SECTION 2

Crops and Soil

Objectives

- Distinguish between traditional and modern agricultural techniques.
- Describe fertile soil.
- Describe the need for soil conservation.
- Explain the benefits and environmental impacts of pesticide use.
- Explain what is involved in integrated pest management.
- Explain how genetic engineering is used in agriculture.

Key Terms

arable land
topsoil
erosion
desertification
compost
salinization
pesticide
biological pest control
genetic engineering

The Earth has only a limited area of **arable land,** land that can be used to grow crops. As our human population continues to grow, the amount of arable land per person decreases. In this section, you will learn how food is produced, how arable land can become degraded, and how we can ensure that we will continue to grow the crops we need in the future.

Agriculture: Traditional and Modern

The basic processes of farming include plowing, fertilization, irrigation, and pest control. Traditionally, plows are pushed by the farmer or pulled by livestock. Plowing helps crops grow by mixing soil nutrients, loosening soil particles, and uprooting weeds. Organic fertilizers, such as manure, are used to enrich the soil so that plants grow strong and healthy. Fields are irrigated by water flowing through ditches. Weeds are removed by hand or machine. These traditional techniques have been used since the earliest days of farming, centuries before tractors and pesticides were invented.

In most industrialized countries, the basic processes of farming are now carried out using modern agricultural methods. Machinery powered by fossil fuels is now used to plow the soil and harvest crops, as shown in **Figure 7.** Synthetic chemical fertilizers are now used instead of manure and plant wastes to fertilize soil. A variety of overhead sprinklers and drip systems may be used for irrigation. And synthetic chemicals are used to kill pests.

Figure 7 ▶ In modern agriculture, machinery is used to do much of the work previously performed by humans and animals.

Fertile Soil: The Living Earth

Soil that can support the growth of healthy plants is called *fertile soil*. Plant roots grow in **topsoil,** the surface layer of soil, which is usually richer in organic matter than the subsoil is. Fertile topsoil is composed of living organisms, rock particles, water, air, and organic matter, such as dead or decomposing organisms.

Most soil forms when rock is broken down into smaller and smaller fragments by wind, water, and chemical weathering. *Chemical weathering* happens when the minerals in the rock react chemically with substances such as water to form new materials. Temperature changes and moisture cause rock to crack and break apart, which creates smaller particles on which the seeds of pioneer plants fall and take root. It can take hundreds or even thousands of years for these geological processes to form a few centimeters of soil.

Other processes also help to produce fertile topsoil. The rock particles supply mineral nutrients to the soil. Fungi and bacteria live in the soil, and they decompose dead plants as well as organic debris and add more nutrients to the soil. Earthworms, insects, and other small animals help plants grow by breaking up the soil and allowing air and water into it. One way to tell whether soil is fertile is to see if it contains earthworms. **Table 2** lists some of the organisms that live in fertile soil.

As you can see in **Figure 8,** several layers of soil lie under the topsoil. The bottom layer is bedrock, which is the solid rock from which most soil originally forms.

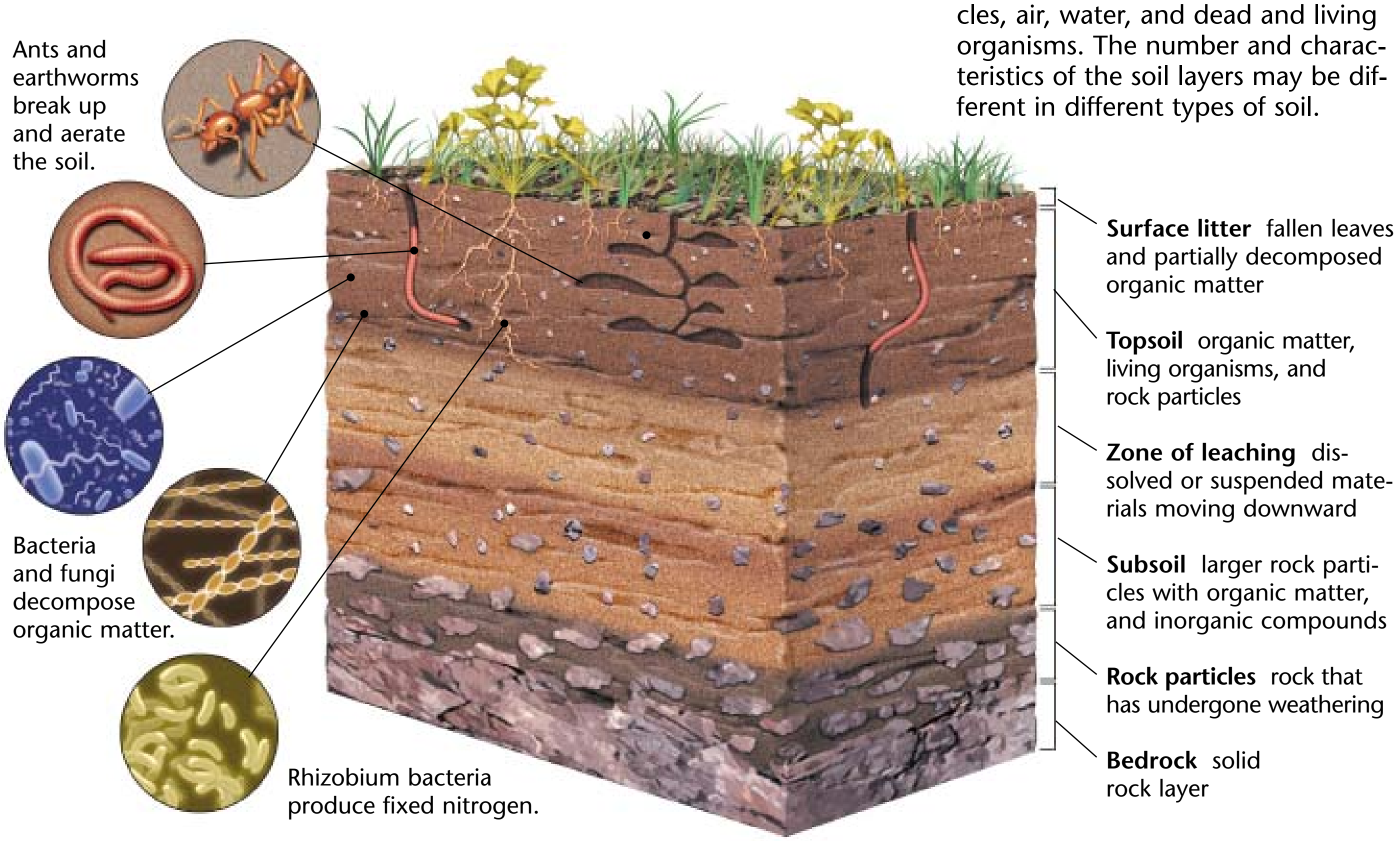
Table 2 ▼

Numbers of Organisms in Average Farm Soil

Organisms	Quantity
Insects	23 million per hectare
All arthropods (including insects)	725 million per hectare
Bacteria	2.5 billion per gram
Algae	50,000 per gram
Earthworms	6 million per hectare

Note: One hectare equals about 2.47 acres.
Source: US Department of Agriculture.

Figure 8 ▶ Soil is made of rock particles, air, water, and dead and living organisms. The number and characteristics of the soil layers may be different in different types of soil.



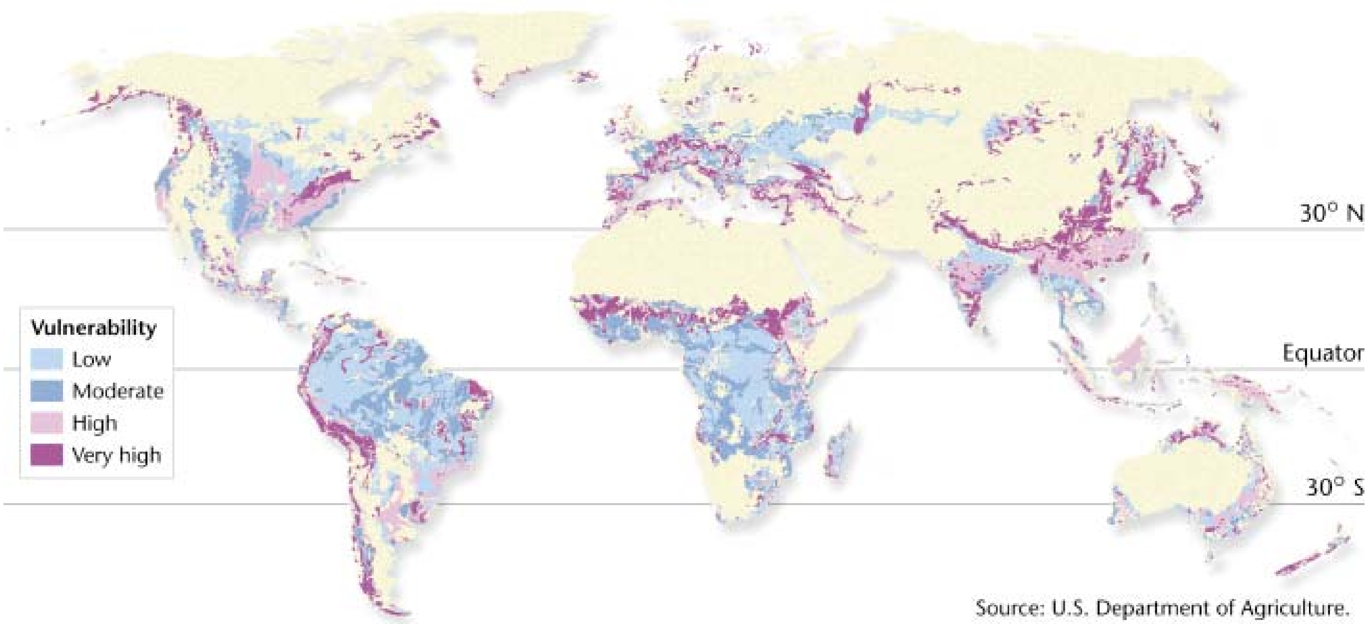


Figure 9 ▶ Soil erosion is one of the most serious environmental problems the world faces. This map shows the vulnerability of soils worldwide to erosion by water.

Soil Erosion: A Global Problem

Erosion is the wearing away of rock or soil by wind and water. In the United States, about half of the original topsoil has been lost to erosion in the past 200 years. **Figure 9** shows potential soil erosion worldwide. Without topsoil, crops cannot be grown.

Almost all farming methods increase the rate of soil erosion. For example, plowing loosens topsoil and removes plants that hold the soil in place. The topsoil is then more easily eroded by wind or rain.

QuickLAB

Preventing Soil Erosion

Procedure

1. Obtain three **trays,** and fill one with **sod,** one with **topsoil,** and one with a type of mulch, such as **hay.**
2. Place each tray at an angle by creating a surface that resembles a hill by using **doorstoppers** and **textbooks.** Place a **large bowl** at the bottom of each tray to catch the runoff.
3. Sprinkle **2L of water** slowly on each tray to simulate heavy rainfall.
4. Use a **scale** to weigh the runoff of soil and water that collected in each bowl.

Analysis

1. Which tray had the most soil erosion and water runoff? Which tray had the least? Why? What does this lab demonstrate about soil erosion?

Land Degradation

Land degradation happens when human activity or natural processes damage the land so that it can no longer support the local ecosystem. In areas with dry climates, desertification can result. **Desertification** is the process by which land in arid or semiarid areas becomes more desertlike because of human activity or climatic changes. This process is causing some of our arable land to disappear.

Desertification has happened in the Sahel region of northern Africa. In the past, people who lived in the drier part of the Sahel grazed animals, whereas people who lived in areas of the Sahel with more rainfall planted crops. The grazing animals were moved from place to place to find fresh grass and leaves. The cropland was planted for only a few years, and then the land was allowed to lie *fallow,* or to remain unplanted, for several years. These methods of farming and grazing allowed the land to adequately support the people in the Sahel. But the population in the region has grown, and the land is being farmed, grazed, and deforested faster than it can regenerate. Now, too many crops are planted too frequently, and fallow periods are being shortened or eliminated. As a result, the soil is losing its fertility and productivity. Because of overgrazing, the land has fewer plants to hold the topsoil in place. So, large areas have become desert and can no longer produce food.


Soil Conservation

There are many ways of protecting and managing topsoil and reducing erosion. Soil usually erodes downhill, and many soil conservation methods are designed to prevent downhill erosion, as shown in **Figure 10.** Building soil-retaining terraces across a hillside may be cost-effective for producers of valuable crops, such as wine grapes and coffee. On gentler slopes, *contour plowing* is used. This method includes plowing across the slope of a hill instead of up and down the slope. An even more effective method of plowing is leaving strips of vegetation across the hillside instead of plowing the entire slope. These strips catch soil and water that run down the hill. Still, many areas of land that have hills are not suited to farming, but may be better used as forest or grazing land.

In traditional farming, after a crop is harvested, the soil is plowed to turn it over and bury the remains of the harvested plants. In *no-till farming,* shown in **Figure 11,** a crop is harvested without turning over the soil. Later, the seeds of the next crop are planted among the remains of the previous crop. The remains of the first crop hold the soil in place while the new crop develops. No-till farming saves time compared with conventional methods. This method can also reduce soil erosion to one-tenth of the erosion caused by traditional methods. However, no-till farming may not be suitable for some crops. Other disadvantages to this method can include soil that is too densely packed and lower crop yields over time.

Figure 10 ▶ Terracing (left) keeps soil in multiple, small, level fields. Contour plowing (right) follows the natural contours of the land. Both methods prevent soil erosion by keeping water from running directly downhill.

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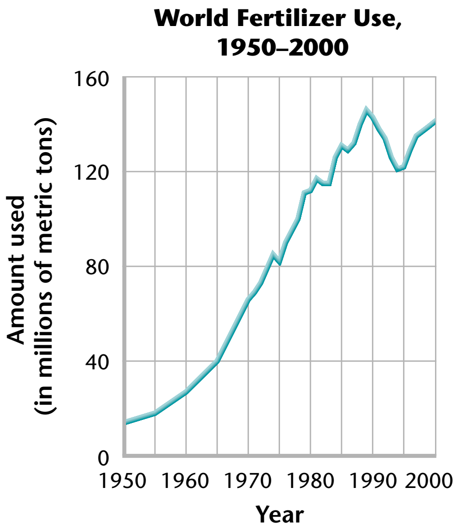
Figure 11 ▶ This farmer is practicing no-till farming. The tractor plants a new crop by poking seeds into the soil through the remains of the old crop.



Source: UN Food and Agriculture Organization.

Figure 12 ▶ The use of inorganic fertilizers has increased dramatically worldwide since 1950.

Enriching the Soil

Soil was traditionally fertilized by adding organic matter, such as manure and leaves, to the soil. As organic matter decomposes, it adds nutrients to the soil and improves the texture of the soil. However, inorganic fertilizers that contain nitrogen, phosphorus, and potassium have changed farming methods. Without these fertilizers, world food production would be less than half of what it is today. Over the past 50 years, the use of such fertilizers has increased rapidly, as shown in **Figure 12.** If erosion occurs in areas where the soil has been fertilized with inorganic chemicals, fertilizers and pesticides may pollute waterways.

A modern method of enhancing the soil is to use both organic and inorganic fertilizers by adding compost and chemical fertilizers to the soil. **Compost** is partly decomposed organic material. Compost comes from many sources. For example, you can buy composted cow manure in a garden store. Also, many cities and industries now compost yard waste and crop wastes. This compost is sold to farmers and gardeners, and the process is saving costly landfill space.

Connection to Geology

Soil Formation Over Time
Most rock breaks down into finer particles over time and changes from gravel to sand to clay. You can tell the age of soil by looking at its rock particles. Young soil is sandy or gravelly, and it falls apart when you squeeze it in your hand. Older soils contain clay, and damp clay stays together in lumps when you squeeze it in your hand.

Salinization

The accumulation of salts in the soil is known as **salinization** (SAL uh nie ZAY shuhn). Salinization is a major problem in places such as California and Arizona, which have low rainfall and naturally salty soil. In these areas, irrigation water comes from rivers or groundwater, which is saltier than rainwater. When water evaporates from irrigated land, salts are left behind. Eventually, the soil may become so salty that plants cannot grow.

Irrigation can also cause salinization by raising the groundwater level temporarily. Once groundwater comes near the surface, the groundwater is drawn up through the soil like water is drawn up through a sponge. When the water reaches the surface, the water evaporates and leaves salts in the soil. Salinization can be slowed if irrigation canals are lined to prevent water from seeping into the soil, or if the soil is watered heavily to wash out salts.

SECTION 2 Mid-Section Review

1. **Explain** the differences between traditional and modern farming methods.
2. **Describe** the structure and composition of fertile soil.
3. **Explain** why the presence of plants helps prevent soil erosion.
4. **Explain** why soil conservation is an important agricultural practice.

CRITICAL THINKING

5. **Inferring Relationships** Study the graph in Figure 12. What do you think might have happened to food production between 1990 and 1995?
6. **Applying Ideas** Erosion is a natural process. Why has it become such a serious environmental problem? Write a paragraph that explains your reasoning. WRITING SKILLS

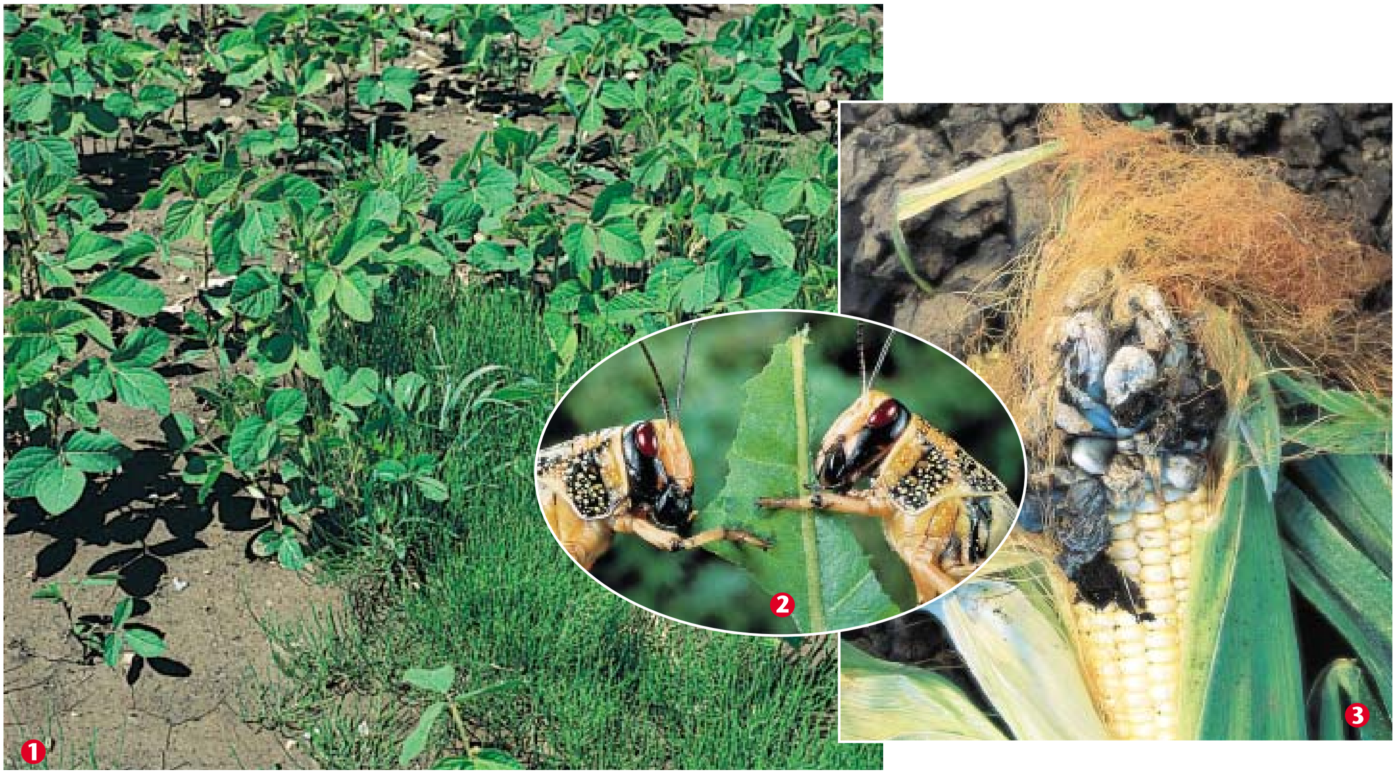


Figure 13 ▸ Examples of major crop pests include ❶ weeds, ❷ plant-eating insects, and ❸ fungi.

Pest Control

In North America, insects eat about 13 percent of all crops. Crops in tropical climates suffer even greater insect damage because the insects grow and reproduce faster in these climates. In Kenya, for example, insects destroy more than 25 percent of the nation's crops. Worldwide, pests destroy about 33 percent of the world's potential food harvest.

As shown in **Figure 13,** insects are one of several types of organisms considered pests. A *pest* is any organism that occurs where it is not wanted or that occurs in large enough numbers to cause economic damage. Humans try to control populations of many types of pests, including many plants, fungi, and microorganisms.

Wild plants often have more protection from pests than crop plants do. Wild plants grow throughout a landscape, so pests have a harder time finding and feeding on a specific plant. Crop plants, however, are usually grown together in large fields, which provides pests with a one-stop source of food. Wild plants are also protected from pests by a variety of pest predators that live on or near the plants. Some wild plants have also evolved defenses to many pests, such as poisonous chemicals that repel pests.

Pesticides

Many farmers rely on pesticides to produce their crops. Pesticides are chemicals used to kill insects, weeds, and other crop pests. During the last 50 years, scientists invented many new pesticides. The pesticides were so effective that farmers began to rely on them almost completely to protect their crops from pests. However, pesticides can also harm beneficial plants and insects, wildlife, and even people.

Ecofact

Crop Rotation Farmers and gardeners have known for centuries that you get higher yields and less pest damage if you plant different crops each year on a piece of land. This method works because most pests are specialists and will only eat one or a few types of plants. The tomato hornworm is an example of one of these pests. If you plant tomatoes in one place every year, the hornworm population grows rapidly and will destroy the crop. If beans are planted in place of the tomatoes in alternate years, the hornworms cannot find food and die.

Figure 14 ▶ A cropduster sprays pesticide on a field of pineapples in Hawaii. Cropdusting is an easy way to apply pesticide to a large area.

Connection to Law

Pesticide Regulation The only pesticides that are fully regulated in the United States are newly introduced pesticides designed for use on some food crops. Many older pesticides in use have not been adequately tested for toxicity and are not effectively regulated. According to the National Academy of Sciences, much of the cancer risk from pesticides in our diet comes from older pesticides used on foods such as tomatoes, potatoes, and oranges.

Pesticide Resistance You might think that the most effective way to get rid of pests is to spray often with large amounts of pesticide, as shown in **Figure 14.** However, over time, this approach usually makes the pest problem worse. Pest populations may evolve *resistance,* the ability to survive exposure to a particular pesticide. More than 500 species of insects have developed resistance to pesticides since the 1940s.

Human Health Concerns Pesticides are designed to kill organisms, so they may also be dangerous to humans. For example, in some areas fruit and vegetable farmers use large amounts of pesticides on their crops. Cancer rates among children in those areas are sometimes higher than the national average, and nervous system disorders may be common. Workers in pesticide factories may also become ill. And people who live near these factories may be endangered by accidental chemical leaks. People who apply pesticides need to follow safety guidelines to protect themselves from contact with these chemicals.

Pollution and Persistence The problem of pesticides harming people and other organisms is especially serious with pesticides that are persistent. A pesticide is *persistent* if it does not break down easily or quickly in the environment. Persistent pesticides do not break down rapidly into harmless chemicals when they enter the environment. As a result, they accumulate in the water and soil. Some persistent pesticides have been banned in the United States, but many of them remain in the environment for many years. DDT, a persistent pesticide banned in the United States in the 1970s, can still be detected in the environment and has even been found in women's breast milk.

Figure 15 ▶ A parasitic wasp injects its eggs into an aphid (left). A predatory mite is attacked by another species of mite (right).

Biological Pest Control

Most farmers practice some form of *pest management*. **Biological pest control** is the use of living organisms to control pests. Every pest has enemies in the wild, and these enemies can sometimes be used to control pest populations, as shown in **Figure 15.** One of the first recorded examples of biological control was in India in the mid-1800s. American prickly pear cactus had been introduced into India to feed insects that are used to make a valuable red dye. Because the cactus had no natural enemies in India, the cactus grew and spread. The plants were finally controlled by the introduction of an American beetle that eats the cactus.

Pathogens Organisms that cause disease, called *pathogens* (PATH uh juhnz), can also be used to control pests. One of the most common pathogens used to control pests is the bacterium *Bacillus thuringiensis* (buh SIL uhs THUHR in JIEN sis), often abbreviated *Bt*. This bacterium can kill the caterpillars of moths and butterflies that we consider to be pests.

Plant Defenses Scientists and farmers have bred plant varieties that have defenses against pests. For example, if you buy tomato plants or seeds, you may see that they are labeled “VNT.” This label means they are resistant to certain fungi, worms, and viruses. Examples of plant defenses include chemical compounds that repel pests and physical barriers, such as tougher skin.

Chemicals From Plants Another type of biological pest control also makes use of plants’ defensive chemicals. For example, chemicals found in chrysanthemum plants are now sold as pesticides. Most insect sprays that contain these chemicals are designed for use in the home because they do not harm humans or pets. These products are biodegradable, which means that they are broken down by bacteria and other decomposers.

FIELD ACTIVITY

Pest Search Make a list of the pests you can find in your area. Look for weeds and insects. What evidence can you find that these organisms are pests? You will not be able to see pests in the soil or microscopic bacteria, fungi, or viruses, but you may be able to see the damage the microscopic pests cause—black spots or dead patches on leaves. Can you think of a way to decrease the damage that is caused by these pests that involves the use of biological pest control? Record your observations in your ***EcoLog.***

Connection to Chemistry

Organic Chemistry All food contains organic chemicals, but the term *organic* is used differently in the field of chemistry than in agriculture. The term generally means "of or pertaining to living organisms." In chemistry, an *organic chemical* is any chemical compound that contians carbon. Most organic chemicals are derived from living organisms, but chemists can now synthesize organic chemicals—and even invent new ones—in the lab. In contrast, *organic agriculture* is the practice of raising crops or livestock without using synthetic chemicals. Foods labeled as organic in the grocery store have been raised using organic methods.

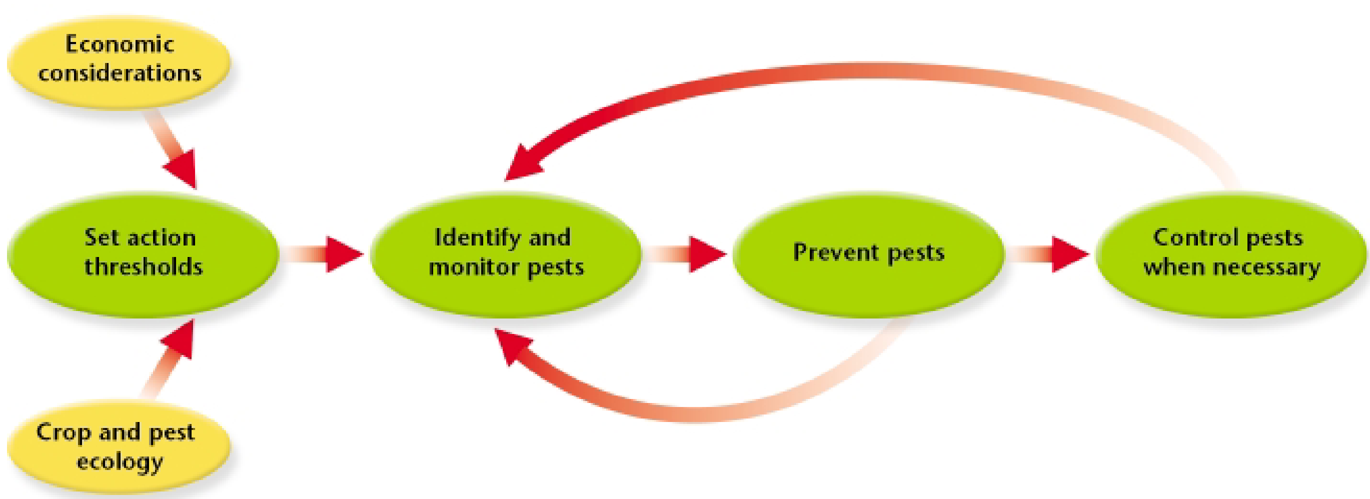
Disrupting Insect Breeding *Growth regulators* are chemicals that interfere with some stage of a pest's life cycle. If you have a dog, you may feed it a pill once a month to keep it free of fleas. The pill contains a growth regulator that prevents flea eggs from developing. When a flea sucks the dog's blood, the flea ingests the growth regulator. The regulator stops the flea's eggs from developing into adult fleas.

Pheromones (FER uh MOHNZ), chemicals produced by one organism that affect the behavior of another organism, can also be used in pest control. For example, female moths release pheromones that attract males from miles away. By treating crops with pheromones, farmers can confuse the male moths and interfere with the mating of the moths. Another way to prevent insects from reproducing is to make it physically impossible for the males to reproduce. For example, male insects are treated with X rays to make them sterile and then are released. When they mate with females, the females produce eggs that do not develop.

Integrated Pest Management

Integrated pest management is a modern method of controlling pests on crops. The steps involved in integrated pest management are shown in **Figure 16.** The goal of integrated pest management is not to eliminate pest populations but to reduce pest damage to a level that causes minimal economic damage. A different management program is developed for each crop. The program can include a mix of farming methods, biological pest control, and chemical pest control. Each of these methods is used at the appropriate time in the growing season. Fields are monitored from the time the crops are planted. When significant pest damage is found, the pest is identified. Then a program to control the pest is created.

Figure 16 ▶ This flow diagram shows the steps involved in integrated pest management.



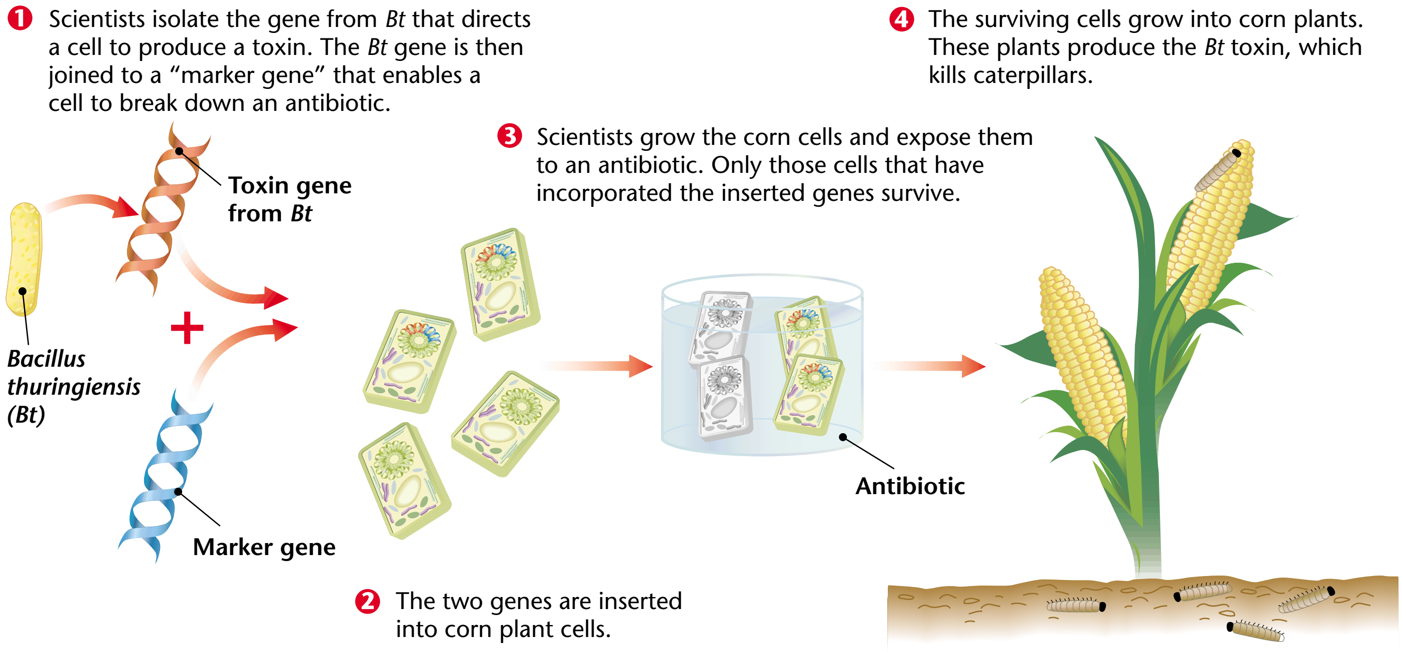


Figure 17 ▶ Genetic Engineering This diagram shows the main steps used to produce a genetically modified plant—in this case, corn that produces its own insecticide.

Biological methods are the first methods used to control the pest. So, natural predators, pathogens, and parasites of the pest may be introduced. Cultivation controls, such as vacuuming insects off the plants, can also be used. As a last resort, small amounts of insecticides may be used. The insecticides are changed over time to reduce the ability of pests to evolve resistance.

Engineering a Better Crop

Plant breeding has been used since agriculture began. Farmers select the plants that have the tastiest tomatoes and the least pest damage. They save seeds from these plants to use in planting the next crop. The selected seeds are more likely to contain the genes for large, tasty fruits and for pest resistance than seeds from other plants are.

A faster way of creating the same result is to use **genetic engineering,** the technology in which genetic material in a living cell is modified for medical or industrial use. Genetic engineering involves isolating genes from one organism and implanting them into another. Scientists may use genetic engineering to transfer desirable traits, such as resistance to certain pests. The plants that result from genetic engineering are called *genetically modified* (GM) plants.

Figure 17 shows an example of the steps used to produce a GM plant. In this case, the gene introduced into the plant is not a plant gene. It is an insecticide gene from *Bt,* a bacterium that produces a chemical that kills plant-eating caterpillars but does not harm other insects. Plants that have the *Bt* gene make this insecticide within their leaves. Hundreds of gene transfers have now been performed to create many other GM crops.

Ecofact

Nitrogen Fixation One of the most valuable families of crop plants is the legumes (LEG YOOMZ), which include peas and beans. Legumes produce higher grade proteins than most plants produce, so legumes are part of diets in many parts of the world. Planting legumes also improves the soil. Their roots have nodules containing bacteria that take nitrogen gas from the air and that convert the nitrogen into a form other plants can use to build proteins.

Implications of Genetic Engineering In the United States, we now eat and use genetically engineered agricultural products every day. Many of these products have not been fully tested for their environmental impacts, and some scientists warn that these products will cause problems in the future. For example, genes are sometimes transferred from one species to another in the wild. Suppose a corn plant that was genetically engineered to be resistant to a pesticide were to pass the resistance genes to a wild plant. That wild plant might be a pest that could not be killed by that pesticide.

Sustainable Agriculture

Farming that conserves natural resources and helps keep the land productive indefinitely is called *sustainable agriculture*. Also called *low-input farming*, sustainable agriculture minimizes the use of energy, water, pesticides, and fertilizers. This method involves planting productive, pest-resistant crop varieties that require little energy, pesticides, fertilizer, and water. **Figure 18** shows an experimental farm where new sustainable agriculture techniques are being researched.

Figure 18 ▶ At the Land Institute in Salina, Kansas, sustainable agriculture techniques are being used to increase seed quantity in wheatgrass (background) and to increase yield in sunflowers (foreground).

SECTION 2 Review

1. **Define** the term *pest*.
2. **Compare** the benefits and environmental impact of pesticide use.
3. **Describe** how biological pest control is part of integrated pest management.
4. **Describe** how genetic engineering is used in agriculture.

CRITICAL THINKING

5. **Inferring Relationships** Write a paragraph to explain the similarities and differences between traditional plant breeding and genetic engineering. WRITING SKILLS
6. **Predicting Consequences** Read the description of integrated pest control in this section. Why do you think this pest control technique is not practiced everywhere? READING SKILLS