HO-96

Cooperative Extension Service

Basic Botany

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In this chapter:

Plants are essential to life on earth. Either directly or indirectly, they are the primary food source for humans and other animals. Additionally, they provide fuel, replenish the earth's oxygen supply, prevent soil erosion, slow down wind movement, cool the atmosphere, provide wildlife habitat, supply medicinal compounds, and beautify our surroundings.

Many plants are familiar to us, and we can identify and appreciate them based on their external structure. However, their internal structure and function often are overlooked. Understanding how plants grow and develop helps us capitalize on their usefulness and make them part of our everyday lives.

This chapter focuses on *vascular* plants—those that contain water-, nutrient-, and food-conducting tissues called "xylem" and "phloem." Ferns and seed-producing plants fall into this category.

In several cases, we will distinguish between *monocotyledonous* and *dicotyledonous* plants. Sometimes called "monocots" and "dicots" for short, these plants have several important distinguishing characteristics. For example, monocots (e.g., grasses) produce only one seed leaf, while dicots (broadleaf plants) have two. The vascular systems, flowers, and leaves of the two types of plants also differ (Table 1.1). These differences will be important in our discussion of plant growth and development.

Plant Life Cycles

Based on its life cycle, a plant is classified as either an annual, biennial, or perennial.

An *annual,* such as a zinnia, completes its life cycle in one year. Annuals are said to go from seed to seed in one year or growing season. During this period, they germinate, grow, mature, bloom, produce seeds, and die. Summer annuals complete their life cycle during spring and summer; most winter annuals complete their growing season during fall and winter. There are both winter and summer annual weeds, and understanding a weed's life cycle is important to controlling it.

A *biennial* requires all or part of two growing seasons to complete its life cycle. During the first season, it produces vegetative structures (leaves) and food storage organs. The plant overwinters and then produces flowers, fruit, and seeds during its second season. Swiss chard, carrots, beets, sweet William, and parsley are examples of biennials.

Sometimes biennials go from seed germination to seed production in only one growing season. This situation occurs when extreme environmental conditions, such as drought or temperature variation, cause the plant to pass rapidly through the equivalent of two growing seasons. This phenomenon is referred to as *bolting.* Sometimes bolting occurs when biennial plant starts are exposed to a cold spell before being planted in the garden.

Perennial plants live more than two years and are grouped into two categories: herbaceous perennials and woody perennials. *Herbaceous perennials* have soft, nonwoody stems that

Table 1.1. Comparison of monocots and dicots.

Structure	Monocots	Dicots
Seed leaves (cotyledons)	one	two
Vascular system	Xylem and phloem are paired in bundles, which are dispersed throughout the stem.	Xylem and phloem form rings inside the stem. The phloem forms an outer ring, the xylem an inner ring. In long-lived woody perennials, yearly concentric rings are produced.
Floral parts	Usually in threes or multiples of three.	Usually in multiples of four or five.
Leaves	Often parallel-veined.	Generally net-veined.

generally die back to the ground each winter. New stems grow from the plant's crown each spring. Trees and shrubs, on the other hand, have woody stems that withstand cold winter temperatures. They are referred to as *woody perennials*.

Internal Plant Parts

Cells are the basic structural and physiological units of plants. Most plant reactions (cell division, photosynthesis, respiration, etc.) occur at the cellular level. Plant *tissues* (meristems, xylem, phloem, etc.) are large, organized groups of similar cells that work together to perform a specific function.

A unique feature of plant cells is that they are readily *totipotent*. In other words, almost all plant cells retain all of the genetic information (encoded in DNA) necessary to develop into a complete plant. This characteristic is the main reason that vegetative (asexual) reproduction works. E.g., the cells of a small leaf cutting from an African violet have all of the genetic information necessary to generate a root system, stems, more leaves, and ultimately flowers.

Specialized groups of cells called *meristems* are a plant's growing points. Meristems are the site of rapid, almost continuous cell division. These cells either continue to divide or begin to differentiate into other tissues and organs. How they divide and whether they ultimately become a tissue or an organ are controlled by a complex array of internal plant hormones but also can be influenced by environmental conditions. In many cases, you can manipulate meristems to make a plant do something you want, such as change its growth pattern, flower, alter its branching habit, or produce vegetative growth.

External Plant Parts

External plant structures such as leaves, stems, roots, flowers, fruits, and seeds are known as plant *organs*. Each organ is an organized group of tissues that work together to perform a specific function. These structures can be divided into two groups: sexual (reproductive) and vegetative. *Sexual* or *reproductive* parts produce seed; they include flower buds, flowers, fruit, and seeds. *Vegetative* parts (Figure 1.1) include roots, stems, shoot buds, and leaves; they are not directly involved in sexual reproduction. Vegetative parts often are used in asexual forms of reproduction such as cuttings, budding, or grafting.

Roots

Often roots are overlooked, probably because they are less visible than the rest of the plant. However, it's important to understand plant root systems because they have a pronounced effect on a plant's size and vigor, method of propagation, adaptation to soil types, and response to cultural practices and irrigation.

Botany Terminology

Anther—The pollen sac on a male flower.

Apex—The tip of a shoot or root.

Apical dominance—The tendency of an apical bud to produce hormones that suppress growth of buds below it on the stem.

Axil—The location where a leaf joins a stem.

Cambium—A layer of growing tissue (meristem) that separates the xylem and phloem and produces new xylem and phloem cells.

Chlorophyll—The green pigment in leaves that is responsible for capturing light energy from the sun.

Chloroplast—A specialized component (organelle) of certain cells; contains chlorophyll and is responsible for photosynthesis.

Cortex—Cells that make up the primary tissue of the root and stem.

Cotyledon—The first leaf that appears on a seedling. Also called a seed leaf.

Cuticle—A relatively impermeable surface layer on the epidermis of leaves and fruits.

Dicot—Having two cotyledons or seed leaves.

Epidermis—The outermost layer of plant cells.

Guard cell—Epidermal cells that open and close to let water, oxygen, and carbon dioxide pass through the stomata.

Internode—The space between nodes on a stem.

Meristem—Specialized groups of cells that undergo cell division and are a plant's growing points.

Mesophyll—A leaf's inner tissue, located between the upper and lower epidermis; contains the chloroplasts and other specialized cellular parts (organelles).

Monocot—Having one cotyledon or seed leaf.

Node—An area on a stem where a leaf, stem, or flower bud is located.

Ovary—The part of a female flower where eggs are located. Also, the base of the pistil.

Petiole—The stalk that attaches a leaf to a stem.

Phloem—Photosynthate-conducting tissue.

Photosynthate—A food product (sugar or starch) created through photosynthesis.

Photosynthesis—The process in green plants of converting carbon dioxide and water into food (sugars and starches) using energy from sunlight.

Pistil—The female flower part; consists of a stigma, style, and ovary.

Respiration—The process of converting sugars and starches into energy.

Stamen—The male flower part; consists of an anther and a supporting filament.

Stigma—The top of a female flower (pistil) part; collects pollen.

Stoma (pl. stomates, stomata)—Tiny openings in the epidermis that allow water, oxygen, and carbon dioxide to pass into and out of a plant.

Style—The part of the female flower (pistil) that connects the stigma to the ovary. Pollen travels down the style to reach the ovary, where fertilization occurs.

Transpiration—The process of losing water (in the form of vapor) through stomata.

Turgor—Cellular water pressure; responsible for keeping cells firm.

Vascular tissue—Water-, nutrient-, and photosynthate-conducting tissue (xylem and phloem).

Xylem—Water- and nutrient-conducting tissue.

Roots typically originate from the lower portion of a plant or cutting. They have a root cap but lack nodes and never bear leaves or flowers directly. Their principal functions are to absorb nutrients and moisture, anchor the plant in the soil, support the stem, and store food. In some plants, they can be used for propagation.

Structure

Internally, there are three major parts of a root (Figure 1.2):

- The *meristematic zone* is at the tip and produces new cells; it is an area of cell division and growth.
- Behind the meristem is the *zone of elongation*. In this area, cells increase in size through food and water absorption. As they grow, they push the root through the soil.

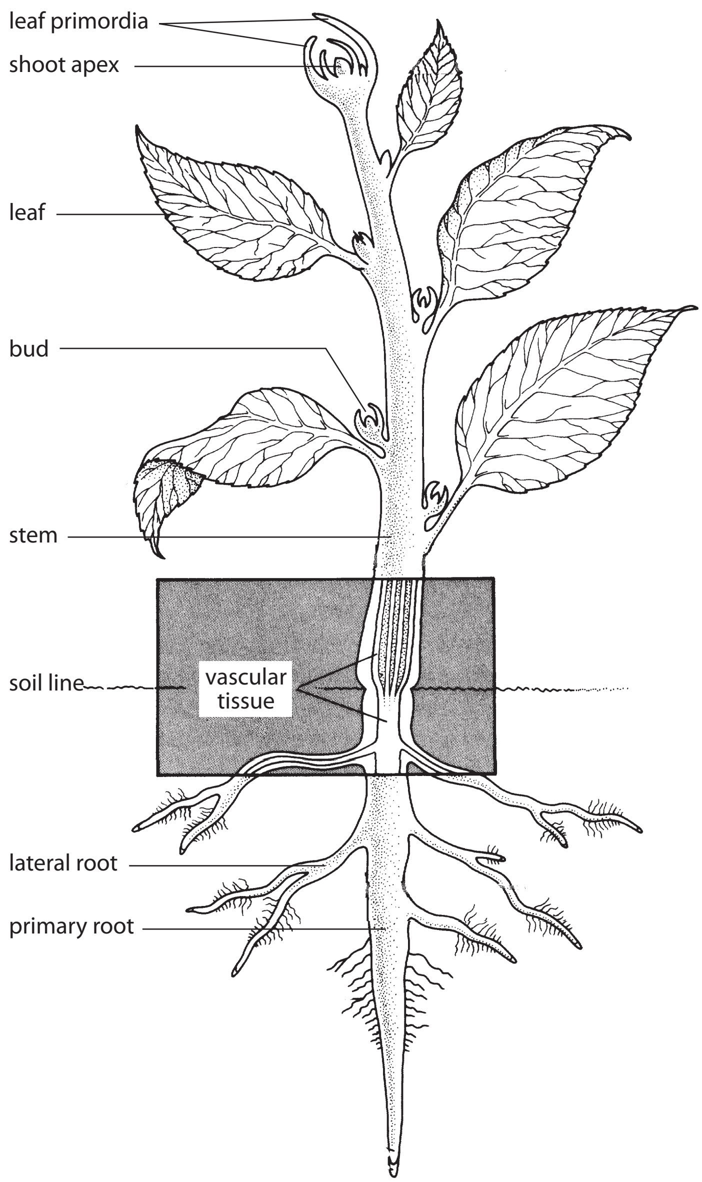

Figure 1.1. Principal parts of a vascular plant. (Adapted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

- The *zone of maturation* is directly beneath the stem. Here, cells become specific tissues such as epidermis, cortex, or vascular tissue.

A root's *epidermis* is its outermost layer of cells (Figure 1.3). These cells are responsible for absorbing water and minerals dissolved in water. *Cortex* cells are involved in moving water from the epidermis to the *vascular tissue* (xylem and phloem) and in storing food. Vascular tissue is located in the center of the root and conducts food and water.

Externally, there are two areas of importance: the root cap and the root hairs (Figure 1.2). The *root cap* is the root's outermost tip. It consists of cells that are sloughed off as the root grows through the soil. Its function is to protect the root meristem.

Root hairs are delicate, elongated epidermal cells that occur in a small zone just behind the root's growing tip. They generally appear as fine down to the naked eye. Their function is to increase the root's surface area and absorptive capacity. Root hairs usually live one or two days. When a plant is transplanted, they are easily torn off or may dry out.

Many roots have a naturally occurring *symbiotic* (mutually beneficial) relationship with *mycorrhizae* fungi, which improves the plant's ability to absorb water and nutrients.

Types of Roots

There are two major types of roots: primary and lateral roots.

A *primary* root originates at the lower end of a seedling's embryo (Figure 1.2). If the primary root continues to elongate downward, becomes the central feature of the root system, and has limited secondary branching, it is called a *taproot* (Figure 1.4a). Hickory and pecan trees, as well as carrots, have taproots.

A *lateral*, or secondary, root is a side or branch root that arises from another root. If the primary root ceases to elongate, and numerous lateral roots develop, a *fibrous* root system is formed (Figure 1.4b). These lateral roots branch repeatedly to form the network of feeding roots found on most plants.

Some plants, such as grasses, naturally produce a fibrous root system. In other cases, severing a plant's taproot by undercutting it can encourage the plant to produce a fibrous root system. Nurseries use this technique with trees that naturally produce a taproot, because trees with a compact, fibrous root system are transplanted more successfully.

How Roots Grow

During early development, a seedling absorbs nutrients and moisture from the soil around the sprouting seed. A band of fertilizer several inches to each side and slightly below newly planted seeds helps early growth of most row crops.

As a plant becomes well established, the quantity and distribution of its roots strongly influence its ability to absorb moisture and nutrients. For most plants, the majority of the absorbing (feeder) roots are located in the top 12 inches of soil. The soil environment in this region generally is best for root growth, with a good balance of fertility, moisture, and air spaces.

The following factors are important in root growth:

- Roots in water-saturated soil do not grow well and ultimately may die due to lack of oxygen.
- Roots penetrate much deeper in loose, well-drained soil than in heavy, poorly drained soil.
- A dense, compacted soil layer can restrict or terminate root growth.
- Container plants not only have a restricted area for root growth, but they are susceptible to cold damage because the limited amount of soil surrounding their roots may not provide adequate insulation. Dark-colored containers may also absorb solar radiation in summer, and the heat generated may also damage root systems.
- In addition to growing downward, roots grow laterally and often extend well beyond a plant's drip line (edge of foliage or canopy). Keep this extensive root system in mind when disturbing the soil around existing trees and shrubs.

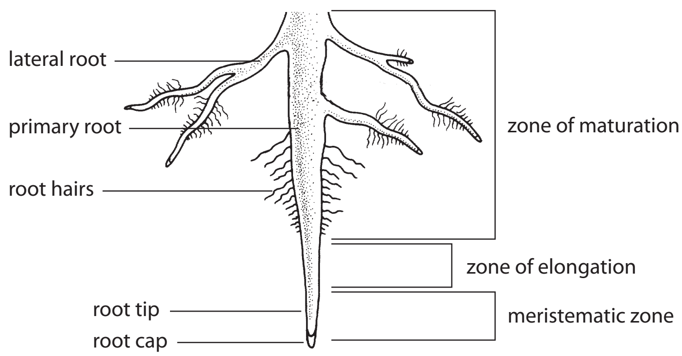

Figure 1.2. Root structure. (Adapted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

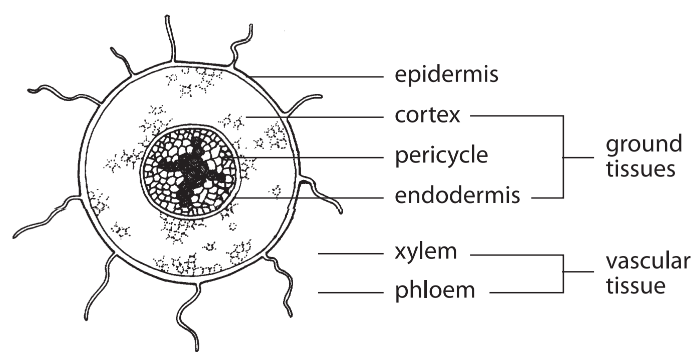

Figure 1.3. Cross section of a root. (Adapted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

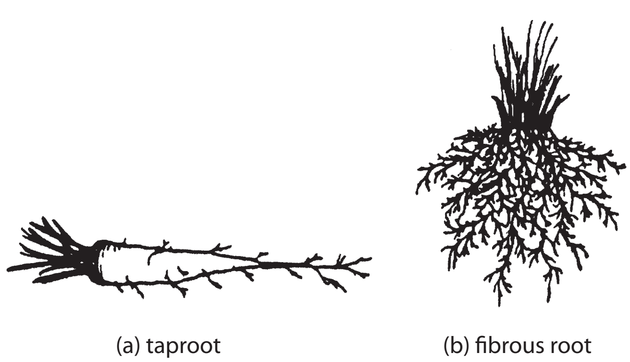

Figure 1.4. Taproot of a carrot (a) and fibrous root of grass (b).

Roots as Food

An enlarged root is the edible portion of several vegetable crops. Sweet potatoes are a swollen tuberous root; and carrots, parsnips, salsify, and radishes are elongated taproots.

Stems

Stems support buds and leaves and serve as conduits for carrying water, minerals, and food (*photosynthates*). The vascular system inside the stem forms a continuous pathway from the root, through the stem, and finally to the leaves. It is through this system that water and food products move.

Structure

Vascular system—This system consists of xylem, phloem, and vascular cambium. It can be thought of as a plant's plumbing. *Xylem* tubes conduct water and dissolved minerals; *phloem* tubes carry food such as sugars. The *cambium* is a layer of meristematic tissue that separates the xylem and phloem and produces new xylem and phloem cells. This new tissue is responsible for a stem's increase in girth.

The vascular cambium is important to gardeners. E.g., the cambial tissues on a grafted scion and rootstock need to line up. In addition, careless weed trimming can strip the bark off a tree, thus injuring the cambium and causing the tree to die.

The vascular systems of monocots and dicots differ (Figure 1.5). Although both contain xylem and phloem, these structures are arranged differently in each. In a monocot, the xylem and phloem are paired in bundles, which are dispersed throughout the stem. In a dicot, the vascular system is said to be continuous because it forms rings inside the stem. The phloem forms the outer ring just under the bark in mature woody stems. The xylem forms the inner ring and may be divided into the sapwood and heartwood. Individual rings may be evident in the xylem that correspond to growth events. In temperate zones or climates with pronounced wet and dry seasons, these individual rings can be used to discern the plant's age and the environmental conditions that may have caused differing rates of yearly growth.

Nodes—A node is an area on a stem where buds are located (Figure 1.6). It is a site of great cellular activity and growth where small buds develop into leaves, stems, or flowers. When pruning, it is important to locate a plant's nodes. Generally, you want to make a pruning cut just above, but not too close to, a node. Pruning in this manner encourages the buds at that node to begin development and ultimately form new stems or leaves.

The area between two nodes is called an *internode*. Its length depends on many factors, including genetics. Several other factors also can influence internode length:

- Reduced soil fertility decreases internode length, while an application of high-nitrogen fertilizer can greatly increase it.
- Lack of light increases internode length and causes spindly stems. This situation is known as stretch, or *etiolation*, and often occurs in seedlings started indoors and in houseplants that do not get enough sunlight.
- Internode length also varies with the season. Early-season growth has long internodes, while late-season growth generally has much shorter internodes.
- If a stem's energy is divided among three or four side stems or is diverted into fruit growth and development, internode length is shortened.
- Plant growth regulator substances and herbicides also can influence internode length.

Types of Stems

Stems may be long, with great distances between the leaves and buds (e.g., branches of trees, runners on strawberries) or compressed, with short distances between buds or leaves (e.g., crowns of strawberry plants, fruit spurs, and African violets). Although stems commonly grow aboveground, they sometimes grow belowground in the form of rhizomes, tubers, corms, or bulbs. All stems must have buds or leaves to be classified as stem tissue.

Specialized aboveground stems—Some plants have specialized aboveground stems known as crowns, spurs, or stolons (Figure 1.7). *Crowns* (on strawberries, dandelions, and African violets) are compressed stems with leaves and flowers on short internodes.

Spurs are short, stubby side stems that arise from a main stem. They are the fruit-bearing stems on pear, apple, and cherry trees. If severe pruning is done too close to fruit-bearing spurs, they can revert to nonfruiting stems, thus eliminating the year's potential fruit crop.

Stolons are fleshy or semiwoody, elongated, horizontal stems that often lie along the soil surface. Strawberry runners are stolons that have small leaves at the nodes. Roots develop from these nodes, and a daughter plant is formed. This type of vegetative reproduction is an easy way to increase the size of a strawberry patch.

Spider plants also produce stolons, which ultimately can become entirely new plants.

Specialized belowground stems—Potato tubers, iris rhizomes, and tulip bulbs are underground stems that store food for the plant (Figure 1.8). It sometimes is difficult to distinguish between roots and stems, but one sure way is to look for nodes. Stems have nodes; roots do not.

In potato *tubers*, for example, the "eyes" are actually the stem's nodes, and each eye contains a cluster of buds. When growing potatoes from "seed" pieces (cut potatoes), it is important that each piece contains at least one eye and be about the size of a golf ball so there will be enough energy for early growth of shoots and roots.

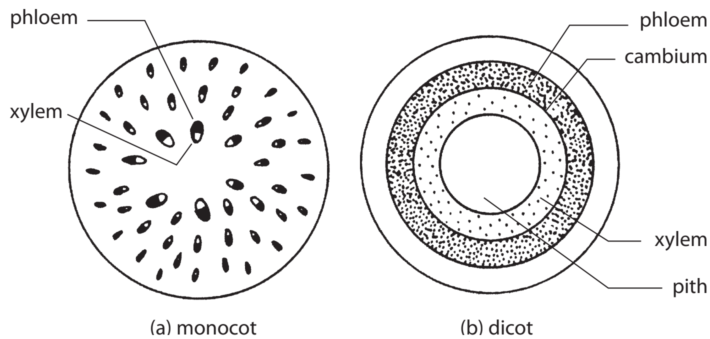

Figure 1.5. Cross sections of stems: (a) discontinuous vascular system of a monocot stem and (b) continuous vascular system of a woody dicot stem.

Stem Terminology

Shoot—A young stem (one year old or less) with leaves.

Twig—A young stem (one year old or less) that is in the dormant winter stage (has no leaves).

Branch—A stem that is more than one year old, typically with lateral stems radiating from it.

Trunk—A woody plant's main stem.

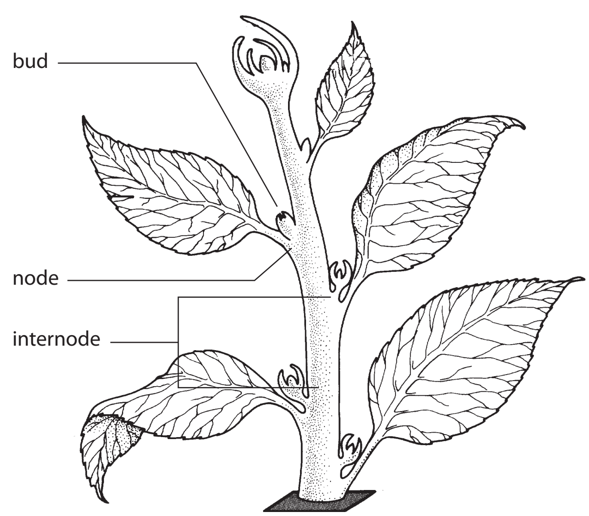

Figure 1.6. Stem structure. (Adapted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

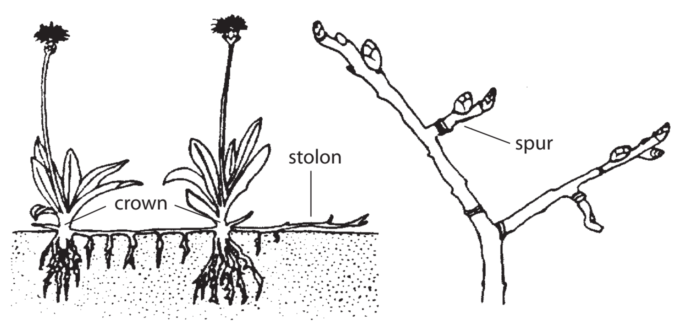

Figure 1.7. Diversified aboveground stem development.

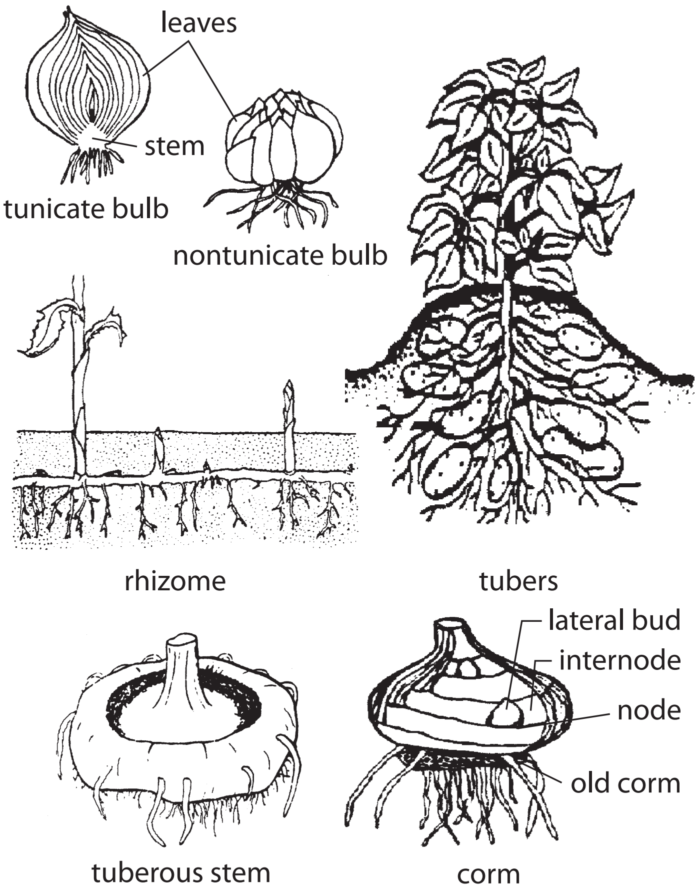

Figure 1.8. Diversified belowground stem development.

Rhizomes resemble stolons because they grow horizontally from plant to plant. Some rhizomes are compressed and fleshy (e.g., iris), while others are slender and have elongated internodes (e.g., bentgrass). Johnsongrass is an insidious weed principally because of the spreading capability of its rhizomes.

Tulips, lilies, daffodils, and onions produce *bulbs*, which are shortened, compressed underground stems surrounded by fleshy scales (leaves) that envelop a central bud at the tip of the stem. In November, you can cut a tulip or daffodil bulb in half and see all of the flower parts in miniature.

After a bulb-producing plant flowers, its phloem transports food reserves from its leaves to the bulb's scales. When the bulb begins growing in the spring, it uses the stored food. For this reason, it is important not to remove the leaves from daffodils, tulips, and other bulb-producing plants until after they have turned yellow and withered. At that time, these plants have finished producing the food that will be used for next year's flowering.

There are two types of bulbs: tunicate and nontunicate (Figure 1.8). *Tunicate* bulbs (e.g., daffodils, tulips, and onions) have concentric scales, actually modified leaves. It helps protect the bulb from damage during digging and from drying out once it is out of the soil. *Nontunicate,* or scaly, bulbs (e.g., lilies) have individual scalelike modified leaves. They are very susceptible to damage and drying out, so handle them very carefully.

Corms are another kind of belowground stem. Although both bulbs and corms are composed of stem tissue, they are not the same. Corms are shaped like bulbs, but do not contain fleshy scales. A corm is a solid, swollen stem with dry, scalelike leaves. Gladiolus and crocuses produce corms.

Other plants (e.g., dahlias and sweet potatoes) produce underground storage organs called *tuberous roots*, which often are confused with bulbs and tubers. However, these are root tissue, not stem tissue, and have neither nodes nor internodes.

Stems and Propagation

Stems often are used for vegetative plant propagation. Using sections of aboveground stems that contain nodes and internodes is an effective way to propagate many ornamental plants. These stem cuttings produce roots and eventually new plants.

Belowground stems also are good propagative tissues. You can divide rhizomes into pieces, remove small bulblets or cormels from the parent, and cut tubers into pieces containing eyes and nodes. All of these tissues will produce new plants.

Types of Plants and Their Stems

Trees generally have one, but occasionally several, main trunks, which usually are more than 12 feet tall when mature. In contrast, shrubs generally have several main stems, which usually are less than 12 feet tall when mature.

Most fruit trees, ornamental trees, and shrubs have woody stems. These stems contain relatively large amounts of hardened xylem tissue in the central core (heartwood or sapwood).

Herbaceous or succulent stems contain only a little xylem tissue and usually live for only one growing season. In perennial plants, new herbaceous stems develop from the crown (root–stem interface) each year.

Canes are stems with relatively large *pith*. They usually live only one or two years.

Examples of plants with canes include roses, grapes, blackberries, and raspberries. For fruit production, it is important to know which canes to prune, how to prune them, and when to prune them.

A *vine* is a plant with long, trailing stems. Some vines grow along the ground, while others must be supported by another plant or structure. Twining vines circle a structure for support. Some circle clockwise (e.g., hops and honeysuckle), while others circle counterclockwise (e.g., pole beans and Dutchman's pipe vine). Climbing vines are supported either by aerial roots (e.g., English ivy and poison ivy), by slender tendrils that encircle a supporting object (e.g., cucumbers, gourds, grapes, and passionflowers), or by tendrils with adhesive tips (e.g., Virginia and Japanese creeper). In temperate areas both woody and herbaceous trailing plants are called vines, but in the tropics, woody trailing plants are called "lianas."

Stems as Food

The edible portion of several cultivated plants, such as asparagus and kohlrabi, is an enlarged, succulent stem. The edible parts of broccoli are composed of stem tissue, flower buds, and a few small leaves. The edible tuber of a potato is a fleshy underground stem. And, although the name suggests otherwise, the edible part of cauliflower actually is proliferated stem tissue.

Buds

A bud is an undeveloped shoot from which leaves or flower parts grow. The buds of temperate-zone trees and shrubs typically develop a protective outer layer of small, leathery scales. Annual plants and herbaceous perennials have naked buds with green, somewhat succulent, outer leaves.

Buds of many plants require exposure to a certain number of days below a critical temperature before resuming growth in the spring. This period, often referred to as rest or chilling requirement, varies for different plants. Forsythia, for example, requires a relatively short rest period and grows at the first sign of warm weather. Many peach varieties, on the other hand, require 700 to 1,000 hours of temperatures below 45°F. During rest, dormant buds can withstand very low temperatures, but after the rest period is satisfied, they are more susceptible to damage by cold temperatures or frost.

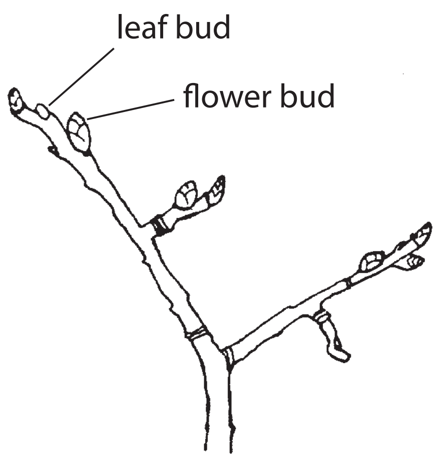

Figure 1.9. Elm leaf and flower buds.

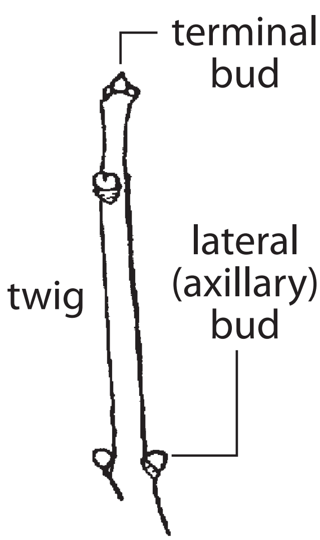

Figure 1.10. Bud location.

A leaf bud is composed of a short stem with embryonic leaves. Leaf buds often are less plump and more pointed than flower buds (Figure 1.9).

A flower bud is composed of a short stem with embryonic flower parts. In the case of fruit crops, flower buds sometimes are called fruit buds. This terminology is inaccurate, however; although flowers have the potential to develop into fruits, they may not do so because of adverse weather conditions, lack of pollination, or other unfavorable circumstances.

Location

Buds are named for their location on the stem (Figure 1.10). *Terminal* buds are located at the apex (tip) of a stem. Lateral (*axillary*) buds are located on the sides of a stem and usually arise where a leaf meets a stem (an *axil*). In some instances, an axil contains more than one bud.

Adventitious buds arise at sites other than the terminal or axillary position. They may develop from roots, a stem internode, the edge of a leaf blade, or callus tissue at the cut end of a stem or root. Adventitious buds allow stem, leaf, and root cuttings to develop into entirely new plants.

Buds as Food

Enlarged buds or parts of buds form the edible portion of some horticultural crops. Cabbage and head lettuce are examples of unusually large terminal buds. Succulent axillary buds are the edible part of Brussels sprouts. In the case of globe artichoke, the fleshy basal portion of the flower bud's bracts is eaten, along with its solid stem. Broccoli is the most important horticultural plant with edible flower buds. In this case, portions of the stem, as well as small leaves associated with the flower buds, are eaten.

Leaves

Function and Structure

The principal function of leaves is to absorb sunlight to manufacture plant sugars through a process called *photosynthesis*. Leaf surfaces are flattened to present a large area for efficient light absorption. The blade, or lamina, is the expanded thin structure on either side of the midrib and usually is the largest, most conspicuous part of a leaf (Figure 1.11).

A leaf is held away from its stem by a stemlike appendage called a *petiole*, and the base of the petiole is attached to the stem at a node. Petioles vary in length or may be lacking entirely, in which case the leaf blade is described as *sessile,* or stalkless.

The node where a petiole meets a stem is called a *leaf axil*. The axil contains single buds or bud clusters, referred to as axillary buds. They may be either active or dormant; under the right conditions, they will develop into stems or leaves.

A leaf blade is composed of several layers (Figure 1.12). On the top and bottom is a layer of thick, tough cells called the *epidermis*. Its primary function is to protect the other layers of leaf tissue. The arrangement of epidermal cells determines the leaf's surface texture. Some leaves, such as those of African violets, have hairs (*pubescence*), which are extensions of epidermal cells that make the leaves feel like velvet.

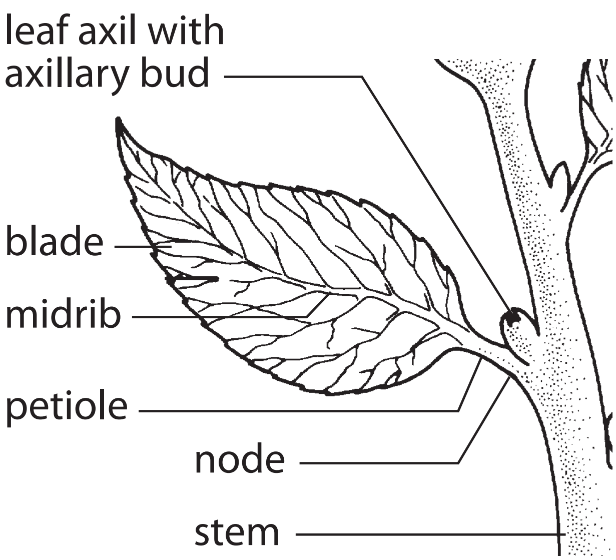

Figure 1.11. Leaf parts. (Adapted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

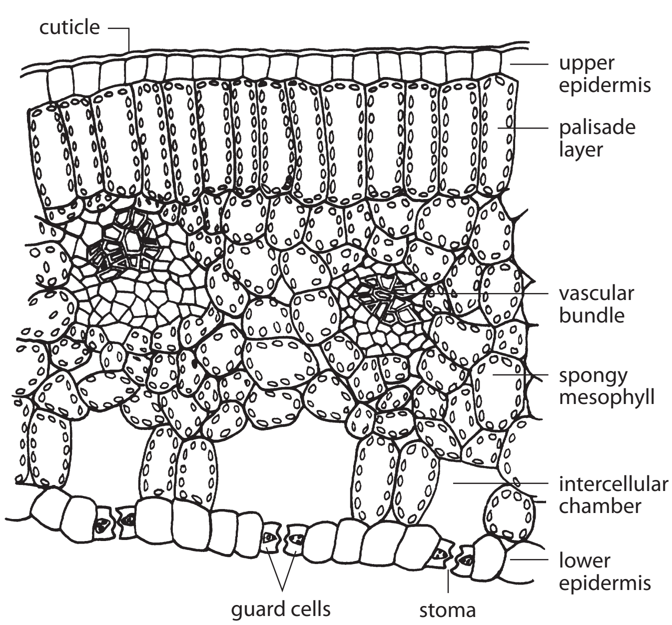

Figure 1.12. Leaf cross section. (Reprinted with permission from *Plant Science: Growth, Development, and Utilization of Cultivated Plants,* Prentice Hall, 1988.)

The *cuticle* is part of the epidermis. It produces a waxy layer called *cutin*, which protects the leaf from dehydration and disease. The amount of cutin on a leaf increases with increasing light intensity. For this reason, when moving plants from shade into full sunlight, do so gradually over a period of a few weeks. This gradual exposure to sunlight allows the cutin layer to build up and protect the leaves from rapid water loss or sunscald.

The waxy cutin also repels water. For this reason, many pesticides contain a spray additive to help the product adhere to, or penetrate, the cutin layer.

Special epidermal cells called *guard cells* open and close in response to environmental stimuli such as changes in weather and light. They regulate the passage of water, oxygen, and carbon dioxide into and out of the leaf through tiny openings called *stomata*. In most species, the majority of the stomata are located on the underside of leaves.

Conditions that would cause plants to lose a lot of water (high temperature, low humidity) stimulate guard cells to close. In mild weather, they remain open. Guard cells also close in the absence of light.

Located between the upper and lower epidermis is the *mesophyll*. It is divided into a dense upper layer (*palisade mesophyll*) and a lower layer that contains lots of air space (*spongy mesophyll*). Located within the mesophyll cells are *chloroplasts*, where photosynthesis takes place.

Types of Leaves

There are many kinds of plant leaves. The most common and conspicuous leaves are referred to as foliage and are the primary location of photosynthesis. However, there are many other types of modified leaves:

- *Scale leaves* (cataphylls) are found on rhizomes and buds, which they enclose and protect.
- *Seed leaves* (cotyledons) are found on embryonic plants. They store food for the developing seedling.
- *Spines* and *tendrils*, such as those on barberry and pea plants, protect a plant or help support its stems.
- *Storage leaves*, such as those on bulbous plants and succulents, store food.
- *Bracts* often are brightly colored. For example, the showy structures on dogwoods and poinsettias are bracts, not petals.

Venation

The vascular bundles of xylem and phloem extend from the stem, through the petiole, and into the leaf blade as veins.

The term *venation* refers to how veins are distributed in the blade. There are two principal types of venation: parallel-veined and net-veined (Figure 1.13).

In *parallel-veined* leaves, numerous veins run essentially parallel to each other and are connected laterally by minute, straight veinlets. Parallel-veined leaves occur most often on monocotyledonous plants. The most common type of parallel veining is found in plants of the grass family, whose veins run from the leaf's base to its apex.

In *net-veined* leaves (also called *reticulate-veined*), veins branch from the main rib or ribs and subdivide into finer veinlets. These veinlets then unite in a complicated network. This system of enmeshed veins makes the leaf more resistant to tearing than does a parallel vein structure. Net-veined leaves occur on dicotyledonous plants.

Net venation may be either pinnate or palmate. In *pinnate* (featherlike) venation, the veins extend laterally from the midrib to the edge (e.g., apples, cherries, and peaches). In *palmate* venation, the principal veins extend outward, like the ribs of a fan, from the base of the leaf blade (e.g., grapes and maples).

Leaves as Plant Identifiers

Leaves are useful for plant identification. A leaf's shape, base, apex, and margin can be important identifying characteristics (Figures 1.14–1.16).

Leaf type (Figure 1.17) also is important for identification. There are two types of leaves: simple and compound. In *simple* leaves, the leaf blade is a single, continuous unit. *Compound* leaves are composed of several separate leaflets arising from the same petiole. Some leaves are doubly compound. Leaf type can be confusing because a deeply lobed simple leaf may look like a compound leaf.

Leaf arrangement along a stem also is used in plant identification (Figure 1.18). There are four types of leaf arrangement:

- *Opposite* leaves are positioned across the stem from each other, with two leaves at each node.
- *Alternate* (spiral) leaves are arranged in alternate steps along the stem, with only one leaf at each node.
- *Whorled* leaves are arranged in circles along the stem.

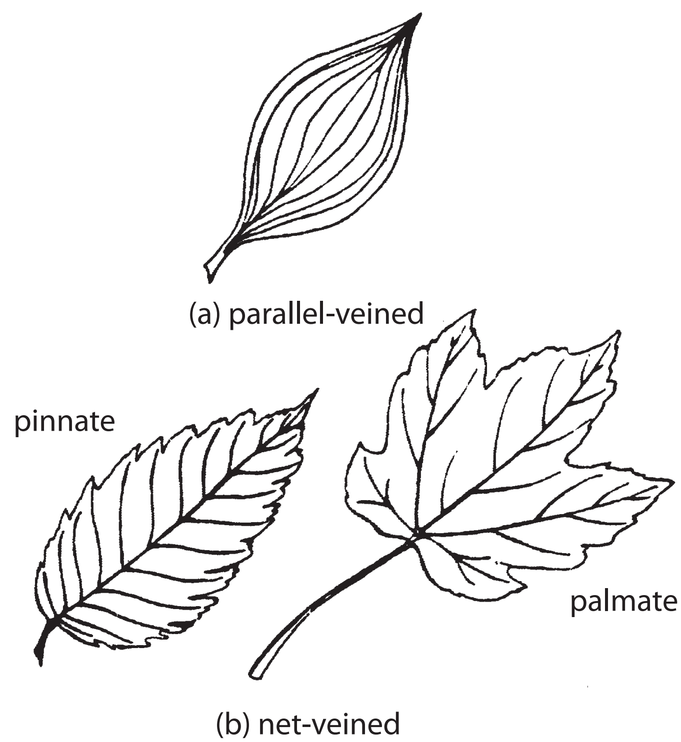

Figure 1.13. Types of venation: (a) parallel-veined; (b) net-veined.

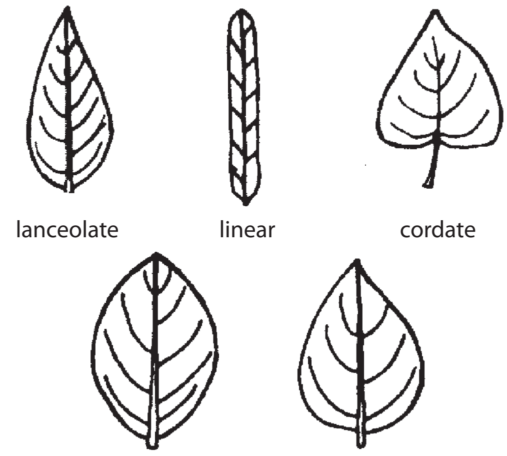

Figure 1.14. Common leaf blade shapes.

Lanceolate—Longer than wide and tapering toward the apex and base.

Linear—Narrow, several times longer than wide and of approximately the same width throughout.

Cordate (heart-shaped)—Broadly ovate, tapering to an acute apex, with the base turning in and forming a notch where the petiole is attached.

Elliptical—About two or three times as long as wide, tapering to an acute or rounded apex and base.

Ovate—Egg-shaped, basal portion wide, tapering toward the apex.

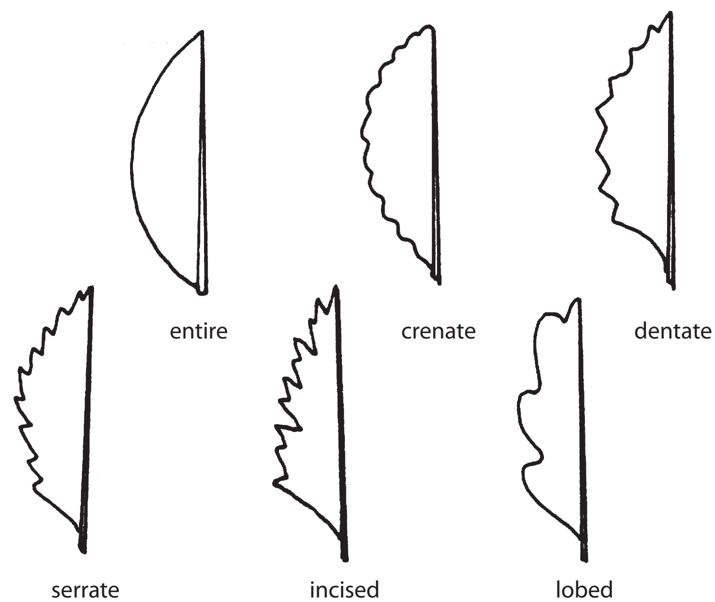

Figure 1.15. Common leaf margin shapes.

Entire—Having a smooth edge with no teeth or notches.

Crenate—Having rounded teeth.

Dentate—Having teeth ending in an acute angle pointing outward.

Serrate—Having small, sharp teeth pointing toward the apex.

Incised—Having a margin cut into sharp, deep, irregular teeth or incisions.

Lobed—Having incisions that extend less than halfway to the midrib.

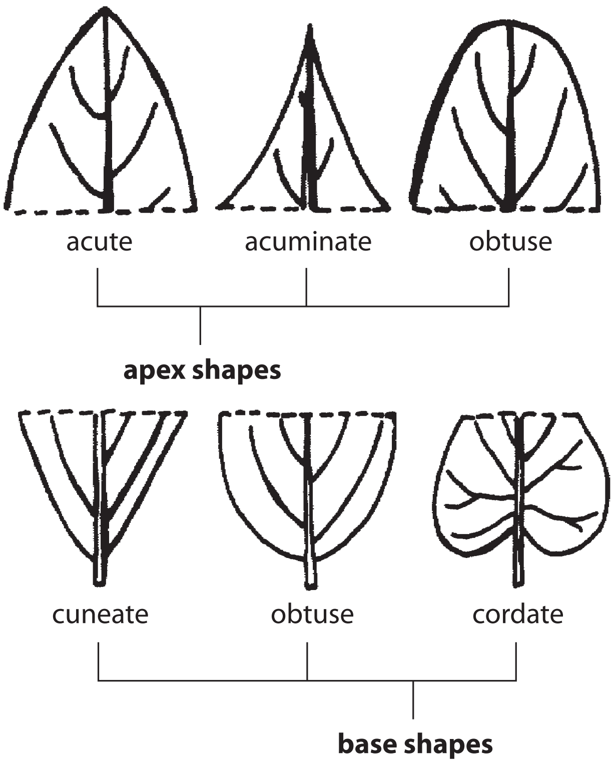

Figure 1.16. Common leaf apex and base shapes.

Acute—Ending in an acute angle, with a sharp, but not acuminate, point.

Acuminate—Tapering to a long, narrow point.

Obtuse—Tapering to a rounded edge.

Cuneate—Wedge-shaped; triangular with the narrow end at the point of attachment.

Cordate (heart-shaped)—Turning in and forming a notch.

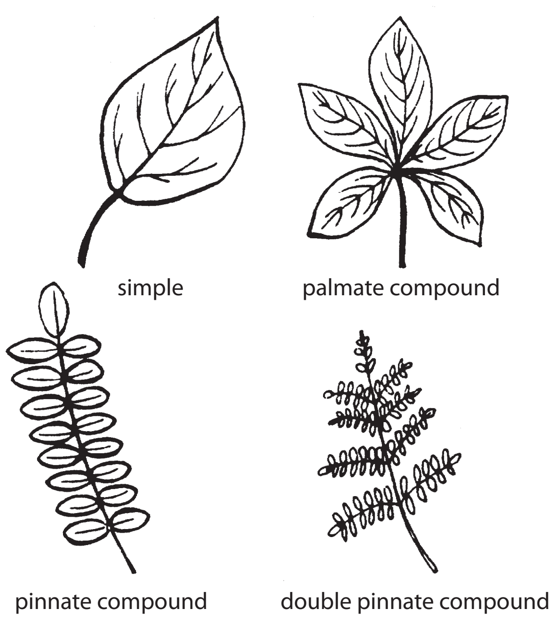

Figure 1.17. Leaf types.

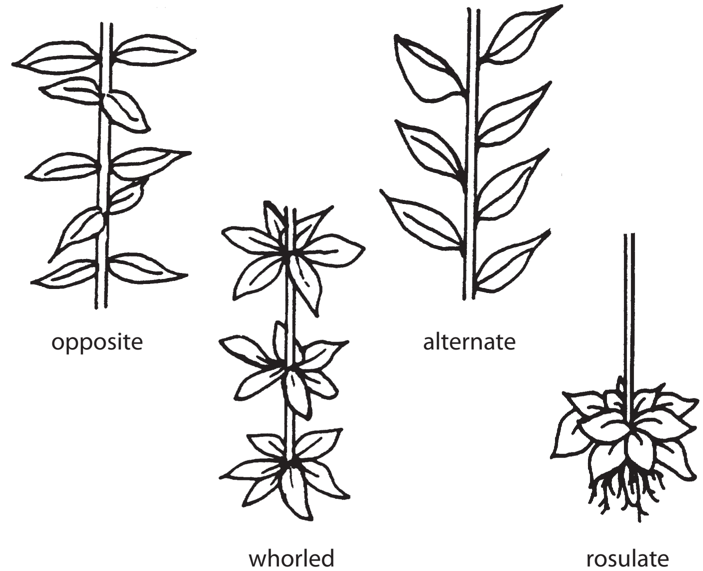

Figure 1.18. Leaf arrangement.

- *Rosulate* leaves are arranged in a rosette around a stem with extremely short nodes.

Leaves as Food

The leaf blade is the principal edible part of several horticultural crops, including chives, collards, endive, kale, leaf lettuce, mustard, parsley, spinach, Swiss chard, and other greens. The edible part of leeks, onions, and Florence fennel is a cluster of fleshy leaf bases. The petiole is the edible product in celery and rhubarb.

Flowers

Flowers, which generally are the showiest part of a plant, have sexual reproduction as their sole function. Their beauty and fragrance have evolved not to please humans but to ensure continuance of the species. Fragrance and color attract pollinators (insects, birds, or other animals), which play an important role in the reproductive process.

Flowers are important for plant classification. The system of plant nomenclature we use today was developed by Carl von Linné (Linnaeus) and is based on flowers and/or reproductive parts of plants. One reason his system is successful is because flowers are the plant part least influenced by environmental changes. Thus, knowledge of flowers and their parts is essential for anyone interested in plant identification.

Structure

As a plant's reproductive part, a flower contains a stamen (male flower part) and/or pistil (female flower part), plus accessory parts such as sepals, petals, and nectar glands (Figure 1.19).

The *stamen* is the male reproductive organ. It consists of a pollen sac (*anther*) and a long supporting filament. This filament holds the anther in position, making the pollen available for dispersal by wind, insects, birds, or other animals.

The *pistil* is a plant's female part. It generally is shaped like a bowling pin and is located in the flower's center. It consists of a stigma, style, and ovary. The *stigma* is located at the top and is connected by the *style* to the ovary. The *ovary* contains eggs, which reside in ovules. If an egg is fertilized, the ovule develops into a seed.

Sepals are small, green, leaf-like structures located at the base of a flower. They protect the flower bud. Collectively, the sepals are called a *calyx*.

Petals generally are the highly colored portions of a flower. Like nectar glands, petals may produce fragrance. Collectively, the petals are called a *corolla*. The number of petals on a flower often is used to help identify plant families and genera. Flowers of dicots typically have four or five sepals and/or petals or multiples thereof. In monocots, these floral parts typically come in threes or multiples of three.

Types of Flowers

If a flower has a stamen, pistil, petals, and sepals, it is called a *complete* flower (Figure 1.19). Roses are an example. If one of these parts is missing, the flower is called *incomplete*.

The stamen and pistil are the essential parts of a flower and are involved in seed production. If a flower contains both functional stamens and pistils, it is called a *perfect* flower, even if it does not contain petals and sepals. If either stamens or pistils are lacking, the flower is called *imperfect* (Figure 1.20). *Pistillate* (female) flowers possess a functional pistil or pistils but lack stamens. *Staminate* (male) flowers contain stamens but no pistils.

Plants with imperfect flowers are further classified as monoecious or dioecious. *Monoecious* plants have perfect flowers of separate male and female flowers on the same plant (e.g., corn and pecans). Some monoecious plants bear only male flowers at the beginning of the growing season but later develop both sexes (e.g., cucumbers and squash).

Dioecious species have separate male and female plants. Examples include holly, ginkgo, and pistachio. In order to set fruit, male and female plants must be planted close enough together for pollination to occur. In some instances (e.g., holly), the fruit is desirable. In the case of ginkgo, however, the fruit generally is not desirable due to its putrid smell when ripe. Kiwis are complicated because they may have one plant with bisexual flowers and another plant with only male flowers. The plant world isn't all absolutes!

Types of Inflorescences

Some plants bear only one flower per stem, which is called a *solitary* flower. Other plants produce an *inflorescence*—a cluster of flowers. Each flower in an inflorescence is called a *floret*.

Most inflorescences belong to one of two groups: racemes and cymes. In the *racemose* group, the florets start blooming from the bottom of the stem and progress toward the top. In a *cyme*, the top floret opens first and blooms progress downward along the stem. Detailed discussions of flower types are found in many botany textbooks. (See "For More Information" at the end of this chapter.)

How Seeds Form

Pollination is the transfer of pollen from an anther to a stigma, either by wind or by pollinators. Species pollinated by insects, animals, or birds often have brightly colored or patterned flowers that contain fragrance or nectar. While searching for nectar, pollinators transfer pollen from flower to flower, either on the same plant or on different plants. Plants evolved this ingenious mechanism in order to ensure their species' survival. Wind-pollinated flowers often lack showy floral parts and nectar because they don't need to attract pollinators.

A chemical in the stigma stimulates pollen to grow a long tube down the style to the ovules inside the ovary. When pollen reaches the ovules, it releases sperm, and fertilization typically occurs. *Fertilization* is the union of a male sperm nucleus from a pollen grain with a female egg. If fertilization is successful, the ovule develops into a seed. It is important to remember that pollination is no guarantee that fertilization will occur.

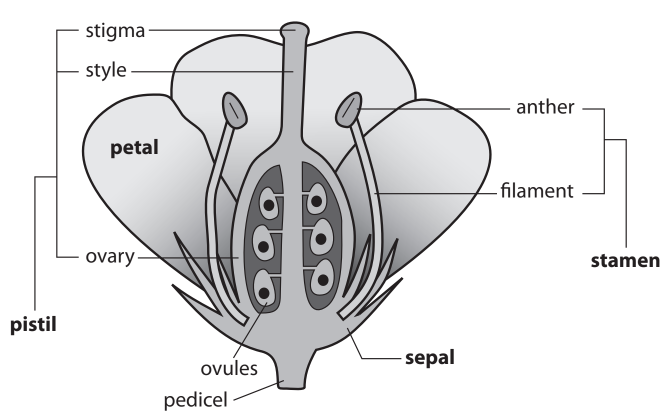

Figure 1.19. Complete flower structure.

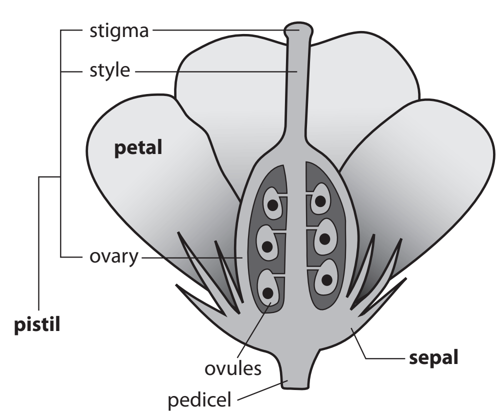

Figure 1.20. Imperfect (pistillate) flower structure.

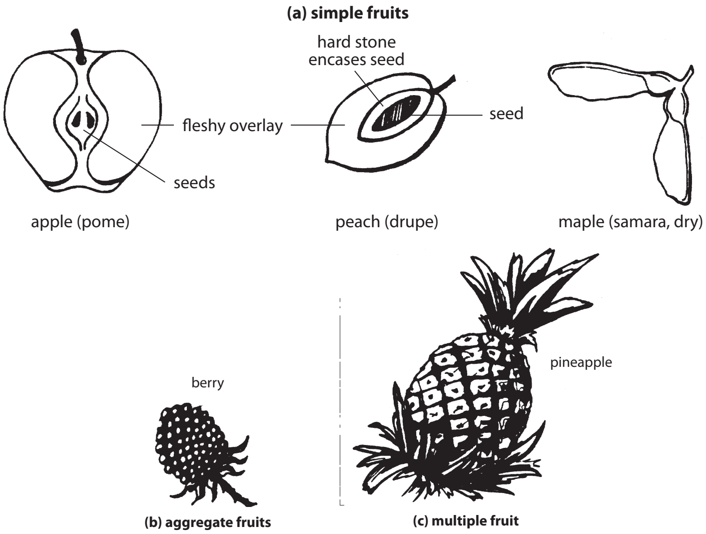

Figure 1.21. Types of fruit: (a) Simple fruits (apple, peach, and maple) and (b) aggregate fruits (berry and cone) and (c) multiple fruit (pineapple).

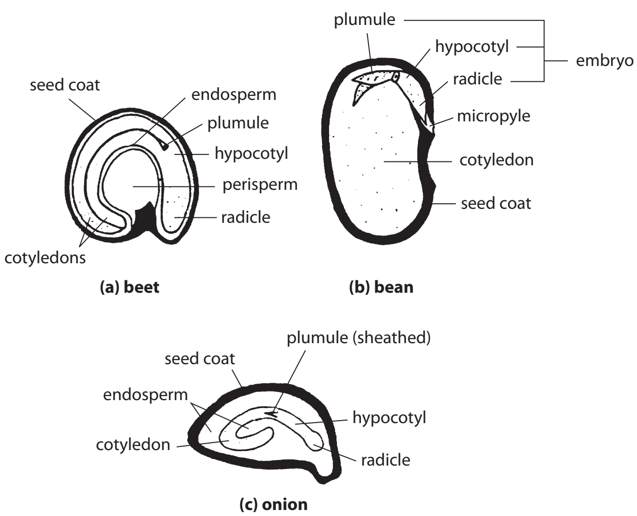

Figure 1.22. Parts of a seed: (a) beet; (b) bean; (c) onion. In bean, the cotyledons replace the endosperm in providing food for the germinating embryo.

Cross-fertilization combines genetic material from two parent plants. The resulting seed has a broader genetic base, which may enable the population to survive under a wider range of environmental conditions.

Fruit

Structure

Fruit consists of fertilized, mature ovules (seeds) plus the ovary wall, which may be fleshy, as in a peach.

The only part of the fruit that contains genes from both the male and female flowers is the seed. The rest of the fruit arises from the maternal plant and is genetically identical to it.

Types of Fruit

Fruits are classified as simple, aggregate, or multiple (Figure 1.21). *Simple* fruits develop from a single flower and a single ovary. They include fleshy fruits such as cherries and peaches (drupe), pears and apples (pome), and tomatoes (berries). Although generally referred to as a vegetable, tomato is technically a fruit because it develops from a flower. Squash, cucumbers, and eggplants also develop from a single ovary and are classified botanically as fruits.

Other types of simple fruit are dry. Their wall is either papery or leathery and hard, as opposed to the fleshy examples just mentioned. Examples are peanuts (legume), poppies (capsule), maples (samara), and walnuts (nut).

An *aggregate* fruit develops from a single flower with many ovaries. Examples are strawberries, raspberries, and blackberries. The flower has one corolla, one calyx, and one stem, but it has many pistils and ovaries. Each ovary is fertilized separately. If some ovules are not pollinated successfully, the fruit will be misshapen.

Multiple fruits are derived from a tight cluster of separate, independent flowers borne on a single structure. Each flower has its own calyx and corolla. Pineapples and figs are examples.

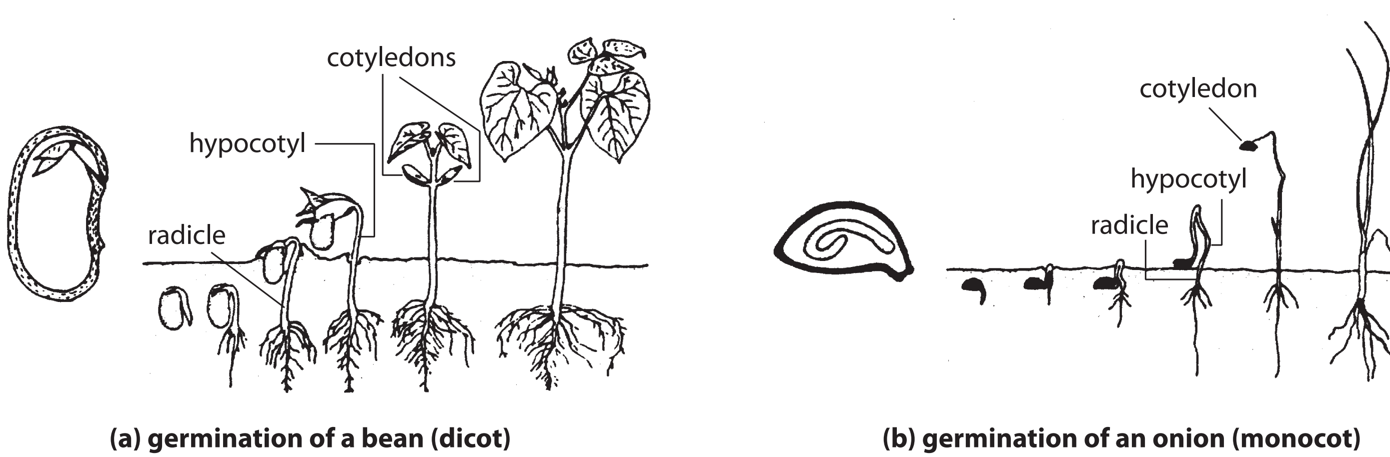

Figure 1.23. Germination of a dicot (a) and a monocot (b).

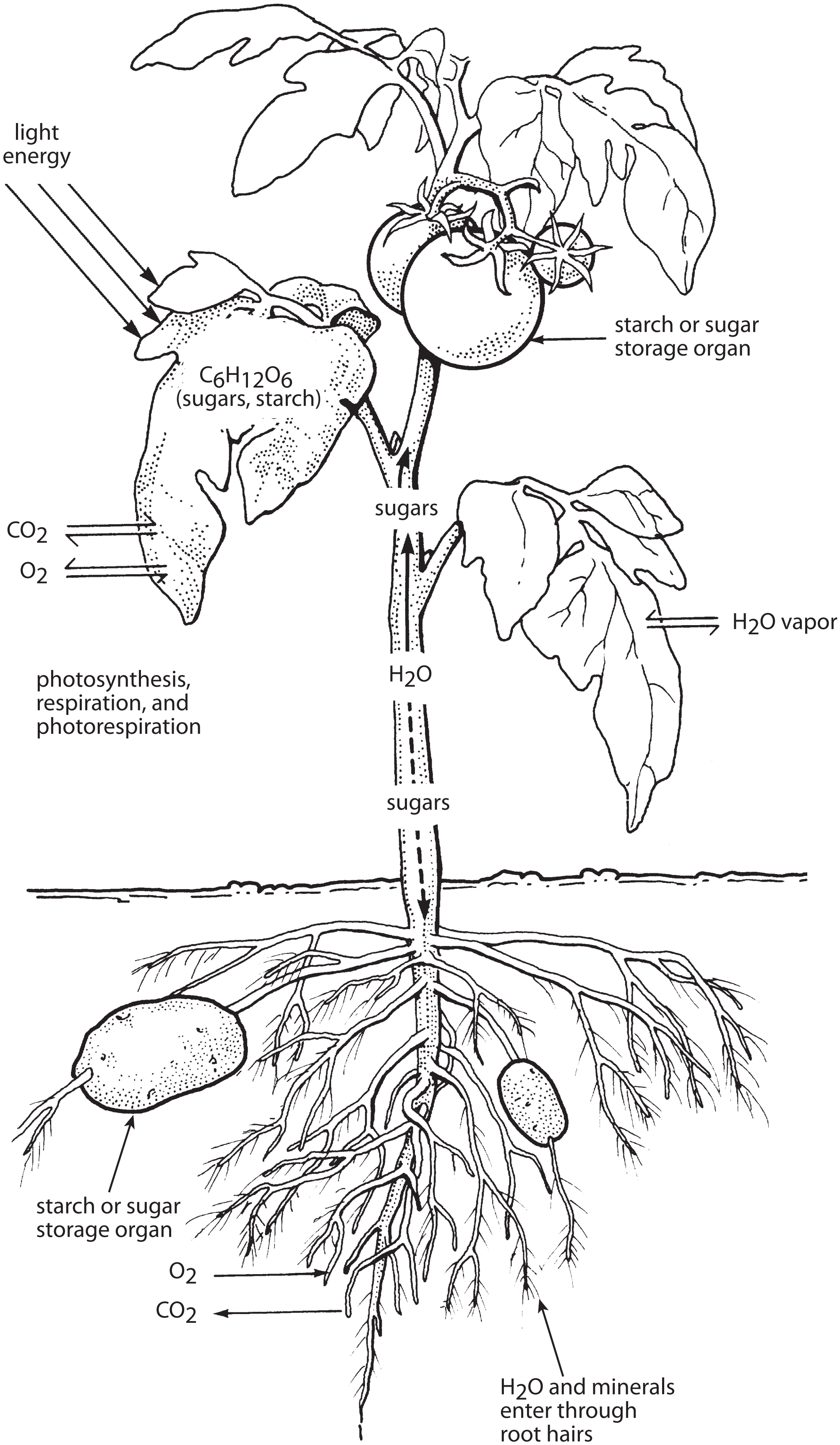

Figure 1.24. Schematic representation of photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant. (Reprinted with permission from *Plant Science: Growth, Development, and Utilization of Cultivated Plants,* Prentice Hall, 1988.)

Seeds

A seed contains all of the genetic information needed to develop into an entire plant. As shown in Figure 1.22, it is made up of three parts:

- The *embryo* is a miniature plant in an arrested state of development. It will begin to grow when conditions are favorable.
- The *endosperm* (and in some species the cotyledons) is a built-in food supply (although orchids are an exception where the seed contains no endosperm), which can be made up of proteins, carbohydrates, or fats.
- The *seed coat*, a hard outer covering, protects the seed from disease and insects. It may also prevent water from entering the seed and initiating germination before the proper time.

Germination

Germination is a complex process whereby a seed embryo goes from a dormant state to an active, growing state (Figure 1.23). Before any visible signs of germination appear, the seed must absorb water through its seed coat. It also must have enough oxygen and a favorable temperature. Some species, such as celery, also require light. Others require darkness.

If these requirements are met, the *radicle* is the first part of the seedling to emerge from the seed. It develops into the primary root and grows downward in response to gravity. From this primary root, root hairs and lateral roots develop. Between the radicle and the first leaflike structure is the *hypocotyl*, which grows upward in response to light.

The seed leaves, or *cotyledons*, encase the embryo. They usually are shaped differently than the leaves produced by the mature plant. Monocots produce one cotyledon, while dicots produce two.

Because seeds are reproductive structures and thus important to a species' survival, plants have evolved many mechanisms to ensure seed survival. One such mechanism is seed dormancy. Dormancy comes in two forms: seed coat dormancy and embryo dormancy.

In *seed coat dormancy*, a hard seed coat does not allow water to penetrate. Redbud, locust, and many other ornamental trees and shrubs exhibit this type of dormancy.

A process called *scarification* is used to break or soften the seed coat. In nature, scarification is accomplished by means such as the heat of a forest fire, digestion of the seed by a bird or mammal, or partial breakdown of the seed coat by fungi or insects. The breakdown can be done mechanically by nicking the seed coat with a file or chemically by softening the seed coat with sulfuric acid. In either instance, it is important to not damage the embryo.

Embryo dormancy is common in ornamental plants, including elm and witch hazel. These seeds must go through a chilling period before germinating. To break this type of dormancy, *stratification* is used. This process involves storing seeds in a moist medium (potting soil or paper towels) at temperatures between 32°F and 50°F. The length of time required varies by species.

Even when environmental requirements for seed germination are met and dormancy is broken, other factors also affect germination:

- The seed's age greatly affects its *viability* (ability to germinate). Older seed generally is less viable than young seed, and if older seed does germinate, the seedlings are less vigorous and grow more slowly.
- The seedbed must be properly prepared and made up of loose, fine-textured soil.

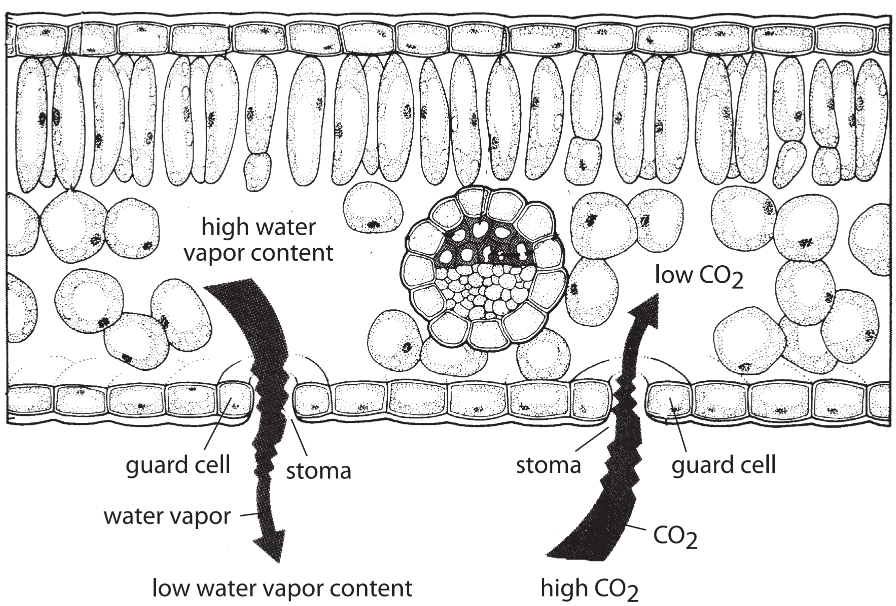

Figure 1.25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave. (Reprinted with permission from *Plant Physiology,* The Benjamin/Cummings Publishing Company, Inc., 1991.)

- Seeds must be planted at the proper depth. If they are too shallow, they may wash away with rain or watering; if they are too deep, they won't be able to push through the soil.
- Seeds must have a continual supply of moisture; however, if overwatered, they will rot.

Many weed seeds are able to germinate quickly and under less-than-optimal conditions. This is one reason they make such formidable opponents in the garden.

Plant Growth and Development

Photosynthesis, respiration, and transpiration are the three major functions that drive plant growth and development (Figure 1.24). All three are essential to a plant's survival. How well a plant is able to regulate these functions greatly affects its ability to compete and reproduce.

Photosynthesis

One of the major differences between plants and animals is plants' ability to manufacture their own food. This process is called *photosynthesis*, which literally means "to put together with light." To produce food, a plant requires energy from the sun, carbon dioxide from the air, and water from the soil. The formula for photosynthesis can be written as follows:

carbon dioxide + water + sunlight
= sugar + oxygen

or

$$6CO_2 + 6H_2O > C_6H_{12}O_6 + 6O_2$$

After producing carbohydrates, a plant either uses them as energy, stores them as starch, or builds them into complex energy compounds such as oils and proteins. All of these food products are called *photosynthates*. The plant uses them to build complex structures or transports them to its roots or developing fruits.

Photosynthesis occurs only in the *mesophyll* layers of plant leaves and, in some instances, in mesophyll cells in the stem. Mesophyll cells are sandwiched between the leaf's upper and lower epidermis (Figure 1.12) and contain numerous *chloroplasts*, where photosynthesis takes place. Chloroplasts are incredibly small. One square millimeter, about the size of a period on a page, would contain 400,000 chloroplasts.

Chlorophyll, the pigment that makes leaves green, is found in the chloroplasts. It is responsible for trapping light energy from the sun. Often chloroplasts are arranged perpendicular to incoming sun rays so they can absorb maximum sunlight.

If any of the ingredients for photosynthesis—light, water, and carbon dioxide—is lacking, photosynthesis stops. If any factor is absent for a long period of time, a plant will die. Each of these factors is described below.

Light

Photosynthesis depends on the availability of light. Generally, as sunlight intensity increases, so does photosynthesis. However, for each plant species, there is a maximum level of light intensity above which photosynthesis does not increase. Many garden crops, such as tomatoes, respond best to maximum sunlight. Tomato production decreases drastically as light intensity drops, and few tomato varieties produce any fruit under minimal sunlight conditions.

Water

Water is one of the raw materials for photosynthesis. It is taken up into the plant by the roots and moved upward through the xylem. Anything that hinders water movement in the plant, such as physical injury or insect/disease damage, will impact photosynthesis. Drought conditions that limit water availability may also cause stomata guard cells to close, limiting CO_2 uptake and slowing photosynthesis.

Carbon dioxide

Photosynthesis also requires carbon dioxide (CO_2), which enters a plant through its stomata (Figure 1.25). In most plants, photosynthesis fluctuates throughout the day as stomata open and close. Typically, they open in the morning, close down at midday, reopen in late afternoon, and shut down again in the evening.

Carbon dioxide is plentiful in the air, so it is not a limiting factor in plant growth. However, it is consumed rapidly during photosynthesis and is replenished very slowly in the atmosphere. Tightly sealed greenhouses may not allow enough outside air to enter and thus may lack adequate carbon dioxide for plant growth. Carbon dioxide generators are used to replenish or supplement CO_2 in commercial greenhouses for crops such as roses, carnations, and tomatoes. In smaller home greenhouses, dry ice is an effective source of CO_2.

Temperature

Although not a direct component in photosynthesis, temperature is important. Photosynthesis occurs at its highest rate between 65°F and 85°F and decreases at higher or lower temperatures.

Table 1.2. Photosynthesis and respiration.

Photosynthesis	Respiration
Produces food	Uses food
Stores energy	Releases energy
Uses water	Produces water
Uses carbon dioxide	Produces carbon dioxide
Releases oxygen	Uses oxygen
Occurs in sunlight	Occurs in darkness as well as in light

Respiration

Carbohydrates made during photosynthesis are of value to a plant when they are converted to energy. This energy is used for cell growth and building new tissues. The chemical process by which sugars and starches are converted to energy is called *oxidation* and is similar to the burning of wood or coal to produce heat. Controlled oxidation in a living cell is called *respiration* and is shown by this equation:

sugar + oxygen = carbon dioxide + water+ energy

or

$$C_6H_{12}O_6 + 6O_2 > 6CO_2 + 6H_2O + \text{energy}$$

This equation is essentially the opposite of photosynthesis. Photosynthesis is a building process, while respiration is a breaking-down process (Table 1.2). Unlike photosynthesis, respiration does not depend on light, so it occurs at night as well as during the day. Respiration occurs in all life forms and in all cells.

Transpiration

When a leaf's guard cells shrink, its stomata open, and water vapor is lost. This process is called *transpiration*. In turn, more water is pulled through the plant from the roots. The rate of transpiration is directly related to whether stomata are open or closed. Stomata account for only 1 percent of a leaf's surface, but 90 percent of the water transpired is released through stomata.

Transpiration is a necessary process and uses about 90 percent of the water that enters a plant's roots. The other 10 percent is used in chemical reactions and in plant tissues. Water moving via the transpiration stream is responsible for several functions:

- Transporting minerals from the soil throughout the plant.
- Cooling the plant through evaporation.
- Maintaining cell firmness.

The amount and rate of water loss depends on factors such as temperature, humidity, and wind or air movement. Transpiration often is greatest in hot, dry (low relative humidity), windy weather. However, transpiration may decrease during drought conditions when a limited water supply will cause stomata to close.

Environmental Factors Affecting Growth

Plant growth and geographic distribution are greatly affected by the environment. If any environmental factor is less than ideal, it limits a plant's growth and/or distribution. For example, only plants adapted to limited amounts of water can live in deserts.

Either directly or indirectly, most plant problems are caused by environmental stress. In some cases, poor environmental conditions (e.g., too little water) damage a plant directly. In other cases, environmental stress weakens a plant and makes it more susceptible to disease or insect attack.

Environmental factors that affect plant growth include light, temperature, water, humidity, and nutrition. It is important to understand how these factors affect plant growth and development. With a basic understanding of these factors, you may be able to manipulate plants to meet your needs, whether for increased leaf, flower, or fruit production. By recognizing the roles of these factors, you also will be better able to diagnose plant problems caused by environmental stress.

Light

Three principal characteristics of light affect plant growth: quantity, quality, and duration.

Quantity

Light quantity refers to the intensity, or concentration, of sunlight. It varies with the seasons. The maximum amount of light is present in summer, the minimum in winter. Up to a point, the more sunlight a plant receives, the greater its capacity for producing food via photosynthesis.

You can manipulate light quantity to achieve different plant growth patterns. Increase light by surrounding plants with reflective materials, a white background, or supplemental lights. Decrease it by shading plants with cheesecloth or woven shade cloth.

Quality

Light quality refers to the color (wavelength) of light. Sunlight supplies the complete range of wavelengths and can be broken up by a prism into bands of red, orange, yellow, green, blue, indigo, and violet.

Blue and red light, which plants absorb, have the greatest effect on plant growth. Blue light is responsible primarily for vegetative (leaf) growth. Red light, when combined with blue light, encourages flowering. Plants look green to us because they reflect, rather than absorb, green light.

Knowing which light source to use is important for manipulating plant growth. For example, fluorescent (cool white) light is high in the blue wavelength. It encourages leafy growth and is excellent for starting seedlings. Incandescent light is high in the red or orange range, but generally produces too much heat to be a valuable light source for plants. Fluorescent grow-lights attempt to imitate sunlight with a mixture of red and blue wavelengths, but they are costly and generally no better than regular fluorescent lights.

Duration

Duration, or *photoperiod*, refers to the amount of time a plant is exposed to light. Photoperiod controls flowering in many plants (Figure 1.26). Scientists initially thought the length of light period triggered flowering and other responses within plants, so they describe plants as short-day or long-day, depending on the plants' flowering conditions. We now know

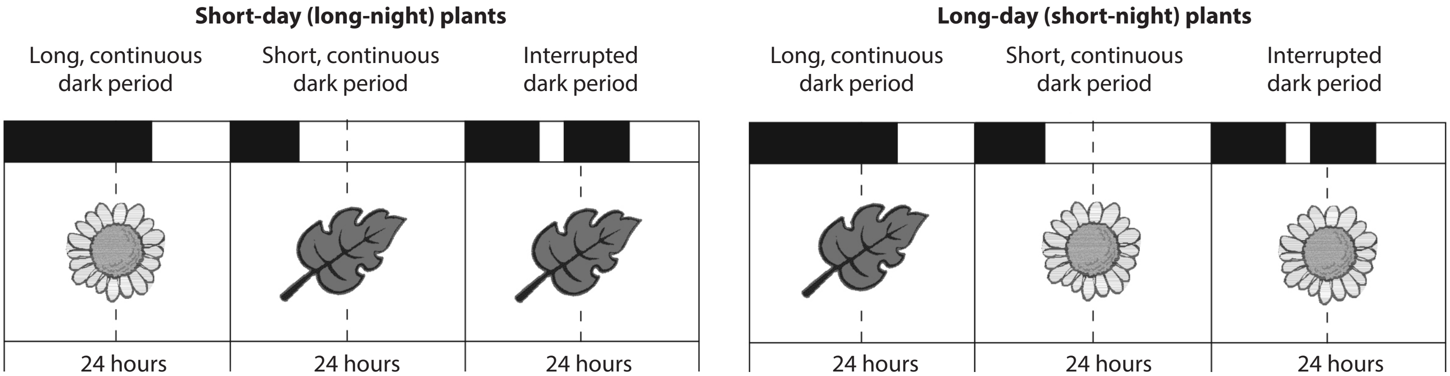

Figure 1.26. Periodicity of plants. Short-day (long-night) plants require a long period of uninterrupted darkness to flower. Long-day (short-night) plants require a short period of uninterrupted darkness to flower.

that it is not the length of the light period but rather the length of uninterrupted darkness that is critical to floral development.

Plants are classified into three categories: short day (long night), long day (short night), or day neutral, depending on their response to the duration of light or darkness. *Short-day* plants form flowers only when day length is less than a critical photoperiod required—for example, 13 hours. Many spring and fall-flowering plants, such as chrysanthemums, poinsettias, and Christmas cactus, are in this category.

In contrast, *long-day* plants form flowers only when day length exceeds a critical photoperiod. Most summer-flowering plants (e.g., rudbeckia, California poppies, and asters), as well as many vegetables (beets, radishes, lettuce, spinach, and potatoes), are in this category.

Day-neutral plants form flowers regardless of day length. Examples are tomatoes, corn, cucumbers, and some strawberry cultivars. Some plants do not fit into any category, but may respond to combinations of day lengths. Petunias, for example, flower regardless of day length, but flower earlier and more profusely with long days.

You can easily manipulate photoperiod to stimulate flowering. For example, chrysanthemums normally flower in the short days of spring or fall, but you can get them to bloom in midsummer by covering them with a cloth that completely blocks out light for longer than the critical photoperiod each day. After several weeks of this treatment, the artificial dark period no longer is needed, and the plants will bloom as if it were spring or fall. This method also is used to make poinsettias flower in time for Christmas.

To bring a long-day plant into flower when day length is less than the critical photoperiod, expose the plant to supplemental light. After a few weeks, flower buds will form. Incandescent rather than fluorescent light is most often used to control photoperiod.

Temperature

Temperature influences most plant processes, including photosynthesis, transpiration, respiration, germination, and flowering. As temperature increases (up to a point), photosynthesis, transpiration, and respiration increase. When combined with day length, temperature also affects the change from vegetative (leafy) to reproductive (flowering) growth. Depending on the situation and the specific plant, the effect of temperature can either speed up or slow down this transition.

Germination

The temperature required for germination varies by species. Generally, cool-season crops (e.g., spinach, radishes, and lettuce) germinate best at 55°F to 65°F, while warm-season crops (e.g., tomatoes, petunias, and lobelias) germinate best at 65°F to 75°F.

Flowering

Sometimes horticulturists use temperature in combination with day length to manipulate flowering. For example, a Christmas cactus forms flowers as a result of short days and low temperatures (Figure 1.26). To encourage a Christmas cactus to bloom, place it in a room with long-night conditions each day and a temperature of 50°F to 55°F until flower buds form.

If temperatures are high and days are long, cool-season crops such as spinach will flower (bolt). However, if temperatures are too cool, fruit will not set on warm-season crops such as tomatoes.

Crop quality

Low temperatures reduce energy use and increase sugar storage. Thus, leaving crops such as ripe winter squash on the vine during cool, fall nights increases their sweetness.

Adverse temperatures, however, cause stunted growth and poor-quality vegetables. For example, high temperatures cause bitter lettuce.

Photosynthesis and Respiration

Thermoperiod refers to daily temperature change. Plants grow best when daytime temperature is about 10° to 15° higher than nighttime temperature. Under these conditions, plants photosynthesize (build up) and respire (break down) during optimum daytime temperatures and then curtail respiration at night. However, not all plants grow best under the same nighttime and daytime temperatures. For example, snapdragons grow best at nighttime temperatures of 55°F; poinsettias, at 62°F.

Temperatures higher than needed increase respiration, sometimes above the rate of photosynthesis. Thus, photosynthates are used faster than they are produced. For growth to occur, photosynthesis must be greater than respiration.

Daytime temperatures that are too low often produce poor growth by slowing down photosynthesis. The result is reduced yield (e.g., fruit or grain production).

Breaking Dormancy

Some plants that grow in cold regions need a certain number of days of low temperature (dormancy). Knowing the period of low temperature required by a plant, if any, is essential in getting it to grow to its potential.

Peaches are a prime example; most varieties require 700 to 1,000 hours between 32°F and 45°F before breaking their rest period and beginning growth. Lilies need six weeks of temperatures at or slightly below 33°F before blooming.

Hardiness

Plants are classified as hardy or nonhardy depending on their ability to withstand cold temperatures. *Hardy* plants are those that are adapted to the cold temperatures of their growing environment.

Woody plants in the temperate zone have very sophisticated means for sensing the progression from fall to winter. Decreasing day length and temperature trigger hormonal changes that cause leaves to stop photosynthesizing and to ship nutrients to twigs, buds, stems, and roots. An *abscission* layer forms where each petiole joins a stem, and the leaves eventually fall off. Changes within the trunk and stem tissues over a relatively short period of time "freeze-proof" the plant.

Winter injury to hardy plants may occur when temperatures drop too quickly in the fall before a plant has progressed to full dormancy. In other cases, a plant may break dormancy in mid- or late winter if the weather is unseasonably warm. If a sudden, severe cold snap follows the warm spell, otherwise hardy plants can be seriously damaged.

It is worth noting that the tops of hardy plants are much more cold-tolerant than the roots. Plants that normally are hardy to 10°F may be killed if they are in containers and the roots are exposed to 20°F. Many nurseries overwinter hardy plants in protective structures or protect plant roots by sinking pots in the ground or insulating pots with sawdust or mulch.

Winter injury also may occur because of *desiccation* (drying out) of plant tissues. People often forget that plants need water even during winter. When the soil is frozen, water movement into a plant is severely restricted. On a windy winter day, broadleaf evergreens can become water-deficient in a few minutes, and the leaves or needles will then turn brown. To minimize the risk of this type of injury, make sure your plants go into the winter well watered.

Water and Humidity

Most growing plants contain about 90 percent water, playing many roles in plants. It is:

- A primary component in photosynthesis and respiration
- The source of *turgor pressure* in cells (Like air in an inflated balloon, water is responsible for the fullness and firmness of plant tissue. Turgor is needed to maintain cell shape and ensure cell growth.)
- A solvent for minerals and carbohydrates moving through the plant
- A means for cooling leaves as it evaporates from leaf tissue during transpiration
- A regulator of stomatal opening and closing, thus controlling transpiration and, to some degree, photosynthesis
- The source of pressure to move roots through the soil
- The medium in which most biochemical reactions take place

Relative humidity is the ratio of water vapor in the air to the amount of water the air could hold at the current temperature and pressure. Warm air can hold more water vapor than cold air. Relative humidity (RH) is expressed by the following equation:

RH = water in air ÷ water air could hold
(at constant temperature and pressure)

Relative humidity is given as a percent. For example, if a pound of air at 75°F could hold four grams of water vapor and there are only three grams of water in the air, then the relative humidity (RH) is

$$3 \div 4 = 0.75 = 75\%$$

Water vapor moves from an area of high relative humidity to one of low relative humidity. The greater the difference in humidity, the faster water moves. This factor is important because the rate of water movement directly affects a plant's transpiration rate.

The relative humidity in the air spaces between leaf cells approaches 100 percent. When a stoma opens, water vapor inside the leaf rushes out into the surrounding air (Figure 1.25), and a bubble of high humidity forms around the stoma. By saturating this small area of air, the bubble reduces the difference in relative humidity between the air spaces within the leaf and the air adjacent to the leaf. As a result, transpiration slows down.

If wind blows the humidity bubble away, however, transpiration increases. Thus, transpiration usually is at its peak on hot, dry, windy days. On the other hand, transpiration generally is quite slow when temperatures are cool, humidity is high, and there is no wind.

Hot, dry conditions generally occur during the summer, which partially explains why plants wilt quickly in the summer. If a constant supply of water is not available to be absorbed by the roots and moved to the leaves, turgor pressure is lost and leaves go limp.

Table 1. 3. Plant macronutrients.

Element	Absorbed forms	Mobility in plants	Signs of excess	Signs of deficiency	Notes
Nitrogen (N)	NO_3- (nitrate) NH_4+ (ammonium)	Leachable, especially NO_3-. Mobile in plants.	Succulent growth; dark-green color; weak, spindly growth; few fruits. May cause brittle growth, especially under high temperatures.	Reduced growth, yellowing (chlorosis). Reds and purples may intensify in some plants. Reduced lateral bud breaks. Symptoms appear first on older growth.	In general, the best NH_4+:NO_3- ratio is 1:1. Under low-sugar conditions (low light), high NH_4+ can cause leaf curl. Uptake is inhibited by high P levels. The N:K ratio is extremely important. Indoors, the best N:K ratio is 1:1 unless light is extremely high. In soils with a high C:N ratio, more N should be supplied.
Phosphorus (P)	H_2PO_4- HPO_4- (phosphate)	Normally not leachable, but may leach from soil high in bark or peat. Not readily mobile in plants.	Shows up as micronutrient deficiency of Zn, Fe, or Co.	Reduced growth. Color may intensify. Browning or purpling of foliage in some plants. Thin stems, reduced lateral bud breaks, loss of lower leaves, reduced flowering.	Rapidly bound (fixed) on soil particles. Under acid conditions, fixed with Fe, Mg, and Al (aluminum). Under alkaline conditions, fixed with Ca. Important for young plant and seedling growth. High P interferes with micronutrient absorption and N absorption. Used in relatively small amounts compared to N and K.
Potassium (K)	K+	Can leach in sandy soils. Mobile in plants.	Causes N deficiency in plant and may affect the uptake of other positive ions.	Reduced growth, shortened internodes. Marginal burn or scorch (brown leaf edges), necrotic (dead) spots in leaves. Reduction of lateral bud breaks, tendency to wilt readily.	N:K balance is important. High N:low K favors vegetative growth; low N:high K promotes reproductive growth (flowers, fruit).
Magnesium (Mg)	Mg++	Leachable. Mobile in plants.	Interferes with Ca uptake.	Reduction in growth. Marginal chlorosis, interveinal chlorosis (yellow between the veins) in some species (may occur on middle or lower leaves). Reduction in seed production, cupped leaves.	Mg commonly is deficient in foliage plants because it is leached and not replaced. Epsom salts at a rate of 1 teaspoon per gallon may be used two times per year. Mg also can be absorbed by leaves if sprayed in a weak solution. Dolomitic limestone can be applied in outdoor situations to correct a deficiency.
Calcium (Ca)	Ca++	Normally not leachable. Moderately limited mobility in plants. Interferes with Mg absorption.	High Ca usually causes high pH, which then precipitates many micronutrients so that they become unavailable to plants.	Inhibition of bud growth, death of root tips. Cupping of maturing leaves, weak growth. Blossom-end rot of many fruits, pits on root vegetables.	Ca is important to pH control and rarely is deficient if the correct pH is maintained. Water stress (too much or too little) can affect Ca relations within plants, causing deficiency in the location where Ca was needed at the time of stress.
Sulfur (S)	SO_4- (sulfate)	Leachable. Not mobile in plants.	Sulfur excess usually is in the form of air pollution.	General yellowing of affected leaves or the entire plant.	S often is a carrier or impurity in fertilizers and rarely is deficient. It also may be absorbed from the air and is a by-product of combustion.

Table 1.4. Plant micronutrients.

Element	Absorbed forms	Signs of excess	Signs of deficiency	Notes
Iron (Fe)	Fe++, Fe+++	Rare except on flooded soils. Interveinal chlorosis, primarily on young tissue, which eventually may turn white.	Soil high in Ca, Mn, P, or heavy metals (Cu, Zn); high pH; poorly drained soil; oxygen-deficient soil; nematode attack on roots.	Add Fe in the chelate form. The type of chelate needed depends on soil pH.
Boron (B)	BO_3-(borate)	Blackening or death of tissue between veins.	Failure to set seed, internal breakdown, death of apical buds.	
Zinc (Zn)	Zn++	Shows up as Fe deficiency. Also interferes with Mg absorption.	"Little leaf" (reduction in leaf size), short internodes, distorted or puckered leaf margins, interveinal chlorosis.	
Copper (Cu)	Cu++, Cu+	Can occur at low pH. Shows up as Fe deficiency.	New growth small, misshapen, wilted.	May be found in some peat soils.
Manganese (Mn)	Mn++	Reduction in growth, brown spotting on leaves. Shows up as Fe deficiency.	Interveinal chlorosis of leaves followed by brown spots, producing a checkered effect.	Found under acid conditions.
Molybdenum (Mo)	MoO_4-(molybdate)		Interveinal chlorosis on older or midstem leaves, twisted leaves (whiptail).	
Chlorine (Cl)	Cl-	Salt injury, leaf burn. May increase succulence.	Leaves wilt, then become bronze, then chlorotic, then die; club roots.	

Plant Nutrition

Plant nutrition often is confused with fertilization. *Plant nutrition* refers to a plant's need for and use of basic chemical elements. *Fertilization* is the term used when these materials are added to the environment around a plant. A lot must happen before a chemical element in a fertilizer can be used by a plant.

Plants need 16 elements for normal growth. Three of them—carbon, hydrogen, and oxygen—are found in air and water. The rest are found in the soil.

Three soil elements are called *primary nutrients* because they are used in relatively large amounts by plants. They are nitrogen, phosphorus, and potassium. Calcium, magnesium, and sulfur are called *secondary nutrients* because they are used in moderate amounts. Often, primary and secondary nutrients are collectively called *macronutrients* (Table 1.3).

Seven other soil elements are used in much smaller amounts and are called *micronutrients*, or trace elements (Table 1.4). They are iron, boron, zinc, copper, manganese, molybdenum, and chlorine.

Most of the nutrients a plant needs are dissolved in water and then absorbed by its roots. In fact, 98 percent are absorbed from the soil-water solution, and only about 2 percent are actually extracted from soil particles.

Fertilizers

Fertilizers are materials containing plant nutrients that are added to the environment around a plant. Generally, they are added to the water or soil, but some can be sprayed on leaves. This method is called *foliar fertilization*. It should be done carefully with a dilute solution, because a high fertilizer concentration can injure leaf cells. The nutrient, however, does need to pass through the thin layer of wax (cutin) on the leaf surface.

Fertilizers are not plant food! Plants produce their own food from water, carbon dioxide, and solar energy through photosynthesis. This food (sugars and carbohydrates) is combined with plant nutrients to produce proteins, enzymes, vitamins, and other elements essential to growth.

Nutrient Absorption

Anything that reduces or stops sugar production in leaves can lower nutrient absorption. Thus, if a plant is under stress because of low light or extreme temperatures, nutrient deficiency may develop.

A plant's developmental stage or rate of growth also may affect the amount of nutrients absorbed. Many plants have a rest (dormant) period during part of the year. During this time, few nutrients are absorbed. As flower buds begin to develop, plants also may absorb different nutrients than they absorb during periods of rapid vegetative growth.

Plants in Communities

The preceding discussion focused on the structure and physiology of individual plants. Interactions among plants also are important for gardeners. The study of these interactions is called plant or landscape *ecology*.

In ornamental gardens, we generally aim to develop a stable community of plants that complement each other in form, color, leaf characteristics, and bloom. We must pay attention to the differing requirements of plants within this community.

A garden's framework often is defined by large shrubs or trees, which cast differing amounts of shade over the course of the year. When choosing plants to grow under or near large framework specimens, be sure their needs match the available light and moisture.

As trees and shrubs grow and mature, you may need to manipulate them, either by removing those that have outgrown their space or by selective pruning and thinning. Often, understory plants that did well when the landscape was young

Table 1.5. Common growth-affecting materials.

Compound	Effect/Use
Hormones	
Gibberellic acid (GA)	Stimulates cell division and elongation, breaks dormancy, speeds germination.
Ethylene gas (CH_2)	Ripening agent; stimulates leaf and fruit abscission.
Indoleacetic acid (IAA)	Stimulates apical dominance, rooting, and leaf abscission.
Plant growth regulators	
Indolebutyric acid (IBA)	Stimulates root growth.
Naphthalene acetic acid (NAA)	Stimulates root growth, slows respiration (used as a dip on holly).
Growth retardants (Alar, B-Nine, Cycocel, A-Rest)	Prevent stem elongation in selected crops (e.g., chrysanthemums, poinsettias, and lilies).
Herbicides (2,4-D, etc.)	Distort plant growth; selective and nonselective materials used for killing unwanted plants.

must be replaced with plants that are more shade tolerant. This process is a kind of plant *succession*, dictated by the changing light and moisture environment and carried out by the owner.

A lawn also is a changing landscape. It starts out as a mix of several adapted grass species on bare ground. Other plants (which we often call weeds) sprout from seed reserves in the soil. Additional seeds and plants move in and grow if conditions are right. Broadleaf weeds may find niches in bare areas or areas with compacted soil, or their low growth habit (dandelion) may escape mowing. Moss begins to take over where the lawn is thin, a common problem in semishaded areas. These changes are another example of plant succession.

To manage invasive plants, keep your lawn grasses competitive by using proper cultural practices, periodically overseeding, and using herbicides in certain situations. In spite of your best efforts, however, plant succession may occur.

Gardeners who plant wildflower mixtures often discover that there is much more variety in flowers the first year than in succeeding years. Some species do very well, and others simply cannot compete. Again, plant succession occurs.

The most short-term assemblage of plants in a garden occurs in annual vegetable and flower beds. Here there is no attempt to create a community that will last more than one season.

Since many of the most competitive weeds thrive in recently disturbed soil, it is a challenge to give desired annual crop plants an advantage. The plant that captures light first will grow and suppress plants beneath it. Early weed competition can have a devastating impact on crop growth. Consistent weeding, mulching, and the use of transplants improve the odds for annual vegetable and flower crops.

Another type of relationship between plants is called *allelopathy*. In this phenomenon, some plants produce compounds in their leaves, roots, or both that inhibit the growth of other plants. Black walnut is the most notorious example. Its roots can suppress many common vegetable plants, and its leaves, if mulched on a vegetable garden over the winter, can affect many annual crops as does an herbicide the following spring. Some of the worst weeds show allelopathic traits and prevent desired ornamental or vegetable species from growing.

Finally, there are relationships between plants that involve pollinators, animals, birds, pests, predators, and even nutrient transport between species through symbiotic fungi called *mycorrhizae*. These relationships are quite complex, and many are not well understood. They are the subject of active research and offer much to think about for thoughtful gardeners.

Plant Hormones and Growth Regulators

Plant hormones and growth regulators are chemicals that affect flowering; aging; root growth; distortion and killing of leaves, stems, and other parts; prevention or promotion of stem elongation; color enhancement of fruit; prevention of leafing and/or leaf fall; and many other conditions (Table 1.5). Very small concentrations of these substances produce major growth changes.

Hormones are produced naturally by plants, while *plant growth regulators* are applied to plants by humans. Plant growth regulators may be synthetic compounds (e.g., IBA and Cycocel) that mimic naturally occurring plant hormones or natural hormones that were extracted from plant tissue (e.g., IAA).

Applied concentrations of these substances usually are measured in parts per million (ppm) and in some cases parts per billion (ppb). These growth-regulating substances most often are applied as a spray to foliage or as a liquid drench to soil around a plant's base. Generally, their effects are short lived, and they may need to be reapplied in order to achieve the desired effect.

There are five groups of plant growth-regulating compounds: auxin, gibberellin (GA), cytokinin, ethylene, and abscisic acid (ABA). For the most part, each group contains both naturally occurring hormones and synthetic substances.

Auxin causes several responses in plants:

- Bending toward a light source (*phototropism*)
- Downward root growth in response to gravity (*geotropism*)
- Promotion of apical dominance
- Flower formation
- Fruit set and growth
- Formation of adventitious roots

Auxin is the active ingredient in most rooting compounds in which cuttings are dipped during vegetative propagation.

Gibberellins stimulate cell division and elongation, break seed dormancy, and speed germination. The seeds of some species are difficult to germinate; you can soak them in a GA solution to get them started.

Unlike other hormones, *cytokinins* are found in both plants and animals. They stimulate cell division and often are included in the sterile media used for growing plants from tissue culture. If a medium's mix of growth-regulating compounds is high in cytokinins and low in auxin, the tissue culture explant (small plant part) will produce numerous shoots. On the other hand, if the mix has a high ratio of auxin to cytokinin, the explant will produce more roots. Cytokinins also are used to delay plant aging and death (*senescence*).

Ethylene is unique in that it is found only in the gaseous form. It induces ripening, causes leaves to droop (*epinasty*) and drop (abscission), and promotes senescence. Plants often increase ethylene production in response to stress, and ethylene often is found in high concentrations within cells at the end of a plant's life. The increased ethylene in leaf tissue in the fall is part of the reason leaves fall off of trees. Ethylene also is used to ripen fruit (e.g., green bananas).

Abscisic acid (ABA) is a general plant growth inhibitor. It induces dormancy; prevents seeds from germinating; causes abscission of leaves, fruits, and flowers; and causes stomata to close. High concentrations of ABA in guard cells during periods of drought stress probably play a role in stomatal closure.

For More Information

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