Chapter 15

Optimizing Food Production

THE MAIN IDEA

Agriculture employs much chemistry.

15.3 Soil Fertility

Soil is a mixture of sand, silt, and clay. All three of these components are ground-up rock; the differences are in how finely the particles are ground. Sand particles are the largest, and clay particles are the smallest.

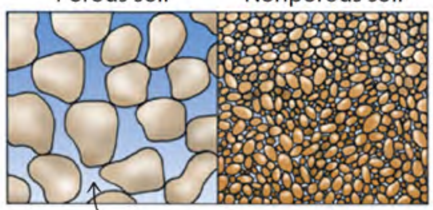
Soil often occurs as a series of horizontal layers called **soil horizons**, shown in **Figure 15.7**. The deepest horizon, which lies just above solid rock, is the *substratum*, which is rock just beginning to be disintegrated into soil by the action of water that has seeped down to this level. No growing plant material is found in the substratum. Above the substratum is the subsoil, which consists mostly of clay. Only the deepest roots penetrate into the subsoil, which may be up to 1 meter thick. Above the subsoil is the *topsoil*, which lies on the surface and varies in thickness from a few centimeters to 2 meters. The topsoil usually contains sand, silt, and clay in about equal amounts. This is the horizon where the roots of plants absorb most of their nutrients.

Fertile topsoil is a mixture of at least four components—mineral particles, water, air, and organic matter. The mineral particles are the particles of sand, silt, and clay. Many of the nutrients that plants need are released

READING CHECK

Fertile topsoil is a mixture of what four components?

Figure 15.7
The vertical structure of soil is a series of layers called soil horizons.



Λ Figure 15.8

Large soil particles create larger pockets of space than do smaller soil particles.

as these particles are formed from the erosion of rock. The size of the particles greatly affects soil fertility. Large particles result in porous soil that has many pockets of space that collect water and air—up to 25 percent of the volume of fertile topsoil consists of pockets. Roots absorb water and the oxygen from the air in these pockets. Small particles pack tightly together so that no or only very few air pockets are present, and as a result, little or no oxygen or water is available to roots. This is why plants do not grow well in clay soils. **Figure 15.8** compares these two extremes of soil.

The organic matter in topsoil is a mixture of fallen plant material, the remains of dead animals, and such decomposers as bacteria and fungi, as **Figure 15.9** illustrates. This organic matter is called **humus**, and it is rich in a variety of plant nutrients. Humus tends to be porous, giving roots access to subterranean water and oxygen. It also binds the soil, helping to prevent erosion.

The flow of water through soil is called *percolation*. The more porous the soil, the greater the rate of percolation. With excessive percolation, flowing water removes many water-soluble nutrients needed to make the soil productive. This process is known as *leaching*. With too little percolation, topsoil becomes waterlogged, choking off a plant's supply of oxygen. Soils with optimal percolation drain water from all but the smallest air pockets.

Soil Readily Retains Positively Charged Ions

Mineral particles play an important role in keeping nutrients in soil. As Table 15.1 shows, many plant nutrients are positively charged ions. The surfaces of most mineral particles, however, are negatively charged. **Figure 15.10** illustrates how the resulting ionic attractions help keep nutrients from being washed away. The degree of nutrient retention is most pronounced in clay soils, because its mineral particles are the smallest and thus have the largest surface area relative to volume.

Decaying matter in humus contains many carboxylic acid and phenolic groups, which at a typical soil pH are ionized to negatively charged carboxylate and phenolate ions. So, like mineral particles, humus helps retain positively charged nutrients.

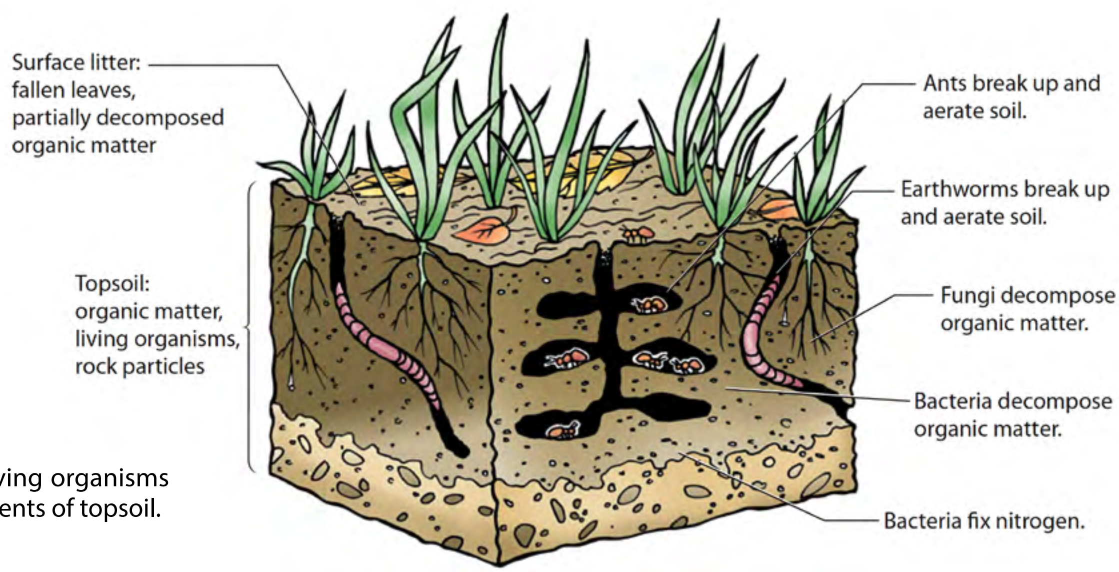
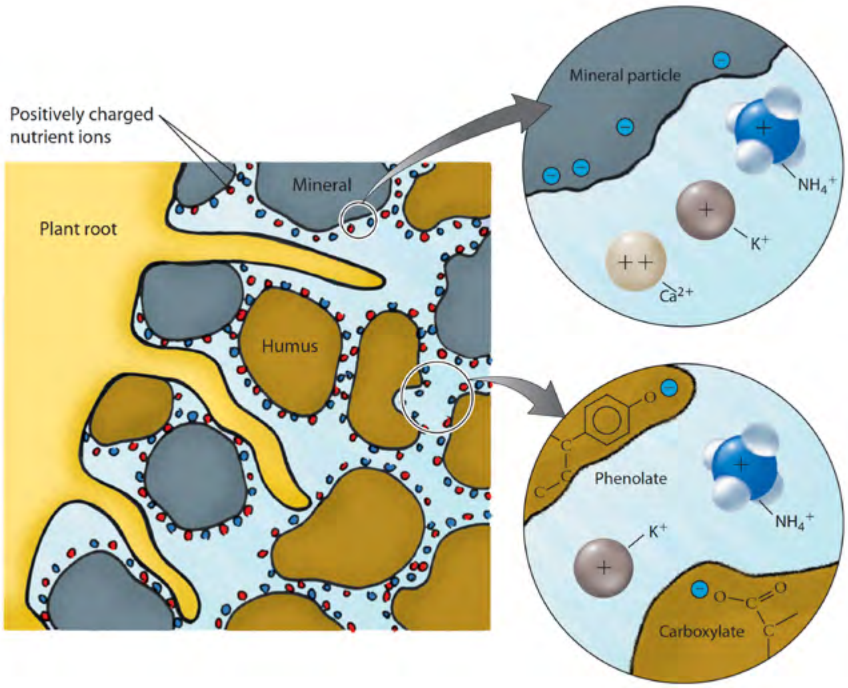


Figure 15.9 >

Organic matter and living organisms are important components of topsoil.



< Figure 15.10

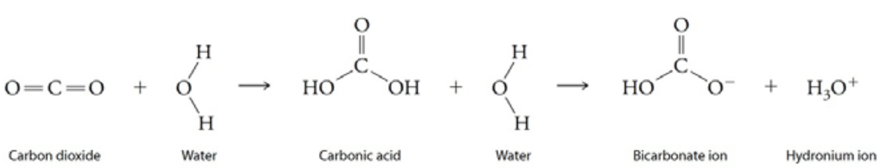
The negatively charged surfaces of soil mineral particles and humus help retain positively charged nutrient ions.

CONCEPT **CHECK**

Soil is able to retain ammonium ions, NH_4^+, better than nitrate ions, NO_3^-. Why?

CHECK YOUR ANSWER Mineral particles and bits of humus in soil are negatively charged and therefore hold on to positively charged ammonium ions but repel negatively charged nitrate ions.

The pH of soil is largely a function of the amount of carbon dioxide present. Recall from Section 10.5 that carbon dioxide reacts with water to form carbonic acid, which in turn forms hydronium ions:



The greater the amount of carbon dioxide in soil, the more hydronium ions, and so the lower the pH. Soil that has a low pH is referred to as sour. (Recall from Chapter 10 that many acidic foods, such as lemons, are characteristically sour.) Two main sources of soil carbon dioxide are humus and plant roots. The humus releases carbon dioxide as it decays, and plant roots release carbon dioxide as a product of cellular respiration. A healthy soil may have enough carbon dioxide released from these processes to give a pH range from about 4 to 7. If the soil becomes too acidic, a weak base, such as calcium carbonate (known as lime or limestone), can be added.

Hydronium ions are able to displace nutrient ions held to mineral particles and humus. Plants use this fact to great advantage. **Figure 15.11** illustrates how a plant releases carbon dioxide through its root system and in doing so generates nutrient-displacing hydronium ions. The displaced nutrients, no longer attached to soil particles, thus become available to the plant.

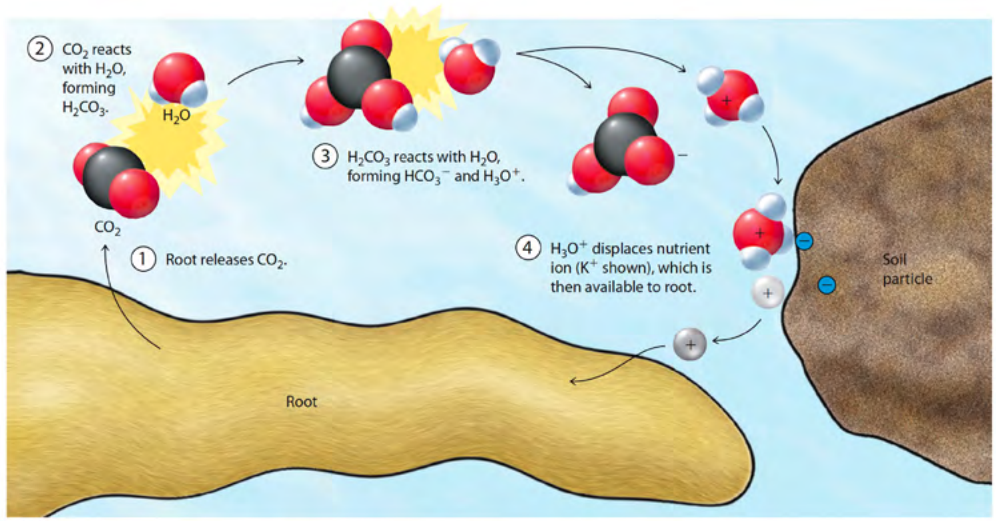


Figure 15.11 >

By releasing carbon dioxide, a plant guarantees a steady flow of nutrients from the soil to its roots.

CONCEPT **CHECK**

How might a below-normal pH in soil lead to nutrient deficiencies in plants?

CHECK YOUR ANSWER When the soil pH is below normal, the water in the soil pockets contains an abundance of hydronium ions, which displace large numbers of nutrient ions from soil and humus particles. Most of these nutrients wash away before the plant is able to absorb them. In a short time, the soils are depleted of nutrients and the plants become nutrient-deficient