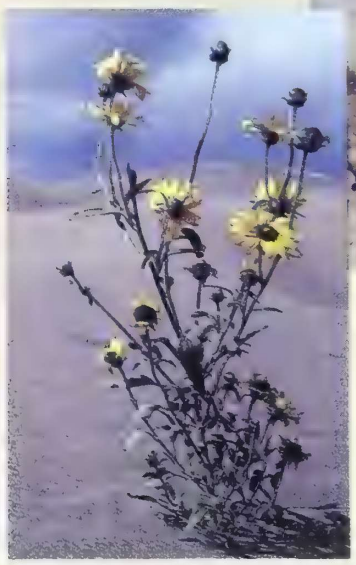
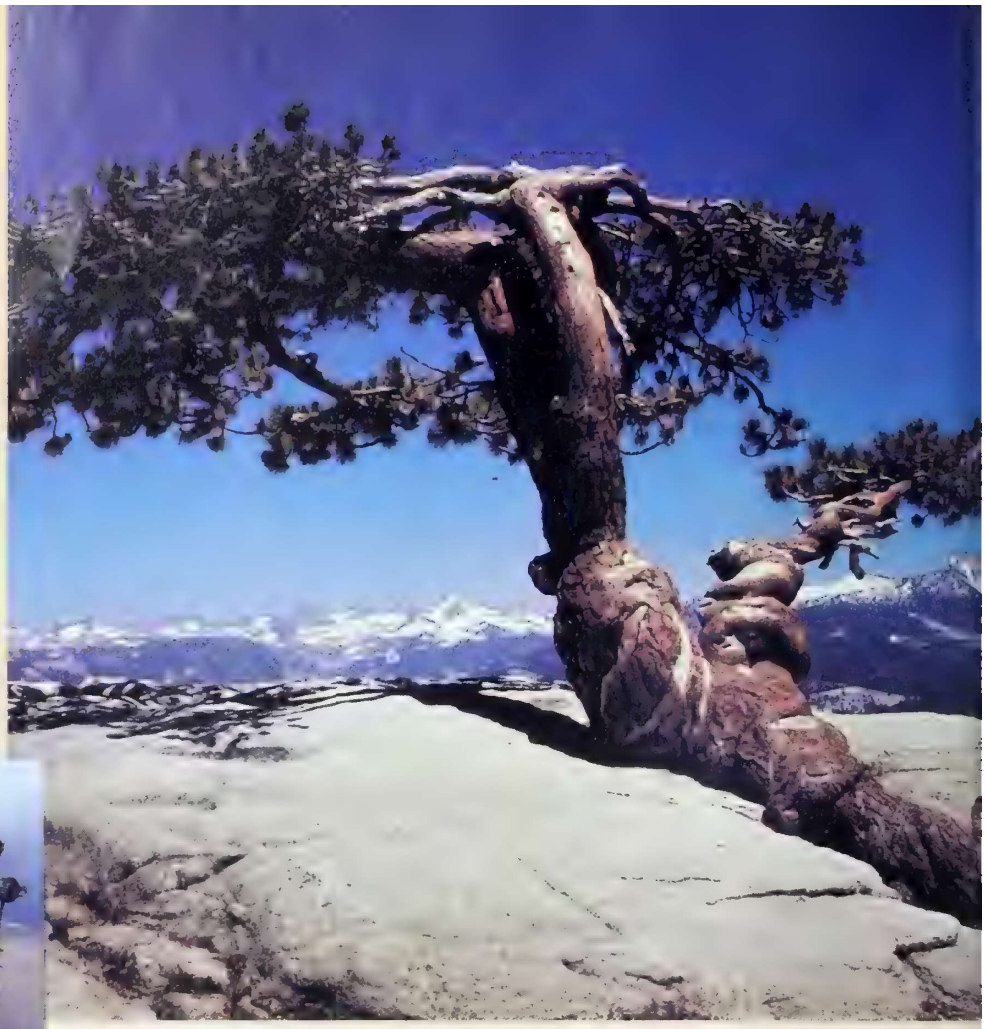
CHAPTER 23

Roots, Stems, and Leaves





Growing through a crack in the top of a mountain, this pine tree demonstrates the ability of plants to grow under adverse conditions. The sunflower, too, growing in the ever-moving desert sands, shows the same tenacity.

On a mountain ridge, the twisted roots of an ancient pine tree cling to solid rock in subzero temperatures. In a desert, a sagebrush plant survives in the blazing sun for months without rain. On a dune by the seashore, a clump of beach grass flowers in poor, salty sand. And in the Everglades, mangrove trees live with their roots submerged in rich, organic mud.

These plants have adaptations that enable them to live under difficult conditions. How do these plants obtain the water and nutrients they need to survive in their harsh surroundings? For that matter, how does any plant extract what it needs from soil and air? The answers to these questions will become clear in this chapter.

CHAPTER OUTLINE

23–1 Soil: A Storehouse for Water and Nutrients
- Types of Soil
- Soil Profiles
- Essential Nutrients

23–2 Specialized Tissues in Plants
- Meristematic Tissue
- Surface Tissue
- Parenchyma
- Sclerenchyma
- Vascular Tissue

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- Root Tissues
- The Epidermis: Uptake of Water and Nutrients
- The Cortex: Transport of Water and Nutrients
- The Endodermis: One-Way Passage
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- Salt-Tolerant Plants
- Climbing Plants
- Plants That Eat Animals

23–1 Soil: A Storehouse for Water and Nutrients

Section Objectives

- Discuss the importance of soil for plant growth.
- Describe the composition of soil.
- List the nutrients essential for plant growth.

Seed plants are autotrophs; they make the organic molecules they need from raw materials such as water, carbon dioxide, and several inorganic nutrients. Where do they get these raw materials? Carbon dioxide is removed from the air by the leaves. Water and inorganic nutrients are taken in from the soil by plant roots. Soil is a "bank" of nutrients plants use to grow.

Types of Soil

An understanding of soil will help explain how plants function. What exactly is soil? **Soil is a complex mixture of sand, silt, clay, and bits of decaying animal and plant tissue.** Soil in different places and at different depths contains varying amounts of these ingredients. The ingredients define the soil and determine, to a large extent, the kinds of plants that can grow in it.

Sandy soil is composed mostly of sand grains. Because sand grains are large and irregularly shaped, there are large empty spaces between them. That's why water poured on sand drains through it so quickly.

Clay soil is composed mostly of very fine clay particles that have extremely small spaces between them. Horticulturists—professional growers of plants—use the word heavy to describe soil that contains large amounts of clay particles. Water poured on clay soil sinks in slowly.

Figure 23–1 *Wildflowers grow well in the dappled forest shade. The soil beneath the trees contains decaying leaves and other organic materials that are used by plants as natural fertilizer.*



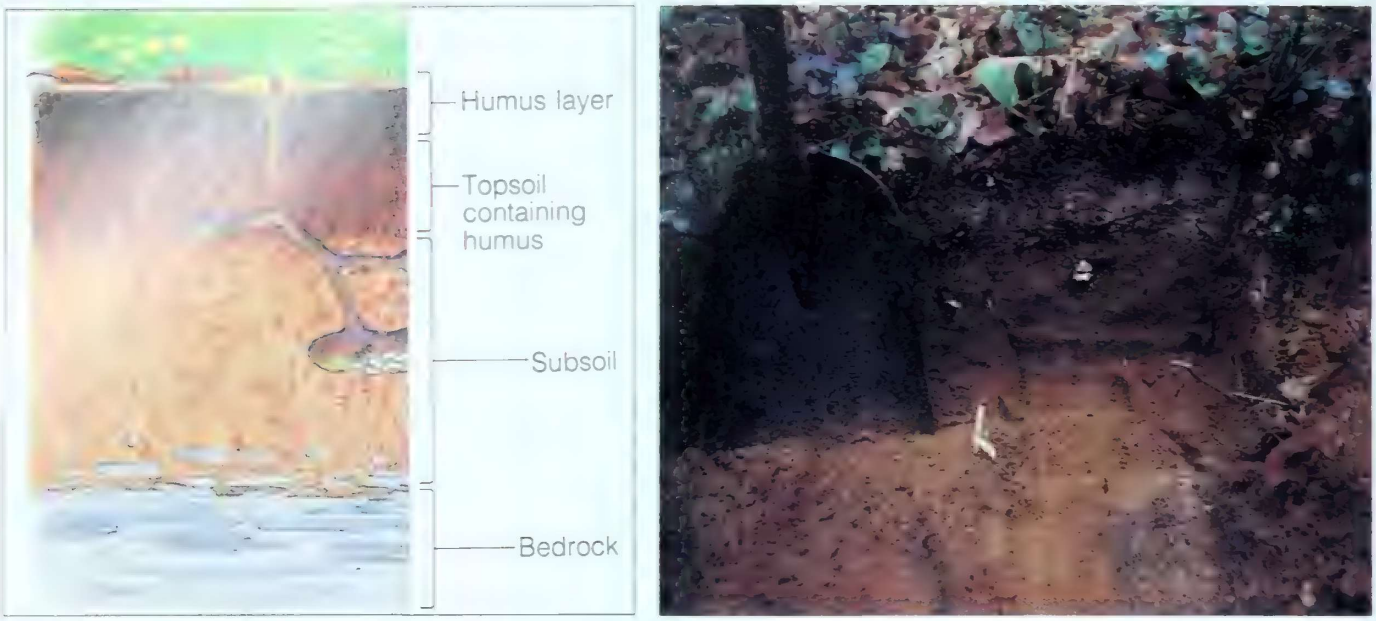


Figure 23–2 *Soil is composed of layers of materials such as humus, sand, clay, minerals, and rocks. The topmost layer is usually richest in organic material. Together the layers make up the soil profile.*

Loamy soil contains decaying organic matter formed from plant and animal tissue, in addition to particles of sand and clay. Particles of organic matter are usually larger than sand or clay particles. Organic matter helps increase the soil's ability to hold air and water. Nitrogen, phosphorus, and other nutrients that can be used by plants are released from the soil as the organic matter is broken down by fungi and bacteria.

Soil Profiles

If you cut a trench in the ground, you will see that the soil is arranged in layers, with each layer corresponding to a different kind of soil. The particular order of layers is called a soil profile. See Figure 23–2. Most organic matter is on top, where it forms the humus layer. The humus layer in forest soil can be several centimeters thick. In grasslands, however, the humus layer may be much thinner.

Under the humus layer is the topsoil, which is a mixture of humus, sand, clay, and minerals. The thickness of topsoil varies with the location. Topsoil in the fertile plains of the Midwest is often a meter thick, whereas in northeastern forests it may be only a few centimeters deep. Plant roots grow best in the humus and topsoil layers.

Beneath the topsoil is the subsoil, a mixture of rocks and inorganic soil particles often tightly packed together. Subsoil offers little room for air, water, and plant roots. Beneath the subsoil is bedrock, a layer of rock that usually cannot be penetrated by plant roots.

Almost half the total volume of good garden soil actually consists of open spaces between soil particles. These open spaces are important for several reasons. They are home to beneficial bacteria, fungi, and protozoa that help plants grow.

The tiny pockets of water and air are essential to the good health of plant roots and soil microorganisms. Air pockets allow roots to breathe. Water pockets are vital because nutrients are available to plants only when they are dissolved in water. Finally, roots do not actually grow "in" soil. Roots really grow into and through the spaces between soil particles. If there are not enough spaces, roots cannot grow properly.

Essential Nutrients

To grow, flower, and produce seeds, plants require a variety of inorganic nutrients in addition to carbon dioxide and water. These inorganic nutrients are located in the soil. And it is from the soil's bank of nutrients that plants withdraw their needs. The most important of these nutrients are nitrogen, phosphorus, potassium, calcium, magnesium, and various trace elements.

Nitrogen is essential for proper leaf growth and color. A lack of nitrogen will stunt plant growth and cause the foliage to turn a sickly yellow color.

Phosphorus is used to make DNA in all cells and is important in the development of roots, stems, flowers, and seeds. Too little phosphorus causes poor flowering and stunted growth.

Potassium (sometimes called potash) plays a critical role in the making of proteins and carbohydrates by plants. Potassium also plays a role in the development of roots, stems, and flowers, and helps plants resist cold and disease. The first sign of a potassium deficiency is usually stunted roots, which soon result in stunted leaves.

Calcium is used in cell metabolism and is necessary for cell growth and division and cell wall strength.

Magnesium is a critical part of the chlorophyll molecule. A lack of magnesium will prevent the manufacture of chlorophyll and may eventually kill the plant.

Trace elements, which plants require in small quantities, include sulfur, iron, zinc, molybdenum, boron, copper, manganese, and chlorine. To maintain proper plant growth, trace elements are needed in very small amounts. In fact, large amounts of trace elements in the soil can be poisonous.



Figure 23–3 *Plants need minerals from the soil in order to grow well. The rhododendron in the top photograph shows the effects of iron deficiency. The rhododendron in the bottom photograph received a good supply of needed minerals. What differences can you observe between the two plants?*

23–1 SECTION REVIEW

1. What is soil? Why is soil important for plant growth?
2. Why are the spaces between soil particles important?
3. What are some of the essential nutrients found in soil? Why is each important for plants?
4. Which type of soil is best for plant growth? Explain your answer.

Small Friends

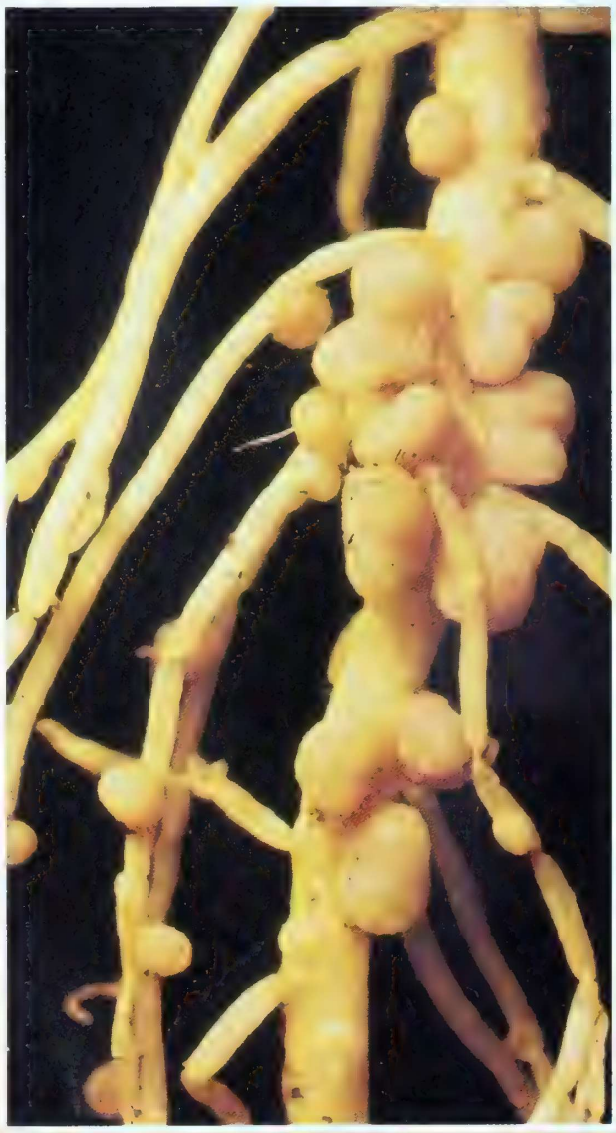
In our daily struggle to live a healthy life, we tend to view all microorganisms as harmful. Microorganisms are the cause of many human and plant diseases. That is a fact. However, many of the microorganisms we rightly view with alarm have relatives that make important contributions to human and plant life. The benefits of microorganisms to humans are discussed elsewhere in this textbook. Here you will read about the benefits to plants.

You know that plants need to take in vital minerals and other inorganic compounds from the soil. These compounds are so important that farmers often spend millions of dollars to add them, in the form of fertilizers, to their soils. However, some plants carry their own "fertilizer factories" right on their roots. The factories are actually hard-working bacteria. The bacteria, many from the genus *Rhizobium*, are able to take nitrogen from the air and convert it into a form that plants can use. (You may remember that nitrogen makes up most of the air we breathe.) In this way the bacteria "fertilize" the plants on which they live. Farmers have found that these bacteria commonly grow on legumes such as peas and beans. Unlike most crop plants, which deplete, or use up, the minerals in the soil, legumes actually improve the soil in which they grow.

Other plants grow well only when they have a fungus infecting their roots. This may seem strange, but the fungus is able to improve the plant's ability to absorb important minerals from the soil. The association of plant roots and fungi is called mycorrhizae. This word comes from two Greek words that mean fungus and root. Pines, orchids, blueberries, and rhododendrons are but a few of the plants that form mycorrhizae. In fact, these plants do not grow well without the fungi!

These are only two of the benefits accrued to plants from microorganisms. Scientists are currently working to improve plant growth by exploiting these unseen relationships. In the future they may be able to harness these tiny microscopic farmers that live in soil.

Bacteria that live in these nodules on the root of a pea plant are able to change atmospheric nitrogen into a form that can be used by plants.



23–2 Specialized Tissues in Plants

Section Objectives

- Describe the importance of meristematic tissue in plants.
- Explain the important functions of different kinds of plant tissues.

Seed plants have several different kinds of tissue, each of which is specialized to perform different tasks. This specialization allows each tissue to perform efficiently. Later in this chapter when we examine the structure of roots, stems, and leaves, you will see how the tissues in plants are exquisitely adapted to perform different functions.

Meristematic Tissue

Mature plant cells can grow in length, and they can also expand to store water or food. But most mature plant cells do not divide to form new cells. Yet plants do grow—which means new cells must be formed.

Meristematic (mer-uh-stuh-MAT-ihk) **tissue** is the only plant tissue that produces new cells by mitosis. Meristematic cells divide rapidly and have thin cell walls. At first, all cells produced in meristematic tissue look alike. As meristematic cells mature, however, they differentiate into tissues of various kinds.

Meristematic tissue is found in several places. At the end, or tip, of each growing stem and root is an **apical meristem**. Apical meristems enable stems and roots to grow in length. In fact, plants have what is known as an open type of growth. They continue to grow from their tips as long as they live. For example, trees increase their height above ground and the length of their roots below ground for the duration of their lives. This is in contrast to humans and animals, who reach a certain size and then cease to grow (in height, not necessarily in width).

Two other kinds of meristematic tissue—**cork cambium** and **vascular cambium**—allow stems and roots to branch as well as to grow thicker. Cork cambium produces the outer covering of stems. Vascular cambium produces vascular tissues and increases the thickness of stems over time. Another kind of cambium, the **pericycle**, is found in roots. The pericycle enables roots to grow thicker and makes it possible for roots to branch.

Surface Tissue

Epidermal (the prefix *epi-* means on or on the outside of; *dermal* means of the skin) tissues form the outer, or surface, layers of leaves, stems, and roots. Some epidermal tissues, like the cork tissue in tree bark, protect plants from water loss. The epidermal tissue of roots, on the other hand, helps in the absorption of water.

Figure 23–4 *Plants are made up of relatively few kinds of tissue. New cells are formed in meristematic tissue found at the tips of both the stem and the roots.*

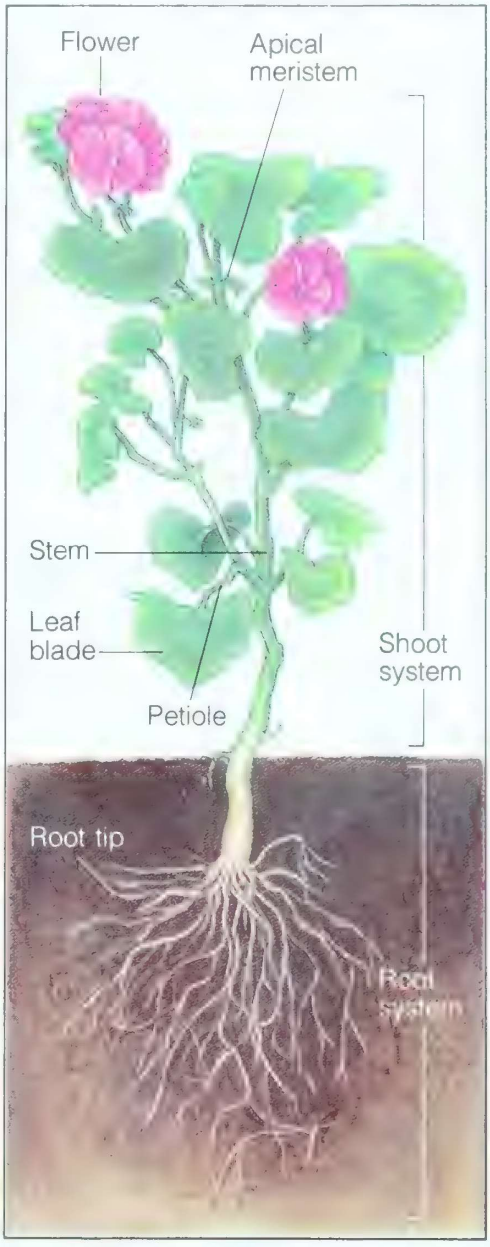




Figure 23–5 *The growing tip of a flax plant in this photomicrograph shows newly dividing cells in the dome-shaped cluster of cells near the top of the stem (left). Over the cluster of cells, forming an arch that resembles two arms held overhead, are two young leaves. Actively dividing cells are also found in roots, as this photomicrograph of a branch root being formed in the root of a willow tree shows (right).*

Parenchyma

Parenchyma (puh-REHNG-kih-muh) tissue is composed of thin-walled cells found in leaves, stems, and roots. These cells often have large central vacuoles surrounded by a thin layer of cytoplasm. Most of the plant roots we eat—such as potatoes and radishes—are composed primarily of parenchyma cells. Certain parenchyma cells in leaves and stems contain chlorophyll. It is in these cells that most photosynthesis takes place. Some parenchyma cells use vacuoles to store the products of photosynthesis.

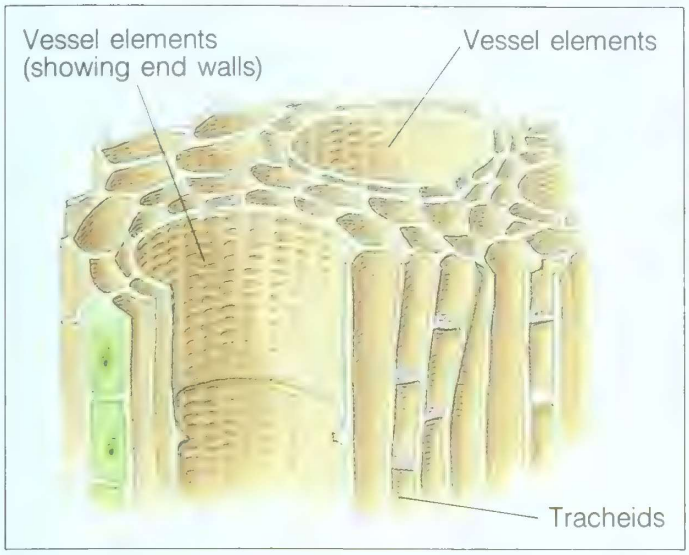
Sclerenchyma

Sclerenchyma (sklih-REHNG-kih-muh) cells have tough, thick cell walls that strengthen and support plant tissues. Some sclerenchyma cells are star-shaped and are scattered throughout parenchyma tissue. Other sclerenchyma cells grow into long, narrow fibers. Linen, a fine cloth, is made from the sclerenchyma fibers of the flax plant.

Vascular Tissue

Xylem tissue conducts water. All seed plants have a type of xylem cell called a **tracheid**. Tracheids are long, narrow cells with walls that are impermeable to water. These walls, however, are pierced by openings that connect neighboring cells to one another. When tracheids mature, they die, and their cytoplasm disintegrates. This leaves a network of hollow connected cells through which water can pass. See Figure 23–6.

Angiosperms have yet another kind of xylem cell called a **vessel element**. Vessel elements are much wider than tracheids, but like tracheids, they mature and die before they



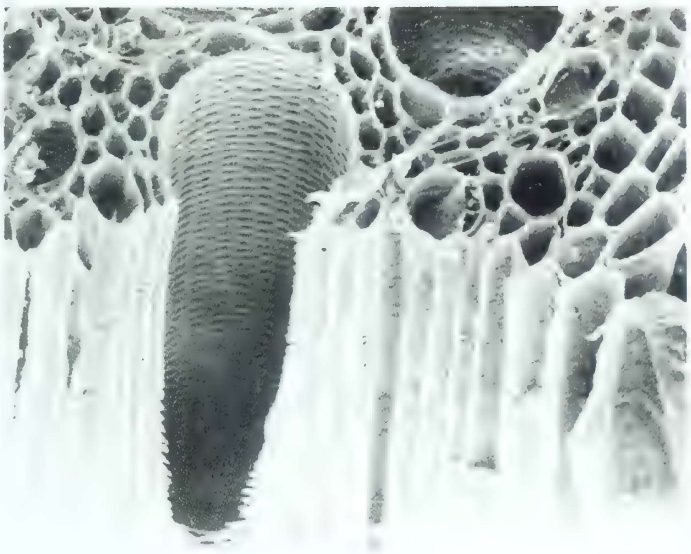


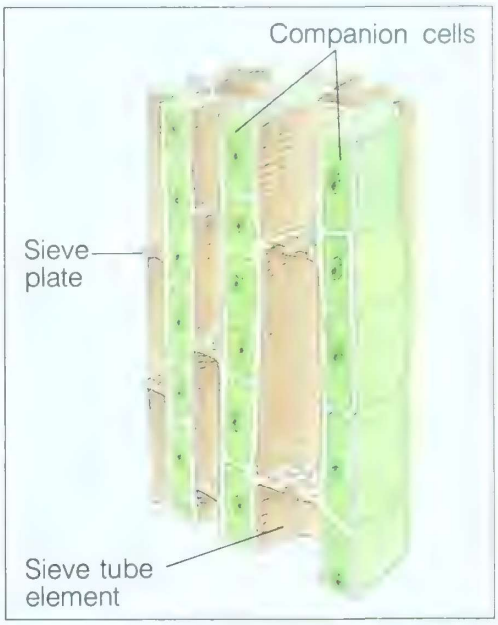
Figure 23–6 *In vascular plants, xylem tissue conducts water from roots to the rest of the plant. The photomicrograph shows the hollow dead cells that make up xylem tissue.*

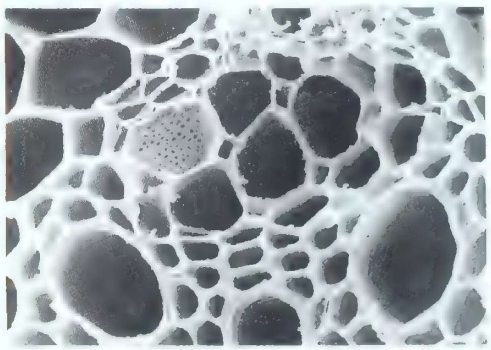
conduct water. Vessel elements are arranged end to end on top of one another like a stack of tin cans. The cell walls at both ends are lost when the cells die. At that time, the stacked vessel elements become continuous tubes through which water can move freely.

Phloem tissue conducts a variety of plant products. The main phloem cells are the **sieve tube elements**. These cells are arranged end to end, like the vessel elements, to form sieve tubes. The end walls of sieve tube elements have many small holes in them. Materials can move from one adjacent cell to another through these holes. As sieve tube elements mature, they lose their nuclei and most of the other organelles in their cytoplasm. The remaining organelles hug the inside of the cell wall. The rest of the cytoplasm can be moved from cell to cell to carry substances around in the plant.

Companion cells are phloem cells that surround sieve tube elements. Companion cells keep their nuclei and other organelles throughout their lifetime. Companion cells are believed to control the activity of the sieve tube elements.

Figure 23–7 *Phloem tissue conducts a variety of materials, mostly carbohydrates, throughout a plant.*





23–2 SECTION REVIEW

1. What is meristematic tissue? Why is it important?
2. What is the function of parenchyma tissue? Sclerenchyma tissue?
3. What is the function of vascular tissue? What are the two types of vascular tissue?
4. What is the most important type of phloem cell? Why?

Section Objectives

- Describe the structure and function of plant roots.
- Relate the structure of plant roots to the movement of water and minerals.

23–3 Roots

As soon as a seedling begins to grow, it puts out its first root: the primary root. Other roots, called secondary roots, branch out from this primary root. See Figure 23–8. When the root first begins to grow, it resembles all other plant roots. Later in its development, the pattern of growth changes.

Taproots and Fibrous Roots

In some plants the primary root grows longer and thicker, whereas secondary roots remain small. This type of primary root is called a **taproot**. Taproots of oak and hickory trees grow so long that they can reach water far below the earth's surface. Carrots, dandelions, beets, and radishes have short, thick taproots that store sugars or starches. Taproots make it extremely difficult to remove certain plants from a lawn. For example, if you pull on the green leaves of a dandelion, it breaks off above the root. The taproot that remains in the ground can grow new leaves. Sometimes even a small piece of a taproot can produce a new plant.

In plants in which taproots do not form, secondary roots grow and branch. In these plants no single root grows larger than the rest. Such plants, of which grasses are an example, are said to have **fibrous roots**. The fibrous root system of a single rye plant—a plant in the grass family—can have as many as 14 million secondary roots. If these roots were laid end to end in a single line, they would have a total length of over 600 kilometers—much longer than the distance from New York City to Washington, D.C.! The extensive root systems produced by some plants are extremely important in holding topsoil so that it does not get washed away by rains.





Root Tissues

The tissues of mature roots can be divided into three groups: epidermis, cortex, and vascular cylinder. The arrangement of these tissues differs between monocots and dicots, as you can see in Figure 23–9.

Each of these tissues performs important functions that are directly related to its structure. The **epidermis** is a thin layer of cells that take in water and nutrients. The **cortex** transports water and nutrients inward through the root and may store

Figure 23–8 *Roots of plants vary greatly in appearance. The long taproot of a dandelion (top) makes it extremely difficult to eradicate this plant from a lawn. If even the smallest piece of the brittle taproot is left in the soil, the dandelion will grow anew. The fibrous root system of an onion (bottom) is different from the taproot of a dandelion. Onions can be pulled from the ground with ease.*

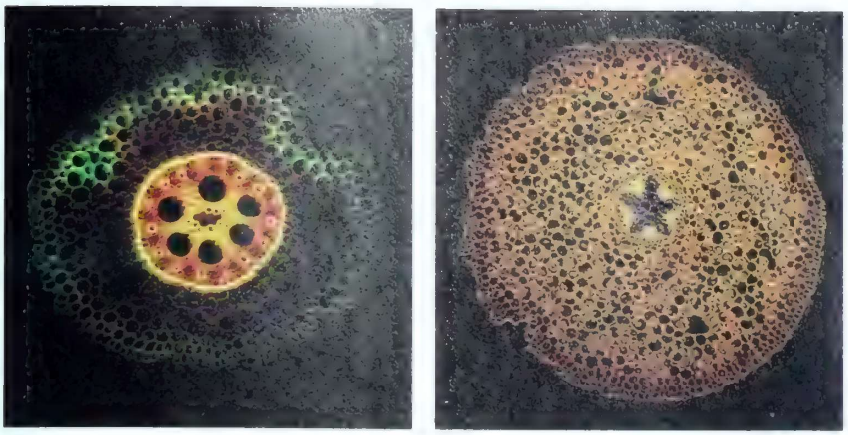


Figure 23–9 Cross sections of the root of a corn plant (left) and the root of a buttercup (right) are shown in these photomicrographs. Most dicot roots have a central column of xylem cells with radiating arms. Which plant is the dicot?

sugars or starches. The **vascular cylinder** contains xylem and phloem. We will discuss these tissues and their functions, in order, from the outside of the root to its center.

The Epidermis: Uptake of Water and Nutrients

The outermost layer of cells, the epidermis, absorbs water and nutrients from the soil. Epidermal cells grow slender projections called root hairs. Although individual root hairs are very small, there are an enormous number of them on a typical plant. The rye plant you just read about can have more than 14 billion root hairs!

Root hairs penetrate the spaces between soil particles. It is through the delicate tissues of the root hairs that water and nutrients enter plant roots. Although each individual root hair has a small surface area, the combined surface area of the huge numbers of root hairs is tremendous. That single rye plant's 14 billion root hairs provide the plant with a root surface area of more than 400 square meters! Root hairs thus enable roots to make close contact with a large area of soil.

NUTRIENT ABSORPTION Root hairs absorb dissolved nutrients from soil spaces through the process of active transport. Recall from Chapter 5 that active transport is a process in which a cell expends energy to move something from one side of a membrane to the other. In roots, active transport is necessary because nutrient ions are present in soil water in lower concentrations than they are in epidermal cells. In fact, these ions would tend to move out of root hairs by diffusion if active transport did not pull them inside.

As you may remember, active transport requires ATP (as a source of energy) and oxygen. Thus roots need a constant supply of oxygen to survive. Normally, roots obtain oxygen from the air in soil spaces. But if soil spaces are filled with water, the roots of most land plants cannot obtain the oxygen they need. This is one reason why floods destroy farm crops so quickly. It

is also the reason why you can kill your houseplants by overwatering them. Later in this chapter we will see how aquatic and swamp plants have evolved solutions to the problem of having their roots constantly in water.

WATER ABSORPTION Despite the importance of water to living cells, there is no active transport mechanism that can grab water molecules on one side of a cell membrane and drag them to the other side. Yet a single corn plant takes in more than 200 liters of water in a growing season that lasts little more than three months! How can plants move so much water into their roots?

To move water across membranes, plants use the power of osmosis. Recall that water will move across a membrane by osmosis from an area of high concentration of water molecules to an area of low concentration of water molecules. The cytoplasm of root epidermal cells is filled with amino acids, sugars, and other dissolved compounds. There are relatively few water molecules in root epidermal cells. The water in soil spaces usually contains only a small amount of dissolved minerals and many molecules of water. Thus the concentration of water molecules is higher in the soil spaces and lower in the root epidermal cells. Because of this difference in water concentration and because the thin cell walls of root hairs are permeable to water, water moves by osmosis from the soil spaces into the cytoplasm of root epidermal cells. See Figure 23–10.

Note that this process will not work if soil water carries a high concentration of dissolved minerals. In fact, if the concentration of water in the soil spaces is too low, water may even move out of root hairs and back into the soil. This situation is called root burn. Root burn can occur in nature if soil is saturated with salty water. Root burn can affect house, garden, and farm plants if too much fertilizer is added to the soil.

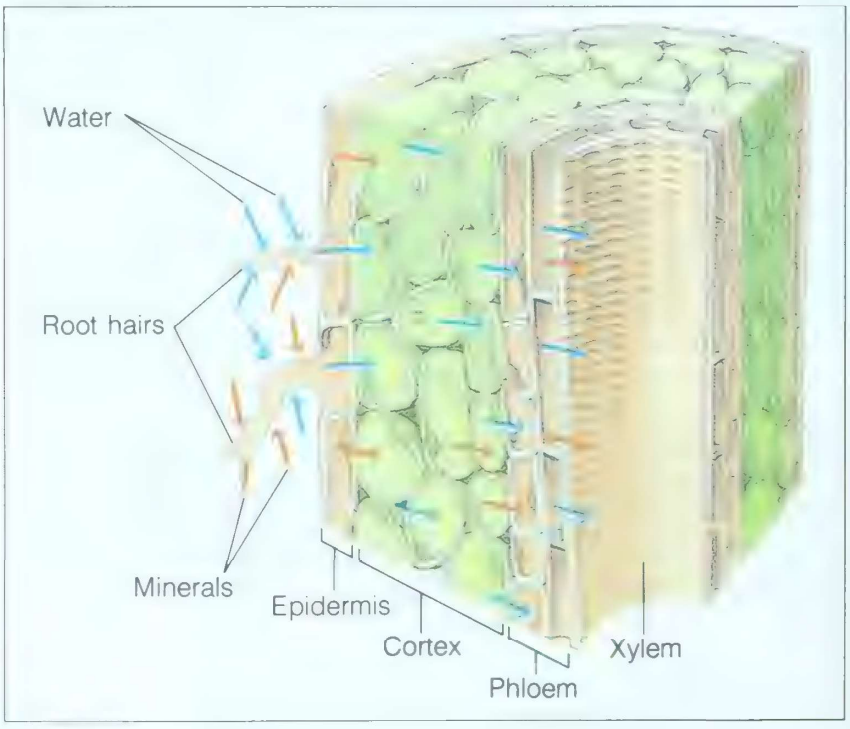


Figure 23–10 *It is through the tiny hairs on plant roots that most molecules of water and minerals enter a plant. Water moves from the outside of the roots into the xylem, where it is then transported throughout the plant.*

The Cortex: Transport of Water and Nutrients

The parenchyma cells of the root cortex perform the next step in the movement of water in plants. The cell walls and cell membranes of root parenchyma cells are permeable to water. Thus water moves easily through and around these cells. Root cortex cells also have active transport mechanisms in their membranes. Active transport in these root cortex cells keeps water and nutrients moving deeper toward the center of the root.

How does this process work? First, active transport moves dissolved nutrients through the cortex toward the center of the root. As the concentration of nutrient ions in the center of the root increases, the relative concentration of water molecules in the cells in that region decreases.

Next, water in the outer cortex moves by osmosis to "follow" the nutrient ions and to "equalize" the water concentration in all cortex cells. Thus, both water and nutrients move toward the center of the root.

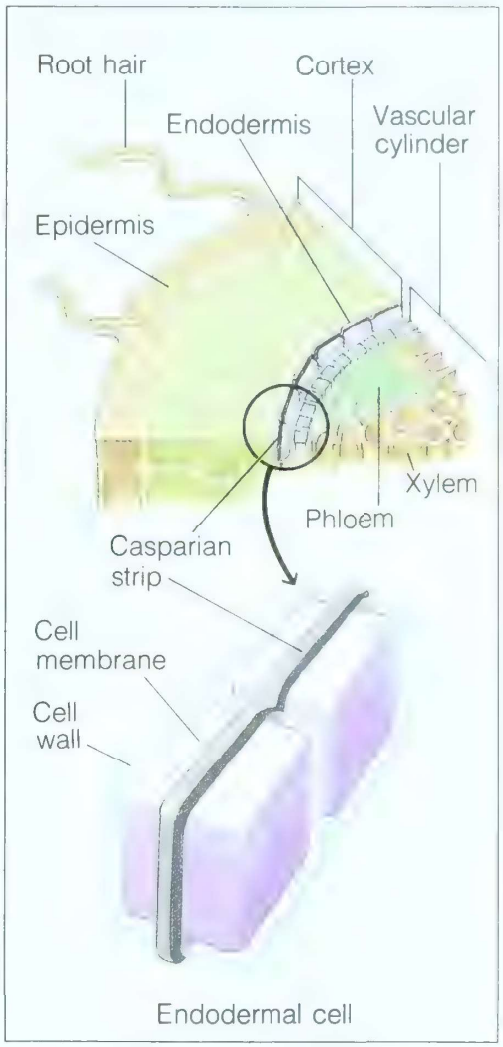
The Endodermis: One-Way Passage

At the inner boundary of the cortex is a single layer of cells called the endodermis (*endo-* means inside; *dermis* means skin). The endodermis, which looks like a circle in cross section, encloses the vascular cylinder and stretches up and down the entire length of the root. The endodermis is composed of many individual cells, each shaped like a brick. Each of these cells is surrounded on four sides by a waterproof strip called the **Casparian strip**. To imagine how the Casparian strip looks, imagine a brick with a thick, sticky rubber band stretched around four sides. See Figure 23–11. Now imagine many such bricks placed edge to edge to build a cylinder. The rubber bands around the individual cells touch each other and stick together like mortar between the bricks in a brick wall.

The Casparian strips of the endodermal cells are not permeable to water. Thus water and nutrients cannot move around endodermal cells—only through them. This is the key to understanding how the root works. Endodermal cells use active transport to pump dissolved nutrients into the vascular cylinder. As dissolved nutrients build up inside the vascular cylinder, water moves through the endodermal cells by osmosis to equalize the relative concentration of water molecules in the tissues.

But neither water nor dissolved nutrients can cross the Casparian strips that seal the spaces between endodermal cells. So both substances are trapped in the vascular cylinder. Dissolved nutrients cannot go back through the endodermal cells because those cells use active transport to force the

Figure 23–11 *Cells in the endodermis are surrounded by Casparian strips. These strips are waterproof and thus prevent water molecules from seeping back between the cells.*



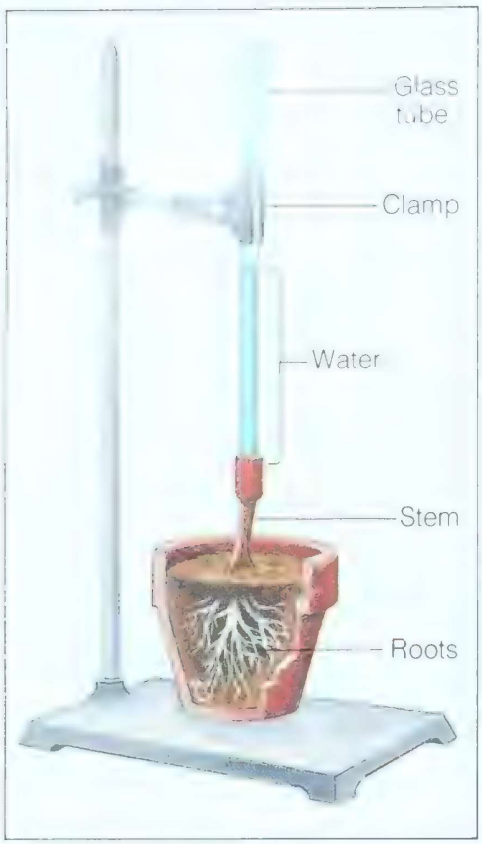


Figure 23–12 Pressure exerted by roots can move water a distance up the tube. However, root pressure alone cannot force water to the top of a tall plant.

nutrients inside. Water cannot move back through the endodermal cells because to do so would mean moving from an area of low concentration of water molecules to an area of high concentration of water molecules. Thus there is a one-way passage of materials into the vascular cylinder in plant roots.

Root Pressure: Pushing Water and Nutrients Upward

As more nutrients are pumped into the vascular cylinder, more molecules of water follow. Because neither nutrients nor water can move back into the cortex, pressure known as root pressure builds up inside the vascular cylinder. This increased root pressure forces water into the xylem. As you will soon see, root pressure is part of the driving force behind the movement of water from roots to leaves.

As root pressure in the vascular cylinder forces water into the xylem, and as more and more water moves from the cortex into the vascular cylinder, the water in the xylem is forced upward through the root into the stem. In short plants such as grasses and strawberries, root pressure alone can push water through stems from roots to leaves. In tall plants such as trees, however, root pressure alone cannot accomplish this process.

You can see root pressure in action if you cut the stem of certain plants close to the ground and place a glass tube over the stump. A liquid called sap will continue to come out of the stump and rise up the glass tube for some distance.

How do we know that active transport by root cells creates root pressure? If we poison the root or cut off its supply of oxygen, the movement of sap stops. Because once the endodermal cells in the root stop pumping dissolved nutrients into the vascular cylinder, water stops moving in by osmosis.

23–3 SECTION REVIEW

1. What is the difference between a taproot and a fibrous root?
2. Why is it difficult to remove dandelions from a lawn by pulling them out by the leaves?
3. Why do roots need a constant supply of oxygen?
4. What is the importance of root hairs in the absorption of water and nutrients?
5. Why is it important that the root epidermis permits only a one-way passage of materials?

23–4 Stems

Section Objectives

- List two important functions of plant stems.
- Describe the four basic types of stem tissue.

Stems vary greatly in size and shape from one plant species to another. Some stems are tiny; others are a hundred meters tall. Some grow entirely underground; others reach far into the air. **Regardless of size and shape, all stems have two important functions: They hold leaves up in the sunlight and they conduct various substances between roots and leaves.** Some stems may also store water and nutrients.

Stems have four basic types of tissue: parenchyma tissue (pith), vascular tissue (xylem and phloem), cambium tissue (vascular cambium and cork cambium), and cork tissue (outer bark). Looking at cross sections of monocot and dicot stems, such as those in Figure 23–13, you can see that some of these tissues are arranged differently in stems than they are in roots.

Parenchyma

In monocot stems, parenchyma, or pith, is distributed throughout the stem and is often used for storage. In dicot stems, a core of pith is laid down in the center of the stem, where it is surrounded by layers of xylem.

Vascular Tissue in Woody Stems

Vascular tissue in stems conducts water, nutrients, and various plant products up and down the plant. To accomplish this, xylem and phloem tissues form continuous tubes from the roots through the stems to the leaves. Stem xylem is connected to root xylem, and stem phloem is connected to root phloem.

In young dicot stems, bundles of xylem, vascular cambium, and phloem are arranged in a ring. The xylem faces the interior of the stem, whereas the phloem faces the exterior. In woody dicots, such as trees, new xylem and phloem cells are produced as the plant grows. Other tissue joins the xylem and phloem bundles into two complete rings. The xylem ring is closest to the center of the stem, and the phloem ring surrounds the xylem.

It is actually xylem tissue that makes up the rings of trees. By counting the number of rings in a cross section of a tree, you can estimate the age of the tree. The size of the rings can provide information about weather conditions in the area over time. Thick rings indicate that weather conditions were favorable for tree growth; thin rings indicate that weather conditions were not. For example, in a year with abundant rainfall, a tree might make thick rings. In a year when rainfall was scarce, the rings might be thin. As woody stems grow thicker from year to year, the older xylem near the center of the stem becomes what is known as heartwood. Heartwood no longer conducts

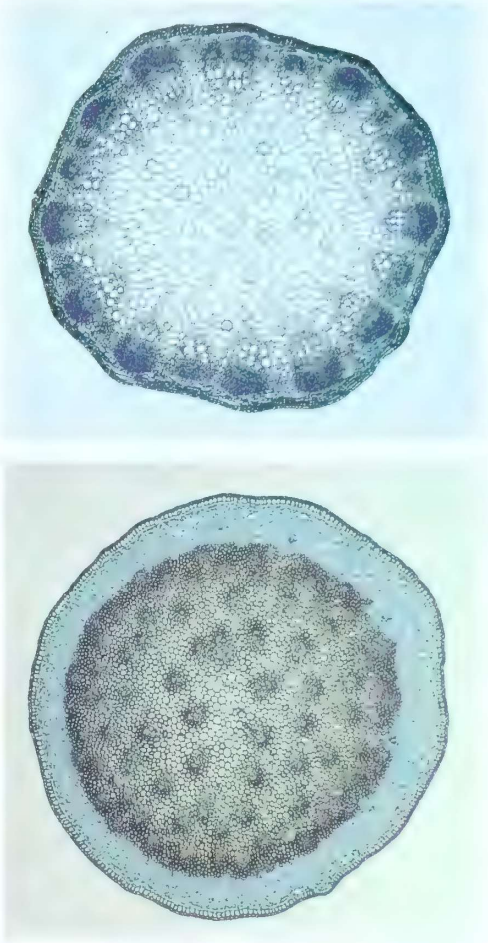


Figure 23–13 *The arrangement of vascular tissue in the stem of a dicot differs from that in the stem of a monocot. In a dicot, vascular tissue is arranged in a ring. In a monocot, it is scattered in bundles throughout the stem. Is the sunflower (top) a monocot or a dicot?*

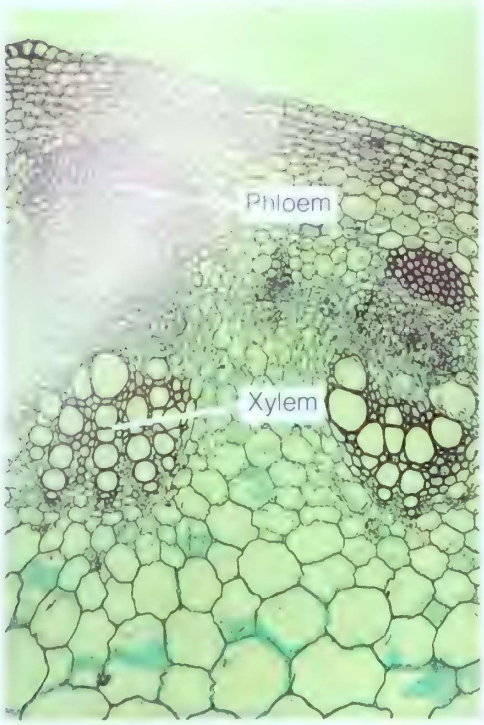


Figure 23–14 *A small portion of the vascular bundles in a dicot stem can be seen in this photomicrograph. The much larger xylem cells are found at the edge of the vascular bundle and point toward the center of the stem. The smaller phloem cells face the outside of the stem.*

Figure 23–15 *Trees can increase their diameter as they grow. In which layer does the division of cells account for this increase?*

water. The outer rings of living cells, known as sapwood, transport liquids.

Phloem tissue forms the inner part of what is called bark. Phloem carries sugars and other products of photosynthesis from the leaves to other plant parts that do not make their own food. For this reason, if the phloem in tree bark is removed in a ring around the trunk, the roots of the tree will starve and the tree will die.

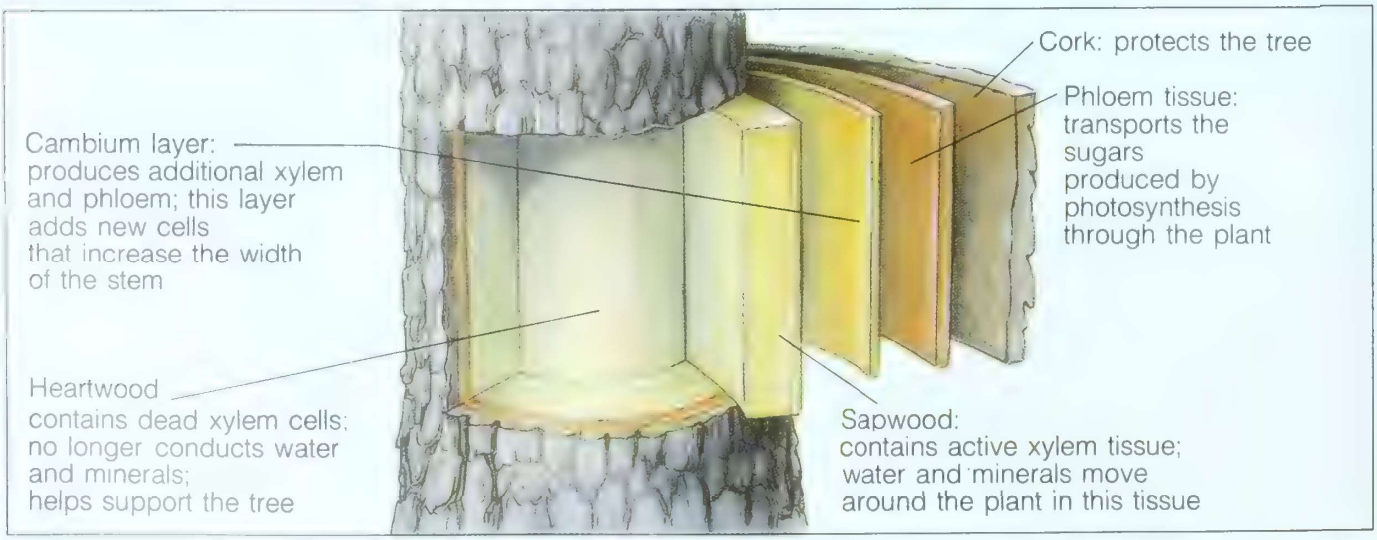
Rings of xylem and phloem are separated by a thin layer of tissue called the vascular cambium. The vascular cambium makes more xylem and phloem cells, enabling the stem to grow thicker. You will learn more about this process in Chapter 24.

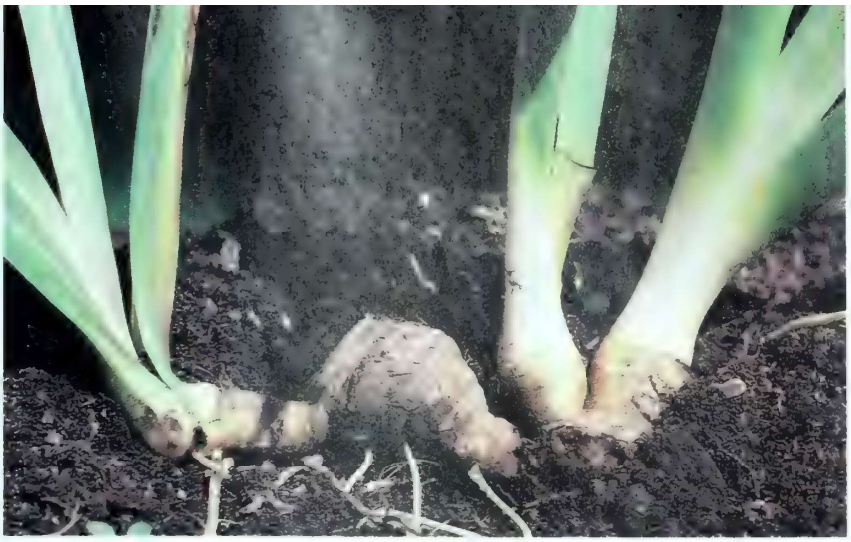
Cork Cambium and Cork

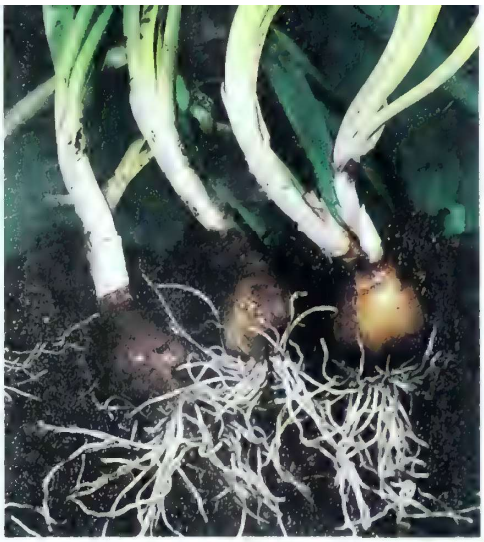
Outside the phloem tissue in woody dicots is the cork cambium, which produces cork tissue—the outer bark of trees. Cork cells have thick walls and usually contain fats, oils, or waxes. These waterproof substances help prevent the loss of water from the stem. The outermost cork cells are usually dead. As the stem increases in size, this dead bark often cracks and flakes off in strips or patches, depending on the tree species.

Stems Modified for Food Storage and Dormancy

In addition to support and the transport of materials from roots to leaves, stems also perform other functions. Plants often store food in their stems during their growth period. Plants need to store food to enable them to survive **dormancy**. During dormancy, a plant's growth slows or stops. Dormancy occurs during cold winters or long dry periods that may last for months or even years. When conditions once again support











plant growth, the dormant plants begin to grow, using the food they previously stored. The plant uses the food stored in the stem until its new growth can make enough food. Several kinds of modified stems are used by plants for this purpose. Refer to Figure 23–16 as you read about these modified stems.

Rhizomes are thick, fleshy, creeping stems that grow either along or just beneath the surface of the ground. Along the length of rhizomes are buds from which leaves and stems can grow. When the frosts of winter kill the above-ground parts of plants, the rhizomes survive to grow again the following spring. Garden plants such as irises, canna lilies, and many species of grasses survive cold winters and grow year after year because of rhizomes.

Tubers are modified underground stems that are swollen with stored food, usually in the form of starch. Many tubers, such as potatoes, hardly look like stems at all. But tubers have one or more prominent "eyes," which are actually lateral buds. From these buds grow new above-ground stems and leaves.

Bulbs, such as those of tulips and daffodils, have underground stems too. The stem at the center of the bulb is small. Most of the food stored in the bulb is located in the layers of short, thick leaves that wrap around and protect the stem.

Figure 23–16 *The rhizome of the iris is a thick creeping stem (top, left). Tubers—underground stems that store food—are characteristic of the potato (bottom, left). Bulbs, like the daffodil, are also underground stems, although the stem is small, cannot be seen, and is found in the center of the bulb (top, right). Corms, such as this gladiolus (bottom, right), are similar to a bulb in structure but they have thinner leaves.*

Corms are similar to bulbs, but they have much thinner leaves. Most of the stored food in corms is located in the stem itself. Thin, scalelike leaves surround the stem and serve mainly to protect it. Crocuses and gladioli are common garden plants that produce corms.

23–4 SECTION REVIEW

1. What are the functions of plant stems?
2. How does vascular tissue contribute to the strength of plant stems?
3. What are tree rings? What important information do tree rings provide?
4. How do rhizomes and corms contribute to a plant's survival?

23–5 Leaves

Section Objectives

- Describe the three specialized leaf tissues.
- Explain how gas exchange and water conservation are balanced in a leaf.

The leaves of green plants are the world's oldest solar energy collectors. Leaves are also the world's most important manufacturers of food. Sugars, starches, and oils manufactured by plants are sources of virtually all food for all land animals. Even animals that do not eat plants must eat other animals that do.

Leaf Structure

To collect sunlight, most leaves have large thin, flattened sections called blades. The blade is attached to the stem by a thin structure called the **petiole**.

Leaf blades occur in an incredible variety of shapes and sizes, depending on the environment to which they are adapted. Simple leaves have only one blade and one petiole. Compound leaves have several blades, or leaflets, that are joined together and to the stem by several petioles. These leaflets can be joined together in several ways. The leaflets of some compound leaves spread out like the fingers of a hand. The leaflets of others grow in pairs along a long central petiole. In still another pattern, leaflets are arranged on petioles that, in turn, are arranged along a long central petiole.



Figure 23–17 Leaves are arranged differently in different plants. The oak leaf is solitary and held to a stem by a single petiole (top). Both the strawberry and the poison ivy have three leaflets attached to a single petiole (bottom).

Leaves contain several specialized tissues. Like roots and stems, leaves have an outer covering of epidermal cells, inner layers of parenchyma cells, and vascular tissues.

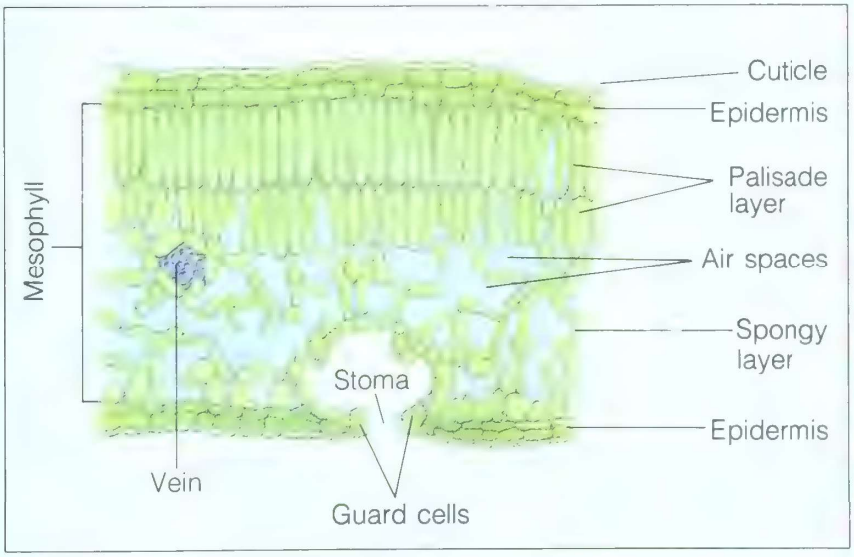
Epidermis: Controlling Water Loss

All leaves are covered on the top and bottom by a layer of tough cube-shaped epidermal cells that do not contain chloroplasts. The epidermal layer of many leaves is also covered by a waterproof waxy coating called the cuticle. The cuticle and epidermal cells together form a waterproof barrier that protects delicate tissues inside the leaf by slowing down the loss of water through evaporation.

But no leaf could survive completely sealed off from the atmosphere that surrounds it. Plants need to "breathe" just as we do. Leaves must take in carbon dioxide and give off oxygen during photosynthesis. And in order to use the food they make, leaves must take in oxygen and give off carbon dioxide (just as animals do). Plants need to exchange enormous amounts of gases with the surrounding atmosphere. But in order for a gas to enter the cells of a leaf, it must be dissolved in a thin film of water. So all leaf cells that need to exchange gases with the air must be kept wet.

But you know what happens to a wet surface exposed to the air—the water evaporates and the surface dries out! To keep the surface wet, more water must constantly be added to it. The more exposed the tissue is to the air, the faster the water will evaporate and the more quickly it will need to be replaced.

If all the moist tissues of leaves were exposed to the air, leaves would lose water much faster than roots could replace it. The plant would wilt and die. This is exactly the problem that mosses have. Without cuticles and vascular tissues, mosses must grow in wet soil and have their green parts in moist air all the time or they will dry out.



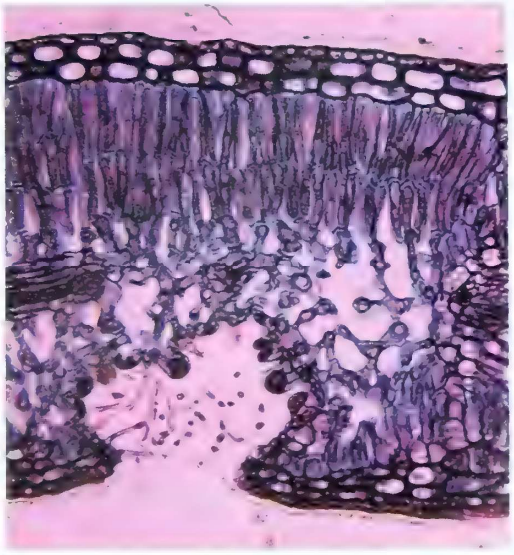
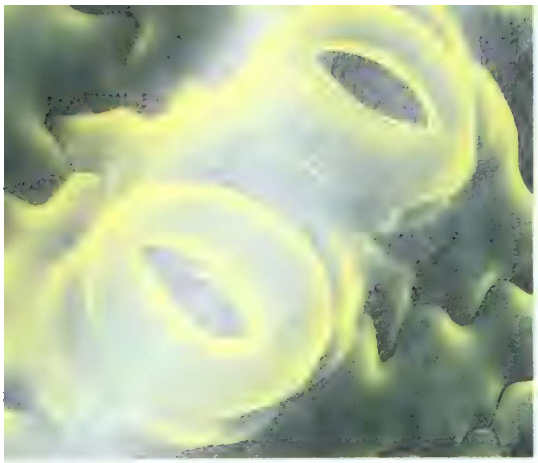
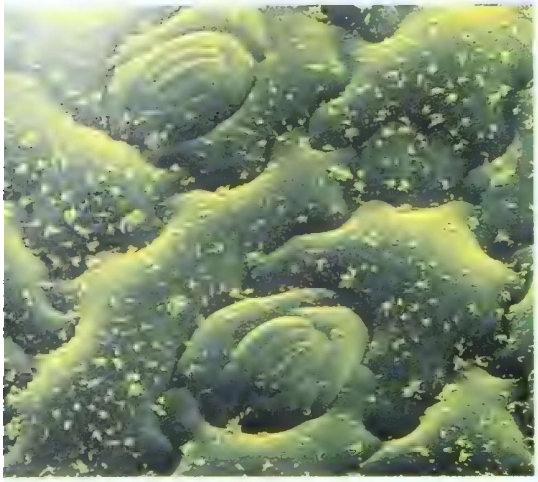


Figure 23–18 *Some of the most important manufacturing sites on Earth are found in the leaves of plants. The cells in plant leaves are able to use light energy to make carbohydrates. What is the opening at the bottom of a plant leaf called?*





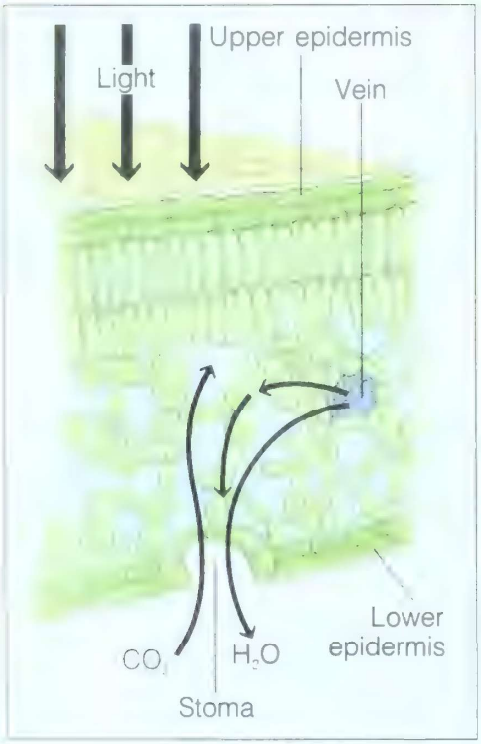


Figure 23–19 *Stomata open (top) and close (center) to let gases in and out of the leaves. On a hot day, are the stomata more likely to be open or closed?*

Seed plants solve this problem by striking a balance between their need for gas exchange and their need to conserve water. Plants control the loss of water from their leaves by allowing air in and out of their waterproof covering only through small openings called **stomata** (singular: stoma). Stomata open to allow the leaf to "breathe" and close when the leaf does not need much air exchange. Stomata also close when the plant loses too much water and begins to wilt. Most of the stomata of terrestrial plants are located on the undersides of their leaves, but there are some stomata along green stems too.

Stomata are formed by two specialized epidermal cells called **guard cells**. The stomata open and close in response to changes in water pressure within the guard cells. When water pressure within the guard cells is high, the thin outer walls of the cells are forced into a curved shape. This pulls the thick inner walls of the guard cells away from each other, opening the stoma. When water pressure within the guard cells decreases, the springiness of the inner walls pulls them together. The stoma closes.

Because water is lost through the same stomata that let in carbon dioxide, guard cells have a difficult job. On hot, dry days, open stomata will allow large amounts of water to leave the leaf. But if the stomata are closed all the time, the inside of the leaf will run out of carbon dioxide, and photosynthesis will slow down or stop. Each type of plant has guard cells that balance water loss against the need for carbon dioxide.

Vascular Tissue: The Veins of a Leaf

The vascular system of leaves is directly connected to the vascular tissues of stems. In leaves, xylem and phloem tissues are gathered together into bundles that run out of the stem and into the petiole. As the bundles enter the leaf blade, they are surrounded by parenchyma and sclerenchyma cells. All these tissues together form the veins of a leaf. In most monocot leaves, veins run parallel to one another. In dicot leaves, they may run in different patterns.

Mesophyll Tissue: The Food Factory of the Leaf

Most leaf tissue is composed of specialized cells called leaf **mesophyll**. Mesophyll cells contain many chloroplasts and perform most of the plant's photosynthesis. Just under the upper epidermal covering of the leaf is a layer of tall, column-shaped mesophyll cells called the **palisade layer**. Under the palisade layer is a thick layer called the **spongy mesophyll**. The spongy mesophyll gets its name from the fact that it really does look like a sponge. Cells of the spongy mesophyll are arranged in a network with a great many air spaces between them. These air spaces connect with the stomata and allow carbon dioxide and oxygen to diffuse into and out of the leaf.

The surfaces of spongy mesophyll cells are kept moist so that gases can enter and leave the cells easily. The water necessary to do this is supplied by the branching network of leaf veins that runs through the mesophyll. The opening and closing of stomata regulate the amount of contact the air in the spongy mesophyll spaces has with the drier air outside. Although the stomata cut down on the loss of moisture through evaporation, a substantial amount of water is still lost to the outside through evaporation.

23–5 SECTION REVIEW

1. Compare simple leaves and compound leaves. How are these shapes related to solar energy collecting?
2. What is the function of the epidermis and cuticle layers? What is the function of the openings in these layers?
3. Describe the structure and function of mesophyll tissue.
4. Describe how vascular plants control gas exchange and water loss.

23–6 Transport in Plants

Section Objectives

- Explain how water is moved through a plant.
- Describe the importance and mechanism of phloem transport.

You now know how the tissues of a typical plant are put together—from the root tips all the way up to the leaves. Remember that water and dissolved nutrients from the soil are absorbed through root hairs by active transport. The pressure created by water entering the tissues of a root can push water upward in a plant stem, but only for a short distance. How then does water reach the topmost needles of a redwood tree 90 meters above the ground?

Water Movement in Xylem

Xylem tissue forms a continuous set of tubes that stretch from roots through stems and out into the spongy mesophyll of leaves. **Root pressure forces water into the xylem, but root pressure alone cannot account for the movement of water and dissolved materials in plants.** Obviously, other powerful forces must also be at work.

ADHESION, COHESION, AND CAPILLARITY If water is not pushed up, could it perhaps be pulled up? It is indeed. Two characteristics of water make this pulling action possible.

Water molecules are attracted to one another by a force called cohesion. Water molecules are also attracted to other molecules by a force called adhesion. The combination of cohesion and adhesion explains the phenomenon known as capillarity, which is the movement of water upward in a small solid tube. Capillarity can be observed when water climbs up a



Figure 23–20 Capillarity—the ability of water molecules to stick to one another and to the walls of a tube—accounts in part for the movement of water up xylem tissue.

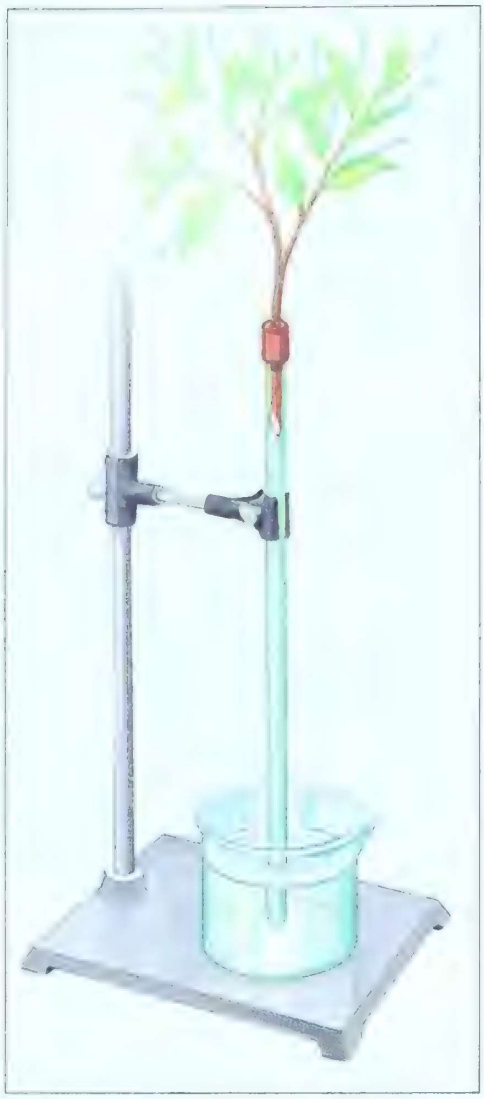


Figure 23–21 *This apparatus shows that transpiration—the movement of water molecules out of leaves—can pull water up a thin tube. The faster water evaporates, the faster it is pulled up in the tube.*

small glass tube placed in a beaker. Although gravity pulls the water in the tube down, the force of adhesion between the water molecules and the walls of the glass tube pulls the water up. At the same time, the water molecules cling to one another by cohesion, pulling molecule after molecule up inside the tube. The smaller the diameter of the tube, the higher the water will climb. Although capillàrity accounts for the movement of water in tiny xylem vessels in short plants, it is much too weak a force to move water up the xylem tubes in a redwood. Another force must be at work.

TRANSPIRATION PULL The final pull necessary to get water up into leaves is provided by the power of evaporation itself. This idea may sound strange, but evaporation is a powerful process. Except in rare cases when the atmosphere is totally saturated with water vapor, water will always evaporate from a wet surface. Therefore, water will almost always evaporate from leaves into the air. The evaporation of water from plant leaves is called **transpiration**.

Remember all those wet cells in the spongy mesophyll layer of leaves? As water evaporates from those cells, their water content drops. When this happens, water from nearby mesophyll cells moves by osmosis into the spongy mesophyll. This in turn causes the water content of these other mesophyll cells to drop below the water content of the cells that surround the veins. Once again water moves by osmosis to replace water lost by evaporation—this time from the cells surrounding the veins into the mesophyll.

As the cells surrounding the veins lose their water, water moves by osmosis out of the xylem into these cells. Finally, as water is removed from xylem vessels in the leaves, adhesion and cohesion pull other water molecules up the tubes from the roots through the stems. Because this entire process is driven by transpiration, it is called **transpiration pull**.

Transpiration pull is a very powerful force. A good-sized tree can move more than 1800 liters of water from the ground into the atmosphere in a single day. The hotter and drier the air, and the windier the day, the greater the amount of water lost by transpiration and the greater the amount of water drawn up from the roots.

Transport of Materials in Phloem

Phloem transports most organic molecules in plants. During the day, phloem transports products of photosynthesis out of the leaves and down into the stems and roots, where they are either stored or used.

But this is not the only job phloem does. For example, many plants pump sugars into their fruits. Such action often requires moving sugars out of leaves or roots into stems and then through stems to the fruits. All this movement of sugars occurs in the phloem. In addition, many plants living in cold climates

pump food down into their roots for winter storage. This stored food must be moved back up into the trunk and branches before the plant begins to grow again in the spring—another job done in the phloem. It is this rich, sugary sap moving through the phloem that is tapped from maple trees in late winter and early spring to make maple syrup.

Botanists at one time thought that the function of phloem tissue was limited to the transport of organic compounds only. But phloem also transports inorganic ions. And this transport is not always away from the leaves. For example, phosphorus is needed in large amounts by young, actively growing leaf tissues. Xylem moves phosphorus from the roots up through the stems into the growing tips of the plant. But when growth in those tissues slows down, phloem helps recycle extra phosphorus. Phloem transport moves phosphorus out of the growing leaves and back down into the main stem of the plant. From there it can be carried up into the growing tip when it is needed.



Figure 23–22 *Tree sap often has industrial uses. After being collected, the sap of a pine tree is made into turpentine, a chemical often used as a solvent for paint.*

How Phloem Transport Works

The exact mechanism by which phloem transport works is not completely understood. We know that the process requires energy. We also know that material moves through phloem cells much faster than it possibly could if it was powered by diffusion alone. For these reasons, it is clear that some kind of active transport is involved.

In order to explain one hypothesis, it is necessary to use the following terminology: When plants move sugars from their leaves to their roots, the leaf mesophyll tissue is called the source of the sugars and the parenchyma tissue of the root is called the sink. Active transport moves sugars into the phloem at the source. Similar active transport moves sugars out of the phloem into storage tissue at the sink.

When sugars are pumped into the phloem at the source, phloem tissue contains more dissolved minerals and less water than the surrounding tissue. Thus water moves into the phloem by osmosis. Pressure increases in the phloem at the source. When sugars are pumped out of the phloem at the sink, water also moves out. The movement of water out of the phloem at the sink causes a drop in pressure at the sink. Because pressure builds up at the source and drops at the sink, the contents of the sieve tube elements are forced down from source to sink.

If the plant needs to move sugars from the roots to the leaves, it simply reverses the pumping action at these two locations. The root tissue thus becomes the source, and the leaf

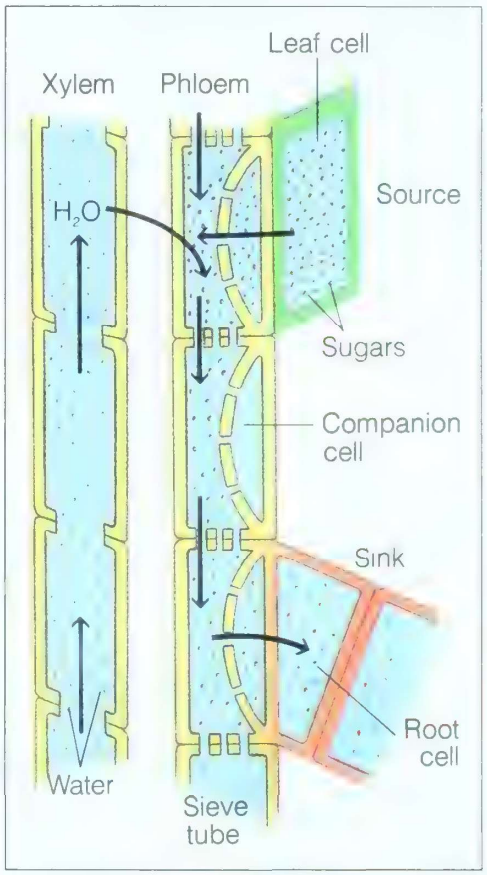


Figure 23–23 *This illustration shows a current hypothesis that explains the movement of sugar molecules in phloem tissue. As you can see, materials move from the source, where they are available in great supply, to the sink, where they are scarce.*

becomes the sink. The phloem then carries sugars upward. Any dissolved compounds can be moved through the phloem in either direction by changing the location of the source and the sink. This hypothesis about phloem function is called the pressure flow hypothesis.

23-6 SECTION REVIEW

1. What role do cohesion and adhesion of water molecules play in the movement of water in xylem tissue?
2. Describe the process of transpiration pull.
3. How does the pressure flow hypothesis explain how phloem functions?

Section Objective

- List some adaptations shown by plants that enable them to survive in many different environments.

23-7 Adaptations of Plants to Different Environments

Flowering plants grow in a variety of places: in deserts, in ponds, on mountaintops, in salt water, in arctic regions, and in the tropics. **Angiosperms can survive in these areas because through natural selection the basic designs of their roots, stems, and leaves have evolved to fulfill the particular needs of each location.** In this section we will see how roots, stems, and leaves have been modified through evolutionary change to serve different functions. In many cases, different families of plants show similar adaptations to similar environmental conditions.

Desert Plants

Desert plants must survive where strong sun and daytime heat combine with sandy soil and infrequent rainfall. Instead of staying near the surface, rainwater sinks rapidly through desert soils. The hot, dry air quickly removes moisture from any wet surface, making life difficult for plants.

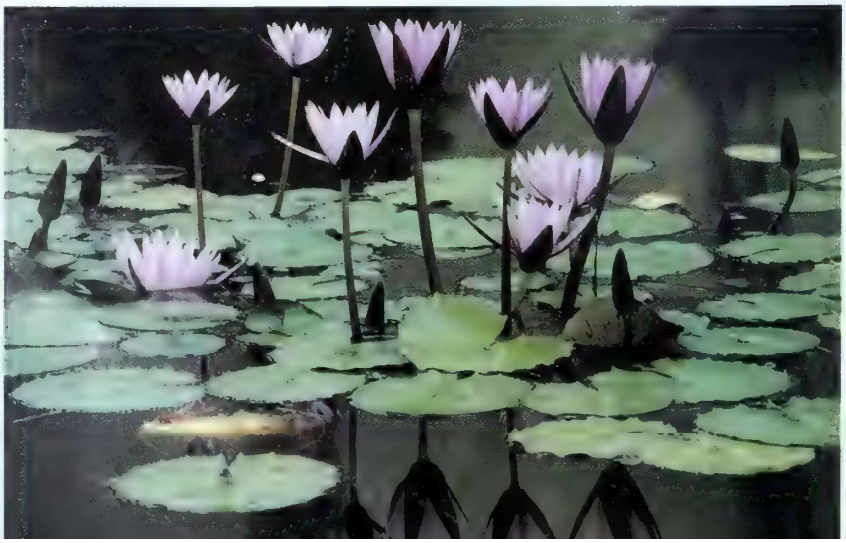
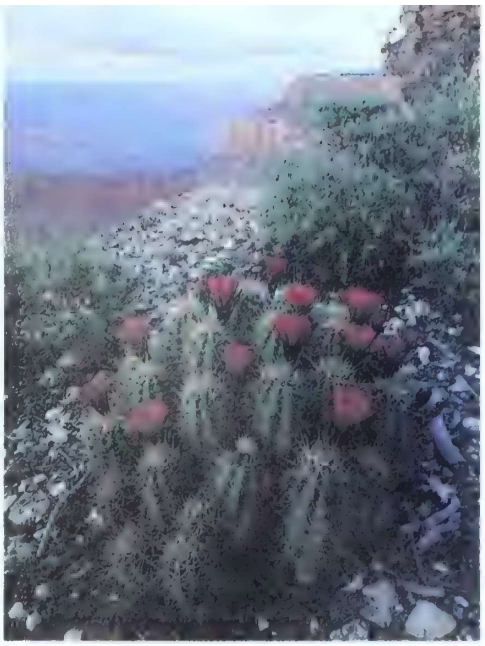


Figure 23-24 Unlike the stomata of most plants, those of water lilies are clustered on the top of their leaves. How is this an adaptation for life in water?

Two families of desert plants are cactuses (family Cactaceae), which evolved in the Americas, and the crown-of-thorns family (family Euphorbiaceae), which evolved in Africa. Figure 23–25 shows examples of these families of desert plants. Both families have either a root system that spreads out for long distances just under the soil surface or a root system that reaches deep down into the soil. In each of these root systems, the roots have many root hairs that quickly pick up water after a rainstorm, before the water sinks too far down in the soil.

Most water loss in plants occurs through transpiration from the leaves. Both families of desert plants either have leaves that are very small or have no leaves at all. In cactuses, leaves have been reduced to thin, sharp spines. In euphorbias, leaves either are tiny or can be dropped if the weather gets too dry. Both plant families have thick green stems, where photosynthesis occurs. These stems are also adapted to store water. The stems of cactuses, in particular, swell during rainy periods, as the plants greedily store water, and shrivel during dry spells, when the plants are forced to use up their water reserves.

Seeds of many desert plants can remain dormant for years, germinating only when sufficient moisture guarantees them a chance for survival. Other desert plants have bulbs, tubers, or rhizomes that can remain dormant for several years if necessary. When rain does come, the plants grow with amazing speed. They mature, flower, and set seed in a matter of weeks or even days—before the water disappears.



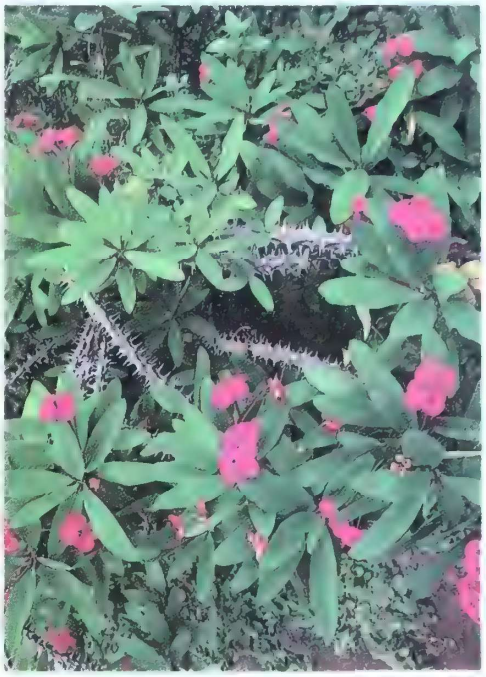


Figure 23–25 *Plants that live in dry environments show adaptations to conserve water. The cactus leaves have been reduced to spines (top). The euphorbia has leaves that drop off in dry seasons (bottom).*

Plants Adapted to Life in Water

Some plants, such as waterlilies, have the opposite problem of desert plants. Their roots and stems grow in water or in mud that is saturated with water and nearly devoid of oxygen. To supply oxygen to their roots, these plants have large open spaces in the long petioles that reach from their leaves down to the roots at the bottom. These open spaces are filled with air through which oxygen can diffuse to the roots.

Many other plants show similar adaptations. Several species of mangrove trees grow in shallow water along tropical seacoasts. Stately baldcypress trees thrive in freshwater



Figure 23–26 *Mangrove roots, which look like a series of stilts, support the plant. In time, a mangrove plant grows to cover a huge area.*

swamps in the southern United States. The roots of these trees, like those of waterlilies, must survive in mud that has little or no oxygen. Mangroves survive by growing special roots called air roots. Air roots have large air spaces in them, just like waterlily stems. These spaces conduct air down to the buried roots so the root tissues can respire normally. Baldcypress trees grow structures called knees, which protrude above the water. The knees bring oxygen-rich air down to the roots.

Salt-Tolerant Plants

In addition to getting air to their roots, mangroves have another problem. As you have seen, when plant roots take in dissolved minerals, a difference in the concentration of water molecules is created between the root cells and the surrounding soil. This concentration difference causes water to enter the root cells by osmosis. For plants growing in salt water, this means taking in much more salt than the plant can use. The roots of plants such as mangroves can tolerate salt concentrations that would quickly burn the root hairs off most plants. And the leaves of these plants have special cells that actively pump salt out of the plant tissues and onto the leaf surfaces, where it is washed off by rain.



Figure 23–27 *The stem of the morning glory twines around and around its support. Twining stems enable plants to grow "taller" by climbing up the stems of other naturally tall plants so that they can capture more of the sun's energy.*

Climbing Plants

In environments such as tropical rain forests, the struggle for sunlight is fierce. Here any plant that can quickly climb up the trunk of another plant to escape the darkness of the forest floor has a considerable advantage over its neighbors. Vines are plants that have evolved specialized root, stem, and leaf structures that enable them to climb on rocks or other plants.

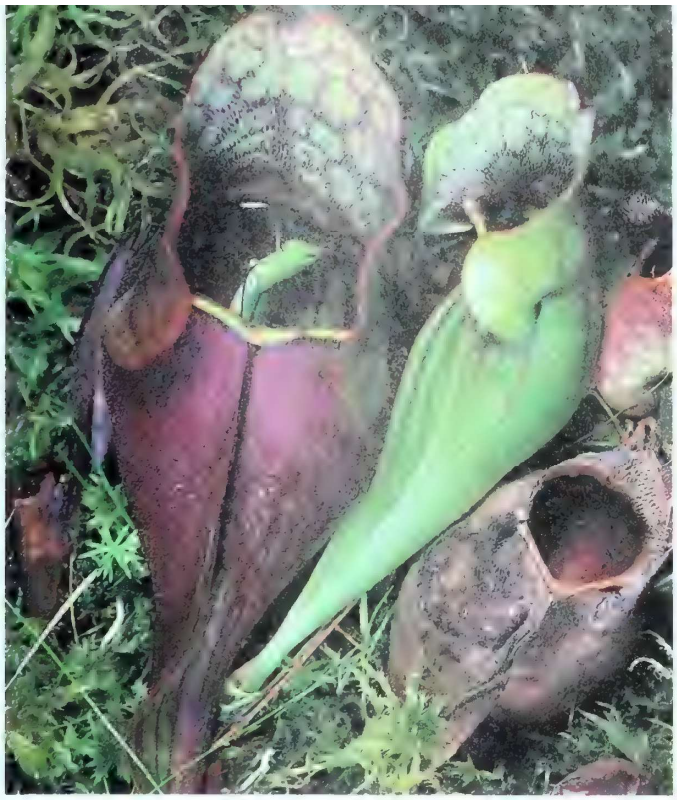
The stems of many climbing plants do not grow straight up. Rather, the growing tips point sideways. See Figure 23–27. As the tip of a shoot grows, it spins around in a circle. In this way, the plant "looks" for something to climb on. When the tip encounters an object, it quickly wraps around it.

Some climbing plants have long, twisting leaf tips or petioles that wrap tightly around small objects. Other plants have extra growths called tendrils that emerge near the base of the leaf petioles and wrap tightly around any object they encounter.

Still other vines, such as the strangler fig, grow aerial roots along the entire length of their stem. These roots attach to rocks or trees and help anchor the climber in place. Sometimes these aerial roots can be so numerous and so large that they end up strangling the host plant.

Plants That Eat Animals

Some plants live in very wet places called bogs, where there is little or no nitrogen present in the watery soil. Because conditions are too wet and too acid in bogs, bacteria of decay





cannot survive. Without these bacteria, neither plant nor animal material is broken down into the nutrients plants can use.

A number of plants have overcome this difficulty by evolving specialized leaves that trap and digest insects. The best known of these carnivorous plants is the Venus' flytrap. This plant has bright-red leaf blades that are hinged at the middle. Insects are attracted to the leaf by the bright color. If an insect touches the trigger hairs on the leaf, the leaf folds up suddenly —trapping the animal inside. During a period of several days, the leaf secretes enzymes that digest the insect and release nitrogen for the plant to use.

There are several other kinds of carnivorous plants. Pitcher plants drown their prey in brightly colored pitchers that hold rainwater and digestive enzymes. Sundews trap insects on leaf hairs tipped with sticky secretions. There are even underwater carnivorous plants, such as bladderworts, that prey upon tiny water insects. See Figure 23–28.

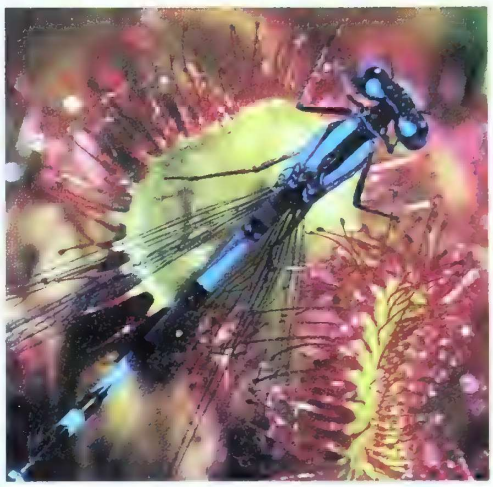


Figure 23–28 *Some plants show special adaptations to catch and digest insects. The pitcher plant (top, left) and the sundew (bottom) are land plants that trap insects. The bladderwort (top, right) is a water plant able to catch its own food.*

23–7 SECTION REVIEW

1. What are two adaptations shown by desert plants to their environment?
2. Why do climbing plants survive better in tropical rain forests than do some nonclimbing plants?
3. Describe the adaptations of a mangrove tree to a saltwater environment.
4. How is insect eating an adaptation that contributes to the survival of the Venus' flytrap?

LABORATORY INVESTIGATION

EXPLORING THE STRUCTURE OF LEAVES

PROBLEM

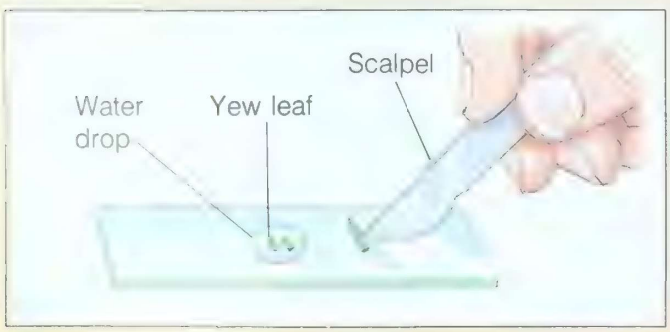
How are leaves suited to their function?

MATERIALS *(per group)*

- 4 clean microscope slides
- 3 coverslips
- microscope
- forceps
- 2 clean medicine droppers
- scalpel
- scissors
- iodine solution
- leaves: *Elodea* and yew *(Taxus)*

PROCEDURE

1. Use a medicine dropper to put a drop of water in the center of a slide.
2. Pull a small leaf from the tip of a sprig of *Elodea* in the drop of water on the slide. Cover the leaf with a coverslip.
3. Place the slide on your microscope. Focus the low-power objective on the *Elodea* leaf. Observe the leaf. Switch to the high-power objective. Focus with the fine adjustment. Look for pigmented structures in the cells. Note their shape and color. Remove the slide.
4. Place another slide on a flat surface. Put a yew leaf on the slide. Cut the tip off the leaf by pressing straight down with a scalpel about 1 mm from the end of the leaf. **CAUTION:** *The scalpel is very sharp. Always cut away from yourself and others.* Discard the tip of the leaf. Shave off 6 thin slices, or cross sections, from the cut end of the leaf. See the accompanying illustration. Make the slices as thin as possible by pressing the scalpel straight down as close to the cut end of the leaf as allowable.
5. Use a medicine dropper to put a drop of water in the center of another slide. Slide the leaf cross sections over to the drop of water. Position the cross sections so that they lie next to each other. Cover the leaf cross sections with a coverslip.
6. Place the slide on a microscope. Focus the low-power objective on the thinnest cross section on the slide. Switch to the medium-power objective.
7. Draw a diagram of the leaf cross section. Locate the following structures and label them on your drawing: epidermis; palisade layer; spongy layer; vein. Remove the slide.



OBSERVATIONS

1. What is the shape and color of the pigmented structures in the *Elodea* leaf?
2. Describe the appearance of the yew leaf cross sections. What is the shape and color of the cells?

ANALYSIS AND CONCLUSIONS

1. What are the pigmented structures in the *Elodea* leaf? What is the function of these structures?
2. What is the function of each labeled structure in the yew leaf?
3. Which parts of the leaf help in food production? In delivering water?
4. How do the shape, structures, and positions of the structures you observed contribute to the functioning of a leaf?

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

23–1 Soil: A Storehouse for Water and Nutrients

- Plants take in the water and inorganic materials they need from the soil.

23–2 Specialized Tissues in Plants

- Vascular tissue, xylem and phloem, is the plant's circulatory system.

23–3 Roots

- Roots anchor a plant in the ground and enable the plant to take in water and nutrients.

23–4 Stems

- Stems hold leaves up to sunlight and conduct water and other substances from roots to leaves.

23–5 Leaves

- Leaves are solar energy collectors as well as the food-making center in most plants.

23–6 Transport in Plants

- Root pressure and transpiration pull are the forces that move water in xylem tubes.
- Scientists offer the pressure flow hypothesis to explain phloem transport. In this hypothesis, materials move from a source, an area of high concentration of materials, to a sink, an area of low concentration of materials.

23–7 Adaptations of Plants to Different Environments

- Flowering plants show a great many adaptations to different environments.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

23–2 Specialized Tissues in Plants

meristematic tissue
apical meristem
cork cambium
vascular cambium
pericycle
parenchyma
sclerenchyma
tracheid
vessel element
sieve tube element
companion cell

23–3 Roots

taproot
fibrous root
epidermis
cortex
vascular cylinder
Casparian strip

23–4 Stems

dormancy
rhizome
tuber
bulb
corm

23–5 Leaves

petiole
stoma
guard cell
mesophyll
palisade layer
spongy mesophyll

23–6 Transport in Plants

transpiration
transpiration pull

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. In order to grow well, roots need
   a. minerals. c. carbon dioxide.
   b. oxygen. d. water.
2. Openings that permit gases to enter and leave the leaf are called
   a. stomata. c. palisade cells.
   b. cuticles. d. chloroplasts.
3. A nutrient that plants use for proper leaf growth and color is
   a. zinc. c. calcium.
   b. potassium. d. nitrogen.
4. The type of plant tissue that divides by mitosis is
   a. meristematic. c. phloem.
   b. xylem. d. surface.
5. The inner part of bark is made of
   a. xylem. c. phloem.
   b. parenchyma. d. cuticle.
6. A meristematic tissue that increases the thickness of plant stems over time is
   a. vascular cambium. c. pericycle.
   b. apical meristem. d. epidermal meristem.
7. Thin-walled cells that store the products of photosynthesis are
   a. tracheids. c. sclerenchyma cells.
   b. companion cells. d. parenchyma cells.
8. A primary root that grows longer and thicker is
   a. a fibrous root. c. easy to remove.
   b. a taproot. d. not found in plants.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Carbon dioxide enters a plant through the roots.
2. Plants lose water through the leaves by perspiration.
3. Trees grow taller because cells in the apical meristem are able to divide.
4. The waterproof covering on the outside of the leaf is the cambium.
5. Xylem tissue conducts the products of photosynthesis up through a plant's stem.
6. There is a one-way passage of materials into the vascular cylinder in plant roots.
7. The rings of a tree are made up of phloem tissue.
8. Tubers are underground roots.

Word Relationships

An analogy is a relationship between two pairs of words or phrases generally written in the following manner: a:b::c:d. The symbol : is read "is to," and the symbol :: is read "as." For example, cat:animal::rose:plant is read "cat is to animal as rose is to plant."

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

1. xylem:water::phloem: _____
2. parenchyma:storage::sclerenchyma: _____
3. root hairs:roots::mesophyll: _____
4. water:osmosis::nutrients: _____

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Plants are said to have an open growth pattern. What does this mean?
2. If you were weeding a lawn, would you be more successful at removing weeds with a taproot or weeds with fibrous roots? Explain your answer.
3. What are three adaptations shown by plants that are able to survive in a desert?
4. Leaves are able to trap solar energy. How does their shape enable them to perform this job efficiently?
5. How are root hairs important to plants?
6. What are stomata? How do they work?
7. Why is it important for tissues in the spongy mesophyll of the leaf to remain constantly moist?

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** Certain Native Americans used bark cut from birch trees to make canoes. Removing the bark did not kill the trees. What precautions did they take when they removed the bark?
2. **Relating concepts** The leaves of cactuses have been modified into thorns. What two functions does this modification have?
3. **Drawing conclusions** Suppose you were going away on vacation and you couldn't find anyone to water your houseplants. You knew that plants lose water through the stomata in their leaves, so you decided to cover the leaves with petroleum jelly to prevent water loss. When you returned home, you found your plants had died. What is the most logical explanation for this?
4. **Designing an experiment** Your friend says it's necessary to fertilize plants every time they are watered. His plants grow well. You decide to test his claim. Design an experiment to test your friend's hypothesis.
5. **Relating cause and effect** A corn farmer decides to save money by not fertilizing the fields. The crop grows well the first year but diminishes each succeeding year. How would you explain this situation?
6. **Relating cause and effect** In Japan, the art of growing miniature trees is highly valued. By cutting the roots and tips of the branches, the tree remains small. The trunk of the tree, however, continues to increase in diameter. How do you explain the ever-increasing diameter of the trunk?
7. **Applying concepts** During the nineteenth century, people often raised ferns and other delicate plants that normally require a great deal of water in enclosed glass containers called Wardian cases. Plants in Wardian cases did not have to be watered for years. What is the most logical explanation for this phenomenon?
8. **Applying concepts** In cold northern climates many trees lose their leaves in autumn. How is this an adaptation that helps the trees survive the cold of winter?
9. **Using the writing process** Many people find insectivorous plants interesting. Most of these plants are collected from the wild. Some scientists are concerned that too many of these plants are being collected. Write a letter to your congressional representative proposing a law to protect these plants.