10. Why is it not surprising that many hydrophytes have little or no xylem tissue?
11. The leaves of many underwater plants are finely divided, dramatically increasing the surface area that is in contact with water. Explain how this leaf structure might be an adaptation for obtaining carbon dioxide.

13.4 Roots

Although usually hidden below ground, a plant's root system is critically important and is often larger than the plant's entire shoot system (**Figure 2**, page 495). Roots absorb water and minerals from the soil, physically support and anchor plants, and store carbohydrates. Water and minerals that enter the roots are transported through vascular tissue up to the stem, leaves, and flowers. Many of the carbohydrates produced in the shoot system are transported down to the roots for storage. Roots are also responsible for producing a variety of compounds, such as hormones, which are used throughout the plant.

primary root: the first root developed from the seed

secondary root: smaller root branches growing sideways from a primary root

taproots: root systems where the primary root remains predominant, though very small secondary roots may be present

fibrous roots: root systems whose primary roots have disintegrated and have been replaced by adventitious roots

adventitious roots: roots that develop from a part of the plant other than a root. They often form huge tufts at the base of the stem. There is no main root because most are the same size as the others. However, smaller secondary roots do branch out from these roots.

root cap: a loose mass of cells forming a protective cap covering the apical meristems of most root tips

root hairs: microscopic extensions of the epidermal cells near the tip of a root. Root hairs function in the absorption of water and minerals.

endodermis: a layer of rectangular cells surrounding the vascular cylinder. It is the innermost layer of the cortex.

pericycle: a thin layer of lateral meristematic cells that surrounds the vascular cylinder

annual: describes plants that complete their entire life cycle, from seed to reproduction to death, in one year

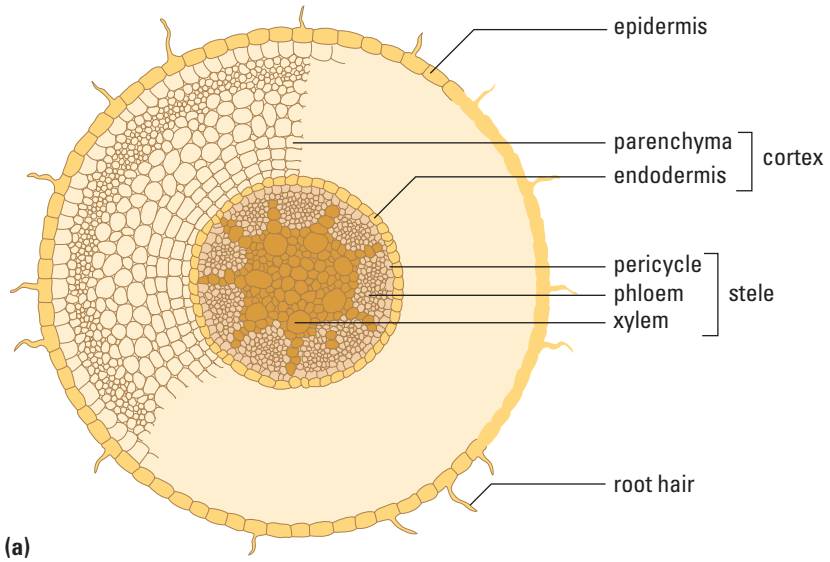
perennial: describes plants that grow and reproduce repeatedly for many years

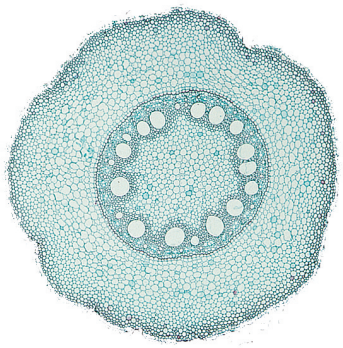
The **primary root** is the very first main root which develops from the seed. A **secondary root**, also called a lateral root, is smaller than the main root and branches from it. The two main types of plant roots are **taproots** and **fibrous roots**. If a young root increases in diameter, grows downward, and develops small lateral roots, it is called a taproot. Examples of plants with taproots are carrots, beets, dandelions, and oak trees. In grasses and other monocots, the primary root is short-lived and is replaced by **adventitious roots**. Adventitious roots and their lateral roots form a fibrous root system. Generally, these fibrous roots do not penetrate as deeply as taproots but their total combined length can be enormous. The fibrous roots of a single rye grass plant were estimated to have a total surface area of over 600 m^2 while occupying just 6 L of soil!

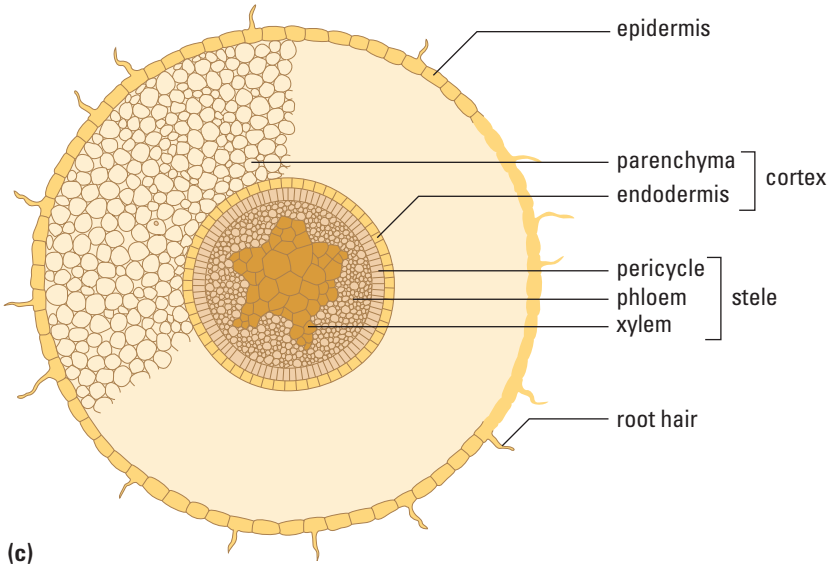
Each root has a protective **root cap** at the tip. Just behind the cap, the epidermal cells often have fine, microscopic **root hairs**. Root hairs increase the root's surface area for absorption. At the centre of each root is the vascular cylinder (stele), which contains the vascular tissues, xylem and phloem, and some ground tissue.

Surrounding the vascular cylinder is the **endodermis**, which regulates lateral movement of water and minerals. The endodermis is really the innermost layer of the cortex. Between the vascular cyclinder and the endodermis is the **pericycle**. The pericycle is important because it is made up of meristematic tissue, which gives rise to secondary roots.

Secondary growth in roots is associated with an increase in diameter of the vascular cylinder and, in much older roots, the formation of bark. Most monocot roots as well as some **annual** dicots do not exhibit secondary growth (**Figure 1**). It is, however, a definite characteristic of **perennial** dicot roots. Some of the ground tissue within the stele becomes meristematic and begins to divide. This tissue is the vascular cambium. Vascular cambium separates the xylem and phloem. When the cambium divides by mitosis, it produces phloem cells to the outside and xylem cells to the inside. As the xylem increases in size, the cambium is displaced outward, causing an increase in the diameter of the root. Primary xylem and phloem are produced in the first year of the plant's life. After that time, all xylem and phloem that are produced are called secondary (**Figure 2**). As







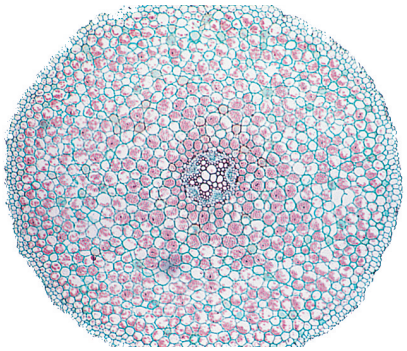


Figure 1
Diagram of very young root cross section of **(a)** *Zea*, a monocot, and **(b)** photomicrograph of *Zea*; diagram of very young root cross section of **(c)** *Ranunculus*, a dicot, and **(d)** photomicrograph of *Ranunculus*

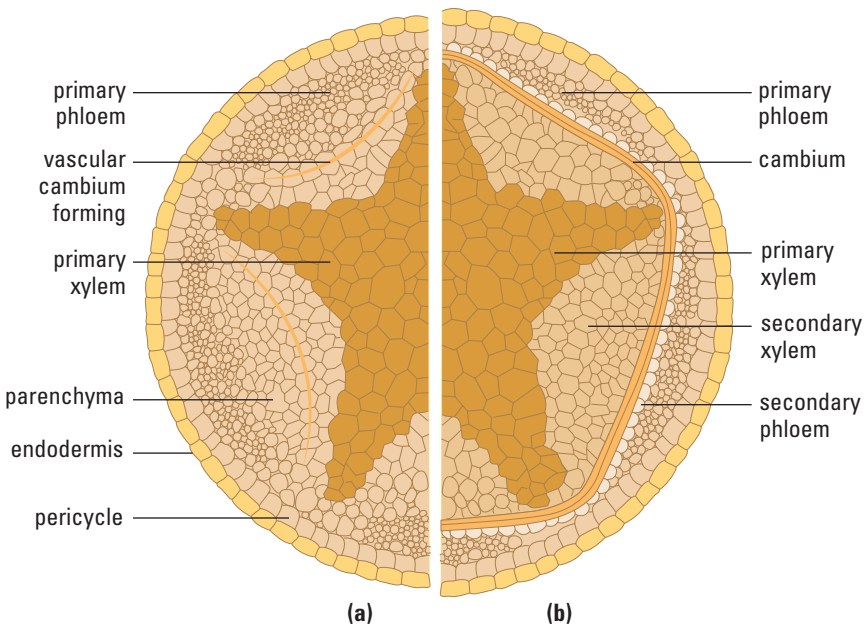


Figure 2
Diagram of the central core of a dicot root to show **(a)** the primary xylem and phloem completed and vascular cambium forming, and **(b)** how the secondary xylem and phloem develop from the cambium in the second and following years of the plant's life. The epidermis and cortex have already died and been sloughed off.

cork cambium: a lateral meristem formed by the pericycle in dicots over two years old

cork: describes the cells produced by the cork cambium that eventually form a layer of dead cells that provide a protective covering for roots over two years old. Cork also describes the protective layers.

the pericycle gets pushed further and further outwards, some of its cells become meristematic and develop into the **cork cambium**, which produces compact layers of **cork** cells. These cells become impervious to water. When the epidermis and remnants of the cortex die and get rubbed off, what remains will be the accumulating corky layers of the bark which help to protect the roots from excess moisture loss, bacterial invasion, and mechanical damage (**Figure 3**).

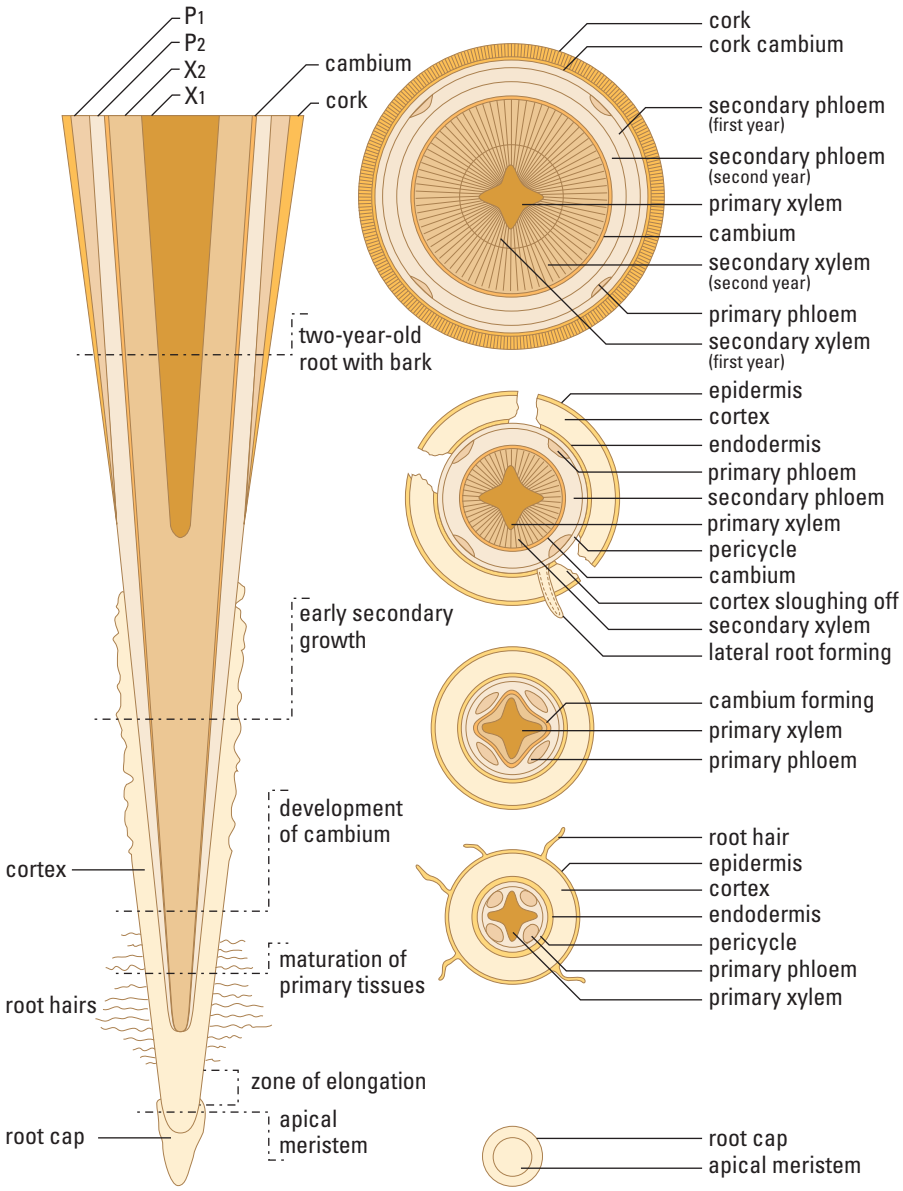


Figure 3
Diagrams to show a longitudinal section of a two-year-old dicot root and five cross sections through different regions of that root. Note the labels carefully. Be aware that in spite of the size of the drawing, this root could be very small.

Root Adaptations

Some plants have roots that have evolved special structures or habits that allow those plants to survive in special situations. In waterlogged, oxygen-poor soils, such as in mangrove swamps, roots may have specialized extensions called **pneumatophores** which grow up out of the water and function to supply oxygen to the root tissues below. In some plants, such as ivy or various types of *Philodendron*, small **aerial roots** grow from the leaf nodes along the stem. They also absorb oxygen from the air. In addition, if this part of the stem contacts the soil, these roots grow downwards as normal roots (**Figure 4**). The aerial roots of

pneumatophores: roots which grow upwards into the air to take in oxygen

aerial roots: adventitious roots that grow from leaf nodes along stems

Figure 4
Aerial roots on a common *Philodendron*. If the stem is cut just below these roots and placed in water for a short period, the roots and stem will grow as a separate plant once planted in soil.

orchids never reach the ground. Many orchids are epiphytes; they grow on the stems and branches of other plants. They are not parasitic because they have retained their ability to photosynthesize. Strangler figs are also epiphytes but their roots do grow down to the ground (**Figure 5**). In many other plants, such as the carrot, roots are greatly expanded and specialized as a major carbohydrate-storage organ. The roots of some plants, such as walnut trees, release toxins into the soil from their roots, seeds, or fallen leaves. These toxins inhibit the germination of other plant seeds, thus reducing competition for light and soil nutrients. This strategy is called **allelopathy**.

allelopathy: the suppression of growth and development of neighbouring plants by a plant of a different species. This effect is caused by chemicals secreted by the roots or contained in the leaves of the allelopathic species. Not all surrounding plants will suffer the same effect.

(a)

(b)

Figure 5
(a) These drawings show the growth of a strangler fig plant over time. The strangler fig begins its life as a small epiphyte growing high up in a tree. The fig grows numerous aerial roots which, over time, grow down the tree trunk to reach the ground. These roots lengthen, thicken, and fuse together. The fig depends on the tree to support its bulky body. Eventually the roots completely engulf and strangle the tree. The tree's death results in greater light exposure for the strangler fig, which is then able to grow quickly, often to immense size.
(b) A photograph of a small section of tree trunk encased in large aerial roots of a strangler fig.

SUMMARY Roots

1. Roots absorb water and minerals, support and anchor the plant, and store carbohydrates.
2. Taproots increase in length and diameter and develop lateral roots. Carrots have taproots.
3. Fibrous roots are branching roots of similar size. They do not penetrate as deeply as taproots but have a very long combined length. Grasses usually have fibrous roots.
4. In the centre of the root is the vascular cylinder.
5. In perennial dicots, the vascular cambium separates xylem and phloem. The cells of the vascular cambium divide by mitosis, producing phloem

cells to the outside and xylem cells to the inside. These new cells cause an increase in the root's diameter.

6. Surrounding the vascular cylinder is the pericycle, which forms lateral roots.
7. The endodermis surrounds the vascular cylinder and pericycle, and regulates the lateral movement of water and minerals in the root.
8. Pneumatophores and aerial roots form on some plants.
9. Epiphytes have roots that seldom reach the soil.
10. Allelopathy, the release of toxins into the soil, is a survival mechanism of a few plants.

Practice

Understanding Concepts

1. State the major functions of plant roots.
2. Compare taproots and fibrous roots.
3. The small roots seen growing laterally from carrots are not root hairs. What are they?
4. Root tips are often covered by large numbers of fine root hairs. How do these hairs assist the root in performing one of its functions?
5. Vascular tissue includes both xylem and phloem cells. Which of these cell types is located closest to the centre of the root?

Activity 13.4.1

Root Anatomy

In this activity, you will identify and compare the tissues in roots from a variety of representative plants. You will base your comparison on examinations of whole specimens and microscopic sections.

Questions

What types of plant tissues and structures are found in the root?
How are these tissues and structures arranged?
How are monocot and dicot root features similar or different?

Materials

microscope slides and cover slips
single-edged razor blade
germinating radish seeds with well-developed root hairs
prepared slides of cross sections of *Ranunculus* (buttercup) and *Zea* (corn) roots
prepared slides of longitudinal sections of an onion root tip
dissecting microscope or compound microscope
aerial root of a *Philodendron* or carrot taproot
fresh or herbarium specimens of a taproot and a fibrous root system
Lugol's solution in dropper bottles

Procedure

Part 1: The Root Tip

Always be careful when using a sharp instrument.

1. Obtain a germinating radish seed. Using a single-edged razor blade, cut off and prepare a wet mount of the bottom 1 cm of the root tip.

2. Examine the root tip using a dissecting microscope or a compound microscope on low power. Locate a mass of cells covering the root tip. This is the root cap. It covers the apical meristem, the region of active cell division.
3. Note the root hairs extending out from the root just behind the root cap. Examine the root hairs carefully. Determine the number of cells which make up each root hair.
4. Obtain a prepared microscope slide of a longitudinal section of an onion root tip. Examine the slide under low and medium power. Locate the root cap and the apical meristem region. Note that the cells of the apical meristem are small. Now look for the region in which the cells appear to be much greater in length. This is the region of cell elongation which functions to push the root tip through the soil.

Part 2: Monocot and Dicot Root Tissues

5. Obtain a prepared slide of a *Zea* root cross section. Observe this monocot root under low and medium power of a microscope. Locate the epidermis and the cortex. Note the presence of starch grains in the cells of the cortex. Locate the endodermis, the large xylem cells, the phloem cells, the vascular cambium, the pericycle, and the pith. Draw a cross-sectional "pie wedge" of the *Zea* root and label each part you located.
6. Obtain a prepared slide of a *Ranunculus* root cross section. This plant is a dicotyledon. Examine the slide and observe the location and arrangement of tissues. Take note of any differences between the *Ranunculus* and the *Zea*, particularly the central vascular tissue with its star-shaped bundle of large xylem cells. Draw a cross-sectional "pie wedge" of the *Ranunculus* root and label the epidermis, cortex, endodermis, and phloem and xylem tissues.
7. Examine fresh or herbarium samples of a taproot and fibrous root system. Note and compare the arrangements and relative sizes of the roots of each of these systems.

Part 3: Testing for the Presence of Starch

8. Lugol's solution contains iodine and is an indicator for starch. Iodine turns blue-black in the presence of starch. Using a single-edged razor blade, cut a very thin cross section of a small fresh root; the aerial root of a *Philodendron* is ideal. Place the section on a slide. Add one drop of Lugol's solution and then place a cover slip on top.
9. Observe the stained root section under low power. Sketch the cross section and show the location of starch grains.

Lugol's solution is toxic and can cause an itchy rash. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Analysis

(a) Based on your observations of both the live root and the prepared section, make a generalized sketch of a growing root tip. Label the root cap, root hairs, apical meristem, and zone of elongation.
(b) What differences did you observe between the actively dividing cells and those a little further back from the tip?
(c) Explain the function of a root cap based on its structure and location.
(d) What tissue gives rise to root hairs? How many cells does a single root hair consist of?
(e) What root function is demonstrated by the presence of starch grains within the cortex?