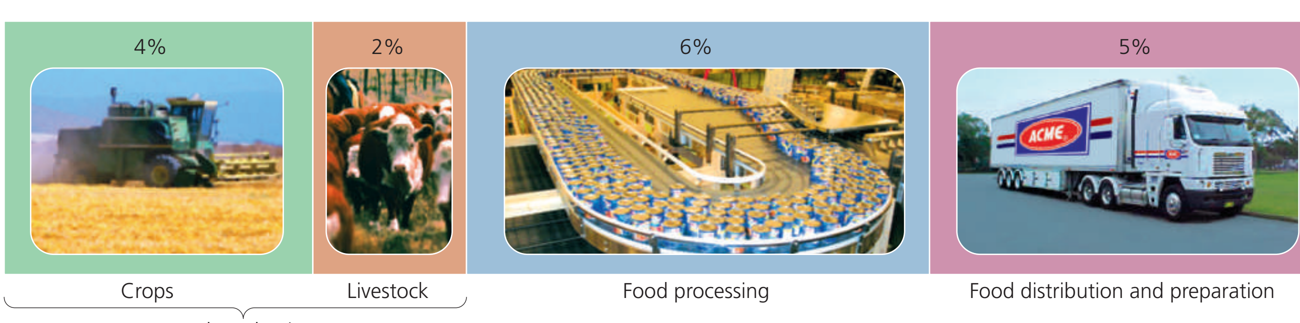


Figure 12-15 Industrialized agriculture uses about 17% of all commercial energy used in the United States, and food travels an average 2,400 kilometers (1,300 miles) from farm to plate. The resulting pollution degrades the air and water and contributes to global warming. (Data from David Pimentel and Worldwatch Institute)

THINKING ABOUT
Food and Oil

What might happen to food production and to your lifestyle if oil prices keep rising sharply in the next 2 decades, as many analysts predict? How would you reduce this risk?

There Is Controversy over Genetically Engineered Foods

Despite its promise, controversy has arisen over the use of *genetically modified (GM) food* (Figure 12-6) and other forms of genetic engineering. Its producers and investors see this kind of food as a potentially sustainable way to solve world hunger problems and improve human health. Some critics consider it potentially dangerous "Frankenfood." Figure 12-16 summarizes projected advantages and disadvantages of this new technology.

Critics recognize the potential benefits of GM crops. But they warn that we know too little about the long-term potential harm to human health and ecosystems from the widespread use of such crops. They point out that genetic engineering mixes genes from widely differing species, which has never occurred in nature or even in selective breeding. They warn that if GM organisms released into the environment cause some unintended harmful genetic and ecological effects, as some scientists expect, they cannot be recalled.

For example, there is the potential for GM plant pollen to spread among nonengineered species, threatening crop biodiversity. In a 2006 study by the Union of Concerned Scientists, half of the nonengineered corn and soybean varieties tested by one laboratory contained DNA from GM varieties. Once experimental GM pollens are in the environment, they are impossible to retrieve.

Most scientists and economists who have studied the genetic engineering of crops believe that its potential benefits outweigh its risks. They also contend that some of the potential problems associated with GM crops can be eliminated by genetically engineering plants without inserting a gene from another species. This new technique, called *chimeraplasty,* involves inserting instead a chemical instruction that attaches to a gene, altering it to give desired genetic traits.

Critics call for more controlled field experiments, long-term testing to better understand the risks, and stricter regulation of this rapidly growing technology. A 2004 study by the Ecological Society of America recommended more caution in releasing genetically engineered organisms into the environment without adequate testing.

THINKING ABOUT
Golden Rice

CORE CASE STUDY

Do you think that the advantages of genetically engineered golden rice (**Core Case Study**) outweigh its disadvantages? Explain.

TRADE-OFFS

Genetically Modified Crops and Foods

Projected Advantages	Projected Disadvantages
Need less fertilizer	Irreversible and unpredictable genetic and ecological effects
Need less water	Harmful toxins in food from possible plant cell mutations
More resistant to insects, disease, frost, and drought	New allergens in food
Grow faster	Lower nutrition
Can grow in slightly salty soils	Increase in pesticide-resistant insects, herbicide-resistant weeds, and plant diseases
May need less pesticides	Can harm beneficial insects
Tolerate higher levels of herbicides	Lower genetic diversity
Higher yields	
Less spoilage	

Figure 12-16 Projected advantages and disadvantages of genetically modified crops and foods. **Question:** Which two advantages and which two disadvantages do you think are the most important? Why?

Food and Biofuel Production Systems Have Caused Major Losses of Biodiversity

Biodiversity and some ecological services (Figure 10-4, left, p. 217) are threatened when forests are cleared and grasslands are plowed up and replaced with croplands (**Concept 12-3**). For example, one of the fastest-growing threats to the world's biodiversity is the clearing or burning of large areas of tropical forest in Brazil's Amazon basin (Figure 10-13, p. 224) and in its *cerrado,* a huge savanna-like region south of the Amazon basin. This land is being burned or cleared for large plantations of soybeans, grown for use as cattle feed, and sugarcane used for making ethanol fuel for cars. Other tropical forests are burned to make way for plantations of oil palm trees increasingly used to produce biodiesel fuel. These activities threaten biodiversity and contribute to climate change by releasing carbon dioxide into the atmosphere.

A closely related problem is the increasing loss of *agrobiodiversity*—the world's genetic variety of animals and plants used to provide food. But we are replacing nature's resilient genetic diversity developed through millions of years of natural selection with human-engineered monocultures. Scientists estimate that since 1900, we have lost three-fourths of the genetic diversity of agricultural crops. For example, India once planted 30,000 varieties of rice. Now more than 75% of its rice production comes from only 10 varieties and soon, almost all of its production may come from just one variety. Rice varieties around the world may drop even more if there is a shift toward genetically engineered golden rice (**Core Case Study**) and other genetically engineered crops. In the United States, about 97% of the food plant varieties available to farmers in the 1940s no longer exist, except perhaps in small amounts in seed banks and in the backyards of a few gardeners.

In other words, we are rapidly shrinking the world's genetic "library," which is critical for increasing food yields. In fact, we might need it more than ever to develop new plant and livestock varieties that can adapt to climate change. This failure to preserve agrobiodiversity is a violation of the biodiversity **principle of sustainability**.

Wild and endangered varieties of crops important to the world's food supply are stored in about 1,400 refrigerated gene or seed banks, agricultural research centers, and botanical gardens scattered around the world. But increasingly, power failures, fires, storms, and war are causing irreversible losses of these stored plants and seeds. However, a new ice vault built underground in the Norwegian Arctic will eventually contain duplicates of much of the world's stock of seeds and will not be vulnerable to such hazards.

Shortages of storage space and money severely limit the number of species that can be preserved, and the seeds of many plants (such as potatoes) cannot be stored successfully in gene banks. Because stored seeds do not remain alive indefinitely, periodically they must be planted (germinated) and new seeds collected for storage. Unless this is done, seed banks become *seed morgues.*

Because of such limitations on seed banks, ecologists and plant scientists warn that the only effective way to preserve the genetic diversity of most plant and animal species is to protect representative ecosystems throughout the world from agriculture and other forms of development.

Industrialized Meat Production Has Harmful Environmental Consequences

Industrialized meat production has advantages and disadvantages (Figure 12-17). Environmental scientists point out that industrialized systems, such as feedlots and other confined animal production facilities, use large amounts of energy and water and produce huge amounts of animal waste that sometimes pollute surface water and groundwater and saturate the air with their odors.

For example, much of the fertilizer used in the midwestern United States to produce corn for animal feed and conversion to ethanol fuel runs off into the Mississippi and Ohio Rivers and ends up overfertilizing coastal waters in the Gulf of Mexico. Each year this creates a "dead zone" about the size of the U.S. state of New Jersey and threatens one-fifth of the nation's seafood yield. In other words, growing corn in the Midwest to produce ethanol and protein-rich meat can decrease the production of protein-rich seafood in the Gulf of Mexico—another example of unintended consequences.

Energy (mostly from oil) is an essential ingredient in industrialized meat production. Using this energy pollutes the air and water and contributes to global warming, with livestock production generating about 20% of the world's greenhouse gases—more than transportation generates—according to the FAO. Cattle and dairy cows release methane, the second most powerful greenhouse gas after carbon dioxide, mostly through belching. This accounts for 16% of the global annual emissions of methane. In 2007, scientists at the University of Wales in the United Kingdom found that adding garlic to the diet of cows can cut their daily methane emissions by up to 50%. They are now investigating whether adding this to cow chow will taint the taste of meat and milk. And a 2003 Swedish study found that raising beef cattle on grass emits 40% less greenhouse gases and used 85% less energy than raising the cattle on grain.

TRADE-OFFS

Animal Feedlots

Advantages	Disadvantages
Increased meat production	Large inputs of grain, fish meal, water, and fossil fuels
Higher profits	Greenhouse gas (CO_2 and CH_4) emissions
Less land use	Concentration of animal wastes that can pollute water
Reduced overgrazing	Use of antibiotics can increase genetic resistance to microbes in humans
Reduced soil erosion	
Protection of biodiversity	

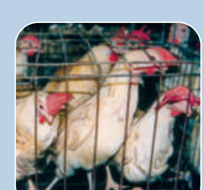


Figure 12-17 Advantages and disadvantages of animal feedlots. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Livestock in the United States produce 20 times more waste than is produced by the country's human population. Globally, only about half of all manure is returned to the land as nutrient-rich fertilizer—a violation of the recycling **principle of sustainability**. Much of the other half of this waste ends up polluting the air, water, and soil and producing foul odors.

Experts expect industrialized meat production to expand rapidly, especially as countries such as China and India become more affluent. This will increase pressure on the world's grain supply. Producing more meat will also increase pressure on the world's fish supply, because about 37% of the marine fish catch is converted to fish meal and fish oil, which are used to feed livestock and carnivorous fish raised by aquaculture.

Producing Fish through Aquaculture Can Harm Aquatic Ecosystems

Figure 12-18 lists the major advantages and disadvantages of aquaculture. Some analysts project that freshwater and saltwater aquaculture production could provide at least half of the world's seafood by 2025. Others warn that the harmful environmental effects of aquaculture could limit future production (**Concept 12-3**).

One problem is that fish raised on fish meal or fish oil can be contaminated with toxins such as PCBs found on ocean bottoms. In 2003, samples from various U.S. grocery stores revealed that farmed salmon had 7 times more PCBs than wild salmon and 4 times more than feedlot beef. A 2004 study found that farmed salmon also had levels of toxic dioxin 11 times higher than wild-caught salmon. Another problem is that wastes, pesticides, and antibiotics from aquaculture operations can pollute aquatic ecosystems.

TRADE-OFFS

Aquaculture

Advantages	Disadvantages
High efficiency	Needs large inputs of land, feed, and water
High yield in small volume of water	Large waste output
Can reduce overharvesting of fisheries	Can destroy mangrove forests and estuaries
Low fuel use	Uses grain to feed some species
High profits	Dense populations vulnerable to disease

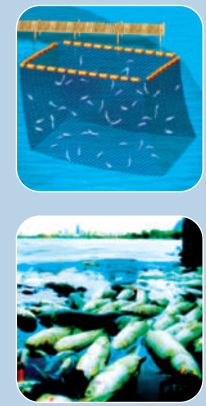


Figure 12-18 Advantages and disadvantages of *aquaculture*. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

Do the advantages of aquaculture outweigh its disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

Later in this chapter (Section 12-5), we consider some possible solutions to the environmental problems resulting from food production and ways to produce food more sustainably. But first, let us consider a special set of environmental problems and solutions related to protecting food supply systems from pests.

12-4 How Can We Protect Crops from Pests More Sustainably?

CONCEPT 12-4 **We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).**

Nature Controls the Populations of Most Pests

A **pest** is any species that interferes with human welfare by competing with us for food, invading lawns and gardens, destroying building materials, spreading disease, invading ecosystems, or simply being a nuisance. Worldwide, only about 100 species of plants ("weeds"), animals (mostly insects), fungi, and microbes cause most of the damage to the crops we grow.

In natural ecosystems and many polyculture agroecosystems, *natural enemies* (predators, parasites, and

Peter J. Bryant/Biological Photo Service

Figure 12-19 **Natural capital:** Spiders are important insect predators. Most spiders, including this ferocious-looking wolf spider, do not harm humans.

disease organisms) control the populations of most potential pest species in keeping with one of the earth's **scientific principles of sustainability** (see back cover). For example, the world's 30,000 known species of spiders, including the wolf spider (Figure 12-19), kill far more insects every year than humans do by using chemicals.

When we clear forests and grasslands, plant monoculture crops, and douse fields with chemicals that kill pests, we upset many of these natural population checks and balances, which implement the population control principle of sustainability. Then we must devise ways to protect our monoculture crops, tree plantations, lawns, and golf courses from insects and other pests that nature once controlled at no charge.

We Use Pesticides to Try to Control Pest Populations

To try to control pest organisms, we have developed a variety of **pesticides**—chemicals used to kill or control populations of organisms that humans consider undesirable. Common types of pesticides include *insecticides* (insect killers), *herbicides* (weed killers), *fungicides* (fungus killers), and *rodenticides* (rat and mouse killers).

We did not invent the use of chemicals to repel or kill other species. For nearly 225 million years, plants have been producing chemicals to ward off, deceive, or poison herbivores that feed on them. This battle produces a never-ending, ever-changing coevolutionary process: herbivores overcome various plant defenses through natural selection (**Concept 4-2B**, p. 80); then new plant defenses are favored by natural selection in this ongoing cycle of evolutionary punch and counterpunch.

CONCEPT LINK

In the 1600s, farmers used nicotine sulfate, extracted from tobacco leaves, as an insecticide. Eventually, other *first-generation pesticides*—mainly natural chemicals borrowed from plants—were developed. Farmers were copying nature.

A major pest control revolution began in 1939, when entomologist Paul Müller discovered that DDT (dichlorodiphenyltrichloroethane), a chemical known since 1874, was a potent insecticide. DDT was the first of the so-called *second-generation pesticides* produced in the laboratory. It soon became the world's most used pesticide, and Müller received the Nobel Prize in 1948 for his discovery. Since then, chemists have made hundreds of other pesticides by making slight modifications in the molecules in various classes of chemicals.

Second-generation pesticides, however, turned out to be hazardous as well as helpful. In 1962, biologist Rachel Carson (Individuals Matter, at right) sounded a warning that eventually led to strict controls on use of DDT and several other widely used pesticides. Since 1970, chemists have returned to natural repellents and poisons produced by plants, again copying nature, to improve first-generation botanical pesticides.

Since 1950, pesticide use has increased more than 50-fold, and most of today's pesticides are 10–100 times more toxic than those used in the 1950s. About three-fourths of these chemicals are used in developed countries, but their use in developing countries is soaring.

Some pesticides, called *broad-spectrum agents,* are toxic to many pest and nonpest species. Examples are chlorinated hydrocarbon compounds such as DDT and organophosphate compounds such as malathion and parathion. Others, called *selective,* or *narrow-spectrum, agents,* are effective against a narrowly defined group of organisms.

Pesticides vary in their *persistence,* the length of time they remain deadly in the environment. Some, such as DDT and related compounds, remain in the environment for years and can be biologically magnified in food chains and webs (Figure 9-19, p. 202). Others, such as organophosphates, are active for days or weeks and are not biologically magnified but can be highly toxic to humans. About one-fourth of pesticide use in the United States is devoted to trying to rid houses, gardens, lawns, parks, playing fields, swimming pools, and golf courses of pests. According to the EPA, the average lawn in the United States is doused with ten times more synthetic pesticides per unit of land area than are put on U.S. cropland.

Modern Synthetic Pesticides Have Several Advantages

Conventional chemical pesticides have advantages and disadvantages. Proponents contend that their benefits (Figure 12-20, left) outweigh their harmful effects (Figure 12-20, right). They point to the following benefits:

- *They save human lives.* Since 1945, DDT and other insecticides probably have prevented the prema-

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson (Figure 12-B) began her professional career as a biologist for the Bureau of U.S. Fisheries (now called the U.S. Fish and Wildlife Service). In that capacity, she carried out research in oceanography and marine biology and wrote articles and books about the oceans and topics related to the environment.

Throughout the 1950s, DDT use was increasing, and in 1958, DDT was sprayed to control mosquitoes near the home and private bird sanctuary of one of Carson's friends. After the spraying, her friend witnessed the agonizing deaths of several birds. She begged Carson to find someone to investigate the effects of pesticides on birds and other wildlife.

Carson decided to look into the issue herself and found that independent research on the environmental effects of pesticides was almost nonexistent. As a well-trained scientist, she surveyed the scientific literature, became convinced that pesticides could harm wildlife and humans, and methodically gathered information about the harmful effects of widespread use of pesticides.

In 1962, she published her findings in popular form in *Silent Spring,* a book whose title alluded to the silencing of "robins, catbirds, doves, jays, wrens, and scores of other bird voices" because of their exposure to pesticides. Many scientists, politicians, and policy makers read *Silent Spring,* and the public embraced it.

Chemical manufacturers viewed the book as a serious threat to their booming pesticide business and mounted a campaign to discredit Carson. A parade of critical reviewers and industry scientists claimed her book was full of inaccuracies, made selective use of research findings, and failed to give a balanced account of the benefits of pesticides.

Some critics even claimed that, as a woman, Carson was incapable of understanding such a highly scientific and technical subject. Others charged that she was an hysterical woman and a radical nature lover trying to scare the public in an effort to sell books.

During these intense attacks, Carson was a single mother, the sole caretaker of an aged parent, and was suffering from terminal breast cancer. Yet she strongly defended her research and countered her critics. She died in 1964—about 18 months after the publication of *Silent Spring*—without knowing that many historians consider her work an important contribution to the modern environmental movement then emerging in the United States.

It has been correctly noted that Carson made some errors in writing *Silent Spring.* But critics concede that the threat to birds and ecosystems—one of Carson's main messages—was real and that her errors can be attributed to the primitive state of research on the topics she covered in her day. And her critics cannot dispute the fact that her wake-up call got the public and the scientific community focused on the potential threats from uncontrolled use of pesticides, which led to many of them being banned for use in the United States and many other countries.

U.S. Fish and Wildlife Service

Figure 12-B Biologist Rachel Carson (1907–1964) greatly increased our understanding of the importance of nature and the harmful effects of widespread use of pesticides.

ture deaths of at least 7 million people (some say as many as 500 million) from insect-transmitted diseases such as malaria (carried by the Anopheles mosquito), bubonic plague (carried by rat fleas), and typhus (carried by body lice and fleas).

- *They increase food supplies.* According to the FAO, 55% of the world's potential human food supply is lost to pests. Without pesticides, these losses would be worse and food prices would rise.
- *They increase profits for farmers.* Officials of pesticide companies estimate that every $1 spent on pesticides leads to an increase in U.S. crop yields worth approximately $4. (However, studies have shown that this benefit drops to about $2 if the harmful effects of pesticides are included.)
- *They work fast.* Pesticides control most pests quickly, have a long shelf life, and are easily shipped and applied. When genetic resistance occurs, farmers can use stronger doses or switch to other pesticides.

TRADE-OFFS

Conventional Chemical Pesticides

Advantages	Disadvantages
Save lives	Promote genetic resistance
Increase food supplies	Kill natural pest enemies
Profitable	Pollute the environment
Work fast	Can harm wildlife and people
Safe if used properly	Are expensive for farmers

Figure 12-20 Advantages and disadvantages of conventional chemical pesticides. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

SCIENCE FOCUS

The Glyphosate-Resistant Crop Weed Management System: A Dilemma for Farmers and Scientists

Glyphosate is the world's best-selling herbicide, considered by farmers to be safe to use and highly effective in killing hundreds of species of weeds. It does not appear to harm animals or insects. And it does not leach into aquatic systems, but instead binds to soil particles and degrades into harmless substances within weeks.

Monsanto started selling glyphosate in 1974 under the trade name Roundup. Within 20 years, seed companies had engineered a variety of crops that are not affected by the herbicide. The idea was to create a system though which farmers could manage weeds easily and increase their yields, while herbicide and seed companies could substantially increase their sales.

The idea worked. The combination of glyphosate and glyphosate-resistant (GR) crops is a system now widely used in 22 countries. Of all the world's genetically modified crops planted in 2006, about 80% were glyphosate-resistant crops.

Another benefit was discovered. Farmers do not have to plow before planting GR crops. Instead they plant crop seeds with little or no tilling and spray emerging crops with glyphosate. This has led to a dramatic reduction in topsoil erosion.

Researchers once doubted that plants could ever evolve to be glyphosate-resistant, because they thought that the complex mutations required for such resistance were unlikely. But those researchers now have learned a lesson in unintended consequences, because GR weeds either evolved quickly or had existed already. By 2007, there were 12 known varieties of GR weeds, found in various parts of the world.

The problem is that glyphosate now dominates the herbicide market, and much of today's agriculture relies on this one chemical—a clear violation of the biodiversity **principle of sustainability** (see back cover).

If we end up with an epidemic of GR weeds, as some researchers fear, it could cost farmers and seed companies billions of dollars in lost productivity. More topsoil could be lost as farmers return to plowing, and farmers could be forced to use more harmful herbicides. Fossil fuel use would increase with more plowing, as would air pollution and greenhouse gas emissions.

The question is, are the benefits worth the costs of continuing the effort to engineer species interactions with use of herbicides and GM crops, or will that effort only result in an ever-escalating, ever more costly evolutionary battle between genetic engineers and weeds?

Critical Thinking

Do you think the benefits of using glyphosate, and new generations of similar herbicides to follow, outweigh their harmful effects on economies and the environment? Explain.

- *When used properly, their health risks are very low relative to their benefits.* Pesticide industry scientists argue that when pesticides are used in the approved regulatory manner, they pose no major risk to farm workers and consumers.
- *Newer pest control methods are safer and more effective than many older ones.* Greater use is being made of chemicals derived originally from plants. They are safer to use and less damaging to the environment than are many older pesticides. Genetic engineering is also being used to develop pest-resistant crop strains and genetically altered crops that produce natural pesticides.

Modern Synthetic Pesticides Have Several Disadvantages

Opponents of widespread pesticide use believe that the harmful effects of these chemicals (Figure 12-20, right) outweigh their benefits (Figure 12-20, left). They cite several serious problems with the use of conventional pesticides.

- *They accelerate the development of genetic resistance to pesticides by pest organisms.* Insects breed rapidly, and within 5 to 10 years (much sooner in tropical areas) they can develop immunity to widely used pesticides through natural selection and then come back stronger than before. Since 1945, about 1,000 species of insects and rodents (mostly rats) and 550 types of weeds and plant diseases have developed genetic resistance to one or more pesticides (Science Focus, above).
- *They can put farmers on a financial treadmill.* Because of genetic resistance, farmers can pay more and more for a pest control program that often becomes less and less effective.
- *Some insecticides kill natural predators and parasites that help control the pest populations.* Wiping out natural predators, such as spiders, can unleash new pests whose populations their predators had previously held in check and can cause other unexpected effects (Case Study, at right). Of the 300 most destructive insect pests in the United States, 100 were once minor pests that became major pests after widespread use of insecticides.
- *Pesticides do not stay put and can pollute the environment.* According to the U.S. Department of Agriculture (USDA), only 0.1–2% of the insecticides applied to crops by aerial spraying or ground spraying reaches the target pests, and less than 5% of herbicides applied to crops reaches the target weeds.

In other words, 98–99.9% of the insecticides and more than 95% of the herbicides we apply end up in the air, surface water, groundwater, bottom sediments, food, and nontarget organisms, including humans and wildlife.

- *Some pesticides harm wildlife.* According to the USDA and the U.S. Fish and Wildlife Service, each year, pesticides applied to cropland in the United States wipe out about 20% of U.S. honeybee colonies and damage another 15%. Pesticides also kill more than 67 million birds and 6–14 million fish. According to a 2004 study by the Center for Biological Diversity, pesticides also menace one of every three endangered and threatened species in the United States.
- *Some pesticides threaten human health.* The WHO and UNEP estimate that, each year, pesticides seriously poison at least 3 million agricultural workers in developing countries and at least 300,000 people in the United States. They also cause 20,000–40,000 deaths per year, worldwide. Each year, more than 250,000 people in the United States become ill because of household pesticide use. Such pesticides are a major source of accidental poisonings and deaths of young children.

According to studies by the National Academy of Sciences, exposure to legally allowed pesticide residues in food causes 4,000–20,000 cases of cancer per year in the United States. Some scientists are concerned about possible genetic mutations, birth defects, nervous system and behavioral disorders, and effects on the immune and endocrine systems from long-term exposure to low levels of various pesticides. (See more on this topic in Chapter 17 and *The Habitable Planet,* Video 7, at **www.learner.org/resources/series209.html**.) The pesticide industry disputes these claims, arguing that the exposures are not high enough to cause serious harm.

Children are much more susceptible to low levels of pesticides and other toxic chemicals, because on an amount-per-weight basis, they eat more food, drink more water, and breathe more air. They also put their fingers in their mouths more often and spend more time playing on grass, carpeting, and soil where pesticides can accumulate.

Figure 12-21 lists some ways in which you can reduce your exposure to pesticides.

Pesticide use has not reduced U.S. crop losses to pests, mostly because of genetic resistance and reduction of natural predators. When David Pimentel, an expert on insect ecology, evaluated data from more than 300 agricultural scientists and economists, he reached three major conclusions.

- *First,* although the use of synthetic pesticides has increased 33-fold since 1942, 37% of the U.S. food supply is lost to pests today compared to 31% in the 1940s. Since 1942, losses attributed to insects almost doubled from 7% to 13%, despite a tenfold increase in the use of synthetic insecticides.

WHAT CAN YOU DO?

Reducing Exposure to Pesticides

- Grow some of your food using organic methods
- Buy organic food
- Wash and scrub all fresh fruits, vegetables, and wild foods you pick
- Eat less meat or no meat
- Trim the fat from meat

Figure 12-21 **Individuals matter:** ways to reduce your exposure to pesticides. **Question:** Which three of these measures do you think are the most important? Why?

- *Second,* estimated environmental, health, and social costs of pesticide use in the United States, according to the International Food Policy Research Institute, are \$5–10 in damages for every dollar spent on pesticides.
- *Third,* alternative pest management practices could halve the use of chemical pesticides on 40 major U.S. crops without reducing crop yields (**Concept 12-4**).

The pesticide industry disputes these findings. Trying to balance the economic and environmental advantages and disadvantages of pesticides is not easy and presents farmers and scientists with serious dilemmas (Science Focus, at left). However, numerous studies and experience show that pesticide use can be reduced sharply without reducing yields. Sweden has cut pesticide use in half with almost no decrease in crop yields. Campbell Soup uses no pesticides on tomatoes it grows in Mexico, and yields have not dropped. After a two-thirds cut in pesticide use on rice in Indonesia, yields increased by 15%.

■ CASE STUDY
Ecological Surprises

Malaria once infected nine of every ten people in North Borneo, now known as the eastern Malaysian state of Sabah. In 1955, the WHO began spraying the island with dieldrin (a relative of DDT) to kill malaria-carrying mosquitoes. The program was so successful that the dreaded disease was nearly eliminated.

Then unexpected things began to happen. The dieldrin also killed other insects, including flies and cockroaches living in houses. The islanders applauded. Next, small insect-eating lizards that also lived in the houses died after gorging themselves on dieldrin-contaminated insects.

Cats began dying after feeding on the lizards. In the absence of cats, rats flourished and overran the villages. When the people became threatened by sylvatic plague carried by rat fleas, the WHO parachuted healthy cats onto the island to help control the rats. Operation Cat Drop worked.

But then the villagers' roofs began to fall in. The dieldrin had killed wasps and other insects that fed on a type of caterpillar that either avoided or was not affected by the insecticide. With most of its predators eliminated, the caterpillar population exploded, munching its way through its favorite food: the leaves used to thatch roofs.

Ultimately, this episode ended well: both malaria and the unexpected effects of the spraying program were brought under control. Nevertheless, this chain of unintended and unforeseen events emphasizes the unpredictability of using insecticides. It reminds us that when we intervene in nature, we need to ask, "Now what will happen?"

HOW WOULD YOU VOTE?

Do the advantages of using synthetic chemical pesticides outweigh their disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

Laws and Treaties Can Help to Protect Us from the Harmful Effects of Pesticides

Each year in the United States, about 2.4 million metric tons (2.6 million tons) of pesticides are used—an average of 4.6 metric tons (4.9 tons) per minute. They consist of 600 active (pest-killing) chemicals mixed with 1,200 solvents, preservatives, and other supposedly inactive ingredients in about 25,000 commercial pesticide products. Three U.S. federal agencies, the EPA, the USDA, and the Food and Drug Administration (FDA), regulate the sale and use of pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), first passed in 1947 and amended in 1972.

Under FIFRA, the EPA was supposed to assess the health risks of the active ingredients in pesticide products already in use. But after more than 30 years, less than 10% of the active ingredients in pesticide products have been evaluated using tests for chronic health effects. Serious evaluation of the health effects of the 1,200 inactive ingredients used in pesticide products began only recently. The EPA says that it has not had the funds to carry out this complex and lengthy evaluation process.

In 1996, Congress passed the Food Quality Protection Act, mostly because of growing scientific evidence and citizen pressure concerning the effects of small amounts of pesticides on children. This act requires the EPA to reduce the allowed levels of pesticide residues in food by a factor of 10 when there is inadequate information on the potentially harmful effects on children.

There is controversy over how well U.S. citizens are protected from the harmful effects of pesticides. Between 1972 and 2007, the EPA used FIFRA to ban or severely restrict the use of 64 active pesticide ingredients, including DDT and most other chlorinated hydrocarbon insecticides. However, according to studies by the National Academy of Sciences, federal laws regulating pesticide use in the United States are inadequate and poorly enforced by the three agencies. One study by the National Academy of Sciences found that as much as 98% of the potential risk of developing cancer from pesticide residues on food grown in the United States would be eliminated if EPA standards were as strict for pre-1972 pesticides as they are for newer ones.

Although laws within countries protect citizens to some extent, banned or unregistered pesticides may be manufactured in one country and exported to other countries. For example, U.S. pesticide companies make and export to other countries pesticides that have been banned or severely restricted—or never even evaluated—in the United States. Other industrial countries also export banned or unapproved pesticides.

But what goes around can come around. In what environmental scientists call a *circle of poison* or the *boomerang effect,* residues of some banned or unapproved chemicals exported to other countries can return to the exporting countries on imported food. The wind can also carry persistent pesticides such as DDT from one country to another (Chapter 7 Core Case Study, p. 140).

Environmental scientists and environmentalists have urged the U.S. Congress—without success—to ban such exports. Supporters of the exports argue that such sales increase economic growth and provide jobs, and that banned pesticides are exported only with the consent of the importing countries. They also contend that if the United States did not export pesticides, other countries would.

In 1998, more than 50 countries developed an international treaty that requires exporting countries to have informed consent from importing countries for exports of 22 pesticides and 5 industrial chemicals. In 2000, more than 100 countries developed an international agreement to ban or phase out the use of 12 especially hazardous persistent organic pollutants (POPs)—9 of them persistent hydrocarbon pesticides such as DDT and other chemically similar pesticides. The United States has not signed this agreement.

THINKING ABOUT
Exporting Pesticides

Should companies be allowed to export pesticides that have been banned, severely restricted, or not approved for use in their home countries? Explain.

There Are Alternatives to Using Pesticides

Many scientists believe we should greatly increase the use of biological, ecological, and other alternative methods for controlling pests and diseases that affect crops and human health (**Concept 12-4**). Here are some of these alternatives:

- *Fool the pest.* A variety of *cultivation practices* can be used to fake out pest species. For example, rotating the types of crops planted in a field each year will keep specialists that eat one type of crop searching from year to year for their food. Other methods include adjusting planting times, so major insect pests either starve or get eaten by their natural predators, and growing crops in areas where their major pests do not exist.

- *Provide homes for pest enemies.* Farmers can increase the use of polyculture, which uses plant diversity to reduce losses to pests. Homeowners can reduce weed invasions by cutting grass no lower than 8 centimeters (3 inches) high. This height provides a dense enough cover to keep out crabgrass and many other undesirable weeds.

- *Implant genetic resistance.* Use genetic engineering to speed up the development of pest- and disease-resistant crop strains (Figure 12-22). But controversy persists over whether the projected advantages of using genetically modified plants and foods such as golden rice (**Core Case Study**) outweigh their projected disadvantages (Figure 12-16, right). CORE CASE STUDY

- *Bring in natural enemies.* Use *biological control* by importing natural predators (Figures 12-19 and 12-23), parasites, and disease-causing bacteria and viruses to help regulate pest populations. This approach is nontoxic to other species, minimizes genetic resistance, and can save large amounts of money—about $25 for every $1 invested in controlling 70 pest species in the United States. However, biological control agents cannot always be mass-produced, are often slower acting and more difficult to apply than conventional pesticides, can sometimes multiply and become pests themselves, and must be protected from pesticides sprayed in nearby fields.

- *Use insect perfumes. Sex attractants* (called *pheromones*) can lure pests into traps or attract their natural predators into crop fields (usually the more effective approach). These chemicals attract only one species, work in trace amounts, have little chance of causing genetic resistance, and are not harmful to nontarget species. However, it is costly and time-consuming to identify, isolate, and produce the specific sex attractant for each pest or predator.

Monsanto

Figure 12-22 **Solutions:** the results of one example of using *genetic engineering* to reduce pest damage. Both tomato plants were exposed to destructive caterpillars. The normal plant's leaves are almost gone (left), whereas the genetically altered plant shows little damage (right). **Question:** Would you have any concerns about eating the genetically engineered tomato? Why or why not?

- *Bring in the hormones. Hormones* are chemicals produced by animals to control developmental processes at different stages of life. Scientists have learned how to identify and use hormones that disrupt an insect's normal life cycle, thereby preventing it from reaching maturity and reproducing. Insect hormones have the same advantages as sex

Scott Bauer/USDA Agricultural Research Service

Figure 12-23 **Natural capital:** biological pest control. Wasp parasitizing a gypsy moth caterpillar.

attractants. But they take weeks to kill an insect, often are ineffective with large infestations of insects, and sometimes break down before they can act. In addition, they must be applied at exactly the right time in the target insect's life cycle, can sometimes affect the target's predators and other beneficial species, and are difficult and costly to produce.

- *Scald them.* Some farmers have controlled certain insect pests by *spraying them with hot water.* This approach has worked well on cotton, alfalfa, and potato fields and in citrus groves in the U.S. state of Florida, and its cost is roughly equal to that of using chemical pesticides. However, it requires large amounts of water and energy to heat it.

Integrated Pest Management Is a Component of Sustainable Agriculture

Many pest control experts and farmers believe the best way to control crop pests is a carefully designed **integrated pest management (IPM)** program. In this more sustainable approach, each crop and its pests are evaluated as parts of an ecological system. Then farmers develop a control program that uses a combination of cultivation, biological controls, and chemical tools and techniques, applied in a carefully coordinated way (**Concept 12-4**).

The overall aim of IPM is to reduce crop damage to an economically tolerable level. Each year, crops are moved from field to field to disrupt pest infestations, and fields are monitored carefully. When an economically damaging level of pests is reached, farmers first use biological methods (natural predators, parasites, and disease organisms) and cultivation controls. They also use large machines to vacuum up harmful bugs. They apply small amounts of insecticides—mostly those naturally produced by plants—only as a last resort and in the smallest amounts possible. Broad-spectrum, long-lived pesticides are not used, and different chemicals are used alternately to slow the development of genetic resistance and to reduce the killing predators of pest species.

In 1986, the Indonesian government banned 57 of the 66 pesticides used on rice and phased out pesticide subsidies over a 2-year period. It also launched a nationwide education program to help farmers switch to IPM. The results were dramatic: between 1987 and 1992, pesticide use dropped by 65%, rice production rose by 15%, and more than 250,000 farmers were trained in IPM techniques. For more information and animations, see *The Habitable Planet,* Video 7, at **www.learner.org/resources/series209.html**. Sweden and Denmark have used IPM to cut their pesticide use by more than half. Cuba, which uses organic farming to grow its crops, makes extensive use of IPM. In Brazil, IPM has reduced pesticide use on soybeans by as much as 90%.

According to a 2003 study by the U.S. National Academy of Sciences, these and other experiences show that a well-designed IPM program can reduce pesticide use and pest control costs by 50–65% without reducing crop yields and food quality. IPM can also reduce inputs of fertilizer and irrigation water, and slow the development of genetic resistance, because pests are assaulted less often and with lower doses of pesticides. IPM is an important form of *pollution prevention* that reduces risks to wildlife and human health and applies the population control **principle of sustainability** (see back cover).

Despite its promise, IPM—like any other form of pest control—has some disadvantages. It requires expert knowledge about each pest situation and takes more time than does using conventional pesticides. Methods developed for a crop in one area might not apply to areas with even slightly different growing conditions. Initial costs may be higher, although long-term costs typically are lower than those of using conventional pesticides. Widespread use of IPM is hindered by government subsidies for using conventional chemical pesticides, opposition by pesticide manufacturers, and a shortage of IPM experts. **GREEN CAREER:** Integrated pest management

A 1996 study by the National Academy of Sciences recommended that the United States shift from chemical-based approaches to ecological-based approaches for managing pests. According to this study, within 5–10 years, such a shift could cut U.S. pesticide use in half, as it has in several other countries.

A growing number of scientists urge the USDA to use three strategies to promote IPM in the United States:

- Add a 2% sales tax on pesticides and use the revenue to fund IPM research and education.
- Set up a federally supported IPM demonstration project on at least one farm in every U. S. county.
- Train USDA field personnel and county farm agents in IPM so they can help farmers use IPM.

The pesticide industry has successfully opposed such measures.

HOW WOULD YOU VOTE?

Should governments heavily subsidize a switch to integrated pest management? Cast your vote online at **academic.cengage.com/biology/miller**.

Several U.N. agencies and the World Bank have joined together to establish an IPM facility. Its goal is to promote the use of IPM by disseminating information and establishing networks among researchers, farmers, and agricultural extension agents involved in IPM.

12-5 How Can We Improve Food Security?

▶ **CONCEPT 12-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.**

Use Government Policies to Improve Food Production and Security

Agriculture is a financially risky business. Whether farmers have a good or bad year depends on factors over which they have little control: weather, crop prices, crop pests and diseases, interest rates, and global markets. Because of the need for reliable food supplies despite fluctuations in these factors, most governments provide various forms of assistance to farmers, fishers, and consumers.

Governments use three main approaches to influence food production:

- *Control prices.* Use price controls to keep food prices artificially low. Consumers are happy, but farmers may not be able to make a living.
- *Provide subsidies.* Give farmers price supports, tax breaks, and other subsidies to keep them in business and to encourage them to increase food production. According to the United Nations, government subsidies account for about 31% of global farm income. Globally, farm subsidies in the developed countries average about $280 billion a year—an average of $530,000 a minute! If government subsidies are too generous and the weather is good, farmers and livestock producers may produce more food than can be sold. The resulting surplus depresses food prices, which reduces the financial incentive for farmers in developing countries to increase domestic food production.

  Some analysts call for phasing out such subsidies. For example, in 1984, New Zealand ended farm subsidies. After the shock wore off, innovation took over, and production of some foods such as milk quadrupled. Other analysts call for replacing traditional farming subsidies with subsidies that promote more sustainable farming practices.

  Similarly, government subsidies to fishing fleets (p. 264) can promote overfishing and reduction of aquatic biodiversity. For example, governments give the highly destructive bottom trawling industry (Figure 11-3, p. 251) about $152 million in subsidies a year, which is the main reason they can stay in business. Many analysts call for replacing those subsidies with payments that promote more sustainable fishing and aquaculture.
- *Let the marketplace decide.* Another approach is to eliminate most or all price controls and subsidies and let farmers and fishers respond to market demand without government interference. Some analysts urge that any phase-out of farm and fishery subsidies should be coupled with increased aid for the poor and the lower middle class, who would suffer the most from any increase in food prices.

HOW WOULD YOU VOTE?

Should governments phase out all or most subsidies for conventional agriculture and phase in subsidies for more sustainable agriculture? Cast your vote online at **academic .cengage.com/biology/miller**.

Government programs that reduce poverty by helping the poor to help themselves can improve food security (**Concept 12-1B**). An essential part of this would be to reduce the population growth rate. Such programs should thus promote family planning, education and jobs (especially for women), and small loans to poor people to help them start businesses or buy land for growing their own food.

Some analysts urge special programs focused on saving children from poverty. Studies by the United Nations Children's Fund (UNICEF) indicate that one-half to two-thirds of nutrition-related childhood deaths could be prevented at an average annual cost of $5–$10 per child with the following measures:

- Immunizing children against childhood diseases such as measles
- Encouraging breast-feeding (except for mothers with AIDS)
- Preventing dehydration from diarrhea by giving infants a mixture of sugar and salt in a glass of water
- Preventing blindness by giving children a vitamin A capsule twice a year at a cost of about 75¢ per child. Other options are fortifying common foods with vitamin A and other micronutrients at a cost of about 10¢ per child annually and widespread planting of golden rice in developing countries (**Core Case Study**). CORE CASE STUDY
- Providing family planning services to help mothers space births at least 2 years apart
- Increasing education for women, with emphasis on nutrition, drinking water sterilization, family planning, and childcare

Analysts note that *preventing* health problems in children is an important step toward global food security.

12-6 How Can We Produce Food More Sustainably?

▶ **CONCEPT 12-6A Sustainable food production will require reducing topsoil erosion, sharply reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies for more sustainable farming, fishing, and aquaculture.**

▶ **CONCEPT 12-6B Producing enough food to feed the rapidly growing human population will require growing crops in a mix of monocultures and polycultures and decreasing the enormous environmental impacts of industrialized food production.**

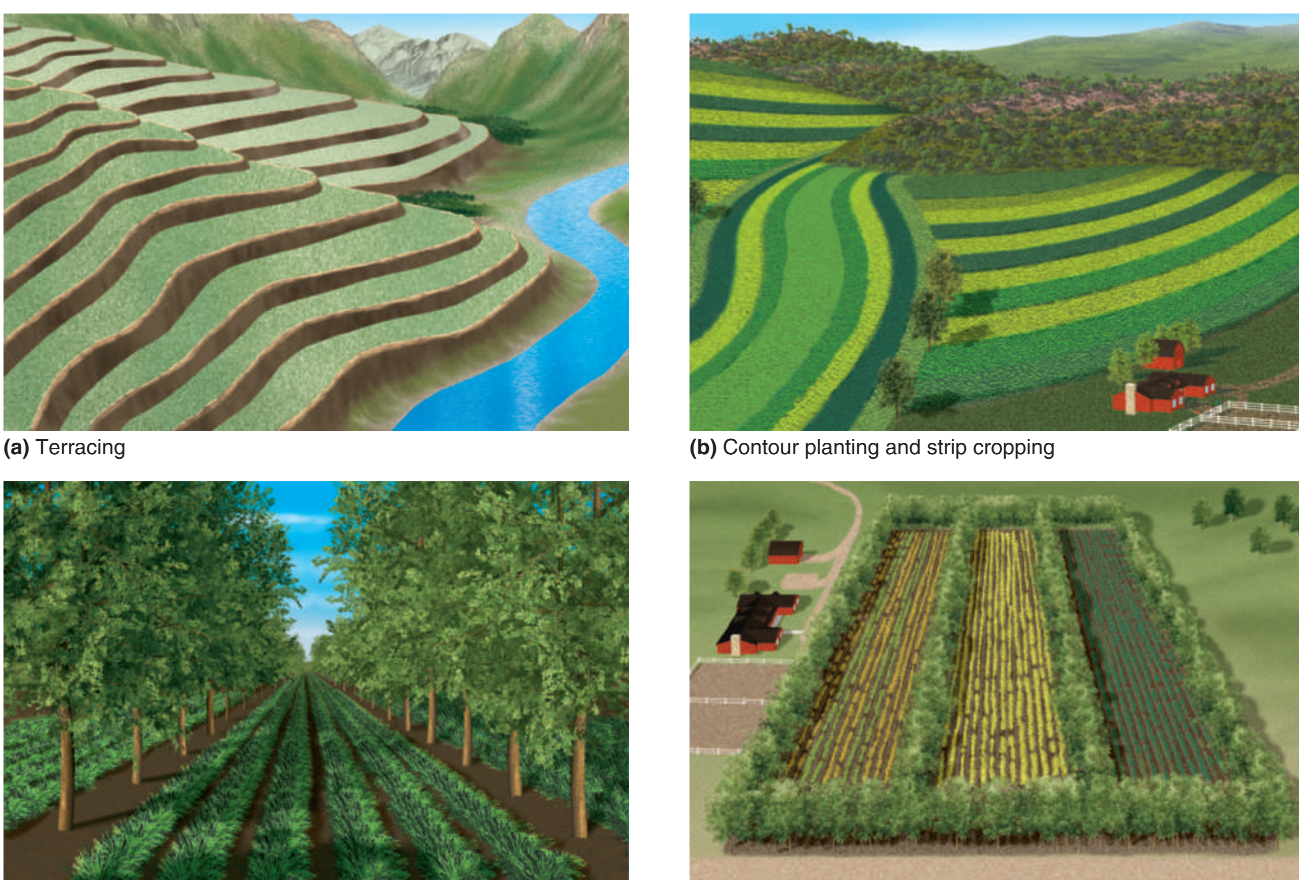
Reduce Soil Erosion

Soil conservation involves using a variety of ways to reduce soil erosion and restore soil fertility, mostly by keeping the soil covered with vegetation.

Figure 12-24 shows some of the methods farmers have used to reduce soil erosion (**Concept 12-6A**). For example, *terracing* is a way to grow food on steep slopes without depleting topsoil. It is done by converting steeply sloped land into a series of broad, nearly level terraces that run across the land's contours (Figure 12-24a and Figure 12-1). This retains water for crops at each level and reduces soil erosion by controlling runoff.

When the ground has a significant slope, a technique known a *contour planting* (Figures 12-24b and 12-25) can be used to reduce soil erosion. It involves plowing and planting crops in rows across the slope of the land rather than up and down. Each row acts as a small dam to help hold topsoil and to slow water runoff.

Strip cropping (Figure 12-24b) involves planting alternating strips of a row crop (such as corn or cotton) and another crop that completely covers the soil, called a *cover crop* (such as alfalfa, clover, rye, or a grass–



(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

Figure 12-24 Soil conservation methods include **(a)** terracing, **(b)** contour planting and strip cropping, **(c)** alley cropping, and **(d)** windbreaks (**Concept 12-6A**).

Ron Nichols/USDA Natural Resources Conservation Service

Figure 12-25 **Solutions:** mixture of monoculture crops planted in strips on a farm in central Wisconsin (USA). This farm practices sound soil conservation by planting crops with the contours of the land (*contour planting*) and alternating crops in strips (*strip cropping*) to help reduce soil erosion and depletion of soil nutrients.

legume mixture). The cover crop traps topsoil that erodes from the row crop and catches and reduces water runoff (Figure 12-25). When one crop is harvested the other strip is left to catch and reduce water runoff. Other ways to reduce erosion are to leave crop residues on the land after the crops are harvested or to plant cover crops immediately after harvest to help protect and hold the topsoil.

Alley cropping, or *agroforestry* (Figure 12-24c), is yet another way to slow erosion. One or more crops are planted together in strips or alleys between trees and shrubs, which provide shade. This reduces water loss by evaporation and helps retain and slowly release soil moisture—an insurance policy during prolonged drought. The trees also can provide fruit, fuelwood, and trimmings that can be used as mulch for the crops (green manure) and as feed for livestock.

Some farmers establish *windbreaks,* or *shelterbelts,* of trees around crop fields to reduce wind erosion (Figure 12-24d). These trees also retain soil moisture, supply wood for fuel, increase crop productivity by 5–10%, and provide habitats for birds, pest-eating and pollinating insects, and other animals.

However, many farmers do not practice these known ways to reduce soil erosion, because they are in a desperate struggle to survive, or they are more interested in increasing short-term income, even if it leads to long-term environmental degradation.

Eliminating the plowing and tilling of soil greatly reduces soil erosion. Many farmers in the United States and several other countries practice *conservation-tillage farming* by using special tillers and planting machines that drill seeds directly through crop residues into the undisturbed soil. The only soil disturbance is a narrow slit, and weeds are controlled with herbicides. Such *no-till* and *minimum-tillage* farming also increases crop yields, reduces the threat of global warming by storing more carbon in the soil, and lowers use of water and tractor fuel.

In 2007, farmers used conservation tillage on about 41% of U.S. cropland, helped by the use of herbicides such as glyphosate (Science Focus, p. 296). The USDA estimates that using conservation tillage on 80% of U.S. cropland would reduce soil erosion by at least half. No-till cultivation is now spreading rapidly into countries such as Brazil, Argentina, Canada, and Australia. It also has great potential to reduce soil erosion and raise crop yields in dry regions in Africa and the Middle East. Conservation tillage, however, is not a cure-all. It requires costly machinery and increases use of herbicides, works better in some areas than in others, and is more useful for some crops than for others.

An additional way to conserve the earth's topsoil is to retire the estimated one-tenth of the world's cropland that is highly erodible and accounts for the majority of the world's soil erosion. The goal would be to identify these *erosion hotspots,* withdraw them from cultivation, and plant them with grasses or trees.

■ **CASE STUDY**

Soil Erosion in the United States—Learning from the Past

In the United States, a third of the country's original topsoil is gone and much of the rest is degraded. In the state of Iowa, which has the world's highest concentration of prime farmland, half of the topsoil is gone after a century of farming. According to the Natural Resources

NOAA George E. Marsh Album

Figure 12-26 **Natural capital degradation:** dust storm, driven by wind blowing across eroded soil, approaching Stratford, Texas (USA), in 1935.

Conservation Service, 90% of American farmland is, on average, losing topsoil 17 times faster than new topsoil is being formed.

In the 1930s, Americans learned a harsh environmental lesson when much of the topsoil in several dry and windy midwestern states was lost because of a combination of poor cultivation practices and prolonged drought. This threatened to turn much of the U.S. Great Plains into a vast desert. Before settlers began grazing livestock and planting crops there in the 1870s, the deep and tangled root systems of native prairie grasses anchored the fertile topsoil firmly in place. But plowing the prairie tore up these roots, and the crops that settlers planted annually in their place had less extensive root systems. After each harvest, the land was plowed and left bare for several months, exposing it to high winds. Overgrazing by livestock in some areas also destroyed large expanses of grass, denuding the ground.

The stage was set for severe wind erosion and crop failures; all that was needed was a long drought. It came between 1926 and 1937 when the annual precipitation dropped by almost two-thirds. In the 1930s, dust clouds created by hot, dry windstorms blowing across the barren exposed soil darkened the sky at midday in some areas (Figure 12-26). Rabbits and birds choked to death on the dust.

During May 1934, a cloud of topsoil blown off the Great Plains traveled some 2,400 kilometers (1,500 miles) and blanketed most of the eastern United States with dust. Laundry hung out to dry by women in the state of Georgia quickly became covered with dust blown in from the Midwest. Journalists gave the most eroded part of the Great Plains a new name: the *Dust Bowl* (Figure 12-27).

This calamity triggered one of the largest internal migrations in U.S. history. Thousands of farm families from the states of Oklahoma, Texas, Kansas, and Colorado abandoned their dust-choked farms and dead livestock and migrated to California or to the industrial cities of the Midwest and East. Most found no jobs because the country was in the midst of the Great Depression.

In May 1934, Hugh Bennett of the USDA went before a congressional hearing in Washington, D.C., to plead for new programs to protect the country's topsoil. Lawmakers took action when Great Plains dust began seeping into the hearing room. As Bennett put it, "This nation and civilization is founded upon nine inches of topsoil. And when that is gone there will no longer be any nation or any civilization."

In 1935, the United States passed the *Soil Erosion Act,* which established the Soil Conservation Service (SCS) as part of the USDA. Soil conservation districts were formed throughout the country, and farmers and ranchers were given technical assistance to set up soil conservation programs. (The SCS is now called the Natural Resources Conservation Service.)

Of the world's major food-producing nations, only the United States is sharply reducing some of its soil losses through a combination of conservation-tillage farming and government-sponsored soil conservation programs (**Concept 12-6A**). Under the 1985 Food Security Act (Farm Act), farmers participating in the Conservation Reserve Program receive a subsidy for taking highly erodible land out of production and replanting it with topsoil-saving grass or trees for 10–15 years. Since 1985, these efforts have cut soil losses on U.S. cropland by 40%.

However, effective soil conservation is practiced today on only half of all U.S. agricultural land. Also, in recent years, some farmers have been taking erodible

Figure 12-27 **Natural capital degradation:** the *Dust Bowl* of the Great Plains, where a combination of extreme drought and poor soil conservation practices led to severe wind erosion of topsoil in the 1930s.

land out of the conservation reserve in order to receive government subsidies for planting corn to make ethanol for use as a motor vehicle fuel.

Restore Soil Fertility

The best way to maintain soil fertility is through soil conservation. The next best option is to restore some of the plant nutrients that have been washed, blown, or leached out of the soil, or that have been removed by repeated crop harvesting. To do this, farmers can use **organic fertilizer** made from plant and animal wastes or **commercial inorganic fertilizer** produced from various minerals.

There are several types of *organic fertilizers.* One is **animal manure:** the dung and urine of cattle, horses, poultry, and other farm animals. It improves soil structure, adds organic nitrogen, and stimulates beneficial soil bacteria and fungi. Another type, called **green manure** consists of freshly cut or growing green vegetation that is plowed into the topsoil to increase the organic matter and humus available to the next crop. A third type is **compost,** produced when microorganisms in soil break down organic matter such as leaves, crop residues, food wastes, paper, and wood in the presence of oxygen. (See the website for this chapter for more details on composting.)

Crops such as corn and cotton can deplete nutrients in the topsoil (especially nitrogen) if they are planted on the same land several years in a row. *Crop rotation* provides one way to reduce these losses. Farmers plant areas or strips with nutrient-depleting crops one year. The next year, they plant the same areas with legumes whose root nodules add nitrogen to the soil. This not only helps to restore soil nutrients but also reduces erosion by keeping the topsoil covered with vegetation.

Many farmers (especially in developed countries) rely on *commercial inorganic fertilizers.* The active ingredients typically are inorganic compounds that contain *nitrogen, phosphorus,* and *potassium.* Other plant nutrients may be present in low or trace amounts. Inorganic fertilizer use has grown more than elevenfold since 1950 and now accounts for about one-fourth of the world's crop yield. Without careful control, these fertilizers can run off the land and pollute nearby bodies of water and coastal estuaries where rivers empty into the sea.

These fertilizers can replace depleted inorganic nutrients, but they do not replace organic matter. To completely restore nutrients to soil, both inorganic and organic fertilizers should be used.

Reduce Soil Salinization and Desertification

We know how to prevent and deal with soil salinization, as summarized in Figure 12-28.

Figure 12-28 Methods for preventing and cleaning up soil salinization (**Concept 12-6A**). **Question:** Which two of these solutions do you think are the most important? Why?

Desertification is not an easy problem to deal with. We cannot control the timing and location of prolonged droughts caused by natural factors. But we can reduce population growth, overgrazing, deforestation, and destructive forms of planting, irrigation, and mining, which have left much land vulnerable to soil erosion and thus desertification.

We can also work to decrease the human contribution to global warming, which is expected to increase severe and prolonged droughts in larger areas of the world during this century. It is possible to restore land suffering from desertification by planting trees and grasses that anchor topsoil and hold water, by establishing windbreaks (Figure 12-24d), and by growing trees and crops together (Figure 12-24c).

Practice More Sustainable Aquaculture

Figure 12-29 (p. 306) lists some ways to make aquaculture more sustainable and to reduce its harmful environmental effects. Open-ocean aquaculture, which the United States is planning to develop, is one such alternative. It involves raising large carnivorous fish in underwater pens located up to 300 kilometers (190 miles) offshore (Figure 11-7, p. 256). The fish are fattened with fish meal supplied by automated buoys. Using another approach, scientists are eliminating damage to coastal areas in Florida by raising shrimp far inland in zero-discharge freshwater ponds. **GREEN CAREER:** Aquaculture

SOLUTIONS

More Sustainable Aquaculture

- Restrict locations of fish farms to reduce losses of mangrove forests and estuaries
- Improve management of aquaculture wastes
- Reduce escape of aquaculture species into the wild
- Raise some aquaculture species in deeply submerged cages to protect them from wave action and predators and to allow dilution of wastes into the ocean
- Certify sustainable forms of aquaculture and label products accordingly

Figure 12-29 Ways to make aquaculture more sustainable and to reduce its harmful effects. **Question:** Which two of these solutions do you think are the most important? Why?

However, making aquaculture more sustainable will require some fundamental changes, one of which is for consumers to choose more often from species that are lower on the food chain—those that feed on plants rather than on other fish. For example, raising carnivorous fishes such as salmon, trout, tuna, grouper, and cod contributes to overfishing of species used to feed these carnivores. Raising plant-eating fishes such as carp and tilapia (called the chicken of fish farming) does not add to this problem.

On the production end, fish farmers could employ *polyaquaculture,* which in fact has been part of aquaculture for centuries, especially in Southeast Asia. Polyaquaculture operations raise fish or shrimp along with algae, seaweeds, and shellfish in coastal lagoons, ponds, and tanks. The wastes of the fish or shrimp feed the other species, and in the best of these operations, there are just enough wastes from the first group to feed the second group. This applies the nutrient recycling and biodiversity **principles of sustainability**.

Produce Meat More Efficiently and Humanely

Ultimately, consumers need to evaluate their use of meat in their diets relative to the harmful environmental impacts caused by its increasingly industrialized production. Currently, about 38% of the world's grain harvest and 37% of the world's fish catch are used to produce animal protein. If everyone in the world today had the average U.S. meat-based diet, the world's current annual grain harvest could feed only about 2.5 billion people. People in many European countries consume about half as much grain per person as people in the United States consume. If everyone followed this diet, the current grain harvest would support about 5 billion people.

A more sustainable form of meat production and consumption would involve shifting from less grain-efficient forms of animal protein, such as beef and pork, to more grain-efficient forms, such as poultry and herbivorous farmed fish (Figure 12-30). Such a shift is under way. Since 1996, poultry has taken the lead over beef in the marketplace, and within a decade or so, production of farmed herbivorous fish may exceed beef production.

We can find alternatives to growing grain to feed livestock. In 1997, India became the world's largest producer of milk and other dairy products. The entire industry is based mostly on feeding dairy cows roughage such as rice straw, wheat straw, corn stalks, and grass gathered from roadsides. Another approach is to develop meat substitutes. Researchers at Vrjie University in the Netherlands are using peas and other protein-rich legumes to develop alternatives to meats that are affordable, highly nutritious, easy to prepare, and tasty.

Some individuals and groups consider it unethical and inhumane to raise livestock in crowded feedlots and pens under factory-like conditions. In 2004, Whole Foods Market, a natural and organic foods supermarket chain in the United States, committed $500,000 to establish a foundation to look for more humane ways to raise livestock in feedlots. And McDonald's, Wendy's, and Burger King have hired specialists to develop new standards for improving animal welfare. In 2005, the 165 member countries of the World Organization for Animal Health adopted voluntary standards for the more humane transportation and slaughter of livestock animals.

Move Down the Food Chain and Slow Population Growth

Food production, especially producing meat, has a huge environmental impact (Figure 12-9). Indeed, eating meat, driving fuel-inefficient motor vehicles, and liv-

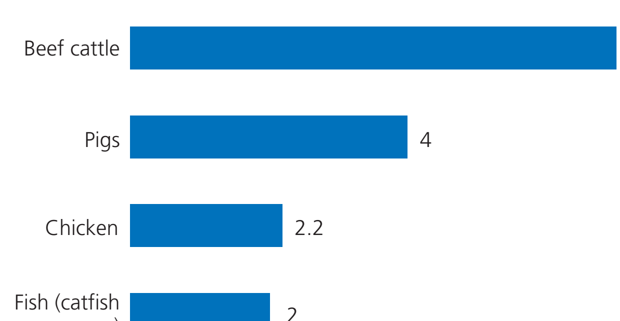


Figure 12-30 Efficiency of converting grain into animal protein. Data in kilograms of grain per kilogram of body weight added. **Question:** If you eat meat, what changes could you make in your meat-eating habits to reduce your environmental impact? (Data from U.S. Department of Agriculture)

ing and working in energy-inefficient buildings make the three largest contributions to the ecological and carbon footprints of most individuals in affluent nations. According to a 2006 study by the U.N. Food and Agriculture Organization, *Livestock's Long Shadow,* meat production and delivery cause 40% more greenhouse gas emissions than all of the world's planes, cars, trucks, and other forms of transport combined.

As a result, some people are eating less meat and switching from energy-inefficient beef, pork, and carnivorous fish produced by aquaculture to more energy-efficient chicken and herbivorous fish produced by aquaculture (Figure 12-29). In addition to reducing their ecological and carbon footprints, this switch can improve their health and increase their life expectancy. Research indicates that people who live on a Mediterranean-type diet, which includes moderate amounts of meat, cheese, and seafood, are healthier and live longer than those who live on a diet that includes high levels of meat consumption.

Some people in affluent societies are going further and eliminating most or all meat from their diet. They are replacing a meat diet with a vegetarian diet that includes a healthy combination of fruits, vegetables, protein-rich foods such as legumes, and in some cases, moderate amounts of fish.

THINKING ABOUT
Meat Consumption

CONCEPT LINK

Would you be willing to live lower on the food chain (**Concept 3-4B**, p. 61) by eating less meat or no meat? Explain.

Slowing population growth (pp. 133–137) reduces the harmful environmental impacts of agriculture by reducing the number of people consuming meat and other types of food. It also applies the population control **principle of sustainability**.

Shift to More Sustainable Agriculture

Sustainability experts agree that sustainable world food production will require us to develop and phase in more sustainable, low-input agricultural systems over the next few decades. One component of this is increased use of **organic agriculture** in which crops are grown with little or no use of synthetic pesticides, synthetic fertilizers, or genetically engineered seeds. Livestock are raised without use of genetic engineering, synthetic growth regulators, or feed additives. Fields must be free of chemicals for 3 years before crops grown there can be certified as organic. Since 1990, organic farming has been the fastest growing sector of the agricultural economy.

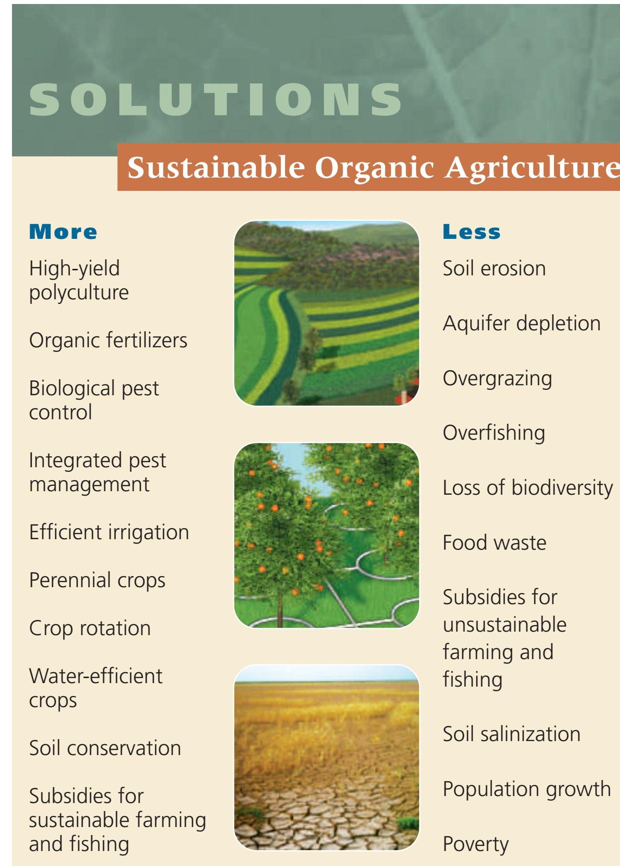


Figure 12-31 Major components of more sustainable, low-throughput agriculture based mostly on mimicking and working with nature (**Concept 12-6B**). **Question:** Which two solutions do you think are the most important? Why?

Figure 12-31 lists the major components of more sustainable agriculture. Compared to high-input farming, low-input agriculture produces similar yields with lower carbon dioxide emissions, uses less energy per unit of yield, improves soil fertility, reduces soil erosion, and can often be more profitable for farmers (**Concept 12-6B**).

Since 1969, Cubans have grown most of their food using low-input sustainable organic agriculture. The government has established centers where organisms used for biological pest control are produced. The government also encourages people to grow organic food in urban gardens.

In 2002, agricultural scientists Paul Mader and David Dubois reported the results of a 22-year study comparing organic and conventional farming at the Rodale Institute in Kutztown, Pennsylvania (USA). Figure 12-32 (p. 308) summarizes their conclusions, along with those from a 2005 evaluation of the study by David Pimentel and other researchers. They concluded that yields of organic crops can be as much as 20% lower than yields of conventionally raised crops. But organic farmers can often make up for this difference by not having to use or pay for expensive pesticides, herbicides, and synthetic fertilizers, and usually,

SOLUTIONS

Organic Farming

- Improves soil fertility
- Reduces soil erosion
- Retains more water in soil during drought years
- Uses about 30% less energy per unit of yield
- Lowers CO_2 emissions
- Reduces water pollution by recycling livestock wastes
- Eliminates pollution from pesticides
- Increases biodiversity above and below ground
- Benefits wildlife such as birds and bats

Figure 12-32 Environmental benefits of organic farming over conventional farming, based on 22 years of research comparing these two systems at the Rodale Institute in Kutztown, Pennsylvania USA. (Data from Paul Mader, David Dubois, and David Pimentel).

by getting higher prices for their crops. As a result, the net economic return per unit of land from organic crop production is often equal to or higher than that from conventional crop production. However, there is a need for more research to evaluate the benefits of organic farming (Science Focus, below).

Currently, certified organic farming is used on less than 1% of the world's cropland—on only 0.3% in the United States, but on 6–10% of the cropland in many European countries. Tiny Liechtenstein devotes 18% of its land to certified organic agriculture.

RESEARCH FRONTIER:

Organic agriculture. See **academic.cengage.com/biology/miller**.

Some farmers have shown that they can use energy from the sun, wind, and flowing water, and natural gas produced from farm wastes in biogas digesters, to produce most or all of the energy they need for food production—an application of the solar energy **principle of sustainability**. What is more, they can make money by selling their excess electricity to power companies.

Most proponents of more sustainable agriculture are not opposed to high-yield agriculture. Instead, they see it as vital for protecting the earth's biodiversity by reducing the need to cultivate new and often marginal land. They call for using more environmentally sustainable forms of both high-yield polyculture and high-yield monoculture, with increasing emphasis on using organic methods for growing crops (Figure 12-31, left)

SCIENCE FOCUS

Scientists Are Studying the Benefits and Costs of Organic Farming

Are organically produced foods really safer to consume and better for the environment? Not all scientists agree on the answer, and much research remains to be done.

In one study reported in 2006, researchers John B. Reganold and Sasha B. Kramer used controlled experiments (Chapter 2 Core Case Study, p. 28) to compare some benefits of growing apples organically and growing them conventionally. In particular, they wanted to compare the amount of nitrogen leaching into soils from orchards treated in different ways. Nitrogen in the form of nitrates can contaminate underground drinking water supplies, which can cause illnesses in people who drink that water, especially small children.

The researchers worked in an apple orchard in the Yakima Valley in the central part of the U.S. state of Washington. They studied three groups of apple trees—one group treated with conventional synthetic fertilizers, including calcium nitrate; one treated organically and fertilized with composted chicken manure and alfalfa residues; and a third group treated through an *integrated approach,* (combining organic and conventional techniques) using equal amounts of chicken manure and calcium nitrate. Each of the fertilizers used—organic and synthetic—contained nitrogen. All three study plots were fertilized once in May and once in October, and each tree received the same amount of nitrogen each time, regardless of the source.

The researchers placed a plastic resin bag about 1 meter (40 inches) below each tree to collect water for measuring nitrate leaching. They found that water from under the conventionally grown trees contained nitrate concentrations 4.4 to 5.6 times higher than those in water from under the organically treated trees. Water from the third group contained concentrations of nitrates at levels between those of the other two groups. This led Reganold to conclude that the study supports organic farming techniques but also gives credibility to the integrated approach.

Critical Thinking

Can you think of any factors, other than the fertilizers applied, that might have affected the results of this experiment? Explain.

SCIENCE FOCUS

Sustainable Polycultures of Perennial Crops

Some plant scientists believe we should rely more on *polycultures of perennial crops,* which can live for many years without having to be replanted and are better adapted to some regional soil and climate conditions than most annual crops.

When you think about farms in the U.S. state of Kansas, you probably picture seemingly endless fields of wheat or corn plowed up and planted each year. By 2040, the picture might change, thanks to over 3 decades of pioneering research at the nonprofit *Land Institute* near Salina, Kansas.

The institute, founded by plant geneticist Wes Jackson, is experimenting with an ecological approach to agriculture on the midwestern prairie.The goal is to grow a diverse mixture (polyculture) of edible perennial plants to supplement traditional annual monoculture crops and to help reduce the latter's harmful environmental effects. Examples in this polyculture mix include perennial grasses, legumes (a source of nitrogen fertilizer), sunflowers, grain crops, and plants that provide natural insecticides. Some of these plants could also be used as a source of renewable biofuel for motor vehicles.

This approach, called *natural systems agriculture*, copies nature by growing a diversity of perennial crops. It has a number of environmental benefits. Because these plants are perennials, there is no need to till the soil and replant seeds each year. This reduces soil erosion and water pollution from eroded sediment, because the unplowed soil is not exposed to wind and rain. And it reduces the need for irrigation because the deep roots of such perennials retain more water than do the shorter roots of annuals (Figure 12-C). Also, there is little or no need for chemical fertilizers and pesticides, and thus little or no pollution from these sources.

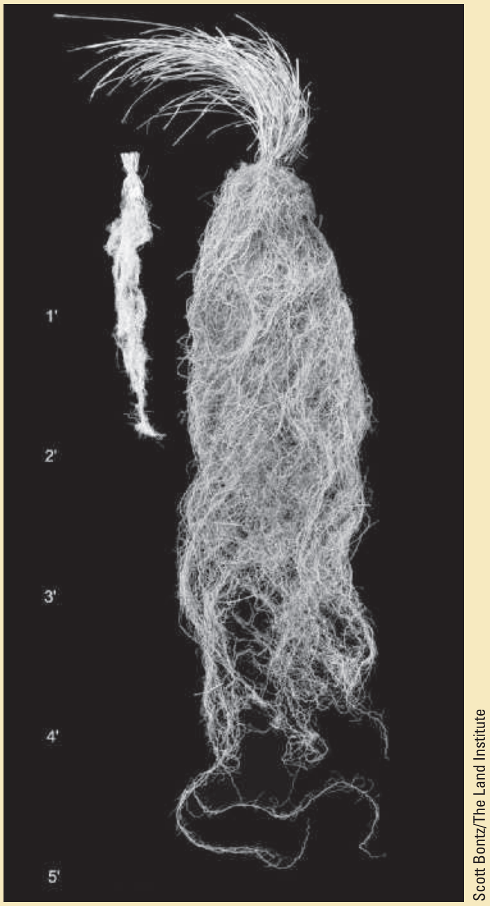


Figure 12-C Comparison of the roots of an annual wheat crop plant (left) with the roots of a tallgrass prairie perennial plant, big bluestem (right). The perennial plant is in the ground year-round and is much better at using water and nutrients and making and maintaining healthy soil. It also needs less fertilizer.

Critical Thinking

Why do you think large seed companies generally oppose this form of more sustainable agriculture?

(**Concept 12-6B**). Some scientists also call for greater reliance on perennial crops as a component of more sustainable agriculture (Science Focus, above).

Analysts suggest four major strategies to help farmers make the transition to more sustainable agriculture (**Concept 12-6B**). *First,* greatly increase research on sustainable organic agriculture (Science Focus, at left) and on improving human nutrition. *Second,* set up demonstration projects so that farmers can see how organic agricultural systems work. *Third,* provide subsidies and foreign aid to encourage its use. *Fourth,* establish training programs in sustainable agriculture for farmers and government agricultural officials, and encourage the creation of college curricula in sustainable agriculture.

Buy Locally Grown Food

Consumers can help farmers to make a transition to more sustainable farming by buying food from local producers in farmers' markets or other outlets. This supports local economies and reduces the environmental impact of food production. Locally grown food does not have to be transported very far from producer to consumer. A typical meal using food imported from other parts of a country or from other countries can easily account for 5 to 17 times more transportation-related greenhouse gas emissions than the same meal using locally produced food would represent. So the option with the least environmental impact is to grow your own organic food or buy organic food that is produced locally. More food can also be grown locally in the world's urban areas in vacant lots, in yards, and on rooftops, as discussed in more detail in Chapter 23.

There are more than 4,300 farmers' markets in the United States, and people are flocking to them. Another growing trend is community-supported agriculture (CSA). Supporters of CSA buy shares in a farm's produce before it is harvested, and these shares are delivered to central points in nearby cities, where shareholders collect them at appointed times each week.

Figure 12-33 **Individuals matter:** ways to promote more sustainable agriculture (**Concepts 12-6A** and **12-6B**). According to Rajendra Pachauri, head of the Intergovernmental Panel on Climate Change, we need to start eating as if the earth's climate mattered. **Question:** Which three of these measures do you think are the most important? Why?

WHAT CAN YOU DO?

Sustainable Organic Agriculture

- Waste less food
- Eat less meat or no meat
- Use organic farming to grow some of your food
- Buy organic food
- Eat locally grown food
- Compost food wastes

(Local Harvest has a searchable online directory to CSA farms in the United States at **localharvest.org/csa**.)

Figure 12-33 lists these and other ways in which you can promote more sustainable agriculture.

REVISITING Golden Rice and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how we might use genetically engineered golden rice (**Core Case Study**) to help prevent blindness in children and increase their resistance to infectious diseases. Carefully evaluated and monitored genetic engineering is only one of many tools discussed in this chapter for developing more sustainable agriculture.

Making this transition involves applying the four **scientific principles of sustainability** (see back cover). All of these principles are violated by modern industrial agriculture because it depends heavily on nonrenewable fossil fuels, includes too little recycling of crop and animal wastes, accelerates soil erosion, does too little to preserve agrobiodiversity, and can destroy or degrade wildlife habitats and disrupt natural species interactions that help to control pest population sizes.

Making the transition to more sustainable agriculture means relying more on solar energy and less on oil, and sustaining nutrient cycling by soil conservation and by returning crop residues and animal wastes to the soil. It also means helping to sustain natural and agricultural biodiversity by relying on a greater variety of crop and animal strains and by controlling pest populations through broader use of polyculture and integrated pest management. All such efforts will be enhanced if we can control the growth of the human population and our use of resources.

The goal is to feed the world's people while sustaining and restoring the earth's natural capital and living off the natural income it provides. This will not be easy, but it can be done if we heed these ecological lessons from nature.

The sector of the economy that seems likely to unravel first is food. Eroding soils, deteriorating rangelands, collapsing fisheries, falling water tables, and rising temperatures are converging to make it difficult to expand food production fast enough to keep up with the demand.

LESTER R. BROWN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 276. Describe the use of genetically engineered golden rice (**Core Case Study**) as a way to decrease vitamin A deficiency in children. CORE CASE STUDY
2. Define **food security** and **food insecurity.** What is the root cause of food insecurity? Distinguish between **chronic undernutrition (hunger)** and **chronic malnutrition** and describe their harmful effects. Describe the effects of diet deficiencies in vitamin A, iron, and iodine. What is a **famine?** What is **overnutrition,** and what are its harmful effects?
3. What three systems supply most of the world's food? Distinguish among **industrialized agriculture (high-input agriculture), plantation agriculture, traditional**

subsistence agriculture, traditional intensive agriculture, polyculture, and **slash-and-burn agriculture.** Define **soil** and describe its formation and the major layers in mature soils. What is a **green revolution?** Describe industrialized food production in the United States.

4. Distinguish between *crossbreeding* and *genetic engineering.* Describe industrialized meat production. What is a **fishery?** What is **aquaculture?**

5. What are the major harmful environmental impacts of agriculture? What is **soil erosion** and what are its two major harmful environmental effects? What is **desertification** and what are its harmful environmental effects? Distinguish between **salinization** and **waterlogging** of soil and describe their harmful environmental effects.

6. What factors can limit green revolutions? Describe the use of energy in industrialized agriculture. Describe the advantages and disadvantages of genetically engineered foods. Explain how most food production systems reduce biodiversity. Describe the advantages and disadvantages of industrialized meat production. Describe the advantages and disadvantages of aquaculture.

7. What is a **pest?** Define and give two examples of a **pesticide.** Describe Rachel Carson's contribution to environmental science. Describe the advantages and disadvantages of modern pesticides. Describe the dilemma over widespread use of glyphosate as an herbicide. Describe the use of laws and treaties to help protect us from the harmful effects of pesticides. Describe seven alternatives to conventional pesticides. Define **integrated pest management (IPM)** and discuss its advantages.

8. Describe three ways in which governments influence food production. What is **soil conservation?** Describe seven ways to reduce soil erosion. Describe soil erosion and soil conservation in the United States. Distinguish among the use of **organic fertilizer, commercial inorganic fertilizer, animal manure, green manure,** and **compost** as ways to help restore soil fertility. Describe ways to prevent and clean up soil salinization.

9. Describe ways to produce meat more efficiently, humanely, and sustainably. How can we make aquaculture more sustainable? Define **organic agriculture** and describe its advantages over conventional agriculture. Describe the advantages of relying more on polycultures of perennial crops. What can individuals do to promote more sustainable agriculture?

10. Describe the relationships among golden rice (**Core Case Study**), sustainable agriculture, and the four **scientific principles of sustainability**.

CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply material from this chapter to make your lifestyle more environmentally sustainable.

2. What are two safeguards that you would want in place before large areas of the world were planted with golden rice (**Core Case Study**)?

CORE CASE STUDY

3. What are the three most important actions you would take to reduce chronic hunger and malnutrition **(a)** in the country where you live and **(b)** in the world?

4. Explain why you support or oppose greatly increased use of **(a)** genetically modified food and **(b)** polyculture.

5. Suppose you live near a coastal area and a company wants to use a fairly large area of coastal marshland for an aquaculture operation. If you were an elected local official, would you support or oppose such a project? Explain. What safeguards or regulations would you impose on the operation?

6. Explain how widespread use of a pesticide can **(a)** increase the damage done by a particular pest and **(b)** create new pest organisms. If increased mosquito populations threatened you with malaria or West Nile virus, would you want to spray DDT in your yard and inside your home to reduce the risk? Explain. What are the alternatives?

7. According to physicist and philosopher Albert Einstein, "Nothing will benefit human health and increase chances of survival of life on Earth as much as the evolution to a vegetarian diet." Are you willing to eat less meat or no meat? Explain.

8. Imagine that everyone in the world began eating only locally produced foods tomorrow. Describe a benefit and a harm that would arise from such a change to **(a)** yourself, **(b)** your community, and **(c)** the world.

9. Congratulations! You are in charge of the world. List the three most important features of your **(a)** agricultural policy, **(b)** policy to reduce soil erosion, **(c)** policy for more sustainable harvesting and farming of fish and shellfish, and **(d)** global pest management strategy.

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

The following table gives the world's fish harvest and population data.

	World Fish Harvest				
Years	Fish Catch (million tons)	Aquaculture (million tons)	Total (million tons)	World Population (billions)	Per Capita Fish Catch (kilograms)
1990	84.8	13.1	97.9	5.270	
1991	83.7	13.7	97.4	5.36	
1992	85.2	15.4	100.6	5.44	
1993	86.6	17.8	104.4	5.52	
1994	92.1	20.8	112.9	5.60	
1995	92.4	24.4	116.8	5.68	
1996	93.8	26.6	120.4	5.76	
1997	94.3	28.6	122.9	5.84	
1998	87.6	30.5	118.1	5.92	
1999	93.7	33.4	127.1	5.995	
2000	95.5	35.5	131.0	6.07	
2001	92.8	37.8	130.6	6.15	
2002	93.0	40.0	133.0	6.22	
2003	90.2	42.3	132.5	6.20	

1. Use the world fish harvest and population data in the table to calculate the per capita fish consumption from 1990–2003 in kilograms/person. (*Hints:* 1 million metric tons equals 1 billion kilograms; the human population data is measured in billions; and per capita consumption can be calculated directly by dividing.)
2. Has per capita fish consumption generally increased or generally decreased between 1990 and 2003?
3. In what years has per capita fish consumption decreased?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 12 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

AP* Review Questions for Chapter 12

1. Industrialized meat production has harmful environmental consequences. These include all of the following EXCEPT
   (A) the use of large amounts of energy.
   (B) contributing to the eutrophication of the Gulf of Mexico.
   (C) contributing to global warming.
   (D) polluting the air, water, and soil with manure.
   (E) natural control of pests.

2. Which of the following techniques help to limit soil erosion?
   (A) Clear-cut logging
   (B) Off-road vehicles
   (C) Terracing
   (D) Deforestation
   (E) Overgrazing

3. Many crops are now being engineered so that insects do not like them. These are called
   (A) genetically modified crops (GMOs).
   (B) plantation agriculture crops.
   (C) high-input agriculture crops.
   (D) hydroponics.
   (E) macronutrients.

4. One way farmers can help to reduce soil erosion is by using soil conservation methods. Which of the following is an example of a soil conservation method?
   (A) Waterlogging
   (B) Deforestation
   (C) Planting on already eroded land
   (D) Alley cropping
   (E) Clear cutting

5. Which of the following would be a disadvantage to using pesticides?
   (A) Pesticides eliminate pests that spread disease.
   (B) Pesticides can bioaccumulate up the food chain.
   (C) Pesticides help keep the price of food down.
   (D) Pesticides work fast.
   (E) Pesticides are profitable.

6. DDT was a very effective pesticide; however, it remained in the environment for years. This is known as
   (A) a broad-spectrum agent.
   (B) genetic resistance.
   (C) the pesticide treadmill.
   (D) persistence.
   (E) the financial treadmill.

7. Which of the following practices would be a way that a farmer could grow crops organically?
   (A) Using pesticides in limited amounts and only on specific days
   (B) Only using pesticides that are water soluble
   (C) Planting crops at times when the bugs are not around to eat them
   (D) Doing aerial spraying for bugs rather than applying at the crop level
   (E) Spraying pesticides on the roots so that the part of the plant that is eaten is not contaminated

8. A method of using biological control to control pests is to
   (A) bring in natural enemies such as predators, parasites, and bacteria.
   (B) use pheromones.
   (C) implant genetic resistance.
   (D) use broad-spectrum agents.
   (E) use a second-generation pesticide.

9. The goal of integrated pest management is to
   (A) wipe out as many of the pest species as possible to save crops.
   (B) wipe out as many of the pest species as possible to save human lives.
   (C) genetically engineer as many crop species as possible so to eliminate the need for pesticides.
   (D) encourage farmers to grow organically, eliminating the need for pesticides.
   (E) integrate biological, chemical, and cultivation techniques in a coordinated way to eliminate pest species.

10. One way to successfully incorporate genetic engineering is to
    (A) add pesticides to the DNA of the crop plant.
    (B) cross a crop plant with a native variety.
    (C) bring in hormones to control developmental processes at different stages.
    (D) use biological controls by importing natural predators.
    (E) get on the pesticide treadmill.

11. Raising fish in underwater pens is one way to solve the overharvesting problem. This is known as
    (A) aquaculture.
    (B) organic fish farming.
    (C) ocean dumping.
    (D) restoration.
    (E) maximum sustainable yield.

12. A more sustainable form of meat production is to
    (A) graze beef on local lands.
    (B) switch to poultry and farm raised fish.
    (C) inject cattle with hormones to get more muscle mass.
    (D) put more animals on each square acre.
    (E) raise beef rather than pork.