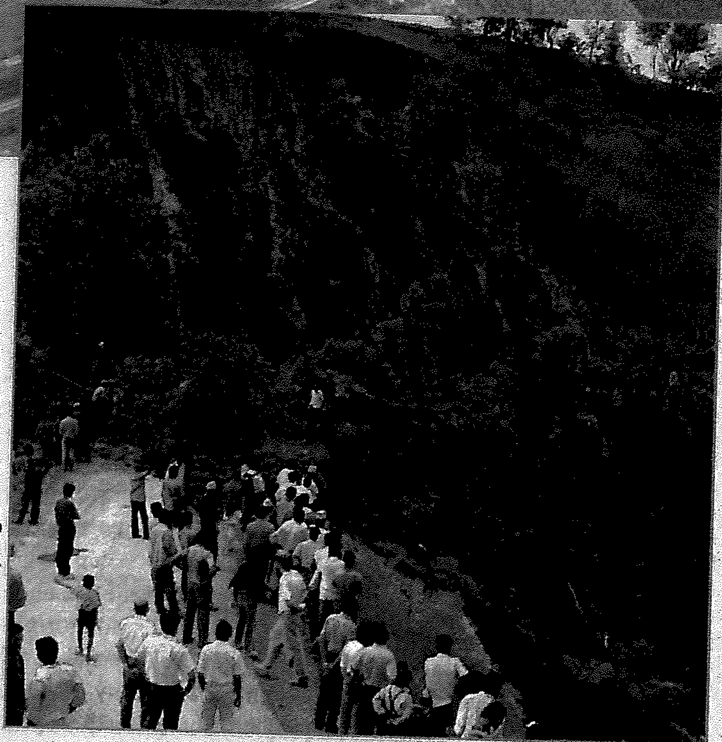
14

Soil Resources



Anders Blomqvist / Getty Images

Clearing a mudslide on the Prithvihighway from Kathmandu to Pokhara during the monsoon.

n March of 2014, a mudslide covered the small town of Oso, Washington. Over 20 residents disappeared beneath the combination of moving soil, water, trees, and debris from the community. This particular mudslide was precipitated by heavy rainfall, soil erosion exacerbated by a history of logging, and a weak streambank at the base of the supporting hillside. Earthquakes, hurricanes, volcanic eruptions, heavy rainfall (**see photograph**), and other natural events can cause mudslides. In Colorado in 2013, wildfires created a situation ripe for mudslide, as mountains were left unprotected by burned vegetation. Human activities such as logging, mining, and construction also make soil vulnerable to erosion events.

Surface mining, such as mountaintop removal coal mining, increases the risks of mudslides in several ways. Mountaintop removal coal mining is the process of exposing coal by removing the mountain (trees, soil, rock layers) above the coal; trees, soil, and rock are then dumped off the mountainside into valleys and streams. First, removal of vegetation leaves soil exposed to heavy rains and eliminates roots that stabilize soil. Second, mountaintop removal buries existing streambeds, changing water channels in unpredictable ways. Altered slopes are less stable than the original slopes. Unlike soil on an undisturbed mountaintop, soil and rock debris (called *overburden*) piled by mining equipment does not have a stable, settled structure. People living downstream from mountaintop removal sites rarely have voice, power, or vote in the mining process. When mudslides or coal waste spills result at these sites, the term *natural disaster* deflects blame from the human actions that made erosion a likely outcome.

Mudslides are a forceful example of soil erosion through the action of water. Wind can also cause soil erosion, as in the 1930s Dust Bowl (see Case in Point in this chapter), when drought and poor agricultural practices in the U.S. Midwest resulted in soil loss so great that blown soil reduced air quality in Europe. Soil is not usually considered a deadly weapon, but when soil moves, human lives are often at risk.

At the same time, many of the most agriculturally productive areas are places where soil has accumulated over time. River valleys and deltas are graced with deep, fertile soils, carried from eroded lands upstream. Many of the world's great cities are located in these areas where soil has landed after a long journey, where waterways facilitate transport of products and where rich soils facilitate food growth. Soil structures are the foundation of human activity and civilization. Soil instability threatens the foundations of human communities, even when mudslides are unlikely.

In this chapter we discuss soil as a valuable natural resource on which humans and many other organisms depend. Many human activities cause or accentuate soil problems, such as erosion and nutrient mineral depletion. The goals of soil conservation are to minimize soil erosion and maintain soil fertility so that this resource can be used in a sustainable fashion. Conserving our soil resources is critical to human survival because more than 99% of our food comes from the land.

In Your Own Backyard...

Visit http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm. Click on "archived soil surveys" to see a list of soil surveys by state. Click on your state, then on your county. Select the manuscript pdf and scroll down to "physiography." What is the geologic history for your area of the county?

The Soil System

LEARNING OBJECTIVES

- Define *soil* and identify the state factors involved in formation of the soil system.
- List the four components of the soil system and explain the ecological significance of each.
- Describe the various soil horizons.
- Name at least two ecosystem services performed by soil organisms and briefly discuss nutrient cycling.

soil The uppermost layer of Earth's crust, which supports terrestrial plants, animals, and microorganisms.

Soil is the relatively thin surface layer of Earth's crust consisting of mineral and organic matter modified by the natural actions of weather, wind, water, and organisms. It is easy to take soil for granted. We walk on it throughout our lives but rarely stop to think about how important it is to our survival.

Soil supports virtually all terrestrial food webs. Vast numbers and kinds of organisms, mainly microorganisms, inhabit soil and depend on it for shelter, food, and water. Plants anchor themselves in soil, and from it they receive essential nutrient minerals and water. Because we depend on plants for our food, humans could not exist without soil either (**Figure 14.1**).

Soil represents an evolving system in which a range of organisms and physical processes interact. The following sections describe portions of the soil system.

STATE FACTORS: SOIL-FORMING FACTORS

State factors determine the state of the soil system. The five main state factors are parent material, climate, topography, organisms, and time. Soil is formed from *parent material*, rock that is slowly broken down, or fragmented, into smaller and smaller particles by biological, chemical, and physical **weathering processes** in nature. It takes a long time, sometimes thousands of years, for rock to disintegrate into finer and finer mineral particles. To form 2.5 cm (1 in.) of topsoil may require between 200 and 1000 years. Time is also required for organic material to accumulate in the soil. Soil formation is a continuous process that involves interactions between Earth's solid crust and the biosphere. The weathering of parent material beneath already-formed soil continues to add new soil. The thickness of soil varies from a thin film on young lands, near the North and South Poles as well as on the slopes near the tops of mountains, to more than 3 m (10 ft) on old lands, such as savannas.

Organisms and climate both play essential roles in weathering, sometimes working together. When plant roots and other soil organisms respire, they produce carbon dioxide, CO_2, which diffuses into the soil and reacts with soil water to form carbonic acid, H_2CO_3. Organisms such as lichens produce other kinds of acids. These acids etch tiny cracks in the rock; water then seeps into these cracks. If the parent material is located in a temperate climate, the alternate freezing and thawing of the water during the winter causes the cracks to enlarge, breaking off small pieces of rocks. Small plants send their roots into the larger cracks, fracturing the rock further.

Topography, a region's surface features, such as the presence or absence of mountains and valleys, is also involved in soil formation. Steep slopes often have little or no soil on them because soil and rock are continually transported down the slopes by gravity; runoff from precipitation tends to amplify erosion on steep slopes. Moderate slopes and valleys, on the other hand, may encourage the formation of deep soils.

Humans are often considered a state factor because of their global influence on environmental processes such as the carbon and nitrogen cycles (see Chapter 4). Human activities that affect the soil system include agriculture, urbanization, mining, pollution, deforestation, and forestation.

Figure 14.1 Agricultural soil. This soil on a hillside in Dongchuan, China, supports growth of many crops. Soil is an important natural resource on which humans and terrestrial organisms rely.

SOIL COMPOSITION

The soil system is composed of four distinct parts: mineral particles, which make up about 45% of a "typical" soil; organic matter (under 5%); water (about 25%); and air (about 25%). Soil occurs in layers, each of which has a certain composition and special properties. The plants, animals, fungi, and microorganisms that inhabit soil interact with it, and nutrient minerals cycle from the soil to organisms, which use them in their biological processes. When the organisms die, bacteria and other soil organisms decompose the dead material, returning the nutrient minerals to the soil.

The mineral portion, which comes from weathered rock, constitutes most of the soil. It provides anchorage and essential nutrient minerals for plants as well as pore space for water and air. Because different rocks are composed of different minerals, soils vary in mineral composition and chemical properties. Rocks rich in aluminum form acidic soils, whereas rocks with silicates of magnesium and iron form soils that may be deficient in calcium, nitrogen, and phosphorus. Even soils formed from the same kind of parent material may not develop in the same way because other factors such as weather, topography, and organisms differ.

The age of a soil affects its mineral composition. In general, older soils are more weathered and lower in certain essential nutrient minerals. Large portions of Australia, Africa, South America, and India have old, infertile soils. In contrast, in geologically recent time, glaciers passed across much of the Northern

Hemisphere, pulverizing bedrock and forming the parent material of fertile soils. At their greatest extent, these ice sheets covered about 10 million km^2 (4 million mi^2) of North America, extending south as far as the Ohio and Missouri Rivers. Essential nutrient minerals are readily available in these geologically young soils and in young soils formed in areas of volcanic activity.

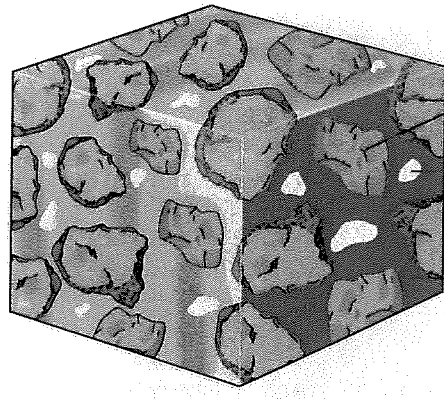
Litter (dead leaves and branches on the soil's surface), animal dung, and dead remains of plants, animals, and microorganisms in various stages of decomposition constitute *soil organic material*. Microorganisms, particularly bacteria, nematodes, and fungi, gradually decompose this material. During organic matter decomposition, essential nutrient mineral ions are released into the soil, where they may be bound to soil particles, absorbed by plant roots, or leached through the soil by water. Organic matter increases the soil's water-holding capacity by acting much like a sponge, and also increases aeration. For these reasons, gardeners often add organic matter to soils, because organic matter fosters optimum air and water conditions for root growth.

The black or dark-brown organic material that remains after much decomposition has occurred is **humus**. Humus, which is not a single chemical compound but a mix of many organic compounds, binds to nutrient mineral ions and holds water. On average, humus persists in agricultural soil for about 20 years. Certain components of humus, however, may persist in the soil for hundreds or even several thousands of years. Although humus is somewhat resistant to further decay, a succession of microorganisms gradually reduces it to the products of decomposition: carbon dioxide, water, and nutrient minerals. Detritus-feeding animals such as earthworms, termites, and ants also help break down humus.

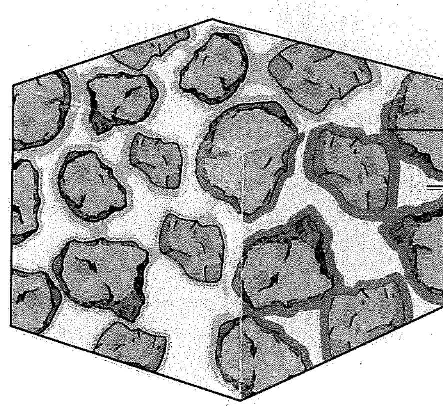
Soil has numerous pore spaces around and among the soil particles. The pore spaces occupy roughly 50% of a soil's volume and are filled with varying proportions of water (called **soil water**) and air (called **soil air**) (**Figure 14.2**); both are necessary to produce a moist but aerated soil that sustains plants and other soil-dwelling organisms. Generally speaking, water is held in the smaller pores (less than 0.05 mm in diameter), whereas air is found in the larger pores. After a prolonged rain, almost all the pore spaces may be filled with water, but water drains rapidly from the larger pore spaces, drawing air from the atmosphere into those spaces.

Soil water originates as precipitation, which drains downward, or as groundwater, which rises upward from the water table (see Chapter 13). Soil water contains low concentrations of dissolved nutrient mineral salts that enter the roots of plants as they absorb the water. Water not bound to soil particles or absorbed by roots **leaches**, or percolates (moves down), through the various layers of the soil, carrying dissolved minerals with it. The deposition of leached material in the lower layers of soil is known as **illuviation**. Iron and aluminum compounds, humus, and clay are some illuvial materials that gather in the subsurface portion of the soil. Some substances completely leach out of the soil because they are so soluble they migrate down into the groundwater. Water can also move upward in the soil, transporting dissolved materials with it, such as when the water table rises.

Soil air contains the same gases as atmospheric air, although they are usually present in different proportions. As a result of cellular respiration by soil organisms, the soil generally contains more carbon dioxide and less oxygen than atmospheric air. (Recall from Chapter 3 that cellular respiration uses oxygen and produces carbon dioxide.) Among the important gases in soil air are oxygen, required by soil organisms for cellular respiration; nitrogen, used by nitrogen-fixing bacteria (see Chapter 4); and carbon dioxide, involved in soil weathering.



(a) In a wet soil, most of the pore space is filled with water.



(b) In a dry soil, a thin film of water is tightly bound to soil particles, and soil air occupies most of the pore space.

Figure 14.2 Pore space.

SOIL HORIZONS

A deep vertical cut through many soils reveals that they are organized into distinctive horizontal layers called **soil horizons**. A **soil profile** is a vertical section from surface to parent material, showing the soil horizons (**Figure 14.3**). While soil horizons often have a general pattern, the specific horizons that develop are a consequence of the interactions among state factors during soil development or human disturbance.

soil horizons The horizontal layers into which many soils are organized, from the surface to the underlying parent material.

The uppermost layer of soil, the **O-horizon**, is rich in organic material. Plant litter accumulates in the O-horizon and gradually decays. In desert soils the O-horizon is often completely absent, but in certain organically rich soils it may be the dominant layer.

Just beneath the O-horizon is the topsoil, or **A-horizon**, which is dark and rich in accumulated organic matter and humus. Plant roots and soil organisms are plentiful in this horizon. In some soils, a heavily leached **E-horizon** develops between the A- and B-horizons.

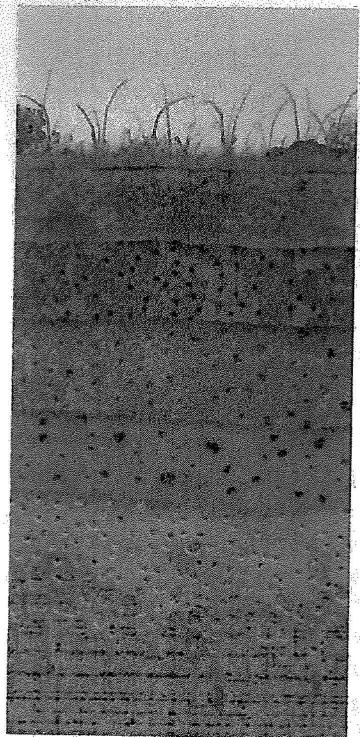


Figure 14.3 Generalized soil profile. Each horizon has its own chemical and physical properties; each soil has its own set of horizons.

The **B-horizon**, the lighter-colored subsoil beneath the A-horizon, is often a zone of accumulation in which nutrient minerals that leached out of the topsoil and litter accumulate. It is typically rich in iron and aluminum compounds and clay.

Beneath the B-horizon is the C-horizon, which contains weathered pieces of rock and borders the unweathered solid parent material. The C-horizon is below the extent of most roots and is often saturated with groundwater.

SOIL ORGANISMS

Although soil organisms are usually hidden underground, their numbers are huge. Millions of microorganisms, including bacteria, fungi, algae, nematodes, and protozoa, may inhabit just one teaspoon of fertile agricultural soil. Many other organisms colonize the soil ecosystem, including plant roots, insects such as termites and ants, earthworms, moles, snakes, and groundhogs (**Figure 14.4**). Most numerous in soil are bacteria, which number in the hundreds of millions per gram of soil. Scientists have identified about 170,000 species of soil organisms, but thousands remain unidentified. Moreover, scientists know little about the roles of most soil organisms, in part because most do not grow well in laboratories where thorough study is possible.

ecosystem services Important environmental benefits that ecosystems provide to people, including clear air to breathe, clean water to drink, and fertile soil in which to grow crops.

Soil organisms provide several essential **ecosystem services**, such as maintaining soil fertility by decaying and cycling organic material, preventing soil erosion, breaking down toxic pollutants, cleansing water, and affecting the composition of the atmosphere.

Worms are important organisms living in soil. Among the most familiar soil inhabitants, earthworms ingest soil and obtain energy and raw materials by digesting some of the compounds that make up humus. **Castings**, bits of soil that have passed through the gut of an earthworm, are deposited near the soil surface. In this way, nutrient minerals from deeper layers in the soil are brought to upper layers. Earthworm tunnels serve to aerate the soil, and the worms' waste products and corpses add organic material to the soil.

Ants live in the soil in enormous numbers, constructing tunnels and chambers that aerate it. Members of soil-dwelling ant colonies forage on the surface for bits of food, which they carry back to their nests. Not all this food is eaten, and its eventual decomposition helps increase the organic matter in the soil. Many ants are also indispensable in plant reproduction because they bury seeds in the soil. Some ants grow fungi underground, which help hold soil moisture and increase organic matter.

The properties of soil affect plant growth, although most plants tolerate a wide range of soil types. In turn, the types of plants that grow in soil affect it. Are the plants growing in a certain locality because of the soil found there, or do the plants determine the soil's type? Different soil systems support both scenarios.

One important symbiotic relationship in the soil occurs between fungi and the roots of vascular plants. These fungi, called **mycorrhizae**, help plants absorb adequate amounts of essential nutrient minerals from the soil. The threadlike body of the fungal partner, its **mycelium**, extends into the soil well beyond the roots. Nutrient minerals absorbed from the soil by the fungus are transferred to the plant, whereas food produced by photosynthesis in the plant is delivered to the fungus. Mycorrhizal fungi enhance the growth of plants (see Figure 5.17). Absence of mycorrhizal fungi from soil following a natural or human-induced disturbance retards the reestablishment of many tree species and other plants, such as orchids.

ENVIRONEWS

Soil Fungi and Plant Communities

Scientists have yet to determine the specific factors that influence plant diversity, but two teams of researchers emphasize the importance of soil-dwelling fungi in shaping plant communities. Researchers in Switzerland and Ontario reported that plant diversity in a given location is strongly influenced by the variety of mycorrhizae present there. In controlled experiments simulating both European and North American landscapes, replicates of the same plant community were grown in the presence of from 1 to 14 mycorrhizal species. The scientists observed that plant communities grown in the presence of 8 or more mycorrhizal species maintained the greatest diversity. When plants grew with fewer kinds of fungi, the structure and composition of plant communities fluctuated considerably, depending on the number and composition of mycorrhizal species present. Researchers think that mycorrhizal diversity plays a significant role in determining plant diversity as well as ecosystem variability and productivity.

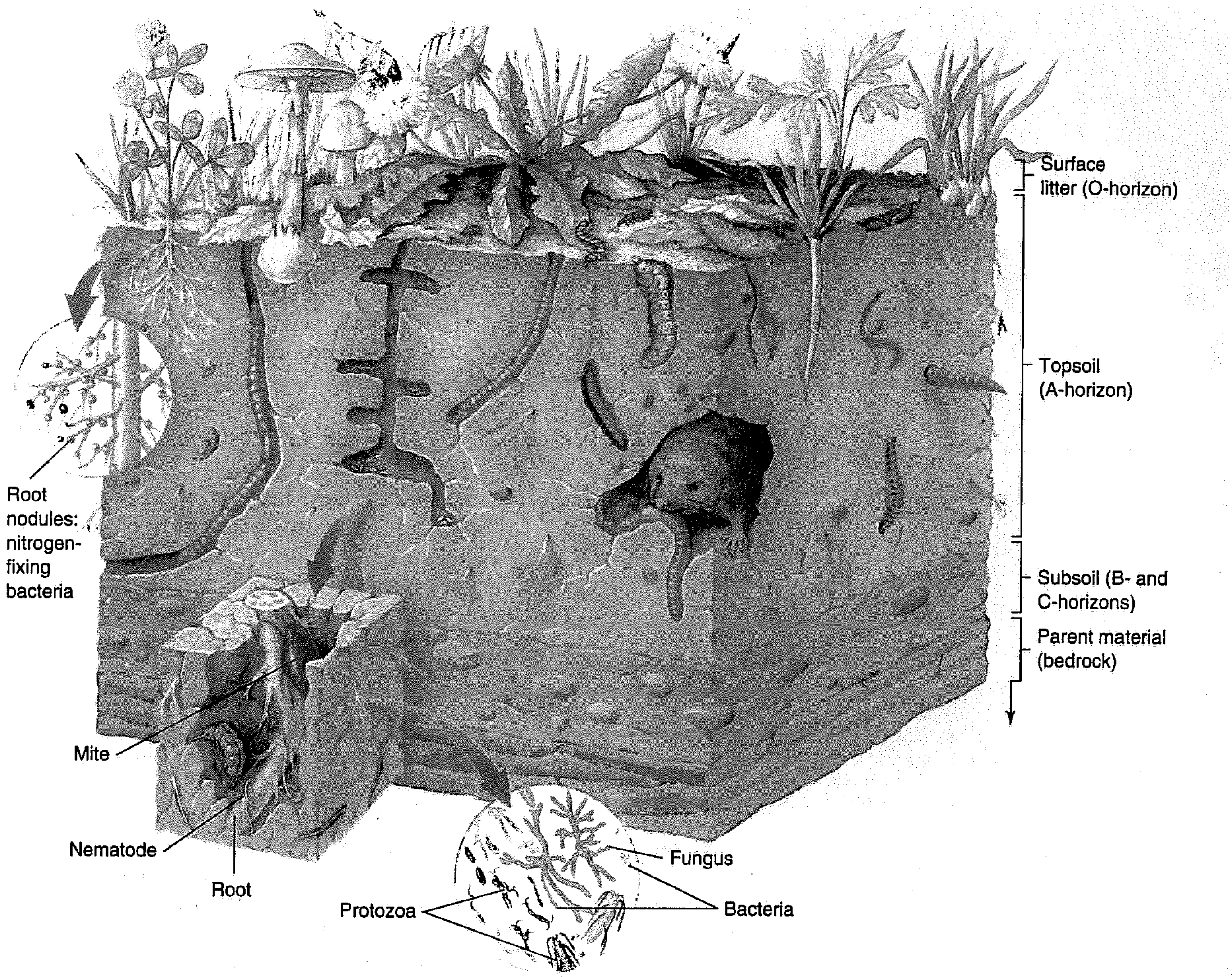


Figure 14.4 Soil organisms. The biodiversity in fertile soil includes plants, algae, fungi, earthworms, nematodes, insects, spiders and mites, bacteria, and burrowing animals such as moles, snakes, and groundhogs.

NUTRIENT CYCLING

In a normally functioning ecosystem, the relationships among soil and the organisms that live in and on it ensure soil fertility. Essential nutrient minerals such as nitrogen and phosphorus are cycled from the soil to organisms and back again to the soil (**Figure 14.5**; also see discussion of the nitrogen and phosphorus cycles in Chapter 4). Decomposition is part of **nutrient cycling**. Bacteria and fungi decompose plant and animal detritus and wastes, transforming large organic molecules into small inorganic molecules, including carbon dioxide, water, and nutrient minerals; the nutrient minerals are released into the soil to be used again.

trient cycling The ray of various nutri- inerals or elements m the environment ugh organisms and o the environment.

Abiotic (nonliving) processes are also involved in nutrient cycling. Although leaching causes some nutrient minerals to be lost from the soil ecosystem to groundwater, weathering of the parent material replaces much or all of this loss. In addition, dusts carried in the atmosphere for hundreds or thousands of kilometers help replace nutrient minerals in certain soils. Hawaiian rainforest soils, for example, receive dust inputs from central Asia, a distance more than 6000 km (about 4000 mi) away.

REVIEW

1. How do weathering processes affect soil formation?
2. What are the four components of soil, and how is each important?
3. What are soil horizons? Distinguish between the O-horizon and A-horizon.
4. Name two ecosystem services that soil organisms perform.

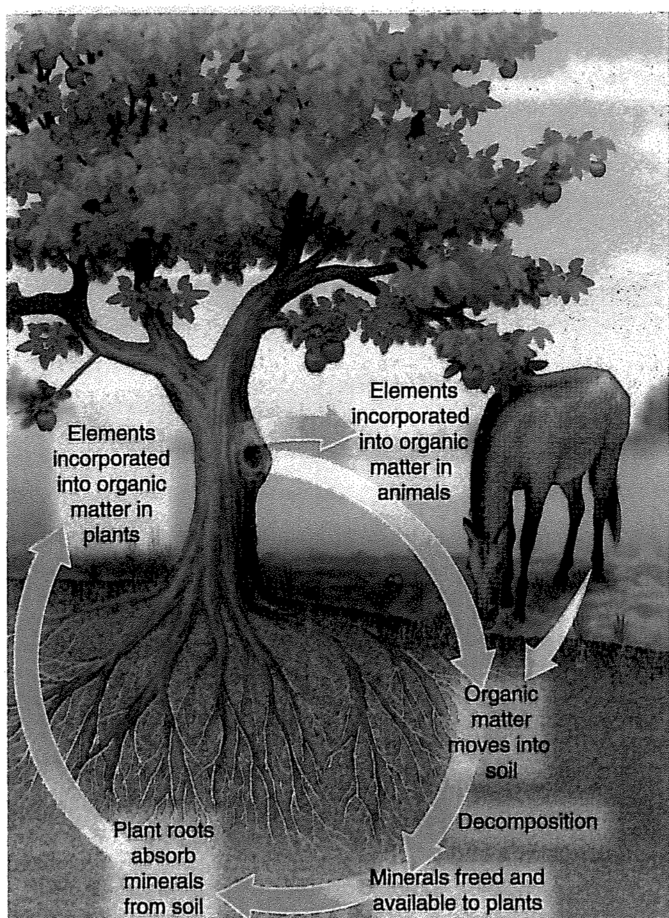


Figure 14.5 Nutrient cycling. In a normally functioning ecosystem, mineral nutrients cycle from soil to organisms and then back to soil.

Soil Properties and Major Soil Types

LEARNING OBJECTIVES

- Briefly describe soil texture and soil acidity.
- Distinguish among spodosols, alfisols, mollisols, aridisols, and oxisols.

Texture and acidity are two parameters that characterize soils. Soil **texture** refers to the relative proportions of different-sized inorganic mineral particles of sand, silt, and clay; soil texture does not refer to the organic material in the soil, only the inorganic minerals. The size assignments for sand, silt, and clay give soil scientists a way to classify soil texture. Particles larger than 2 mm in diameter, called gravel or stones, are not considered soil particles because they do not have any direct value to plants. The largest soil particles (0.05 to 2 mm in diameter) are **sand**, medium-sized particles (0.002 to 0.05 mm in diameter) are **silt**, and small particles (less than 0.002 mm in diameter) are **clay** (**Figure 14.6**). Sand particles are large enough to be seen easily with the eye; silt particles are about the size of flour particles and are barely visible to the eye; clay particles are only seen under an electron microscope. A soil's texture affects many of a soil's properties, which in turn influence plant growth. Clay is particularly important in determining many soil characteristics because clay particles have the greatest surface area of all soil particles. If the surface areas of 500 g (about 1 lb) of clay particles were laid out side by side, they would occupy 1 hectare (2.5 acres).

Soil minerals are often present in charged forms, or **ions**. Mineral ions may be positively charged (K^+, for example) or negatively charged (OH^-, for example). Each clay particle has predominantly negative electrical charges on its outer surface that attract and reversibly bind positively charged mineral ions (**Figure 14.7**). Many of these mineral ions, such as potassium (K^+) and magnesium (Mg^{2+}), are essential for plant growth and are "held" in the soil for plant use by their interactions with clay particles. In contrast, negatively charged mineral ions are usually not held as tightly in the soil and are often washed out of the root zone.

Soil always contains a mixture of different-sized particles, but the proportions vary from soil to soil. A **loam**, which is an ideal agricultural soil, has an optimum combination of different soil particle sizes. It contains approximately 40% each of sand and silt and about 20% clay. Generally, the larger particles provide structural support, aeration, and permeability to the soil, whereas the smaller particles bind into aggregates, or clumps, and hold nutrient minerals and water (**Table 14.1**). Soils with larger proportions of sand are not as desirable for most plants because they do not hold mineral ions or water as well. Plants grown in such soils are more susceptible to mineral deficiencies and drought. Soils with larger proportions of clay are not as desirable for most plants because they provide poor drainage and often do not contain enough oxygen. Clay soils used for agriculture tend to get compacted, which reduces the number of pore spaces that water and air can fill.

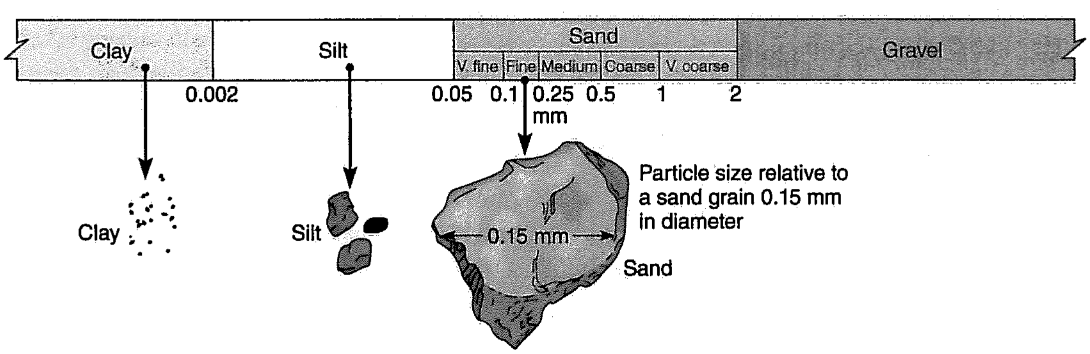
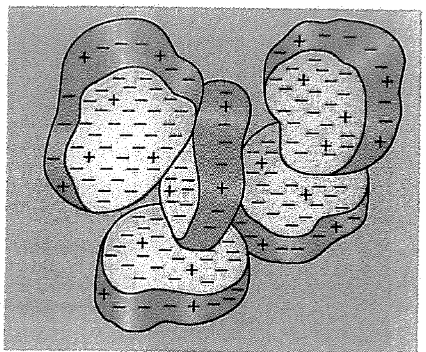
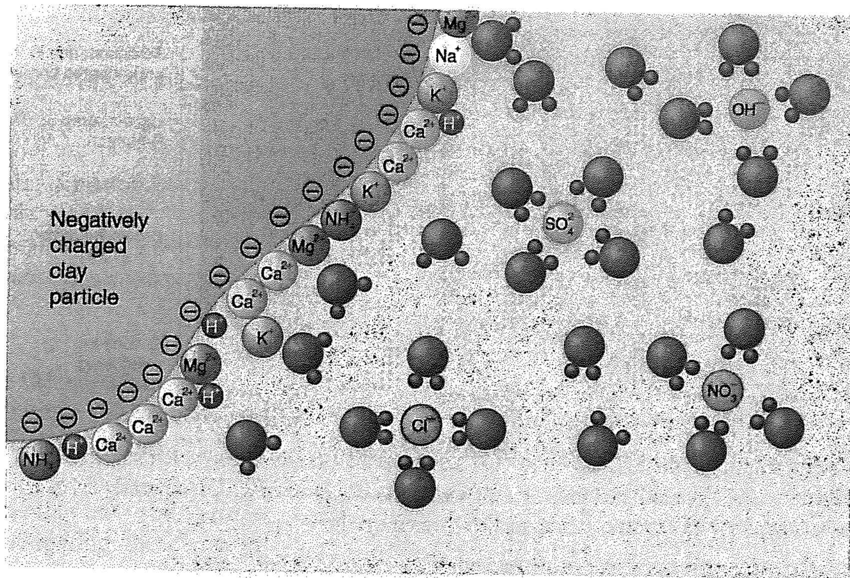


Figure 14.6 Relative sizes of soil particles.



(a) The outer surfaces of clay particles are predominantly negatively charged.



(b) In this close-up of a clay particle and the thin film of water (red oxygen spheres with two blue hydrogens attached) around it, note the large number of positively charge ions attracted to the surface of the clay particle. Also note how the positive (blue) ends of water molecules surround the negatively charged ions dissolved in solution.

Figure 14.7 Availability of nutrient minerals.

Table 14.1 Soil Properties Affected by Soil Texture

	Soil Texture Type		
Soil Property	*Sandy Soil*	*Loam*	*Clay Soil*
Aeration	Excellent	Good	Poor
Drainage	Excellent	Good	Poor
Nutrient mineral–holding capacity	Low	Medium	High
Water-holding capacity	Low	Medium	High
Workability (tillage)	Easy	Moderate	Difficult

SOIL ACIDITY

Soil acidity is measured using the pH scale, which extends from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). (See Appendix I for a discussion of pH.) The pH of most soils ranges from 4 to 8, but some soils are outside this range. Soil pH affects plants partly because the solubility of certain nutrient minerals varies with differences in pH; that is, soil nutrients are available to plants or unavailable depending on the pH. Plants absorb soluble mineral elements but cannot absorb insoluble forms. At a low pH, the aluminum and manganese in soil water are more soluble, and the roots sometimes absorb them in toxic concentrations. Certain mineral salts essential for plant growth, such as calcium phosphate, become less soluble and less available to plants at a higher pH.

Soil pH greatly affects the leaching of nutrient minerals. The more acidic a soil the less capacity it has to bind positively charged ions. As a result, certain nutrient mineral ions essential for plant growth, such as potassium (K^+), leach more readily from an acidic soil. The optimum soil pH for most plant growth is 6.0 to 7.0 because most nutrient minerals needed by plants are available in that pH range.

Soil pH affects plants and, in turn, is influenced by plants and other soil organisms. Litter composed of the needles of conifers contains acids that leach into the soil, lowering its pH. The decomposition of humus and the cellular respiration by soil organisms also decrease the pH of soil.

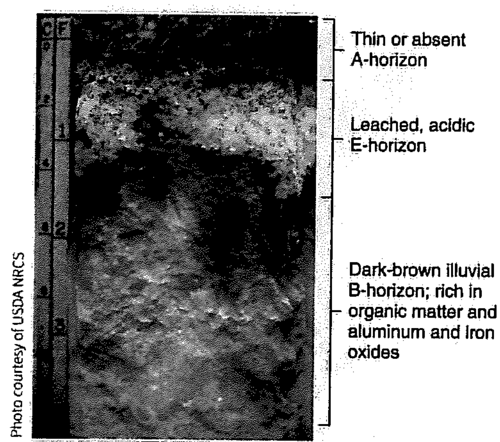
Acid precipitation is a type of air pollution in which human-produced sulfuric and nitric acids fall to the ground as acid rain, acid sleet, acid snow, or acid fog. Acid precipitation alters soil chemistry, damages plants, and causes forest decline in some areas (see Chapter 19). Studies of acid rain at Hubbard Brook, New Hampshire, show that the effects of acid rain can be reversed by adding calcium to soil, which helps restore the pH balance.

MAJOR SOIL GROUPS

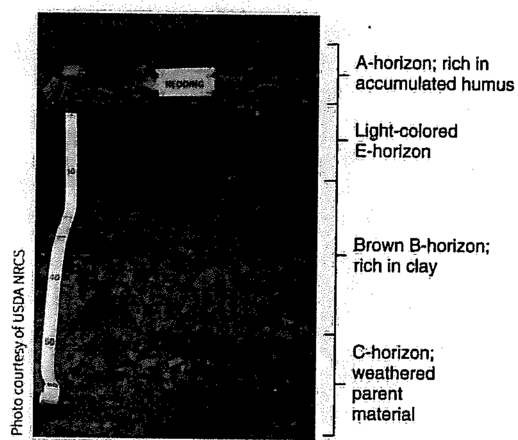
Variations in climate, local vegetation, parent material, underlying geology, topography, and soil age result in thousands of soil types throughout the world. These soils differ in color, depth, mineral content, acidity, pore space, and other properties. **Soil taxonomy** is the method of classification of these soils into 12 distinctive *orders*; each order is subdivided into many different *series*. In the United States alone, more than 20,000 soil series are known.

Here we focus on five common soil orders: spodosols, alfisols, mollisols, aridisols, and oxisols. Regions with colder climates, ample precipitation, and good drainage typically have soils called **spodosols**, with distinct layers (**Figure 14.8a**). A spodosol usually forms under a coniferous forest and has an O-horizon of acidic litter composed primarily of needles; an ash-gray, acidic, leached E-horizon; and a dark-brown, illuvial B-horizon. Spodosols do not make good farmland because they are too acidic and are nutrient-poor because of leaching.

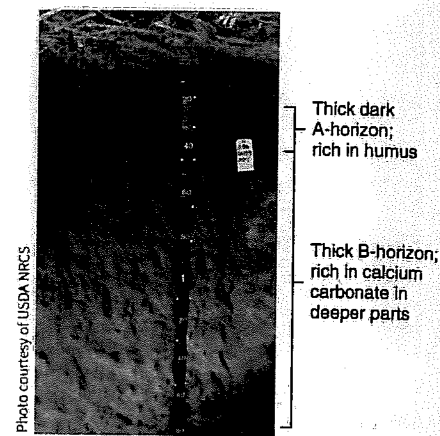
Temperate deciduous forests grow on **alfisols**, soils with a brown to gray-brown A-horizon (**Figure 14.8b**). Precipitation is



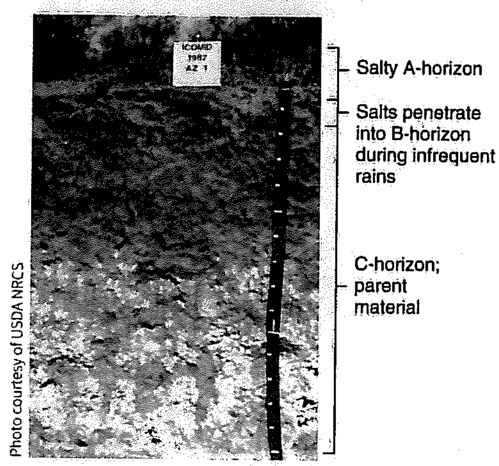
(a) **Spodosol** in cold (subarctic) climate. Characteristic of evergreen forests.



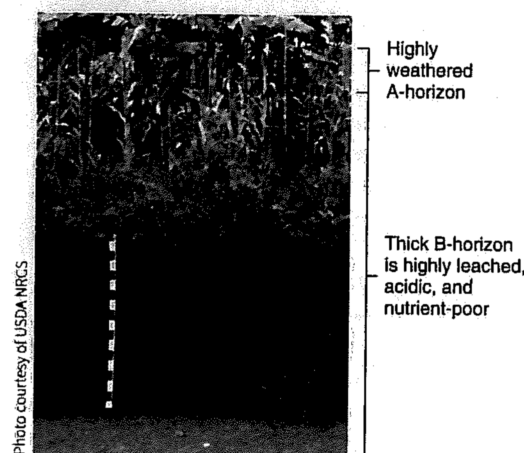
(b) **Alfisol** in humid climate with hot summers and cold winters. Characteristic of temperate, deciduous forest.



(c) **Mollisol** in semiarid climate with hot summers and cold winters. Characteristic of temperate grassland.



(d) **Aridisol** in arid (dry) climate. Characteristic of desert.



(e) **Oxisol** in warm, wet climate. Characteristic of tropical rain forest.

Figure 14.8 Five representative soil orders. As climate change occurs, plant life on each of these soils will change. How might the changes in plant life affect the characteristics of soil orders?

great enough to wash much of the clay and soluble nutrient minerals out of the A- and E-horizons and into the B-horizon. When the deciduous forest is intact, soil fertility is maintained by a continual supply of decaying plant litter. When the soil is cleared for farmland, soil fertility drops unless it is supplemented with organic or inorganic fertilizer.

Mollisols, found primarily in temperate, semiarid grasslands, are fertile soils (**Figure 14.8c**). They possess a thick, dark-brown to black A-horizon rich in humus. Some soluble nutrient minerals remain in the upper layers because precipitation is not great enough to leach them into lower layers. Most of the world's grain crops are grown on mollisols. These soils provide an excellent example of the involvement of organisms in soil formation: without the deep-rooting grasses, mollisols would not form.

Aridisols are found in arid regions of all continents. The lack of precipitation in these deserts precludes much leaching, and the lack of lush vegetation precludes the accumulation of much organic matter. As a result, aridisols do not usually have distinct layers of leaching and illuviation. Some aridisols have a salic (salty) A-horizon (**Figure 14.8d**). Some aridisols provide rangeland for grazing animals, and crops can be grown on aridisols if water is conserved for irrigation.

Oxisols, which are low in nutrient minerals, exist in tropical and subtropical areas with ample precipitation (**Figure 14.8e**). Little organic material accumulates on the forest floor (O-horizon) because leaves and twigs are rapidly decomposed in the hot, humid climate. The A-horizon is enriched with humus derived from the rapidly decaying plant parts. The B-horizon, which is quite thick, is highly leached, acidic, and nutrient-poor. Oddly enough, lush tropical rain forests grow on oxisols. Most of the nutrient minerals in tropical rain forests are locked up in the vegetation rather than in the soil. As soon as plant and animal remains touch the forest floor, they promptly begin to decay, and plant roots quickly reabsorb the nutrient minerals. Even wood, which may take years to decompose in temperate soils, decomposes in a matter of months in tropical rain forests, largely by subterranean termites.

REVIEW

1. What is soil texture?
2. What is the optimum pH of most soils? What happens if the soil pH falls outside this range?
3. Which of the five soil orders (spodosols, alfisols, mollisols, aridisols, and oxisols) is associated with deserts? With tropical rain forests? With semiarid grasslands?

Environmental Problems Related to Soil

LEARNING OBJECTIVES

- Define *sustainable soil use.*
- Explain the impacts of soil erosion, mineral depletion, soil salinization, and desertification on plant growth.
- Describe the American Dust Bowl and explain how a combination of natural and human-induced factors caused this disaster.

Humans disrupt soil systems that would be balanced (i.e., functioning normally) in nature. Human activities often cause or exacerbate soil problems, including erosion, mineral depletion of the soil, soil salinization, and desertification, all of which occur worldwide (**Figure 14.9**). Understanding how soil systems work is essential to mitigating these disruptive effects and promoting **sustainable soil use.** Soil used in a sustainable way renews itself by natural processes, sometimes fostered by human management, year after year.

stainable soil use The wise use of soil sources, without a tion in soil fertility, at the soil remains oductive for future generations.

SOIL EROSION

Water, wind, ice, and other agents promote **soil erosion.** Water and wind are particularly effective in moving soil from one place to another (**Figure 14.10**). Rainfall loosens soil particles, which are then transported away by moving water. Wind loosens soil and blows it away, particularly if the soil is barren and dry. Soil erosion is a natural process accelerated by human activities.

erosion The wear-away or removal of especially topsoil, from the land.

Erosion reduces the amount of soil in an area and therefore limits the growth of plants. Erosion causes a loss of soil fertility because essential nutrient minerals and organic matter in the soil are removed. As a result of these losses, the productivity of eroded agricultural soil drops.

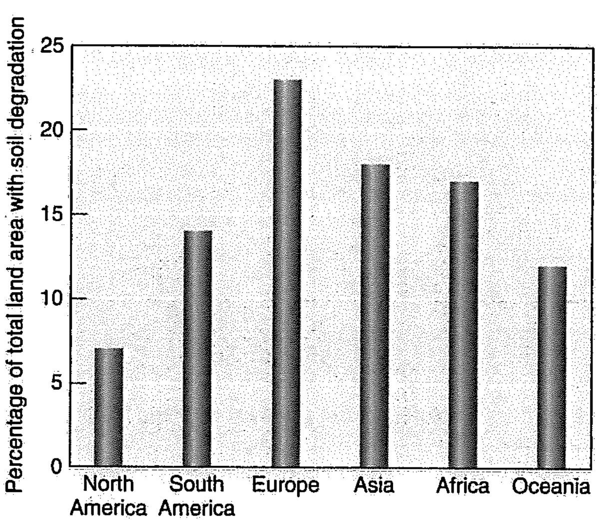
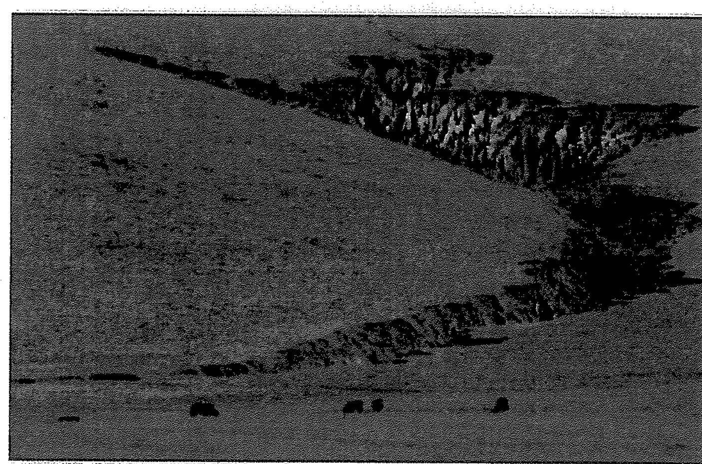


Figure 14.9 Soil degradation. This graph shows the degree of soil degradation (eroded, desertified, or salinized soil) by continent. (*World Atlas of Desertification*, UN Environment Programme, 2002.)



Richard Hansen/Science Source

(a) Water erosion in a field in San Simeon, California. The branchies gullies will continue to deepen unless checked by some type of erosion control.

© Joel Day/Alamy

(b) Wind erosion on a farm in northern Maryland. When soil is dry, wind picks up topsoil and can move it long distances. Machinery or foot traffic can exacerbate wind erosion.

Figure 14.10 Soil erosion.

Humans often accelerate soil erosion with poor soil management practices. Although soil erosion is often caused by poor agricultural practices, agriculture is not the only culprit. Removal of natural plant communities, such as during the construction of roads and buildings, and unsound logging practices, such as clear-cutting large forested areas, accelerate soil erosion.

Soil erosion has an impact on other natural resources as well. Sediment that gets into streams, rivers, and lakes affects water quality and fish habitats. If the sediment contains pesticide and fertilizer residues, they further pollute the water. When forests are removed within the watershed of a hydroelectric power facility, accelerated soil erosion causes the reservoir behind the dam to fill with sediment much faster than usual. This process results in a reduction of electricity production at that facility.

Sufficient plant cover limits the amount of soil erosion. Leaves and stems cushion the impact of rainfall, and roots help hold the soil in place. Although soil erosion is a natural process, abundant plant cover makes it negligible in many natural ecosystems.

Soil Erosion in the United States and the World Every five years the Natural Resources Conservation Service (NRCS), formerly called the Soil Conservation Service, measures the rate of soil erosion at thousands of sites across the United States. It also uses satellite data and models to estimate annual soil erosion. These measurements and estimates indicate that erosion remains a serious threat to cultivated soils in many regions throughout the United States, particularly in parts of southern Iowa, northern Missouri, western and southern Texas, and eastern Tennessee. The good news is that soil erosion on all U.S. croplands declined about 55% between 1982 and 2007, although the Environmental Working Group suggests that erosion has been underestimated both before and after 2007.

Water erosion is particularly severe in the Midwestern grain belt along the Mississippi and Missouri Rivers, as well as in the Central Valley of California and in the hilly Palouse River region of the Pacific Northwest. The NRCS estimates that about 25% of U.S. agricultural lands are losing topsoil faster than natural soil-forming processes regenerate it. This loss is often so gradual that even farmers fail to notice it. A severe rainstorm may wash away 1 mm (0.04 in.) of soil, which seems insignificant until the cumulative effects of many storms are taken into account. Twenty years of soil erosion amounts to the loss of about 2.5 cm (1 in.) of soil, an amount that could take hundreds of years for natural soil-forming processes to replace.

Soil erosion is a significant problem worldwide. Although estimates vary widely, depending on what assumptions are made, soil erosion results in an annual loss of as much as 75 billion metric tons (83 billion tons) of topsoil around the world. Soil erosion is greatest in certain parts of Asia, Africa, and Central and South America. In India and China, soil experts estimate that erosion causes an annual loss of as much as 4.5 billion metric tons and 5.5 billion metric tons of soil, respectively. These two countries have 13% of the world's total land area, from which they must feed 2.6 billion people—more than 35% of the world's human population.

CASE IN POINT

THE AMERICAN DUST BOWL

Semiarid lands, such as the Great Plains of North America, have low annual precipitation and are subject to periodic droughts. Prairie grasses, the plants that grow best in semiarid lands, are adapted to survive droughts. Although the above-ground portions of the plant may die, the root systems survive several years of drought. When the rains return, the root systems send up new leaves. Soil erosion is minimal because the dormant but living root systems hold the soil in place and resist the assault by wind and water.

The soils of semiarid lands are often of high quality, owing largely to the accumulation over many centuries of a thick, rich humus. These lands are excellent for grazing and for growing crops on a small scale. Problems arise when large areas of land are cleared for crops or when animals overgraze the land. The removal of the natural plant cover opens the way for climate conditions to "attack" the soil, and it gradually deteriorates from the onslaught of hot summer sun, occasional violent rainstorms, and wind. If a prolonged drought occurs under such conditions, disaster can strike.

The effects of wind on soil erosion were vividly experienced over a wide region of the central United States during the 1930s (**Figure 14.11**). Throughout the late 19th and early 20th centuries, much of the native grasses were removed to plant wheat. Then, between 1930 and 1937, the semiarid lands stretching from Oklahoma and Texas into Canada received 65% less annual precipitation than was normal. The rugged native prairie grasses could have survived these conditions, but not the wheat. The prolonged drought caused crop failures, which left fields barren and particularly vulnerable to wind erosion.

Winds from the west swept across the barren, exposed soil, causing dust storms of incredible magnitude. Topsoil from Colorado, Texas, Oklahoma, and other prairie states was blown eastward for hundreds of kilometers. Women hanging out clean laundry in Georgia went outside later to find it covered with dust. Bakers in New York City and Washington, D.C., had to keep freshly baked bread away from open windows so that it would not get dirty. The dust even discolored the Atlantic Ocean several hundred kilometers off the coast. On April 14, 1937, known as Black Sunday, the most severe dust storm in U.S. history darkened the sky and blotted out the sun.

The Dust Bowl years occurred during the Great Depression, and ranchers and farmers quickly went bankrupt. Many abandoned

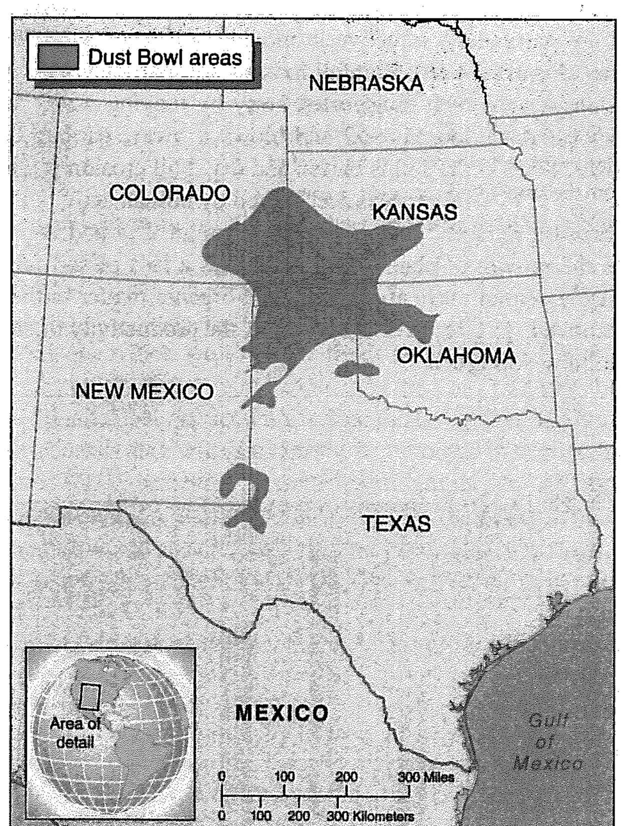


Figure 14.11 Location of the greatest damage from the American Dust Bowl. More than 30 million hectares (74 million acres) of land in the Great Plains were damaged during the Dust Bowl years. Shaded parts of Colorado, Kansas, Oklahoma, Texas, and New Mexico suffered the most extensive damage. Note the significant overlap between Dust Bowl erosion and the extent of the Ogallala Aquifer (Figure 13.16).

their dust-choked land and dead livestock and migrated west to the promise of California (**Figure 14.12**). The plight of these dispossessed farmers is movingly portrayed in the novel *The Grapes of Wrath*, written in 1939 by **John Steinbeck**, for which he won the Pulitzer Prize in 1940.

When the rains finally arrived in the Great Plains, many areas were too eroded to support agriculture. In the years following the Dust Bowl, the U.S. Soil Conservation Service planted fence rows of shrubs and trees (to slow the winds) and seeded many badly eroded areas with native prairie grasses. Agriculture returned, largely because irrigation protected against crop loss from droughts. However, the Ogallala Aquifer, which provides irrigation water for this region, is being drained faster than its rate of replacement (see Chapter 13). When farmers are forced to abandon irrigation and revert to dryland farming, only careful management practices will prevent Dust Bowl conditions from returning during the next drought.

Although the United States no longer has a dust bowl, the Great Plains are still subject to droughts and soil erosion. For example, a severe five-year drought in the early 2000s ruined crops in parts of Montana, Wyoming, Colorado, Kansas, Texas, and New Mexico. Dust storms (brownouts) reoccurred on the High Plains, reminding people of the "Dirty Thirties." ■

NUTRIENT MINERAL DEPLETION

In a natural ecosystem, essential nutrient minerals cycle from the soil to organisms, particularly plants, which absorb them through their roots. When those organisms die and microorganisms decompose them, the essential nutrient minerals are released into the soil, where they become available for use by organisms again. An agricultural system disrupts this pattern of nutrient cycling when the crops are harvested. Much of the plant material that contains nutrient minerals is removed from the cycle, so it fails to decay and release its nutrient minerals back to the soil. Over time, agricultural soil loses its fertility (**Figure 14.13**).

Worldwide, more than 1 billion people depend on agricultural soils that are not productive enough to adequately support them. Unsound farming methods, extensive soil erosion, and desertification contribute to nutrient mineral depletion. In addition, the needs of a rapidly expanding population exacerbate soil problems worldwide.

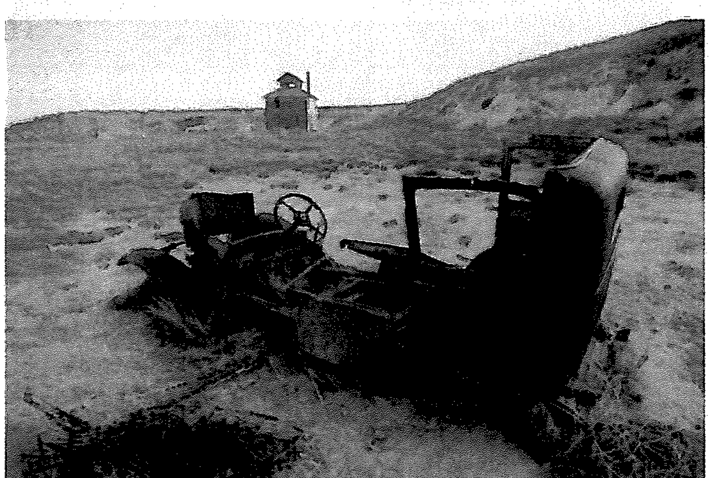


Figure 14.12 Dust Bowl remnants. A car and a house mark and date a farm abandoned in the Dust Bowl.

In tropical rain forests, the climate, the typical soil type (oxisols), and the removal by humans of the natural forest community result in a particularly severe type of mineral depletion. Soils found in tropical rain forests are somewhat nutrient-poor because the nutrient minerals are stored primarily in the vegetation. Any nutrient minerals that are released as dead organisms decay in the soil and are promptly reabsorbed by plant roots and their mycorrhizae. If this did not occur, the heavy rainfall would quickly leach the nutrient minerals away. Nutrient reabsorption by vegetation is so effective that tropical rainforest soils support luxuriant plant growth despite the relative infertility of the soil, as long as the forest remains intact.

When a forest is cleared to sell the wood or make way for crops or rangeland, the efficient nutrient cycling in the forest is disrupted. Removal of the vegetation that so effectively stores the forest's nutrient minerals allows them to leach out of the system. Crops can be grown on these soils for only a few years before the small mineral reserves in the soil are depleted. When cultivation is abandoned, the forest may eventually return to its original state, provided forest is nearby to serve as a source of seeds. The regrowth of forest is a slow process, however, and not all forest ecosystems return after being destroyed. (Chapter 17 discusses deforestation in detail.)

SOIL SALINIZATION

Soils found in arid and semiarid regions often contain high natural concentrations of inorganic compounds as mineral salts (see Figure 14.8d). In these areas, the amount of water that drains into deeper soil is minimal because the little precipitation that falls quickly evaporates, leaving behind the salt. In contrast, humid climates have enough precipitation to leach salts out of soils and into waterways and groundwater.

Irrigation of agricultural fields often results in their becoming increasingly saline (salty), an occurrence known as **salinization** (**Figure 14.14**). Irrigation water contains small amounts of dissolved salts (fresh water always contains some salts). The continued application of such water, season after season, year after year, leads to the gradual accumulation of salt in the soil. When the water evaporates, the salts are left behind, particularly in the upper layers of the soil, which are the layers that are most important for agriculture. Given enough time, the salt concentration can rise to such a high level that plants are poisoned or their roots dehydrated. Also, when irrigated soil becomes waterlogged, capillary movement may carry salts from groundwater to the soil surface, where they are deposited as a crust of salt.

salinization The gradual accumulation of salt in a soil, often as a result of improper irrigation methods.

DESERTIFICATION

Asia and Africa have large land areas with extensive soil damage, and in both places rapid population growth compounds the problem. Consider the Sahel, a broad band of semiarid land that

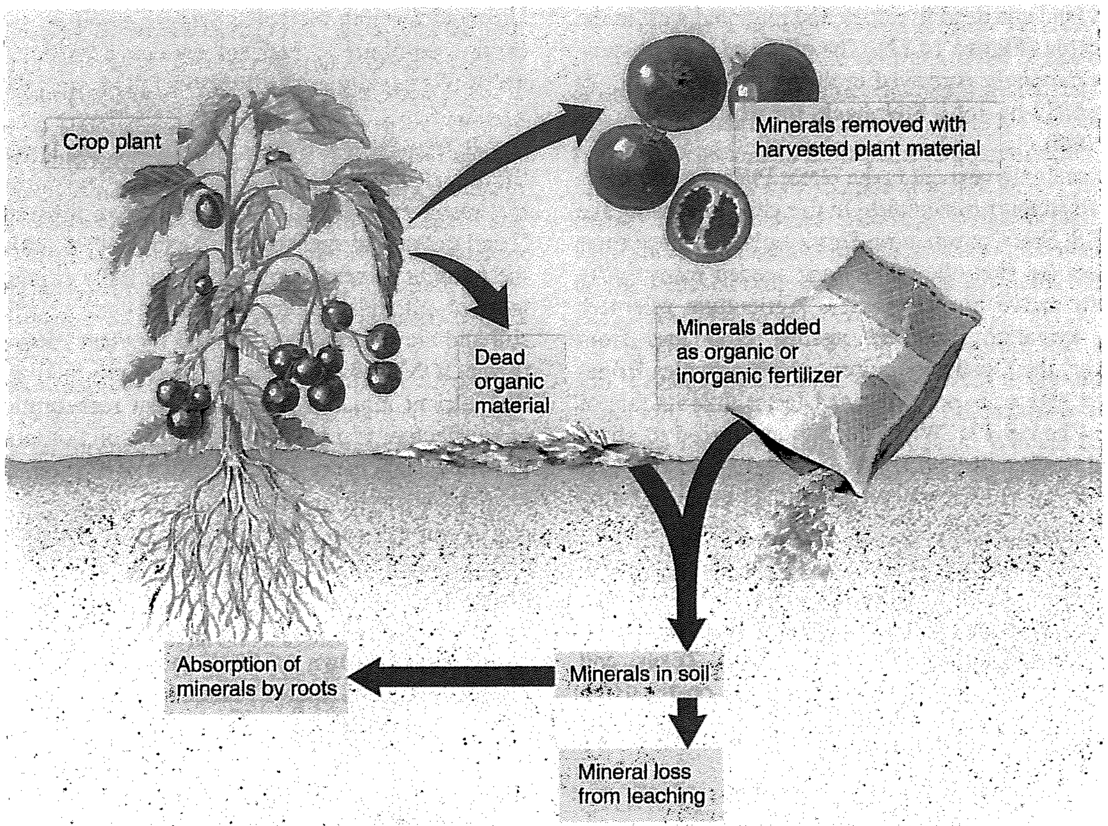


Figure 14.13 Mineral depletion in agricultural soil. In agriculture, much of the plant material is harvested. Because the nutrient minerals in the harvested portions are unavailable to the soil, the nutrient cycle is disrupted, and fertilizer must be periodically added to the soil.

Jim Richardson / Getty Images

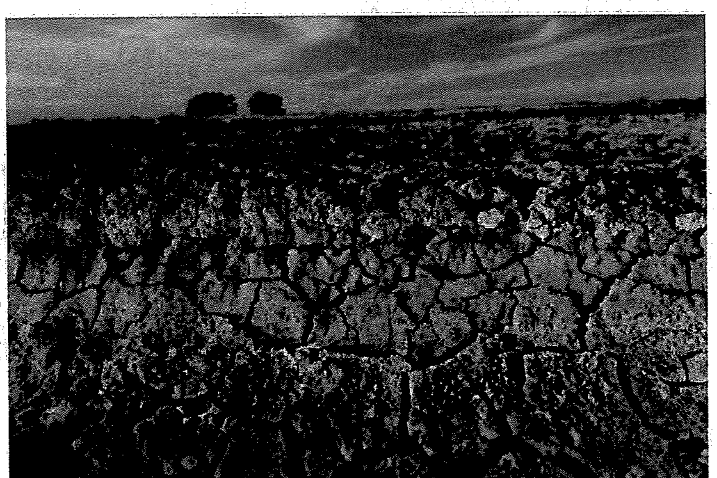


Figure 14.14 Soil salinization. A Colorado farm soil with white salt residues from irrigation.

K. Tumanowicz / Science Source

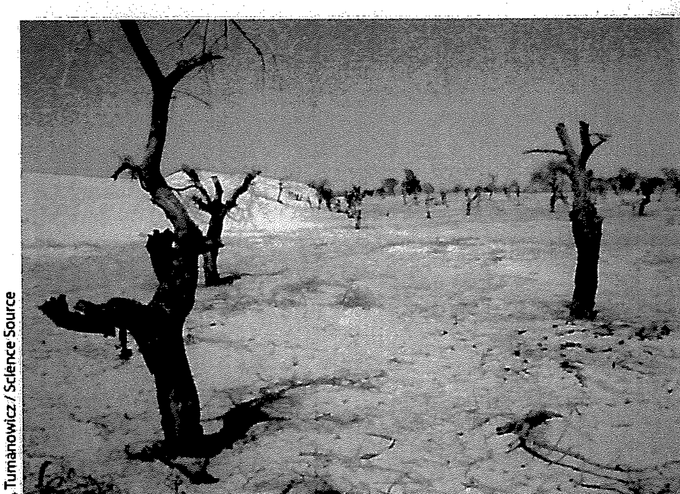


Figure 14.15 Desertification. Livestock in Mali, Africa, have eaten all the ground cover. The dead trees were stripped of branches to feed livestock and provide firewood. Overexploitation by desperately poor people, in combination with extended drought, is increasing the desert area in the Sahel.

stretches across Africa just south of the Sahara Desert and includes all or parts of many countries (see Figure 4.22). The Sahel normally experiences periodic droughts, but for the past 40 years there has been a sustained rainfall deficit—that is, substantially less precipitation than normal. During droughts, the soil cannot support as many crops or grazing animals. Despite the drought, the Sahelians must use their land to grow crops and animals for food or they will starve. The soil is so overexploited under these circumstances that it supports fewer and fewer people; the day is approaching when much of the Sahel could become unproductive desert (**Figure 14.15**).

The degradation of once-fertile rangeland or forest into nonproductive desert caused partly by soil erosion, forest removal,

desertification Degradation of once-ile rangeland, agricultural land, or tropical ry forest into nonproductive desert.

overcultivation, and overgrazing is called **desertification**. To reclaim the land would require restricting its use for many years so it could recover. If these measures were taken, the Sahelians would have no means of obtaining food. Land degradation, including desertification, is discussed in greater detail in Chapters 17 and 18.

REVIEW

1. What is sustainable soil use?
2. How would you distinguish between soil erosion and nutrient mineral depletion?
3. What was the American Dust Bowl?

Soil Conservation and Regeneration

LEARNING OBJECTIVES

- Summarize how conservation tillage, crop rotation, contour plowing, strip cropping, terracing, cover crops, shelterbelts, and agroforestry minimize erosion and mineral depletion of the soil.
- Briefly describe the Conservation Reserve Program.

Courtesy U.S. Department of Agriculture

Figure 14.16 Conservation tillage. Decaying residues from the previous year's crop (rye) surround young soybean plants in a field in Iowa. Conservation tillage reduces soil erosion by as much as 70% because plant residues from the previous season's crop protect soil from wind and water erosion.

Although agriculture may cause or accelerate soil degradation, good soil conservation practices promote sustainable soil use. Conservation tillage, crop rotation, cover crops, contour plowing, strip cropping, terracing, shelterbelts, and agroforestry help to minimize erosion and mineral depletion of the soil. Land badly damaged by soil erosion and mineral depletion can be successfully restored, but it is a costly, time-consuming process.

CONSERVATION TILLAGE

Conventional methods of tillage, or working the land, include spring plowing, in which the soil is cut and turned in preparation for planting seeds, and harrowing, in which the plowed soil is leveled, seeds are covered, and weeds are removed. Conventional tillage prepares the land for crops, but in removing all plant cover, it greatly increases the likelihood of soil erosion. Conventionally tilled fields contain less organic material and generally hold less water than undisturbed soil.

An increasing number of farmers have adopted **conservation tillage**, which causes little disturbance of the soil (**Figure 14.16**). During planting, special machines cut a narrow furrow in the soil for seeds. Several types of conservation tillage fit different areas of the country and different crops. The most extreme of these, **no-tillage**, does not involve any tilling (that is, no plowing or disking) of the soil. Conservation tillage is one of the fastest-growing trends in U.S. agriculture. Over 60% of U.S. soybeans are currently farmed using conservation tillage; the remainder is planted using conventional tillage. In comparison, less than 7% of the world's farmland is planted using conservation tillage methods.

ervation tillage A ethod of cultivation which residues from ous crops are left in soil, partially covering it and helping to l it in place until the y planted seeds are established.

In addition to reducing soil erosion, conservation tillage increases the organic material in the soil, which, in turn, improves the soil's water-holding capacity. Decomposing organic matter releases nutrient minerals more gradually than when conventional tillage methods are employed. Farmers who adopt no-tillage save on fuel costs, machinery wear and tear, and labor time when they do not plow their land. However, use of conservation tillage requires new equipment, new techniques, and greater use of herbicides to control weeds. Research to develop alternative methods of weed control for use with conservation tillage is under way. (Chapter 18 discusses *sustainable agriculture*, which includes conservation tillage and the other soil conservation practices presented in this chapter.)

CROP ROTATION

Farmers who practice effective soil conservation measures often use a combination of conservation tillage and **crop rotation**. When the same crop is grown continuously, pests for that crop tend to accumulate to destructive levels, so crop rotation lessens insect damage and disease. Many studies have shown that continuously growing the same crop for many years depletes the soil of certain essential nutrient minerals faster and makes the soil more prone to erosion. Crop rotation is therefore effective in maintaining soil fertility and in reducing soil erosion.

crop rotation The planting of a series of different crops in the same field over a period of years.

A typical crop rotation would be corn → soybeans → oats → alfalfa. Soybeans and alfalfa, both of which are members of the legume family, increase soil fertility through their association with bacteria that fix atmospheric nitrogen into the soil. Thus, soybeans and alfalfa provide nutrients for the grain crops they alternate with in crop rotation. Organic farmers often use crop rotations of seven or more crops in a cycle, further breaking pest cycles and reducing demand for the same arrays of crop nutrients.

CONTOUR PLOWING, STRIP CROPPING, AND TERRACING

Hilly terrain must be cultivated with care because it is more prone to soil erosion than flat land. Contour plowing, strip cropping, cover crops, and terracing help control erosion of farmland with variable topography.

contour plowing Plowing that matches the natural contour of the land.

strip cropping Crops laid out in alternating, narrow strips along natural contours, as on a hillside.

cover crop A crop which is planted primarily to protect soil from erosion after the harvest of one crop and before the next harvestable crop is planted.

In **contour plowing**, furrows run around hills rather than in straight rows. **Strip cropping**, a special type of contour plowing, produces alternating strips of different crops (**Figure 14.17a**). For example, alternating a row crop such as corn with a closely sown crop such as wheat reduces soil erosion. Even more effective control of soil erosion is achieved when strip cropping is done in conjunction with conservation tillage. **Cover crops** are grown between seasons of other crops (**Figure 14.17b**) and help protect soil during seasons when it would otherwise be bare of plants.

Farming is undesirable on steep slopes, but if it must be done, **terracing** produces level areas and thereby reduces soil erosion (**Figure 14.17c**). Nutrient minerals and soil are retained on the horizontal platforms instead of being washed away. Soils are preserved in a somewhat similar manner in low-lying areas that are diked to make rice paddies. The water forms a shallow pool, retaining sediments and nutrient minerals.

terracing A soil conservation measure that involves building dikes on hilly terrain to produce level areas for agriculture.

PRESERVING SOIL FERTILITY

The two main types of fertilizer are organic and commercial inorganic. *Organic fertilizers* include such natural materials as animal manure, crop residues, bone meal, and compost. Organic fertilizers are chemically complex, and their exact compositions vary. The nutrient minerals in organic fertilizers become available to plants only as the organic material decomposes. For that reason, organic fertilizers are slow-acting and long-lasting. (For a discussion of compost, see You Can Make a Difference: Composting and Mulching. Also see discussion of municipal solid waste composting in Chapter 23.)

Commercial inorganic fertilizers are manufactured from chemical compounds, and their exact compositions are known. Because they are soluble, they are immediately available to plants. However, commercial inorganic fertilizers are available in the soil for only a short period because they quickly leach away or may volatilize into the air. In sustainable soil management, use of manufactured fertilizers is avoided or limited. First, because of their high solubility, commercial inorganic fertilizers are mobile and often leach into groundwater or surface runoff, polluting the water. Second, manufactured fertilizers do not improve the water-holding capacity of the soil as organic fertilizers do. Another advantage of

Courtesy U.S. Department of Agriculture

(a) Strip cropping is evident on this farm. Crop rotation in such strips often include a legume, which contributes nitrogen to future crops. Photographed in Wisconsin.

Macduff Everton / Getty Images

(b) A vineyard in autumn, after the harvest. Napa Valley, California.

©Dennis Cox/Alamy

(c) Terracing hilly or mountainous areas, such as these rice fields in Guangxi, China, reduces the amount of soil erosion. However, some slopes are so steep that they are vulnerable to extensive erosion if not left covered by natural vegetation.

Figure 14.17 Strip cropping, terracing, and cover cropping. These techniques help control erosion on hilly terrain that is farmed.

YOU CAN MAKE A DIFFERENCE

Composting and Mulching

Gardeners often dispose of grass clippings, leaves, and other plant refuse by bagging it for garbage collection or burning it. But these materials are a valuable resource for making **compost**, a natural soil and humus mixture that improves both soil fertility and soil structure. Grass clippings, leaves, weeds, sawdust, coffee grounds, ashes from the fireplace or grill, shredded newspapers, potato peels, and eggshells are just some of the materials that can be composted, or transformed by microbial action into compost.

To make compost, spread a 15- to 30-cm (6- to 12-in.) layer of grass clippings, leaves, or other plant material in a shady area, sprinkle it with an organic garden fertilizer or a thin layer of farm animal manure, and cover it with several inches of soil. Continually add layers of more organic debris. Water the mixture thoroughly, and turn it over with a pitchfork each month to aerate it. Although it is possible to make compost on the open ground, an enclosure allows temperatures to build from the heat generated by microbial action. (Organic material decomposing efficiently in a compost heap has a really hot core.) An enclosed compost heap is also less likely to attract animals. The enclosure should allow some air flow and should allow water to drain out of the material.

When the compost is uniformly dark in color, is crumbly, and has a pleasant, "woodsy" odor, it is ready to use. The time it takes for decomposition will vary from one to six months, depending on the climate, the materials in the mixture, and how often it is turned and watered.

Whereas compost is mixed into soil to improve the soil's fertility, **mulch** is placed on the surface of soil, around the bases of plants (see the photograph). Mulch helps control weeds and increases the amount of water in the upper levels of the soil by reducing evaporation. It lowers the soil temperature in the summer and extends the growing season slightly by providing protection against cold in the fall. Mulch decreases soil erosion by lessening the amount of precipitation runoff.

Although mulches can consist of inorganic materials such as plastic sheets or gravel, organic mulches of compost, grass clippings, straw, chopped corncobs, or shredded bark have the added benefit of increasing the organic content of the soil. Grass clippings are an effective mulch in a lawn, where they slowly enhance lawn fertility. Some gardeners prefer mulches of more expensive materials, such as shredded bark, because they take longer to decompose and are more attractive.

Courtesy U.S. Department of Agriculture

Mulch. Mulch discourages the growth of weeds and helps keep the soil moist. Organic mulches such as this shredded bark have the added benefit of increasing soil fertility as they slowly decay.

organic fertilizers is that, in ways not completely understood, they change the types of organisms that live in the soil, sometimes suppressing microorganisms that cause certain plant diseases. Commercial inorganic fertilizers are a source of nitrogen-containing gases (nitrous and nitric oxides) that are air pollutants and greenhouse gases. Finally, the production of commercial inorganic fertilizers requires a great deal of energy, which is largely obtained from our declining reserves of fossil fuels.

SOIL RECLAMATION

Soil reclamation involves two steps: (1) stabilizing the land to prevent further erosion and (2) restoring the soil to its former fertility. The United States has largely reversed the effects of the 1930s Dust Bowl, and China has reclaimed badly eroded land in Inner Mongolia (northern China). To stabilize the land, the bare ground is seeded with plants that eventually grow to cover the soil, holding it in place. The plants start to improve the quality of the soil almost immediately, as dead portions are converted to humus. The humus holds nutrient minerals in place and releases them a little at a time; humus also improves the water-holding capacity of the soil.

One of the best ways to reduce the effects of wind on soil erosion is to plant **shelterbelts** to lessen the impact of wind (**Figure 14.18**). Restoration of soil fertility to its original level is a slow process. During soil recovery, use of the land must be restricted. Disaster is likely if the land is put back to agricultural use before the soil has completely recovered. But restriction of land use for a period of years is sometimes difficult to accomplish. Landowners often object to government dictates about how to manage their lands, and soil erosion in poorer regions of the world is often driven by farmers trying to produce enough food to satisfy basic needs.

shelterbelt A row of trees planted as a windbreak to reduce soil erosion of agricultural land.

AGROFORESTRY

Organizations such as the International Centre for Research in Agroforestry, established in Nairobi, Kenya, are developing techniques to lessen the environmental degradation of the Sahel and other tropical areas. One of their research aims is to use **agroforestry**—land use practices in

agroforestry Concurrent use of forestry and agricultural techniques on the same land area to improve degraded soil and offer economic benefits.

© David Wall/Alamy

Figure 14.18 Aerial view of shelterbelts surrounding row crops. Trees protect the soil from the wind, while also protecting the crops. Photographed in South Island, New Zealand.

which trees and crops are planted together to improve soil fertility in degraded soils.

For example, nitrogen-fixing acacias and other trees might be intercropped with traditional crops such as millet and sorghum. Other crops planted in agroforestry include shade coffee, cocoa, jatropha (a biofuel crop) and bananas. The trees grow for many years and provide several environmental benefits, such as reducing soil erosion, regulating the release of rainwater into groundwater and surface waters, and providing habitat for the natural enemies of crop pests. Acacia trees fix nitrogen, thereby improving soil fertility. When the leaves fall off the trees, they gradually decompose, returning mineral nutrients to the soil. The leaf layer also improves the soil's ability to hold moisture (less moisture evaporates from leaf-covered soil). Over time, the degraded land slowly improves. The result is higher crop yields. When the trees are so tall that they shade out the crops, the forest provides the farmers with food (such as fruits and nuts), fuelwood, lumber, and other forestry products.

SOIL CONSERVATION POLICIES IN THE UNITED STATES

During the late 1920s and early 1930s, **Hugh H. Bennett**, a soil scientist in the U.S. Department of Agriculture, spoke out about the dangers of soil erosion. A report he published in 1928 was largely ignored until the disastrous effects of the Dust Bowl years focused attention on soil as a valuable natural resource. The **Soil Conservation Act** of 1935 authorized the formation of the Soil Conservation Service (now called the Natural Resources Conservation Service, or NRCS); its mission is to work with U.S. citizens to conserve natural resources on private lands. To that end, the NRCS assesses soil damage and develops policies to improve and sustain soil resources.

The **Food Security Act (Farm Bill)** of 1985 contained provisions for two main soil conservation programs: a conservation compliance program and the Conservation Reserve Program. The conservation compliance program requires farmers with highly erodible land to develop and adopt a five-year conservation plan for their farms that includes erosion-control measures. If they don't comply, they lose federal agricultural subsidies such as price supports.

The **Conservation Reserve Program (CRP)** is a voluntary subsidy program that pays farmers to stop producing crops on highly erodible farmland. It requires planting native grasses or trees on such land and then "retiring" it from further use for 10 to 15 years. During that period the land may not be grazed, nor may the grass be harvested for hay. The CRP has benefited the environment. Since its inception in 1985, annual loss of soil on CRP lands planted with grasses or trees has been reduced from an average of 7.7 metric tons of soil per hectare (8.5 tons per acre) to 0.6 metric ton per hectare (0.7 ton per acre). Because the vegetation is not disturbed once it is established, it provides wildlife habitat. Small and large mammals, birds of prey, and ground-nesting birds such as ducks have increased in number and kind on CRP lands. The reduction in soil erosion has improved water quality and enhanced fish populations in surrounding rivers and streams.

The future of the Conservation Reserve Program is unclear. Historically, farmers are more likely to practice soil conservation during hard financial times and periods of agricultural surpluses, both of which translate into lower prices for agricultural products. When prices are high, with a good market for agricultural products, farmers have more incentive to put every parcel of land into production, including marginal, highly erodible lands. Because food prices have risen in recent years, and federal mandates support converting corn crops into ethanol fuel, some farmers are beginning to grow crops on former CRP lands.

REVIEW

1. What is crop rotation? Strip cropping?
2. How can degraded soils be reclaimed? What is the Conservation Reserve Program?

REVIEW OF LEARNING OBJECTIVES WITH SELECTED KEY TERMS

- **Define *soil* and identify the state factors involved in formation of the soil system.**

Soil is the uppermost layer of Earth's crust, which supports terrestrial plants, animals, and microorganisms. Soil formation involves interactions among five main **state factors**: parent material, climate, topography, organisms, and time. Biological, chemical, and physical **weathering processes** slowly break parent material into smaller and smaller particles.

- **List the four components of the soil system and explain the ecological significance of each.**

The soil system is composed of inorganic nutrient minerals, organic materials, soil air, and soil water. The inorganic portion, which comes from weathered parent material, provides anchorage and essential nutrient minerals for plants as well as pore space for water and air. Organic material decomposes, releasing essential nutrient mineral ions into the soil, where they may be absorbed by plant roots. **Soil air** and **soil water** produce a moist but aerated soil that sustains plants and other soil-dwelling organisms.

- **Describe the various soil horizons.**

Soil horizons are the horizontal layers into which many soils are organized, from the surface to the underlying parent material. The uppermost layer of soil, the **O-horizon**, contains plant litter that gradually decays. Just beneath the O-horizon is the topsoil, or **A-horizon**. In some soils, a heavily leached **E-horizon** develops between the A- and B-horizons. The **B-horizon** beneath the A-horizon is often a zone of **illuviation** in which nutrient minerals that leached out of the topsoil and litter accumulate. Beneath the B-horizon is the **C-horizon**, which contains weathered pieces of rock and borders the unweathered solid parent material.

- **Name at least two ecosystem services performed by soil organisms and briefly discuss nutrient cycling.**

Soil organisms are important in two **ecosystem services**: forming soil and cycling nutrient minerals. **Nutrient cycling** is the pathway of various nutrient minerals or elements from the environment through organisms and back to the environment. In nutrient cycling the nutrient minerals removed from the soil by plants are returned when plants and animals die and are decomposed by soil microorganisms.

- **Briefly describe soil texture and soil acidity.**

The **texture** of a soil refers to the relative proportions of **sand**, **silt**, and **clay**. The pH of most soils ranges from 4 (acidic) to 8 (slightly alkaline), but some soils are outside this range. The soil properties of texture and acidity affect a soil's water-holding capacity and nutrient availability, which, in turn, determine how well plants grow.

- **Distinguish among spodosols, alfisols, mollisols, aridisols, and oxisols.**

Regions with colder climates, ample precipitation, and good drainage typically have **spodosols** with distinct layers. Temperate deciduous forests grow on **alfisols**, soils with a brown to gray-brown A-horizon. **Mollisols**, found primarily in temperate, semiarid grasslands, are fertile. **Aridisols** are found in arid regions of all continents. **Oxisols** are low in nutrient minerals and exist in tropical and subtropical areas with ample precipitation.

- **Define *sustainable soil use*.**

Sustainable soil use is the wise use of soil resources, without a reduction in soil fertility, so that the soil remains productive for future generations.

- **Explain the impacts of soil erosion, mineral depletion, soil salinization, and desertification on plant growth.**

Soil erosion is the wearing away or removal of soil from the land. Mineral depletion occurs in all soils that are farmed. **Salinization** is the gradual accumulation of salt in a soil, often as a result of improper irrigation methods. **Desertification** is degradation of once-fertile rangeland, agricultural land, or tropical dry forest into nonproductive desert. Soil erosion, mineral depletion, salinization, and desertification limit the growth of plants.

- **Describe the American Dust Bowl and explain how a combination of natural and human-induced factors caused this disaster.**

The 1930s Dust Bowl in the western United States is an example of accelerated wind erosion caused by use of marginal land for agriculture. Much of the native grasses were removed to plant wheat. Then, for several years the semiarid lands received less annual precipitation than was normal. The prolonged drought caused crop failures. Winds from the west swept across the barren, exposed soil, causing dust storms.

- **Summarize how conservation tillage, crop rotation, contour plowing, strip cropping, cover crops, terracing, shelterbelts, and agroforestry minimize erosion and mineral depletion of the soil.**

Conservation tillage is a method of cultivation in which residues from previous crops are left in the soil, partially covering it and helping to hold it in place until the newly planted seeds are established. **Crop rotation** is the planting of a series of different crops in the same field over a period of years, thereby maintaining soil fertility. **Contour plowing** reduces soil erosion because it matches the natural contour of the land. In **strip cropping**, a type of contour plowing, different crops are laid out in alternating, narrow strips along natural contours, as on a hillside. **Cover crops** are grown between seasons of other crops and help protect soil during seasons when it would otherwise be bare of plants. **Terracing** is a soil conservation measure for hilly terrain, in which dikes are built to produce level areas for agriculture. A **shelterbelt** is a row of trees planted as a windbreak to reduce soil erosion of agricultural lands. **Agroforestry** is the use of both forestry and agricultural techniques to improve degraded areas and offer economic benefits.

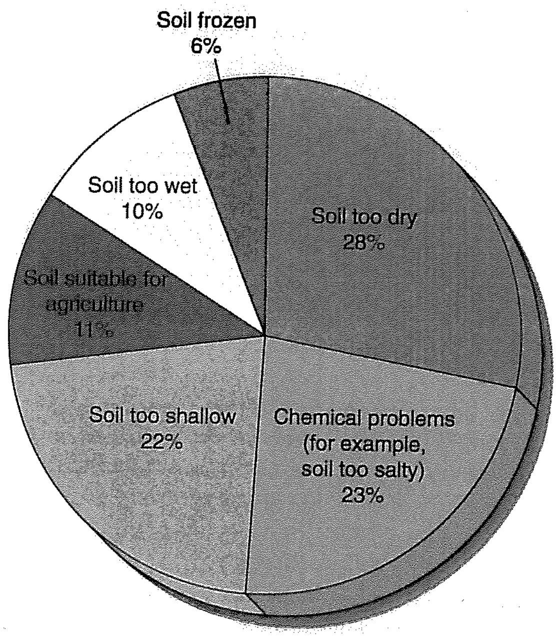
- **Briefly describe the Conservation Reserve Program.**

The **Conservation Reserve Program**, which is voluntary, pays farmers to stop producing crops on highly erodible farmland.

Critical Thinking and Review Questions

1. Why do we consider soil to be a system?
2. Explain the roles of weathering, organisms, climate, and topography in soil formation.
3. What are the four distinct parts of the soil system?
4. Which soil horizons are most prone to erosion? How might your answer be significant to farmers?
5. How do organisms contribute to nutrient cycling in the soil system?
6. How does the presence of various-sized particles (sand, silt, and clay) affect soil characteristics?
7. Give an example of how plants affect soil pH. Give an example of how soil pH affects plants.
8. Which two of these soil orders are best suited for agriculture: spodosol, alfisol, mollisol, aridisol, and oxisol? Why?

9. The pie chart shows an overview of the world's total land area with respect to its suitability for agriculture. How could soil that is too dry for agriculture be converted to cropland? How could soil that is too wet for agriculture be converted to cropland? Explain why each of the remaining categories in the pie chart cannot be converted to agricultural land.



One Planet, Many People: Atlas of Our Changing Environment. UN Environment Programme, 2005.

10. How does sustainable soil use protect the agricultural soil system?
11. Describe two ways in which nutrient minerals are lost from the soil.
12. Where does eroded soil go after it is transported by water, wind, or ice?
13. How is human overpopulation related to world soil problems?
14. The American Dust Bowl is sometimes portrayed as a "natural" disaster brought on by drought and high winds. Present a case for the view that this disaster was not caused by nature as much as by humans.
15. Distinguish among conservation tillage, crop rotation, contour plowing, strip cropping, terracing, shelterbelts, and agroforestry as methods of sustainable soil use.
16. President Franklin D. Roosevelt once sent a letter to the state governors in which he said, "A nation that destroys its soils, destroys itself." Would he have supported the Conservation Reserve Program? Explain your answer.
17. Does conversion of undisturbed land to farmland impact the global carbon cycle and climate change? Explain your answer.

Food for Thought

Philosophy and science both inform the process of biodynamic farming, a system invented by Rudolf Steiner. Orchards, vineyards, gardens, crops, and livestock can all be grown in a biodynamic system. Soil nutrition is a key part of biodynamic management.

Biodynamic farming aims to replicate natural ecosystems as closely as possible, using specific plants as organic fertilizers and fermenting the plants in combination with animal products. Where is the nearest biodynamic farm in your area? What kinds of products are grown there?