Chapter 2 from California Master Gardener Handbook (Publication 3382)

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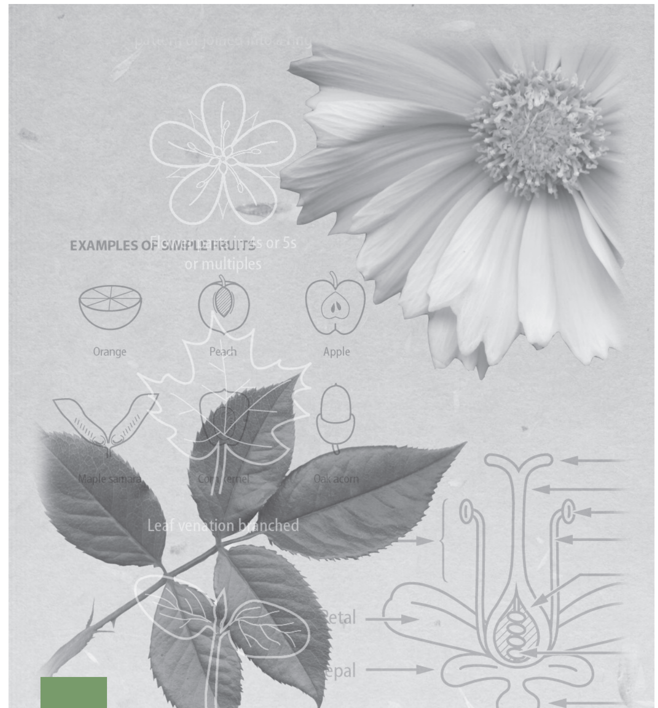
2

Introduction to Horticulture

Dennis R. Pittenger



LEARNING OBJECTIVES

- Learn principal characteristics of green plants, their structure, and common horticultural terminology.
- Understand general vegetative and reproductive growth processes of plants and the factors that influence them.
- Learn classic applications of fundamental horticultural knowledge.

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Introduction to Horticulture

Horticulture is usually described as both an art and a science. Understanding fundamental principles of plant physiology and basic botany combined with skill and intuition in employing these scientific principles ensures the maximum use and enjoyment of plants.

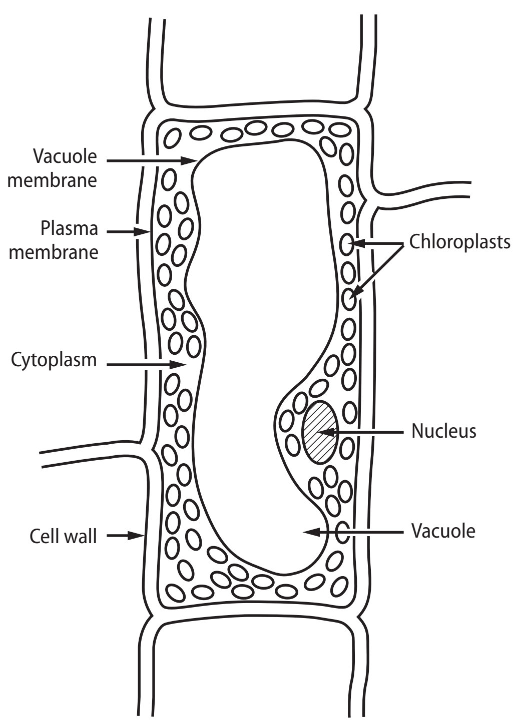
Botany is the study of plants and all facets of their structure and physiology. Horticulture is an applied science because it uses basic scientific principles, largely from botany, to develop practical technologies. The present classification of agricultural crops into the specialties of horticulture and agronomy can be traced back to the medieval period, when land was divided into large districts called manors. Extensive field plantings of grains and forages were possible under the manor system, giving rise to the discipline of agronomy.

Horticulture originates from the medieval practice of growing intensively managed kitchen gardens that provided fruits, vegetables, herbs, and ornamental plant materials for the lord's manor. The English word *horticulture* is derived from the Latin words *hortus* [garden] and *colere* [to cultivate]. Today, horticulture embraces the intensive culture of fruits, vegetables, ornamentals, herbs, and other high-value, often perishable, specialty crops. In contrast, agronomy includes crops such as corn, wheat, rice, alfalfa, and other grains and forages that are usually grown on a large scale with less intensive management.

The size, productivity, or other quantitative characters of a given plant are determined by the interaction of its genetic potential (traits) with the environment. The range of expression for any trait is set by the plant's genetic blueprint, whereas the specific expression within the range depends on the environment. For example, a given tomato variety may be genetically able to produce up to 25 pounds (11.3 kg) of fruit, but can produce only 10 pounds (4.5kg) when inadequately watered. Horticulturists employ scientific methods to investigate and understand plant responses to various environmental conditions and then develop and employ technologies to manipulate the environment to yield predictable plant responses. Such intensive management is often required to produce horticultural commodities. Intensive management is economically feasible because the produce grown commands premium prices or has high intrinsic value to consumers and home gardeners.

Figure 2.1

Simplified plant cell showing the nucleus, chloroplasts (plastids that contain chlorophyll), cytoplasm, and vacuole. Plant cells are bounded by a membrane and cell wall. Most of the cell volume is occupied by the vacuole in this plant cell.



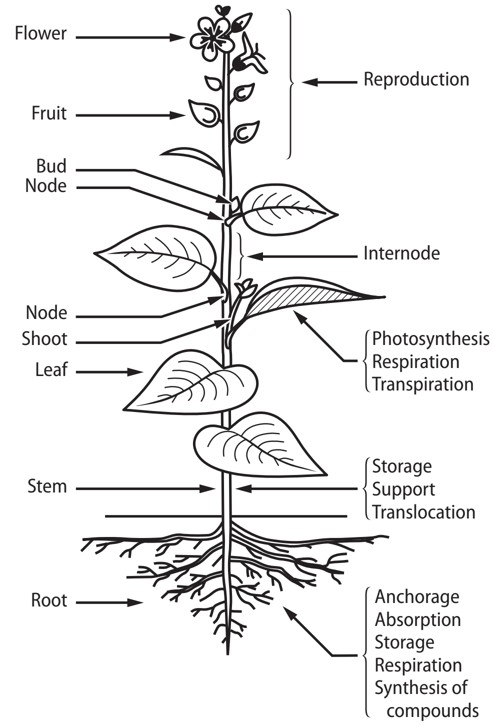
What Plants Are

Plants are living organisms without consciousness or mobility. Green plants are essentially living factories that produce their own food and serve directly or indirectly as the source of food and support for nearly all other living organisms. Like animals, they are composed of microscopic cells, three-dimensional blocklike structural units. Unlike animals, however, green plants produce their own food via photosynthesis, regenerate certain lost organs and tissues, and possess rigid cell walls made mostly of cellulose.

All essential life processes occur within cells or groups of cells. A simplified plant cell is shown in figure 2.1. The content of cells, known as *cytoplasm*, is composed of 85 to 90 percent water (by weight), 1 to 3 percent minerals dissolved in the cell sap, and 10 to 15 percent assorted organic compounds and substances. Water serves as the solvent in sap that transports dissolved minerals from the soil and sugars from the leaves to all cells in the plant. It also serves as an essential component in many plant processes, maintains cell turgor (rigidity), and indirectly regulates growth. Thus, water typically constitutes 85 percent or more of the weight of a plant. *Pectin* serves as a cementing agent between cells. Immediately inside the cell wall lies a selectively permeable membrane that serves to help regulate inflow and outflow of materials and compounds. Within the cell, most of the liquid substances (cell sap) are found in the *vacuole*, a large cavity. Important solid structures in cells are the nucleus and plastids. The control center of the cell, the *nucleus*, contains the genetic code information (DNA) that controls the physiological functions of cells and the overall features of the whole plant (the information is identical from cell to cell). *Plastids* are specialized bodies within plant cells; plastids containing the green pigment chlorophyll (*chloroplasts*) are the most significant because they conduct photosynthesis.

Figure 2.2

Important structures and functions of a seed plant.



Plant Structure

Although plant cells are independent units, the sophisticated organization and specialization of cells make up the whole plant and carry out essential life processes (fig. 2.2). Masses of similar kinds of cells form tissues, and groups of tissues may form organs. Many horticultural crops are prized for their production of unique adaptations of certain tissues or organs (fig. 2.3).

Meristems

Meristems are plant tissues in which cells divide to reproduce, grow, and develop new tissue. The most common meristems are *apical* (terminal) and *lateral*. Found in shoot tips, root tips, and buds, apical meristems are responsible for the increase in the length of these plant parts. The increase in stem and root diameter or thickness is due to the growth of a lateral meristem called the *cambium* (figs. 2.4, 2.6). In many grasses, the meristem responsible for shoot growth is found near the base of the plant. For example, mowing turfgrass at the proper height does not injure or remove the growing point of the plants.

Meristematic areas, which are normally just a few cells deep, may produce shoots (vegetative growth) or flowers (reproductive growth), depending on when and where the meristem is active. All active meristems receive priority for the food materials and minerals available within the plant. For this reason, they are often referred to as *sinks*.

Roots

The primary functions of roots are to take up water and soluble mineral nutrients from the soil, produce essential compounds, store excess food materials, and anchor the plant (see fig. 2.2). Roots require water and oxygen from the soil and food materials produced in the shoots in order to function and grow properly. Examples of horticultural crops grown for their edible roots include carrots and sweet potatoes.

Structurally, roots may be woody or nonwoody. Cambial (meristematic) tissue in roots causes them to increase in diameter over time, particularly in perennial and woody plants.

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Figure 2.3

Modified structures of selected horticultural plants. (A) Tuberous root (sweet potato; modified root). (B) Tuber (Irish/white potato; modified stem). (C) Corm (gladiolus; modified stem). (D) Rhizome (bermudagrass; modified stem). (E) Runner or stolon (strawberry; modified stem). (F) Bulb (onion: modified stem and leaves).

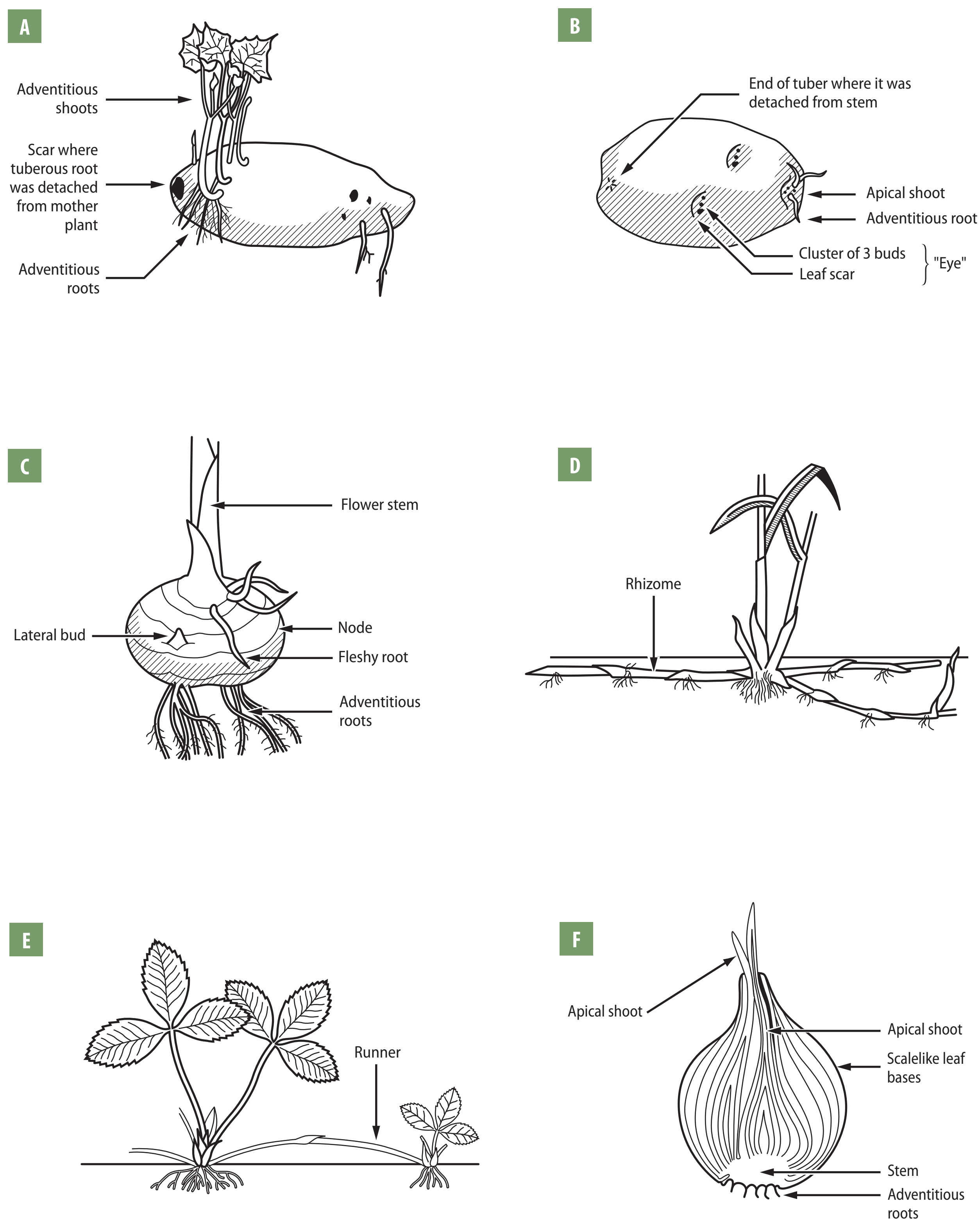


Figure 2.4

Apical meristems of shoots and roots. The shoot apical meristem (left) and root apical meristem (right) are involved in the formation of new cells via cell division and in plant growth via cell enlargement. Note that the root apical meristem is not at the very tip of the root but instead is protected by the root cap.

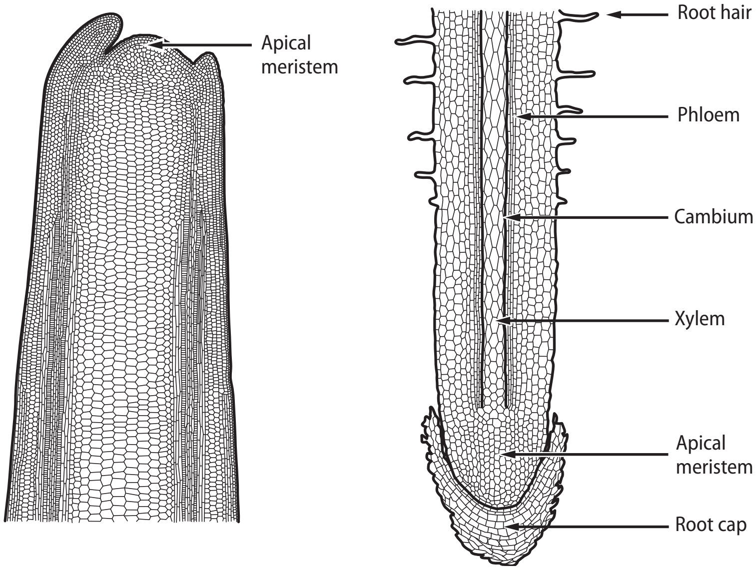
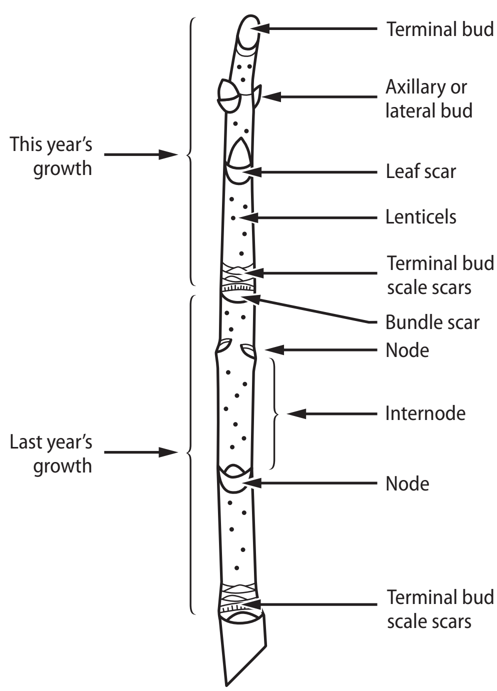


Figure 2.5

Structures of a woody twig (stem) with opposite bud and leaf arrangement. Annual growth is measured by the distance between terminal bud scale scars and the current terminal bud.



Most of the water and nutrient uptake occurs in the fine nonwoody roots of plants.

The root tip is the meristematic area responsible for increasing root length. Frequently, root hairs are present just behind the root tip. These hairs serve to increase the surface area of the root system and allow it to take up water and minerals more efficiently. Particularly in woody plants, a large main root, the taproot, develops with a small number of smaller structural or fibrous roots growing from it, whereas other plants form only a dense network of fine, fibrous roots. Plants grown from cuttings and those grown in containers seldom develop a taproot system. Taproots diminish in size as the plant matures.

Some plant parts, such as leaves and stems, have the capacity to regenerate roots after being removed from the plant. Roots arising from some plant part other than roots are known as *adventitious* roots (see fig. 2.3).

Stems and Shoots

Stems and shoots are often the most prominent aboveground portion of a plant (see fig. 2.2). *Shoot* refers to tissue made up of developing stems and leaves (leafy shoots) or stems and flowers (flowering shoots). Shoots support the food-producing foliage, store food materials, and contain tissues that conduct water and photosynthetically produced food materials throughout the plant. Unique features of stems are that they contain buds and nodes. *Nodes* are enlarged portions of a stem from which leaves or buds grow, and the portion of stem between two nodes is an *internode* (fig. 2.5).

The *phloem* is tissue that conducts photosynthetically produced food and other compounds from the leaves to other plant parts. Materials can move up or down in the phloem. Water and dissolved mineral nutrients from the soil are conducted from the roots upward to all the aboveground parts via the *xylem*. Together, phloem and xylem are known as *vascular tissue* and usually form a continuous multibranched system from every root tip to every shoot and leaf tip (fig. 2.6).

The cambium is responsible for the increased diameter growth of stems and roots and is usually associated with the vascular tissue. In typical woody stems, the xylem and phloem occur as concentric zones separated by the cambium, which is a few cells wide. Plants in the grass family, however, have xylem

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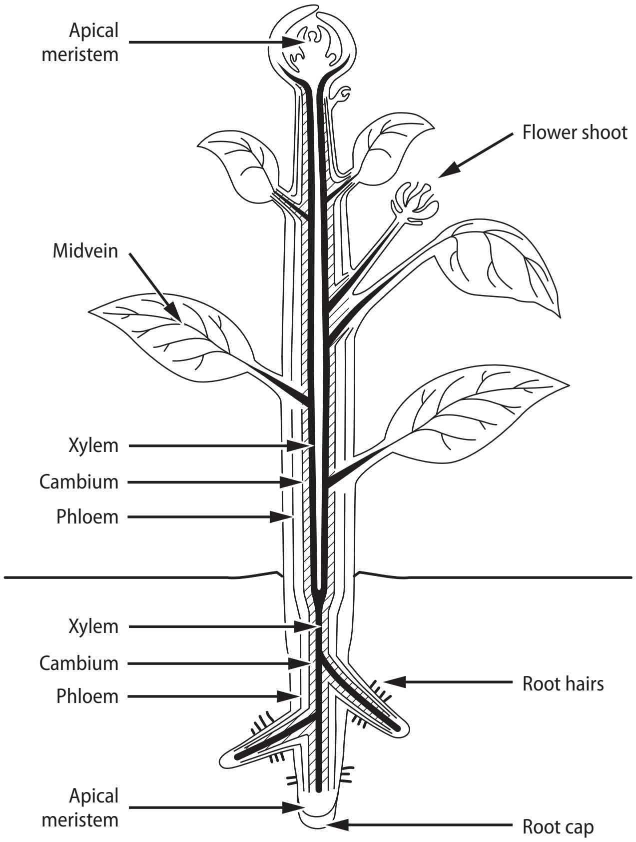
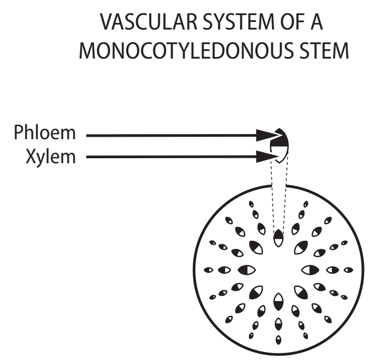
Figure 2.6

Vascular tissues are continuous from the root tips to the shoot tips. They are organized differently in monocots and dicots.





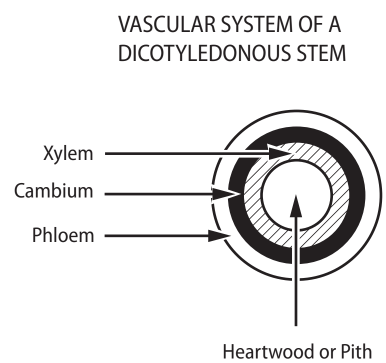
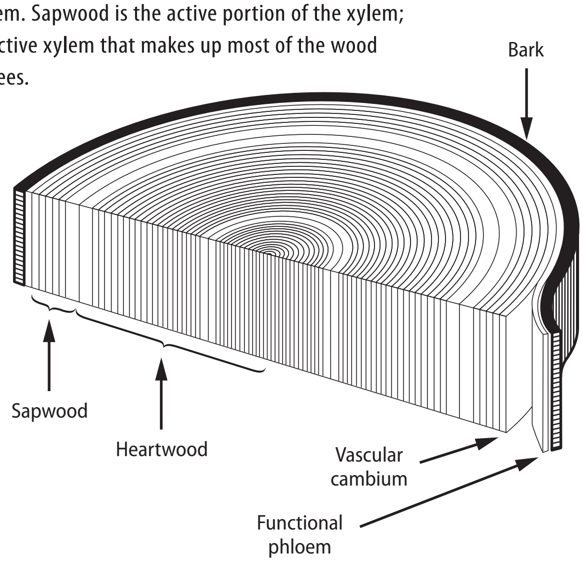


Figure 2.7

Cross-section of a hardwood dicot tree trunk. Vascular tissues, phloem and xylem, are concentrically arranged. The functional phloem is a narrow layer of cells immediately underneath the bark. Cambial tissue separates the phloem from the xlyem. Sapwood is the active portion of the xylem; heartwood is the inactive xylem that makes up most of the wood in large stems and trees.



and phloem occurring together in numerous vascular bundles scattered throughout the stem. Cambial tissue is present in each bundle. The two types of xylem in woody plants are active xylem, or *sapwood,* and inactive xylem, or *heartwood* (fig. 2.7). Although the sapwood is usually not very thick, the heartwood is the "wood" that makes up the trunk and the center portion of large tree limbs. Inactive xylem cannot transport water and minerals, but it does provide structural integrity and a food storage area for the plant. The inactivity of the heartwood explains why "hollow" trees can often remain alive: the active xylem, cambium, and phloem exist in the very outer perimeter of the trunk.

Nonwoody (*herbaceous*) plants and stems have a thin outer protective tissue, or *epidermis*. In herbaceous plants, the water-filled cells provide adequate strength to support the plant, much like the stiffening of a garden hose under pressure. Because this mechanism is insufficient to support larger plants, a stiffening process called *secondary*

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Figure 2.8

Common arrangements of buds and resulting shoots around a stem.

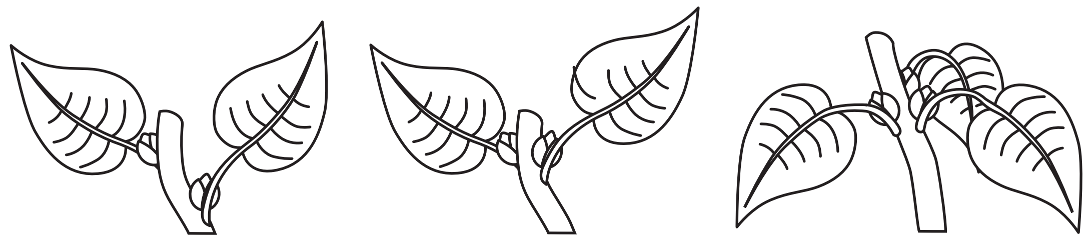
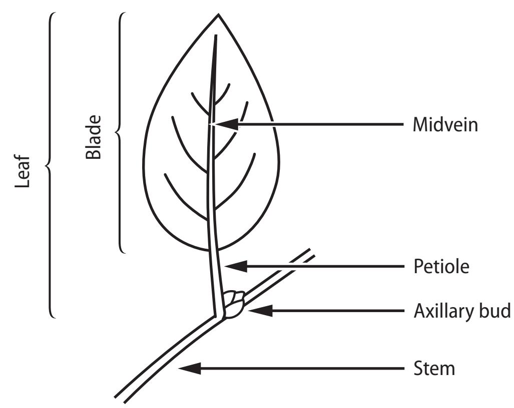


Figure 2.9

Simple leaf. The parts of a simple leaf are shown in relation to typical stem and bud structures.



growth occurs, giving rise to woody plants. Woody stems, such as those in trees and shrubs, may develop a thick or tough protective exterior tissue, or *bark* (see fig. 2.7). In woody plants, specialized tissues (*fibers*) begin to form as the stem elongates, and the stem becomes more or less rigid a short distance below the apical meristem. Because the stem cannot elongate in growth below the apical meristem, it is limited to increases in diameter. Thus, the length of the nodes (the distance between leaves and branches) remains constant for the life of the plant.

Stems may be greatly modified from the classic form, and many horticultural crops are grown for their unique stems. Aboveground stem modifications consist of crowns, runners, stolons, and spurs; belowground modifications are bulbs, corms, tubers, and rhizomes (see fig. 2.3).

Buds

Buds are meristematic structures along the stem that are composed of compressed, immature leafy shoots, flowers, or both. They may be dormant for a portion of the year or for many years before they become active.

Buds are named according to position (see fig. 2.5). Those found at the tips of shoots are *terminal* or *apical* buds, and those found along the sides of stems are *lateral* buds. Lateral buds that occur in the area where the leaf attaches to the stem (the leaf *axil*) are *axillary* buds.

The arrangement of buds and resulting shoots around a stem occurs in a particular pattern for each plant species. These patterns, along with bud appearance, are particularly useful when identifying a plant. The most common arrangement patterns are alternate, opposite, and whorled. In the *alternate* arrangement, singular buds occur in one plane but alternate from one side to the other in a zigzag fashion. Buds in an *opposite* arrangement occur in pairs with one bud on each side of a plane simultaneously. A *whorled* arrangement occurs when three or more buds occur in different planes at one point on a stem or when single buds occur in three or more planes along a stem (fig. 2.8).

There are some specialized buds in horticultural crops (see fig. 2.3). For example, the "eyes" of Irish potato tubers are actually leaf scars or nodes in which three buds occur. The center buds normally break dormancy and produce new leafy shoots. Brussels sprouts are large vegetative lateral buds occurring on the main stem of the plant.

Leaves

Leaves provide the surface area needed for the plant to collect sunlight and conduct photosynthesis, which produces food for the plant. A simple leaf and its components are shown in figure 2.9. Note the distinct blade and petiole. A bud is present and can be seen at the point where the petiole attaches to the stem. Horticultural plants possess leaves that vary greatly in appearance, structure, and function. Blades

Figure 2.10

Compound leaves are composed of multiple petiole and blade segments referred to as *leaflets*. Note the absence of any buds where leaflets attach to the petiole.

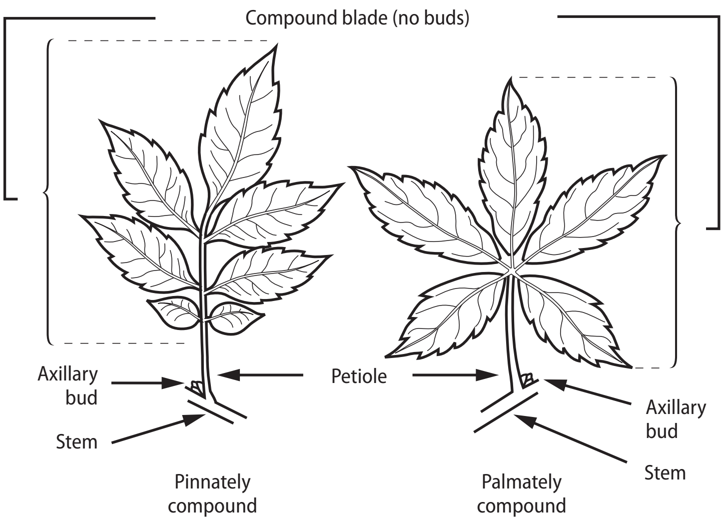


Figure 2.11

Leaf venation patterns.

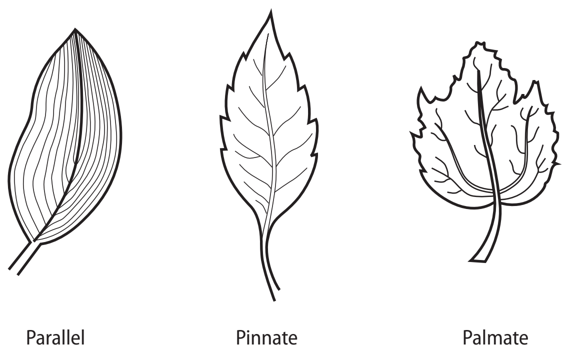
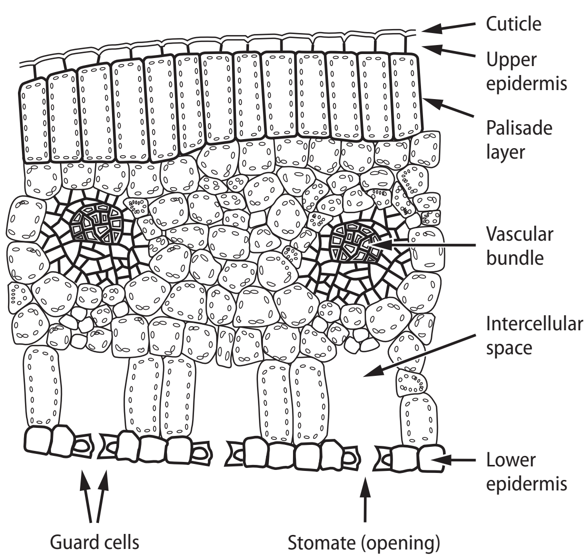


Figure 2.12

Internal structure of a leaf in cross-section.



vary widely and may be simple (if not divided) or compound (if divided into smaller segments, or *leaflets*; see fig. 2.10). In compound leaves, buds are not present where the leaflet attaches to the petiole. Compound leaves may be *palmate*, if they are handlike in form, or *pinnate,* if the segments are arranged like a feather. The margins of leaf blades also vary in pattern among species. The area on the stem or shoot that is above where a leaf attaches is the *axil*.

Leaf veins are the continuation and termination of xylem and phloem from the roots and stems. The *midvein* (or midrib) is the most prominent. Three patterns of venation (palmate, pinnate, and parallel) commonly occur in plants (fig. 2.11).

Leaves have a thin protective layer of cells, or *epidermis*, on their upper and lower surfaces (fig. 2.12). Some species have a wax or varnishlike coating (cuticle) that provides additional protection and reduces water loss. The epidermis and cuticle thicken as the leaf matures. The thickness of the epidermis and cuticle depends on the amount of light the leaf receives. A plant in a shady location has a thinner cuticle and epidermis than the same plant in full sun.

Immediately under the upper epidermis are densely packed cells that contain *chlorophyll*, the green pigment necessary in photosynthesis. Inside the lower epidermis are widely spaced cells that also have chlorophyll. The open spaces between these cells permit free movement of water vapor, carbon dioxide, and oxygen in and out of the leaves through tiny openings, or *stomata* (see fig. 2.12). Pairs of specialized cells (guard cells) control the opening and closing of each stomate. Guard cells respond to light so that stomata are normally open in daylight and closed in the dark. The number and size of stomata vary widely among species. Among tree species, for example, the number varies from approximately 100 stomata per square millimeter to 600 stomata per square millimeter of leaf surface. Stomata are usually found in higher numbers on the lower leaf surface.

Flowers

Flowers contain the male or female (or both) sexual structures of plants and are, therefore, the organs where sexual reproduction occurs. Depending on the species, flowers may contain both male and female structures (*perfect* or

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complete) or have only male or only female structures (*imperfect* or *incomplete*) (fig. 2.13). The principal male structure is the *stamen*, and the principal female structure is the *pistil*. Incomplete flowers that have only male structures are *staminate*, whereas those that have only female structures are *pistillate*. Plants with both staminate and pistillate flowers (e.g., corn, squash, pumpkins, melons, begonias, oaks, some maples, some ashes, and birches), are *monoecious*. Species in which staminate and pistillate flowers occur on separate individuals (e.g., asparagus, date palm, kiwifruit, holly, poplars, spinach, and willow) are *dioecious*.

Within the stamen, the *anther* holds the *pollen grains*, and in the pistil, the *ovary* contains the *ovules*. When pollination and fertilization occur (see "Reproductive Development" in this chapter), the ovary and sometimes the receptacle swell to form a fruit and one or more ovules develop into seeds. *Petals* are normally the most conspicuous part of a flower, although some plants (poinsettia, *Anthurium*, sunflower, broccoli) are known and grown for their other flower parts. *Sepals* are the small, green, leaflike structures found at the base of flowers (see fig. 2.13) and are the "caps" on tomatoes and strawberries. The *receptacle* is the plant part where the floral structures are attached, and in some species, such as apple, it becomes integrated into the fruit as it develops.

Seeds

In most species, the seed is the product of sexual reproduction. The seed is important because it contains an embryonic plant in a dormant state of development along with food reserves to sustain it through germination (fig. 2.14). The food reserves may be carbohydrates, fats, oils, or proteins. A protective covering, the seed coat, is also found on most seeds.

Fruits

Botanically speaking, a fruit is the plant part that contains the mature, swollen ovary and seed, such as an orange, apple, or tomato (fig. 2.15). In some species, other flower parts may be included as part of the fruit (e.g., the receptacle in apples). Numerous horticultural plants are grown specifically for their delicious or aesthetic fruit. Some fruits are commonly (and erroneously) called vegetables because they are consumed as vegetables at meals and because nutritionists speak of them as vegetables. Botanically speaking, however, squashes, (zucchini, pumpkin, acorn, etc.), green beans, cucumbers, tomatoes, and eggplant are fruits, as are apples, pears, plums, strawberries, oranges, and lemons.

Fruits, similar to meristems, are referred to as *sinks* since they also receive priority for food materials within the plants.

Figure 2.13

Complete, male, and female flowers. (A) Generic complete (perfect) flower in vertical section. (B) Male squash flower. (C) Female squash flower.

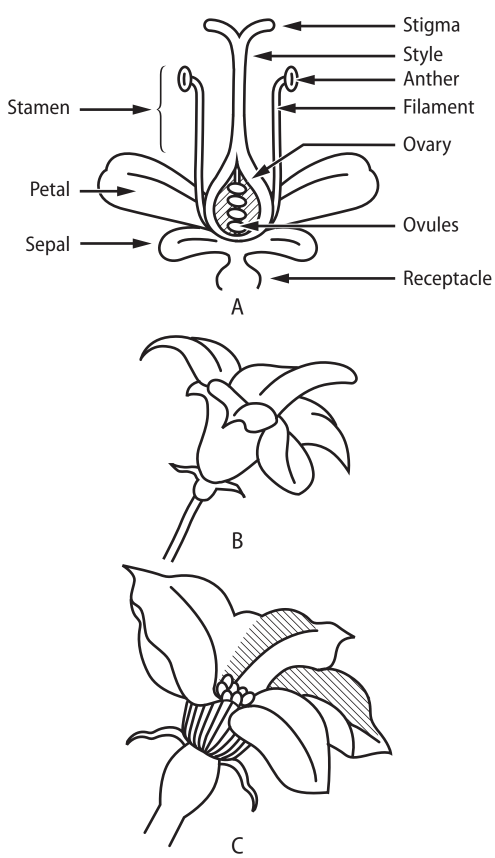

Figure 2.14

Typical seed structures illustrated in a garden bean seed.

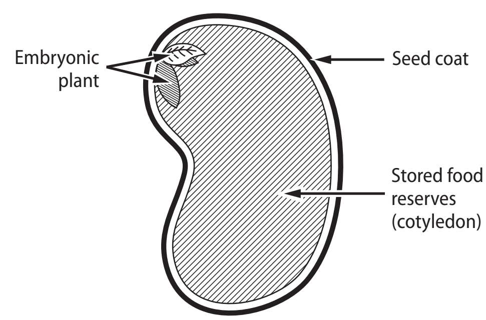

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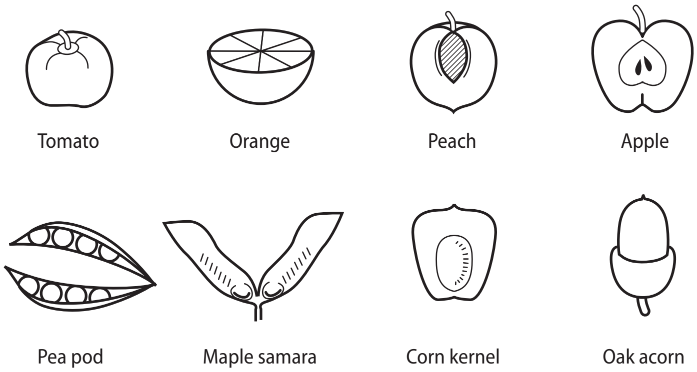
Figure 2.15

Simple fruits.



Classification of Plants

In order to study and fully understand plants, it is necessary to record and communicate information about them in a structured, orderly fashion. Grouping and classifying plants according to their use or readily observed characteristics provides methods for achieving this. Although various terms are employed in systems that classify and characterize plants, the most common classification systems are growth habit, structure or form, leaf retention, climatic adaptation, use, and scientific or botanical classification.

Growth Habit

Plants can usually be classed as annuals, perennials, or biennials. Annuals complete a life cycle from seed to flowering to reseeding in 1 year or one growing season and then die. Perennials continue growing for several years. A perennial may go through repeated annual flowering and seed-producing cycles before it dies, or it may grow for several years before it performs a single seed-production cycle and then dies. Agave species are classic examples of the latter, whereas common woody landscape plants are examples of the former. Horticulturists often use the term perennial to describe the diverse assortment of ornamental plants that are nonwoody but continue to live from year to year. The aboveground parts of perennials such as daffodils, yarrow, and foxglove die back and regrow each year.

Biennials require 2 years or two growing seasons to complete their life cycle. Plants grow leaves and shoots the first year, then flower the second year. These plants typically require a cold dormant period after the first year in order to develop flowers the second year. Cabbage is a good example of a biennial plant.

It is important to note that a crop may be an annual under certain environmental conditions and a perennial under other conditions. Tomatoes, for example, are usually considered annual plants, but they may live more than one season in areas where freezing temperatures are infrequent.

Structure or Form

The basic structure, size, and form of plants can be used to group or classify them in very broad terms. Plants that have hard, fibrous stems are *woody*, whereas those that do not are *herbaceous*. Tender-stemmed species in general are sometimes called *herbs*.

When woody plants are grouped according to their form, the terms *vine*, *shrub*, and *tree* are often used. Vines trail along the ground unless offered some type of support. Short, upright-growing plants with several main stems are considered to be shrubs, and tall ones with a single or a few main stems are usually considered to be trees. Trees may be further defined according to the general shape that their canopies naturally develop. A number of terms are used to describe them (fig. 2.16).

Leaf Retention

Perennial plant species generally fall into one of two categories: deciduous or evergreen. *Deciduous* plants lose all their leaves for some period of time in the fall and winter months. *Evergreen* plants do not lose all their leaves, although they do cast off old leaves on a periodic basis. At any one time, however, an evergreen plant always has green leaves. Evergreens are further divided into broadleaf (e.g., azalea, some magnolias) and needle-leaved (e.g, pine, redwood).

Climatic Adaptation

Perennial plants are classified according to the minimum temperatures they normally tolerate. *Tropical* plants are injured severely or killed when temperatures remain near freezing (32°F, or 0°C). *Subtropical* plants tolerate short exposures to temperatures at or slightly below freezing and usually tolerate overnight temperatures around freezing. In contrast, *temperate* plants are well adapted to

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prolonged subfreezing temperatures that occur in cold winter climates and can endure temperatures considerably below freezing.

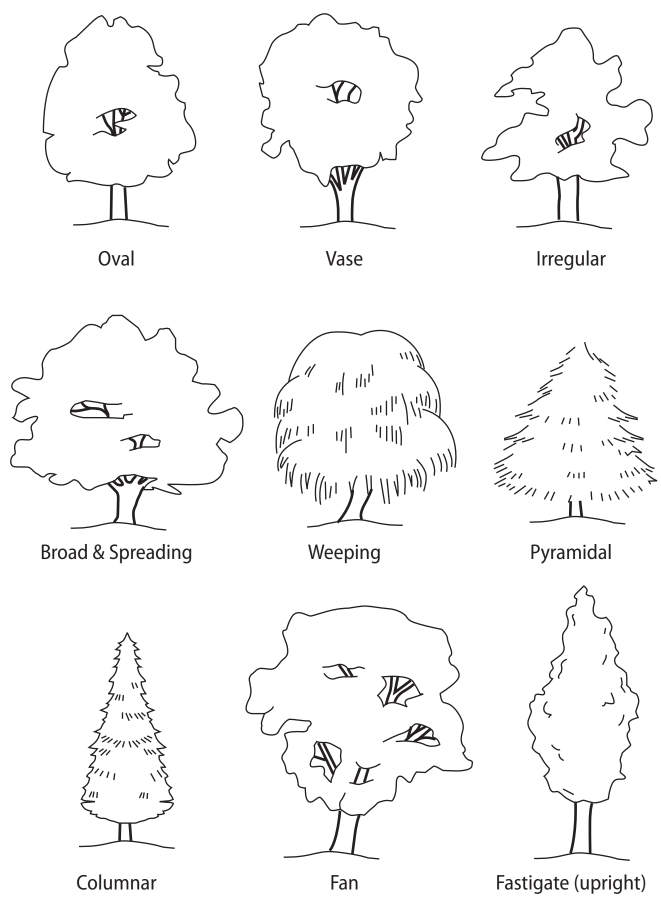
Most annual vegetables, flowers, and turfgrasses are classified in a similar fashion. Those that tolerate some amount of short-term freezing are known as *cool-season* or *hardy* crops, whereas those that are killed or injured by freezing temperatures are *warm-season* or *tender* crops. Cool-season crops grow best and produce highest-quality produce during seasons that feature average daytime temperatures of 55º to 75ºF (13º to 24ºC), and warm-season crops grow and develop best when average daytime temperatures are 65º to 95ºF (18º to 35ºC).

Use

Plants are often categorized by their use or the part of the plant consumed. When a plant is cultivated primarily for its aesthetic beauty or environmental enhancement qualities, it is considered an ornamental. Horticultural plants grown principally for some edible organ(s) are called fruits, nuts, herbs, or vegetables. Although, botanically, a fruit is the plant structure that contains the seed, from a use standpoint, a fruit is any plant part consumed for its dessert qualities; parts consumed during the main portion of a meal are considered herbs or vegetables. For example, tomatoes contain seed and are technically fruits, but they are consumed in salads and other main course dishes (and rarely in desserts) and are therefore considered vegetables.

Figure 2.16

Forms and shapes of trees.



Botanical or Scientific Classification

The most precise and least confusing method of classifying or categorizing plants is the internationally recognized botanical or scientific binomial classification system, which provides specific, positive identification for thousands of plants worldwide. Use of this system eliminates the confusion arising from multiple common names for the same plant. The common name of a given plant can vary from one locality or country to another, but its scientific name is consistent from one location to another over time.

The scientific binomial name of a plant consists of two parts—the genus followed by the *specific epithet,* sometimes incorrectly called the species—that are taken from Latin or Greek. Together, the two words are referred to as a “species.” For example, *Rubus idaeus* is the scientific name of the species red raspberry. Latin is the primary language used for these terms because it was the scholarly language in use when the scientific classification system was developed. Scientific names are italicized or underlined. Genus names are nouns and are always capitalized, whereas the specific epithets are usually adjectives and are always lowercase.

The scientific system is based on the principle that plants can be grouped according to similarities in morphological structures that are a result of their common ancestral history. As an analogy, the generic name of a plant is somewhat like the last name of a person. Thus, the last name Smith is analogous to the genus *Quercus* (oak).

All plants within a genus are closely related and possess similar morphological characteristics. Similarities of flowers and fruits are the most widely used criteria in classification. Species within a genus vary according to slight differences in these common morphological characters. The genetic makeup of individual plants in a species is very similar, so individuals may be identical in appearance. Plants in the same species and often those in the same genus can be grafted to one another. Moreover, plants in a species, and among species within a genus, are often sexually compatible. There are a number of exceptions to this general rule among horticultural commodities, however.

A great deal of confusion surrounds the term *variety* because it is used in two different ways. In scientific classification, a variety is a subclassification of a species in which plants growing in the wild developed and possess some minor but important morphological trait that is readily heritable. However, *variety* can also refer to a subclassification of a species that was developed and retains desirable characteristics only through human propagation and cultivation; but this is properly termed a *cultivar* (cultivated variety). For example, the three botanical varieties of the pea plant are:

Pisum sativum var. *sativum*: common English pea

Pisum sativum var. *arvense*: field pea

Pisum sativum var. *saccharatum*: sugar pea

Each botanical variety of the pea has some unique morphological characteristic that developed naturally. When pea seeds are sold, however, only cultivated variety or cultivar names are used, as in Progress #9 or Little Marvel, to identify the variety of pea.

In another example, the tomato is scientifically known *as Lycopersicon esculentum*, but there are a number of tomato cultivars that are not botanical varieties, based on their unique fruit or plant characteristics (i.e., Celebrity, Big Boy). Many other examples come from fruit, vegetable, and ornamental species.

The convention for writing a species and its cultivar is demonstrated as follows: *Liquidambar styraciflua* 'Palo Alto' or *Liquidambar styraciflua* cv. Palo Alto, which is the Palo Alto cultivar of the sweet gum tree species. It has unique, consistent fall color and growth habit and is maintained through budding or grafting.

The term *clone* is related to variety and cultivar. A clone is a group of genetically identical plants originating from a single individual and reproduced by vegetative means such as cuttings, grafts, etc. A clone is a specific type of cultivar, but a cultivar is not necessarily a clone, because cultivars may be propagated by sexual (seed) or asexual means.

A basic understanding of the plant classification system is helpful, as it enables horticulturists to identify or predict problems and similarities among related plants. Historically, plants have been classified in the kingdom Plantae, whereas the other kingdom, Animalia, comprised animals. Today, plants have been divided among four kingdoms, one of which contains most of the horticulturally important species. Of the 12 divisions within this kingdom (Plantae), 8 include plants with vascular systems (xylem and phloem), roots, stems, and leaves. Most of the horticulturally important plants belong to two divisions of seed-bearing plants: the cone-bearing plants, or *conifers* (Coniferphyta), including pines, firs, and spruces; and the true flowering plants, or *angiosperms* (Anthrophyta) comprising most of the plants familiar to gardeners. Flowering plants are called angiosperms because their seeds are typically enclosed in a dry or fleshy fruit that develops from the ovary within the flower. Ferns, cycads, and ginkgos belong to other divisions. Conifers, cycads, and ginkgos are often called *gymnosperms* because their seeds lie exposed at the base of scales, usually in a cone.

Flowering plants, the most diverse group, are subdivided into two classes: monocotyledons (grasses, palms, lilies, orchids) and dicotyledons, which comprise all other flowering plants. The terms *monocotyledon* (monocot) and *dicotyledon* (dicot) mean “one seed leaf” and “two seed leaves,” respectively. Thus, the first shoots that arise from monocot seeds have a single leaf, whereas those from dicot seeds have a pair of leaves.

Monocots and dicots differ in other morphological features. Monocots are characterized by one seed leaf, flower parts in threes or multiples of three, vascular tissues arranged in bundles, and usually parallel leaf veins. Dicots are characterized by two seed leaves, flower parts in fours or fives or multiples of these, vascular tissues arranged in concentric zones, and a netted pattern of leaf veins. In addition, monocots and dicots differ in certain physiological processes (fig. 2.17).

At the family level of classification, a number of structural and cultural similarities among plants often becomes evident. For example, a well-known family of monocots are the grasses (Gramineae), and a well-known

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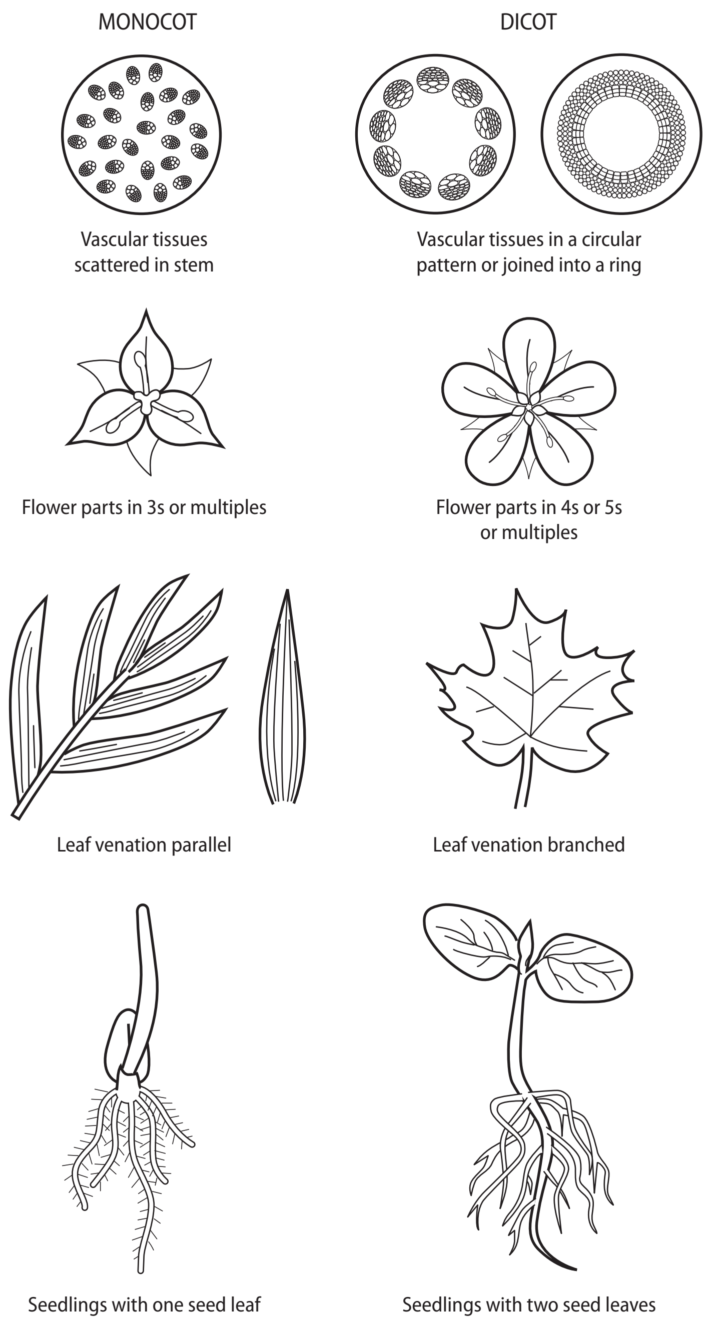
family of dicots includes roses, apples, pears, and firethorn (Rosaceae). (Family names, unlike the genus and specific epithet, are never italicized.) Although these two families are very different, the individuals within them have many similar structural features, cultural requirements, and pest problems.

The scientific system of plant classification can be a very useful tool to horticulturists for identifying unknown plants and developing or understanding the cultural practices and problems associated with a given plant.

Figure 2.17

Differences between monocots and dicots.



Plant Growth

Plant growth is an irreversible increase in plant size caused by an increase in cell number and/or size, which results in the development of new or expanded plant tissues, organs, or other structures. The process of growth is controlled by the integration of a plant's genetic potential and the surrounding environmental conditions. Plant growth requires a source of water, carbohydrates, chemical energy, and mineral nutrients. In green plants, the essential physiological processes responsible for producing and using these items are carried out in individual cells, multicellular tissues, and organs.

Photosynthesis

Photosynthesis is the process by which green plants produce their own carbohydrates, or nutrients, and obtain a source of chemical energy. Plant cells, in the presence of chlorophyll and light, convert carbon dioxide (CO_2) and water (H_2O) to carbohydrates (simple sugars), thereby transforming light energy into stored chemical energy. Energy is stored in the chemical bonds of the carbohydrate molecules ($C_6H_{12}O_6$) that are synthesized in the process. A by-product of this reaction is the evolution of free oxygen (O_2) (fig. 2.18). The chemical equation that describes photosynthesis is

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6\ O_2$$

In order for photosynthesis to occur, the stomata must be open to allow carbon dioxide to enter the leaf, adequate light must be striking the leaf, and water must be available to the plant. Plant species vary somewhat in the light levels needed for optimal photosynthesis. In addition, certain mineral elements must be present in adequate concentration for photosynthesis to occur efficiently. Information provided in chapter 3, "Soil and Fertilizer Management," clarifies the importance of minerals in photosynthesis, as components of chlorophyll molecules, and as catalysts of the process.

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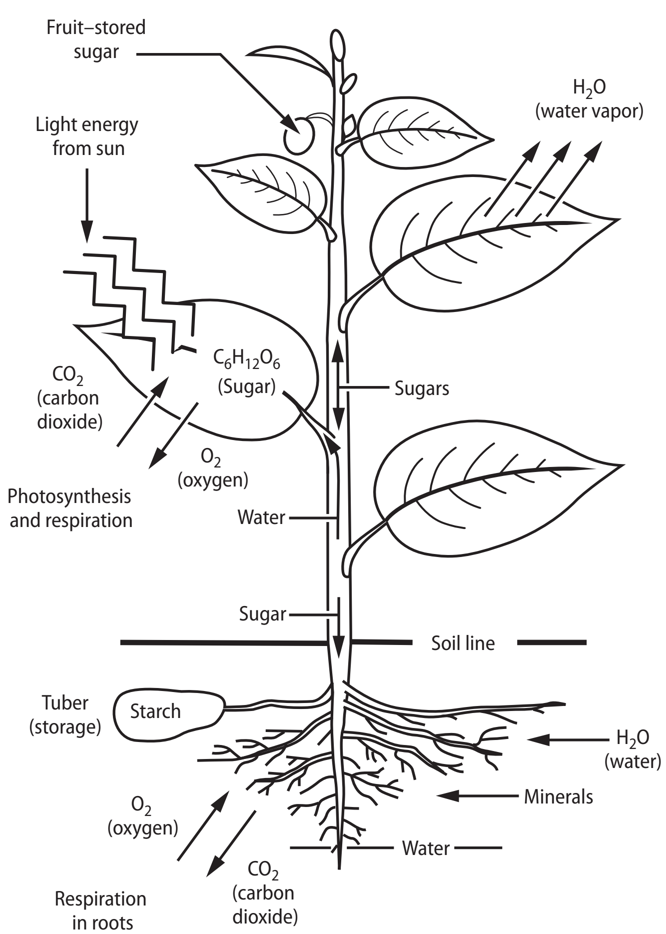
The chemically rich carbohydrates formed in photosynthesis are first metabolized and then combined with certain essential mineral elements (e.g., nitrogen, sulfur, magnesium, phosphorus) to synthesize more complex compounds needed to produce new cells (growth); or converted to more complex carbohydrates (sugars and starch) or fats and stored in fruits, seeds, stems, or roots; or biologically combusted to release the chemical energy needed for cells to function.

Figure 2.18

Schematic representation of photosynthesis and respiration. In photosynthesis, which occurs in green leaves, light energy is converted to chemical energy and oxygen (O_2) is liberated. Carbon dioxide (CO_2) from the air and water (H_2O) taken up by the plant's roots combine in the presence of light and chlorophyll (which reflects the color green) and other co-factors to synthesize sugars (carbohydrates, such as glucose [$C_6H_{12}O_6$]), and oxygen as a by-product. The sugars synthesized in photosynthesis are translocated throughout the plant and are often converted to starch in storage organs such as fruits or tubers. Respiration occurs in all plant cells above and below the soil line. Carbohydrates such as glucose react with oxygen in the presence of enzymes to release chemical energy and carbon dioxide as a by-product. The energy released serves as fuel for plant growth and developmental processes.



Respiration

Respiration is the process in which chemical energy is obtained from the controlled biological breakdown of carbohydrates. Superficially, it is the reverse process of photosynthesis. Respiration is accomplished in cells through a complicated series of reactions regulated by enzymes. Complex carbohydrates are broken down into simple carbohydrates, carbon dioxide, and water. The energy released is used in many other cell processes and functions. In plants, respiration normally uses oxygen along with carbohydrates (see fig. 2.18). The chemical equation that describes respiration is

$$C_6H_{12}O_6 + 6\,O_2 \xrightarrow{\text{enzymes}} 6\,CO_2 + 6\,H_2O + \text{Energy}$$

The relative rate of respiration depends largely on temperature and the availability of oxygen and carbohydrates. It nearly doubles for every 18ºF (10ºC) rise in temperature between 40ºF (4ºC) and 96ºF (36ºC) (fig. 2.19). At any given temperature, plant tissues also vary in their respiration rates, with the highest rates occurring in rapidly growing tissues and the lowest in dormant ones. Respiration occurs at all times in living material, including plant parts removed from the plant during harvest. For recommended storage conditions (temperature, length of time, preservation methods) of produce, see table 14.2. These recommendations are based on scientific knowledge of postharvest respiration and pathology.

Cycling of Photosynthesis and Respiration

Photosynthesis and respiration form a cycle by which plants acquire the basic building blocks and the energy needed for growth and development. The photosynthetic portion of the cycle requires light, which typically peaks during midday and ceases at night and at nearly dark periods of the day. Meanwhile, the respiration portion occurs 24 hours a day at variable rates, depending largely on temperature. In order for a plant to grow and develop normally, photosynthesis must occur at a rate that greatly exceeds the respiration rate so that there are enough stored energy and carbohydrates available to support

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nighttime respiration and other growth and development processes (fig. 2.19).

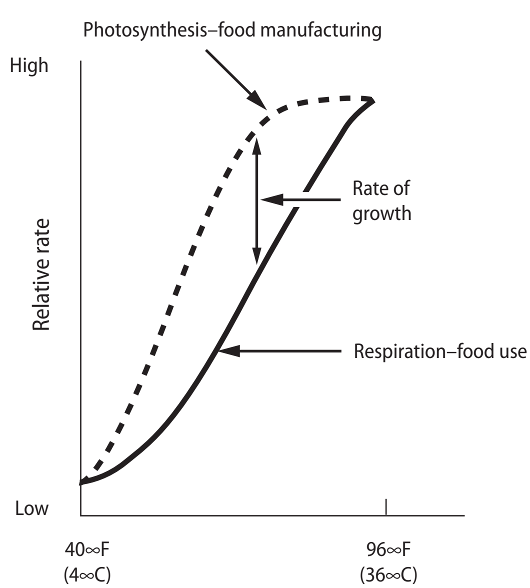
An adverse imbalance between photosynthesis and respiration can occur for various reasons. If water becomes limited during the plant's growing season because of drought or damage to the root system while the temperature remains seasonal, respiration could easily exceed photosynthetic production and cause a decline in vigor. When this daily cycle is unbalanced for a prolonged period, plant growth and development will stop unless the plant has sufficient stored food reserves (e.g., complex carbohydrates, starches, fats, oils) that can be used. Without such reserves, a plant will typically become severely stressed and enter premature dormancy or die. The use of stored food reserves may reduce the vigor of a plant and its ability to develop high-quality flowers, fruit, seed, or storage organs such as tubers.

Water and Nutrient Uptake

Plant growth and development depend on the availability of water and several essential mineral nutrients (see chapter 3, "Soil and Fertilizer Management"). These mineral nutrients are needed in various processes, including photosynthesis and respiration, and are combined with carbohydrates to form important compounds.

Figure 2.19

Relationship of respiration, photosynthesis, and plant growth to temperature.



Plants obtain all of their water and most of their mineral nutrients from the soil. Most of the water and mineral uptake occurs in roots along the very small fibrous portions of a plant's root system through a combination of chemical and physical processes. Some of these processes require root cells to expend chemical energy. Most of the soil water, however, moves into the plant passively by diffusion or movement along a force gradient. Soil water is largely pulled from the soil up through the plant and out of the stomata by means of this force gradient. Some of the plant-essential nutrients are dissolved in the soil water and are transported to the root surface during this process. Nutrients also move to the root surface by diffusing along a concentration gradient or by physically intercepting growing root tips. Once nutrients are near the root surface, their uptake by the roots often involves the expenditure of chemical energy.

Transpiration

Transpiration, the evaporative loss of water vapor from plant leaves through the stomata, is closely related to the translocation of water and dissolved minerals from the roots through the xylem. Water moves along a force gradient from relatively high in the soil and root area to relatively low in the air and leaf area. A continuous, flowing column of water is maintained in the xylem as long as the stomata are open and water is available in the soil. The transpiration process depends on the unique properties of water, which allow a long column of water to be pulled up like a thread from the roots to the top of the plant. A coast redwood, for example, has a column more than 300 feet (90 m) long (see also "How Water Moves Through Plants" in chapter 4, "Water Management").

The rate of transpiration depends on environmental factors (temperature, relative humidity, wind, etc.) that affect the evaporation rate and the degree of stomatal opening, as well as the amount of available soil water. Transpiration ceases at night in most plant species adapted to temperate climates because their stomata are closed. Transpiration helps to cool plants on hot days and serves to transport minerals from the soil and organic compounds produced in the roots to plant cells.

In succulents and some other plants native to hot, tropical climates, stomata are open at night and closed during the day (the opposite of the temperate pattern), allowing carbon dioxide used in photosynthesis to accumulate in leaves at night and reducing water loss via transpiration during the day.

Translocation

Translocation is the movement of water, mineral nutrients, food (carbohydrates), and other dissolved compounds from one part of the plant to another. It can occur from cell to cell in the space between cells, but it takes place largely in the xylem and phloem tissues. By this process, water and essential mineral nutrients are distributed from the roots to other tissues, and carbohydrates produced in the leaves are moved to meristematic areas (shoot and root tips, cambium, buds), storage organs (fruits, seeds, stems, and roots), and other tissues in need. Certain externally applied substances (e.g., systemic pesticides) may enter some plant parts and be moved to others by this process.

Plant Development

Like growth, plant development is an integrated expression of a plant's genetic potential and its environment. Although horticultural plants vary widely in their specific growth and development patterns, they are all basically annuals, biennials, or perennials that go through vegetative and reproductive phases of a growth cycle. Vegetative growth involves the development and increase in root, stem, or leaf tissues, whereas reproductive growth involves the development and increase of flower, fruit, and seed tissue. A generalized growth and development cycle starts with seed germination and proceeds through juvenility, maturity, flowering, and fruiting. Once the fruit matures, the cycle is essentially completed. For annual plants, the development of fruit is followed by the final phase of growth, which is senescence and death. For perennials, the vegetative and reproductive phases of a growth cycle may be repeated each year, or each phase may continue for more than a year.

Internal Regulation of Plant Growth and Development

Although growth and development are indirectly controlled by the availability of light, water, carbohydrates, chemical energy, and mineral nutrients, hormones provide direct internal regulation of these processes. *Plant hormones* are substances that are produced in one plant part or organ and are translocated to another part where they have a pronounced effect. Plant hormones (sometimes called *phytohormones*) are effective in relatively small quantities and provide control or regulation of most plant processes. The five major groups of plant hormones—gibberellins, auxins, cytokinins, ethylene, and abscisic acid—and their major effects on growth and development are listed in table 2.1. The production of hormones often occurs in meristematic tissue or new-growth regions and is sometimes triggered by specific environmental conditions. Plant age and species also dictate the type and amount of hormone that is produced. Depending on the amount present, the hormone's effect may be dramatically different. For example, at low concentrations, auxins promote root formation, but at higher concentrations, auxins can kill broadleaf weeds (see table 2.1).

Dormancy

Plant growth is not always continuous. Shoots, buds (leaf and flower), and other vegetative parts of a plant that are alive but not actively growing are said to be dormant. Seeds that are alive and viable and yet do not germinate under favorable conditions are also dormant. Dormancy is a mechanism by which plants survive unfavorable environmental conditions and seeds delay germination until they are in a favorable environment. In order to survive such periods, a plant or seed must contain sufficient stored food reserves (carbohydrates) to support ongoing low-level respiration.

Seed dormancy may be physical, physiological, or a combination of the two, depending on the plant species. Physical dormancy is most frequently caused by a hard, impervious seed coat that prevents water or oxygen from entering the seeds. Several treatments can be applied to seeds that are physically dormant (see chapter 5, "Plant Propagation"). Physiological dormancy may be caused by special internal processes, certain plant hormones, or other inhibitory compounds that are present

in the seed or fruit. Sometimes physiological dormancy is caused by the presence of an immature embryo in the seed, and the seed must first go through an after-ripening process before an embryo can develop fully. More commonly, the hormone abscisic acid or some other inhibitory compound is present in the seed, and a specific set or series of environmental conditions (i.e., cold, heat, rainfall, etc.) must occur to either remove the substances or trigger physiological processes that overcome them.

Dormancy of plants is usually triggered by the onset of unfavorable environmental conditions, such as the shorter days and colder weather of autumn and winter or inadequate soil moisture that may severely stress plants during summer droughts. Once sufficient hours of cold temperatures (i.e., hours below 45ºF [7 ºC]) have accumulated and warmer weather returns, winter-dormant plants resume growth. Similarly, plants that are dormant because of drought stress may resume growth once sufficient soil moisture is restored.

Because of *apical dominance*, many lateral buds remain dormant and lateral shoots show reduced vigor under favorable growth conditions until the terminal bud or shoot is removed. Removing terminal growth removes the source of auxin production that has been suppressing the lateral growth (see table 2.1).

Vegetative Development

For annual and biennial plants as well as some perennial plants, the vegetative growth phase begins with seed germination or the breaking of leaf buds and ends with the initiation of flower development. In woody perennials, vegetative and reproductive phases often exist concurrently. Seeds and buds are usually dormant until specific environmental conditions are present or a series of environmental conditions and physiological processes occurs. Seeds and buds are alive and respiring. Seeds depend on internal stored food reserves to survive, whereas buds have access to food compounds produced or stored by the plant.

Seed Germination

Annual plants and most biennial plants begin their growth and development cycles at seed

Table 2.1

FIVE GROUPS OF PLANT HORMONES AND THEIR EFFECTS

Hormone group	Effects
auxins	regulate cell enlargement
	suppress lateral bud development, creating apical dominance of main buds and shoots
	direct shoot growth toward a light source
	direct horizontal growth upward
	suppress fruit- or leaf-drop mechanisms
	promote formation of adventitious roots from stems or leaves
	low concentration: promote root formation
	high concentration: kill broadleaf weeds
	promote fruit set and development or fruit abortion, depending on the plant species
gibberellins	regulate cell division and stem elongation
	promote flowering in some plant species
	activate enzymes in germinating seeds
cytokinins	stimulate cell division, frequently in conjunction with auxins and gibberellins, to regulate processes listed under each of those
ethylene	accelerates fruit ripening
	induces flowering in some species
	hastens senescence and abscission of leaves and fruits
	interacts with auxins in certain processes often produced by plants or plant parts that have been injured
abscisic acid	regulates and promotes dormancy in shoots and seeds
	responsible for abscission (dropping-off) of leaves on deciduous plants and closing of stomata on leaves of plants under severe stress

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germination. Many perennial plants also begin their first growth cycle this way. Seeds capable of germination are said to be *viable*. They contain a living embryo that is respiring at a low level.

Germination starts when a seed first takes in water and ends when the seedling is self-sustaining. Before germination can occur, a seed must be surrounded by suitable environmental conditions. The environmental factors affecting seed germination are water, oxygen, temperature, and light. All species require a continuous supply of oxygen and water for germination, but they vary considerably in their specific temperature and light requirements. Usually a species only needs the temperature to remain within a certain range, rather than at a specific degree, in order to germinate. Germination rates under optimal environmental conditions vary among species, but the relative rate of germination for a species is determined largely by how closely the surrounding environmental conditions match the optimal ones. For a detailed discussion of seed germination, see "How to Store Seeds" in chapter 14, "Home Vegetable Gardening," and "Sexual Propagation" in chapter 5, "Plant Propagation."

Juvenility

A plant is considered juvenile from the time it is a seedling until it is mature and capable of initiating flowers. Juvenility is the portion of the vegetative growth phase marked by relatively vigorous, uninterrupted growth (except for normal seasonal dormancy). In annual species, juvenility may last for a few weeks to a few months. In some perennial plants like fruit trees, juvenility may last for a few years. A small number of plants, such as bamboo and agave, remain juvenile for 10 years or more.

Some species exhibit distinctly different morphological features during juvenility and maturity. Juvenile pears may have thorns, whereas mature ones do not; leaves of *Hedera* species are clearly lobed on juvenile plants and smooth on mature ones; the opposite occurs in *Philodendron* species. Juvenile *Hedera* stems are trailing and require support to grow upright, whereas mature stems freely grow upright with no support.

As a general rule, juvenile plants or plant parts more readily initiate adventitious roots than mature plants or plant parts do. Juvenile plant parts are also more readily grafted than older sections of the plant.

Maturity

Maturity is reached when the plant is fully developed and is capable of initiating flowers. Certain morphological and physiological changes may occur in mature plants. During the mature phase of vegetative growth, bulbs, tubers, fleshy roots, and runners are produced by horticultural crops with the genetic potential to do so (see fig. 2.3).

Although a plant is capable of developing flowers and other specialized organs when it reaches maturity, it may not do so. The environmental conditions at maturity usually control whether the plant will flower.

Reproductive Development

Flower, fruit, or seed production is the goal for growing many horticultural plants. Understanding reproductive physiology and how reproductive development may be manipulated is therefore very important to horticulturists and home gardeners.

Flower Induction

In flowering plants, the reproductive growth phase begins when certain vegetative meristems (actively growing shoot tips or buds) are induced to produce reproductive organs (flowers), and it ends with the formation of fruit or the senescence of the plant. Once a meristem is induced to flower, it follows a process of initiating cells that form new tissues of a flower or a flower cluster known as an *inflorescence*. The process is normally irreversible after it is initiated. In other words, the meristem will no longer initiate the vegetative cells of shoots it initiated previously. The length of time needed to induce a meristem to become reproductive and the length of time needed for induced meristems to produce flowers vary among species from a few weeks to several months. These time frames may also vary slightly within a species, depending on temperature or other factors. The number of meristems on a plant that are induced to flower may also vary widely from plant to plant.

The time of year when flower induction occurs and the length of time from induction to flowering for a given species are important for home gardeners to know. Many perennial plants initiate cells of flower tissue within meristems months before flowers develop. Flower buds of spring-flowering woody plants, for example, are usually initiated the previous summer. Pruning such species during winter months will thus reduce the number of flowers they produce in the spring. Annual plants, however, may reach maturity and flower within several weeks of seed germination.

Flower and Fruit Development

Some plant species are self-induced to flower and are not greatly influenced by environmental factors. In many other species, a number of factors, aside from a plant's genetic potential, control flower induction and development. The primary factors are day length (the photoperiod, or the number of daylight hours), light intensity, temperature, soil moisture content, and the internal nutritional status of the plant. Many of these factors also influence the development of fruits from flowers.

Once a flower is developed and opens fully, a number of events must take place for a fruit to develop. As noted earlier, the ovary of the flower, and sometimes other flower parts, mature to form a fruit. For normal fruit development, the flower's stigma must receive viable pollen, which in turn must germinate and fertilize the ovule(s) (see fig. 2.13). Fertil-ization is not assured even when pollination takes place. Each ovule must be fertilized by a separate pollen grain. Several physiological processes are initiated upon pollination that result in *fruit set,* or the inhibition of flower or fruit drop. Fertilization does not always occur even though pollination and fruit set take place.

Pollination and fertilization are complex processes that require precise environmental conditions to proceed normally. After ovules in the flower are fertilized, the size of the developing fruit increases rapidly. The raw materials and energy needed for this growth are supplied by the plant's photosynthetic activity. The nutritional status of the plant and moisture availability greatly affect fruit size and quality. There must be a sufficient number of leaves to produce the photosynthetic products needed to support developing fruits and to meet the other basic needs of the plant. For example, it has been calculated that a minimum of 40 illuminated leaves are needed to support the growth of one apple on a mature tree. Ade-quate soil moisture must be available for the same reason, or fruit may be small and poorly developed, or they may drop prematurely.

It is possible, though less common, for fruit development to continue without fertilization. No seed develop in this situation, which results in seedless fruit. A few crops normally develop fruit without ovule fertilization, including bananas, navel oranges, some grapes, pineapple, persimmon, and some cucumbers. Sometimes fruit set even though only a portion of the ovules are fertilized, which results in small or misshapen fruit, as is common in some tomato cultivars.

Only a fraction of the flowers normally produce mature fruit in most tree fruit crops. A significant number of set fruit drop from tree fruit crops just after the petals fall or about 4 to 6 weeks later in what is known as a June drop. Even when fertilization appears to have been completed, plants may drop some or all of their immature fruit. Incomplete or faulty fertilization, internal nutrition imbalances, water stress, or temperature extremes may cause fruit drop. However, fruit drop during the early stages of development may be normal and may serve to adjust the fruit load to a level that the plant can adequately support.

Flowers may be self-pollinated or cross-pollinated. Most plants are cross-pollinated. In self-pollination, pollen from a plant usually pollinates a flower of that same plant. This is common in beans, eggplant, peas, peppers, and tomatoes. In cross-pollination, pollen from one plant normally pollinates flowers of another plant of the same species. Wind and insect (particularly bee) activity are usually important in cross-pollination. Species that normally cross-pollinate have more genetic variation among plants and have a greater chance of adapting to long-term changes in the environment. A number of physical and physiological plant characteristics ensure that cross-pollination occurs. Self-incompatibility of many temperate tree fruit varieties is a good example. Entire varieties of these crops are often self-incompatible so that two or more varieties must be interplanted to allow cross-pollination between varieties (see chapter 17, "Temperate Tree Fruit and Nut Crops").

Although the term *hybrid* is defined as the progeny of any two parents, it is used in most of the horticultural trade to describe the progeny or cultivar that comes from genetically diverse parents of the same species in which cross-pollination is controlled or manipulated.

Fruit Quality and Ripening

As fruit matures, sugars and aromatic compounds that contribute to flavor begin to accumulate. During this final development phase, the ripening fruit typically change color and may soften. Fruit of some species may be picked from the plant when they are physiologically mature but not fully ripened, and they will develop good eating quality (e.g., tomatoes, bananas, pears, avocados, apples, etc.). Fruit of other crops must be allowed to fully ripen on the plant in order to reach good eating quality (e.g., grapes, citrus, strawberries, etc.). Adequate soil moisture, bright sunny days, and, for many fruit crops, cool nights, are necessary during the ripening stages to ensure that fruit is sweet and has good flavor and color. Environmental conditions that maximize photosynthetic sugar production and minimize its loss through respiration result in high-quality fruit.

Two widely held notions are that planting cantaloupes or muskmelons near cucumbers will result in poorly flavored melons, and that planting a yellow-fruited apple tree near a red-fruited one will result in poorly colored fruit. Neither of these beliefs is true. First, cross-pollination between two plant species, as would be necessary for cantaloupes and cucumbers, very rarely occurs and does not occur between these two species. Second, when cross-pollination does occur, as it can between yellow- and red-fruited apple cultivars, only the resulting seed would be affected. Fruit develops from the ovary and sometimes other parts of the flower, which develop from tissue of the mother plant. Thus, pollen cannot affect melon flavor or apple fruit color. Poor flavor in melons and poor color in apples most often occurs when plants are diseased, fruits are harvested too immature, or cloudy, cool weather persists during the final ripening period.

How Plants Function

Environmental conditions and plant nutrition can dramatically influence plant growth and development. These factors can greatly influence when a plant switches from the vegetative growth phase to the reproductive growth phase. Light, temperature, soil moisture content, and nitrogen nutrition are the principal factors that affect plant development. It is important to note that two or more environmental factors often interact in very complex ways to impact the growth and development of a given plant. The regulatory mechanisms in plants that are influenced by environmental conditions are not fully understood, because they involve a series of biochemical processes and interactions with plant hormones, whose effects depend on their concentration. At a low concentration, a hormone may induce a particular response, and at higher concentration it may inhibit that same response.

As discussed previously, the degree to which flowering or other developmental processes are induced by environmental conditions varies among plant species. These processes are largely self-induced in some plants and are not significantly influenced by environmental factors. For many horticultural plants, a great deal of effort focuses on controlling or manipulating environmental or nutritional factors that promote the development of desirable plants or plant parts. For other plants, their entire growth cycle may be carefully scheduled so they reach maturity in the season that naturally provides the environmental conditions that promote flowering or other desirable growth and development phases.

Plant Responses to Day Length

Some horticultural crops initiate flowers, form specialized vegetative organs, or initiate dormancy in response to a specific length of daylight in a 24-hour period (known as a *photoperiod*). Such plants are called photoperiodic. Plant leaves are the sensors or receptors of critical photoperiods, and the stimulus is transported by some unknown biochemical or hormonal mechanism to meristems. A number of successive days (often 60 or more) in which the critical photoperiod occurs is needed before the specific organ initiation occurs. Once a particular plant response is induced, altering the photoperiod does not interfere with the growth response that was initiated.

Short-day plants are induced to flower or develop other special organs in response to a succession of days that have a light period less than 12 hours long. Conversely, *long-day* plants are sensitive to photoperiods that are 12 hours or longer (usually 14 hours or more).

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Many plants are called *day-neutral* because their flowering or other developmental processes are not affected by specific day lengths (see table 2.2).

The natural leaf-drop and color-change responses of deciduous plants in the fall are largely short-day responses. As day length shortens during late summer and fall, deciduous plants are induced to stop chlorophyll production in their leaves and develop a zone of special cells at the base of the leaf petioles that allows the leaves to separate from the plant. The consequences are a loss of green color that unmasks other leaf pigments and the eventual dropping of leaves.

Knowledge of photoperiodic responses has been used widely in the commercial chrysanthemum industry. Although chrysanthemums are short-day plants, they are now available in flower year-round. Growers use artificial lighting to maintain long days during the months when the natural photoperiod is less than 12 hours until the plants reach the desired height. When lighting is stopped, the plants receive natural short-day conditions and are induced to flower. When natural photoperiods are too long for mums to initiate flowers, growers cover plants of the desired size with black cloth about 5:00 P.M. This practice artificially shortens the days and induces the plants to flower.

The important processes of photosynthesis and transpiration are affected by day length. Theoretically, total photosynthetic production and the amount of water transpired is lower on short days than long days if everything else is held constant. Photosynthesis uses light directly, but transpiration depends on light to trigger the opening of stomata, which in turn enables transpiration to occur.

Specific vegetative growth responses that are controlled by photoperiod in some species include seed germination, tuber formation, bulb formation, shoot dormancy, leaf abscission, and runner and stolon development.

Table 2.2

LONG-DAY, SHORT-DAY, AND DAY-NEUTRAL PLANTS

Category	Common name	Scientific name
long-day	bentgrass	*Agrostis palustris*
	coneflower	*Rudbeckia bicolor*
	dill	*Anethum graveolens*
	fuchsia	*Fuchsia hybrida*
	ryegrass, perennial	*Lolium perenne*
	sedum	*Sedum spectabile*
	spinach	*Spinacia oleracea*
short-day	chrysanthemum	*Chrysanthemum morifolium*
	cosmos	*Cosmos sulphureus*
	kalanchoe	*Kalanchoe blossfeldiana*
	poinsettia	*Euphorbia pulcherrima*
	strawberry (June-bearing)	*Fragaria* × *ananassa*
	violet	*Viola papilionacea (V. cucullata)*
day-neutral	bluegrass, annual	*Poa annua*
	Cape jasmine	*Gardenia jasminoides*
	corn (maize)	*Zea mays*
	cucumber	*Cucumis sativus*
	fruit and nut trees	
	grapes	*Vitis* spp.
	strawberry (everbearing)	*Fragaria* × *ananassa*
	tomato	*Lycopersicum esculentum*
	Viburnum spp.	

Plant Responses to Light Intensity

The intensity or brightness of light influences a number of processes and qualitative characteristics of horticultural plants. A widely used unit of light intensity is the foot-candle. Full sun measures about 10,000 foot-candles; bright, naturally lighted interiors are typically 400 to 1,000 foot-candles, whereas poorly lighted interiors are as low as 30 foot-candles. Plants have an optimal range of light intensity in which they grow and develop best. If light conditions are consistently beyond either end of the optimal range, the plant will not grow normally and may eventually die. Horticulturists strive to place plants where they will receive near-optimal light intensity, or they manipulate the light by supplementing it or by providing shade to produce near-optimal levels.

Light intensity may affect plants at any developmental stage, depending on the species. For a few species, seed germination is inhibited by the presence of light, whereas in a few others, it is required for germination. As light intensity increases, air and leaf temperatures often increase, stomata open fully, and the relative rate of transpiration may increase. For many fruit, vegetable, and ornamental crops, high light intensity is necessary for development of maximum color and for the best sugar and flavor in edible crops. Leaves of plants that are in full sun all day are often relatively smaller in area and slightly thicker than those on the same plant that are shaded all day.

Shoot bending in response to light is very common. The mechanism is believed to be linked to larger auxin concentrations on the shaded side of the stem. Light apparently stimulates either a transfer of auxin to the shaded portion of a stem or a breakdown of auxin on the lighted portion of the stem. In either case, the auxin concentration is higher on the shaded stem portion where it stimulates growth, causing the stem to bend toward the light source.

At relatively low light intensities or in shaded conditions, shoots of plant species that are not adapted to shade become elongated and thin. This stretching of shoots causes them to be weak, less vigorous, and spindly and results in a plant that is of very low quality. Plants of such species may die if more intense light is not provided.

Many plants adjust to a change in light intensity if the change is gradual. Abrupt changes in light intensity may harm foliage. In most plant species, reducing light intensity abruptly causes leaf drop, whereas an abrupt increase in light intensity causes leaf yellowing or sunburning.

Plant Responses to Light Quality

Light quality is an expression of the color of the light source. Sunlight has equal amounts of all colors and appears white. Most artificial light sources do not have a balance of all colors and impart some color other than white. Because photosynthesis is most efficiently conducted with red and blue light, reddish-blue fluorescent light bulbs have been designed specifically for growing plants under artificial lighting. Recent research, however, has demonstrated that cool-white fluorescent lamps are actually the most effective for growing foliage plants without natural light.

The color of light can affect seed germination in a few plants. Blue and red light stimulate or inhibit germination, depending on the species. Under natural full-sun conditions, there is enough red and blue light present to cause these effects.

Plant Responses to Temperature

Many plant growth phases and physiological processes are controlled or affected by temperature. The effects of temperature on a sensitive species usually depend on the length of time that a critically high or low temperature is maintained. Plant metabolic processes gradually shut down in many species as temperatures exceed 96ºF (36ºC) or drop below 40ºF (4ºC).

The respiration rate in plants and other organisms greatly depends on temperature. Within the range of 40º to 96ºF (4º to 35ºC), the respiration rate doubles for every 18ºF (10ºC) increase in temperature (fig. 2.19). Growth rates of healthy plants also increase as temperature increases within a species' critical temperature range. Harvested crops (vegetables, fruits, cut flowers, etc.) remain alive and continue to respire stored carbohydrates after they are removed from a plant. Holding these products at low, near-freezing temperatures until they are used can greatly extend their shelf life quality because respiration is significantly reduced. Some crops of tropical origin (e.g., tomatoes and bananas) may be injured or lose quality if storage temperatures are too cool, however. For optimal temperatures in vegetable crops, refer to table 14.2.

Transpiration in many species also increases as temperature increases, provided there is adequate soil moisture. The stomata of some species close during hot daylight hours even though the sun remains bright. This reaction halts transpiration and provides a drought-avoidance mechanism for such species.

Seed germination in some species is controlled by temperature. Many temperate species produce seed that require several weeks of exposure to cold (45ºF [7ºC] or less), moist soil in order to break dormancy and germinate, a process called *stratification*. Seed of a few species, like lettuce, express a high temperature dormancy if they are exposed to soil temperatures that are too warm, usually above 85ºF (30ºC).

Dormancy of buds and shoots of deciduous plants is generally controlled by temperature. Although photoperiod triggers the onset of dormancy in these plants, a certain amount of cold exposure is necessary to break their dormancy. These chilling requirements vary widely among species and are important characteristics to know for most varieties of temperate tree fruit crops. Buds and shoots of these species remain dormant until a critical number of hours (typically 200 to 800) of cold temperature (usually below 45ºF [7ºC]) accumulates. The occurrence of warm temperatures

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between episodes of cold, such as day-night fluctuations, before the chilling requirement is met does not offset previous cold hours (see "Dormancy and Winter Chill" in chapter 17, "Temperate Tree Fruit and Nut Crops").

In some plants, an exposure to cold temperatures for a sufficient period (usually 41ºF [5ºC] or less for 6 to 12 weeks) is required before they will initiate flowers. This phenomenon, known as *vernalization*, is usually the mechanism that controls flowering in biennial plants. Active shoot meristems are the receptor for this stimulus. Vernalization can be reversed if plants are subsequently exposed to high temperatures. Onion growers can use this knowledge commercially. Onion sets are commonly harvested and then stored for several weeks at near-freezing temperatures to reduce respiration and retard spoilage. They are vernalized during this time and will flower quickly after spring planting from storage. Thus, onion sets from cold storage must be exposed to temperatures above 80ºF (27 ºC) for 2 to 3 weeks before planting to devernalize them and facilitate bulb formation. Sometimes the terms *vernalization* and *chilling requirement* are used synonomously when discussing crop culture.

The development of flowers and fruit is often affected by temperature. Extremes in temperature can reduce or inhibit pollination and fruit set in crops. Color development, particularly red pigments in flowers and fruits, can be inhibited by high temperatures during the maturation period. Color intensity is typically enhanced by the occurrence of clear, bright, moderately warm days and cool nights.

Interactions of Photoperiod and Temperature

Temperature can interact with light to modify plant responses to a given photoperiod. Poinsettias initiate flowers in 65 days when grown in short-days at 70ºF (21ºC) but require 85 days if the temperature is 60ºF (16ºC). June-bearing strawberry cultivars initiate flowers under short-day conditions and runners under long-day conditions unless temperatures remain below 67ºF (20ºC). At temperatures below 67ºF (20ºC) these cultivars initiate flowers under any day-length conditions. In similar fashion, flowering in Christmas cactus is a short-day response, but plants will flower at any day length if temperatures are below 65ºF (18ºC).

Plant Responses to Soil Moisture Conditions

All plant growth and development processes are adversely affected when soil moisture is inadequate or when a plant's root or vascular system becomes impaired and cannot supply adequate amounts of water to plant tissues. Photosynthesis, transpiration, and nutrient uptake are among the processes first affected by insufficient water. The tissue in drought-stressed plants is usually less succulent; leafy vegetable crops thus become tough when water is limiting. A reduction in the rate of growth in shoots and roots, poor fruit set, and poorly developed flowers, fruits, or storage organs follows closely afterward. Without adequate moisture in the soil, seeds will not germinate.

In general, plants suffering from drought will be stunted and light green or grayish-green in color, and leaves and shoots may wilt. Additional information regarding soil moisture, drought, and growing plants in the home garden is found in chapter 3, "Soil and Fertilizer Management," and in chapter 4, "Water Management."

Plant Responses to Carbon Dioxide and Oxygen Concentrations

Carbon dioxide is an essential component in the process of photosynthesis, and oxygen is essential to all plant tissues so that they can carry on respiration. Air surrounding plants, including indoor air, normally supplies adequate amounts of these two gases to the shoots of plants. However, the soil surrounding plant roots does not always contain enough air to provide adequate amounts of oxygen to plant roots. When soils are severely compacted, water-logged, or are artificially deepened more than a few inches over a plant's root system, oxygen may be insufficient for root respiration. Roots die if these conditions occur for an extended period.

Germinating seeds also require oxygen because they are respiring. Thus, the soil or propagation media in which they are placed must be well aerated.

The fact that respiration requires the presence of oxygen is exploited to extend the shelf life of many horticultural commodities that are held in commercial storage. Remember that plant tissues and organs continue to respire even though they are removed from the plant. By removing the oxygen from the air in storage rooms or containers, the respiration rate of these commodities is stopped, and the product will remain fresh for a long time, so long as temperatures are kept cool to minimize spoilage and moisture is maintained to prevent dehydration.

Relationship of Nitrogen Nutrition to Plant Growth and Development

Abundant levels of available nitrogen stimulate growth of new root and shoot tissue and may lead to increased disease problems and reduced fruit quality. The presence of new vegetative growth usually inhibits initiation of flowers. If nitrogen levels in the plant subside as the new vegetative growth matures, plants often have an abundance of carbohydrates produced by the new growth. At this point, flower initiation readily occurs while growth and photosynthetic production of carbohydrates is maintained to support flower and fruit development. If a combination of relatively low nitrogen and low photosynthesis occurs, growth and flowering are both usually reduced. Thus, a relative balance of nitrogen and carbohydrates is essential in the plant for it to flower readily.

Plant Responses to Stress

Stress can be defined as any combination of nonoptimal growing conditions for a given plant. Stress includes extremes in temperature, insufficient light or water, inadequate nutrients, poor soil aeration, or any combination of these factors. Under conditions of stress, a plant will have a shorter juvenile growth phase, low vigor, and weak, tough vegetative growth. A stressed plant may enter dormancy prematurely or remain in extended dormancy. Premature defoliation and abnormal color may occur under severe stress. In general, the quality of vegetable, fruit, and ornamental crops is reduced if severe or prolonged stress occurs.

Reproductive development is also affected by stress. Early flower initiation along with heavy flowering and fruit set often occur in plants under moderate to severe stress. However, the size and overall quality of flowers and fruit of stressed plants are often greatly reduced. Seed produced from stressed plants may be small or have low viability.

A short period of mild stress is often imposed on bedding plants and other plants just before they are transplanted into the landscape or garden. Withholding water and nitrogen fertilizer along with gradual exposure to full sun are known as *hardening* or *hardening-off* plants. These practices reduce plant growth slightly and toughen them somewhat so that they can readily adjust and survive the transplant operation.

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