

## Plants and Their Environment

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Plants are living organisms that contain chlorophyll and use it to manufacture their own food. Their cell walls are more or less rigid and support both the individual cells and the whole structure. Even when plants have reached what we regard as their full, mature size, they continue to expand and develop new leaves, flowers, fruit and shoots.

Unlike animals, plants cannot move when the environment changes. They are at the mercy of the climate and the gardener because they are rooted in place. Even though it appears that many plants, especially larger ones, are quite tolerant of change, they sometimes do not show adverse effects until long after the event. For example, tree roots are often damaged or killed by suffocation during building projects or flooding. An established tree may still have strength to leaf out and may appear to thrive for several years. But in its weakened state, the tree is more likely to blow down, become infested or simply decline.

To understand why plants respond as they do to natural influences and to cultivation, gardeners must understand something about their structure and how they grow. This publication provides such an introduction.

### Ways to group plants

#### Uses

Gardeners tend to group plants by their horticultural uses: fruits, vegetables, flowers, trees, shrubs, turf and so on. These categories are a convenient way to think and learn about plants.

#### Life cycle

Plants can also be categorized by the length of their life cycles. Annual, biennial and perennial are terms that describe how long a plant will live and also indicate when it is likely to bloom.

#### Annual

An annual plant's entire life cycle from seed germination to seed production occurs in one growing season, and then the plant dies. Many flowering plants that we consider to be annuals are not annuals in their native habitats. They would continue to grow and flower in future years if freezing temperatures did not kill them. Tuberous begonia (*Begonia × tuberhybrida*) is an example of an ornamental plant treated as an annual in the Midwest, although it is a perennial in the southern states.

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Annuals may be further subdivided into summer and winter annuals:

- Winter annuals begin their life cycle in late summer or fall, survive in the vegetative state through winter, and then flower quickly in the spring before dying.
- Summer annuals begin their life cycle in spring or summer and complete their entire life cycle before fall or winter.

## Biennial

A biennial plant starts from seed and produces vegetative structures and food storage organs in its first full season. A rosette of basal leaves persists through winter. During the second season, the plant's life cycle is completed with flowers, fruit and seed. The plant then usually dies. These plants will often reseed themselves. Examples of biennials are carrots, beets, cabbage, celery, onions, hollyhock, Canterbury bells and Sweet William.

Sometimes plants that typically develop as biennials may complete their entire cycle of growth from seed germination to seed production in only one growing season. Conditions of drought, unusual variations in temperature or other climatic changes can cause the plant to pass through the physiological equivalent of two full growing seasons in one year.

## Perennial

A perennial plant is a plant that lives for more than two years. Typically, perennials die back in the fall and return in the spring because of some sort of overwintering structure, such as a rhizome or crown. Examples include flowers such as daylilies, blackeyed-susan and coneflower; and vegetables such as asparagus and rhubarb. Plants often characterized as weeds such as common milkweed and morning glory are also perennials.

Perennials are classified in various ways:

- Herbaceous — Plants that die back to the ground each winter and have new stems that grow from the roots each spring.
- Woody — Plants where the top persists, such as shrubs or trees.
- Deciduous — Plants that shed their leaves and are leafless during a portion of the year.
- Evergreen — Plants with leaves that persist throughout the year.
- Tender — Plants that do not survive cold winters. Tender perennials are often grown as annuals.
- Hardy — Plants that tolerate cold temperatures.

## Structure

The structure and appearance of plants' flowers, leaves, fruit and seed play a large part in how we think of them and also provide useful information about their classification. For example, the flowers of a daisy indicate a probable relationship with other plants that have similar flowers. The majority of grasses are easily recognized by their long leaf blades.

More than 500,000 different kinds of plants and plantlike organisms exist in the world. Of these, the flowering plants classified as angiosperms are the most abundant and familiar to us. Gymnosperms are the other main group of seed-bearing plants. There are also more primitive plants such as mosses and ferns that reproduce by spores.

Adapted from text originally written by Denny Schrock, formerly with the Department of Horticulture, University of Missouri.

### Differences in angiosperm plant structure and function

	Monocots	Dicots
<b>Seedlings</b>	One seed leaf	Two seed leaves
<b>Stems</b>	Xylem and phloem paired in bundles and randomly dispersed throughout stem.	Continuous rings form inside the stem. Phloem is near the bark or external stem cover, becomes part of bark in mature woody stems. Xylem forms inner rings, is sapwood and heartwood of woody plants.
<b>Leaves</b>	Parallel-veined	Net-veined
<b>Flowers</b>	Floral parts in 3s or in multiples of 3.	Floral parts in 4s or 5s or in multiples of 4 or 5.

## Angiosperms

Angiosperms have seeds encased in closed ovaries that become plants' familiar fruits, pods, grains or capsules. They represent virtually all crop plants and those we think of as flowers.

The angiosperms are further classified into two groups according to the number of seed leaves, called cotyledons, that emerge from a germinating seed:

- Monocotyledonous plants (monocots) are those such as grasses whose seed first extends a single cotyledon or seed leaf. Lilies and other bulb plants are also monocots.
- Dicotyledonous plants (dicots) have seed that forms a pair of cotyledons; examples are bean, petunia and tomato.

## Gymnosperms

Gymnosperms are plants that develop exposed or naked seeds. These include the coniferous plants such as fir, pine and spruce. Ginkgo and the tropical cycads are also gymnosperms.

## Modern plant taxonomy

Modern plant taxonomy is based on a system developed by the Swedish physician and botanist Carl von Linné, who later changed his name to Carlos Linnaeus. His classification is based on the flowers and reproductive parts of a plant. Because these are the parts of a plant least influenced by environmental changes, this system has been found to be the best.

Grouping plants with similar botanical structure helps us to understand how they are related to one another. Close relatives often have similar pest problems. Botanical similarities may also show, for example, how long certain plants can be expected to live and why they react as they do to certain conditions. In addition, their botanical, Latin or "proper" names help to avoid confusion when the same or similar common names exist for different plants.

### Binomial nomenclature

Each plant is assigned two names. The genus or generic name can be likened to a person's last name, as in "Doe." The specific epithet or species name is that person's given name, "Jane" or "John." This combination of two names is the plant's botanical, scientific or Latin name.

For example, the botanical name for sugar maple is *Acer saccharum* (pronounced AY-ser sa-KAH-rum). The genus name *Acer* is a classical (Latin) name. The genus name for the Indian bean tree *Catalpa* is a Native American name. Other botanical names provide descriptions of the flower: for example, *Antirrhinum* (snapdragon) is from the Greek *anti*, which means "like," and *rhinos* meaning nose or snout. One familiar genus is *Narcissus* (daffodil) named for the mythological character who was turned into this flower when he drowned attempting to reach the person he saw reflected in a pool of water.

### Taxonomy

The science of classifying plants and animals according to their morphology (form and structure), and morphological relationships and principles.

## Botanical classification of four plants

	Colorado blue spruce	Ornamental pear	Cauliflower	Sweet corn
<b>Kingdom</b>	Plantae	Plantae	Plantae	Plantae
<b>Division</b>	Tracheophyta	Tracheophyta	Tracheophyta	Tracheophyta
<b>Class</b>	Gymnospermae	Angiospermae	Angiospermae	Angiospermae
<b>Subclass</b>	–	Dicotyledones	Dicotyledones	Monocotyledones
<b>Order</b>	Coniferales	Rosales	Papaverales	Cyperales
<b>Family</b>	Pinaceae	Rosaceae	Cruciferae	Graminae
<b>Genus</b>	<i>Picea</i>	<i>Pyrus</i>	<i>Brassica</i>	<i>Zea</i>
<b>Species</b>	<i>pungens</i>	<i>calleryana</i>	<i>oleracea</i>	<i>mays</i>
<b>Variety (botanical)</b>	<i>glauca</i>	–	<i>botrytis</i>	<i>rugosa</i>
<b>Cultivar</b>	'Fat Albert'	'Bradford'	'Snow Crown'	'Silver Queen'

Specific epithets may have similar descriptive value, such as *rubra* for red and *major* for large or larger. In the sugar maple example, the word *saccharum* is from the Latin for sugar cane, and it is similar to words we know that mean sweet. Some species commemorate a botanist or plant explorer. The late 18th century Swedish naturalist Carl Peter Thunberg introduced many Asian plants. He is remembered in plant names, including the species *Berberis thunbergii*, the Japanese barberry, and a genus of the warm-climate, climbing blackeyed-susan, *Thunbergia*.

Words in many complete Latin names include botanical variety, subspecies and cultivar. These build upon the basic binomial naming system to further separate individuals that differ from one another in, for instance, flower color or growth habit. They are not so different as to require new specific names.

### Botanical classification

Every living organism, be they a plant or animal, can be classified into the following categories, or taxa:

- Kingdom
- Division
- Class, Subclass
- Order
- Family
- Genus (plural: genera)
- Species (abbreviated sp. [singular] or spp. [plural])
- Cultivar or variety

For plants, the kingdom is Plantae and division is Tracheophyta. Class is usually either Angiospermae or Gymnospermae, the angiosperms and gymnosperms that make up most of our cultivated plants. At the subclass and order level, further groupings of similar plants are named.

### Family

A family of plants shares similar characteristics. For example, the spring-flowering magnolia trees, whose deciduous forms are best known in the north, and the evergreen southern forms are in the same family, not surprisingly called *Magnoliaceae*. Different magnolia specimens can be “keyed out” using a botanical key. The combination of characteristics that identify this family are enclosed ovules, flowers that are not catkins, flowers with calyces, clear and separate “distinct” carpels (reproductive portion of flower), overlapping or imbricate sepals, and alternate, simple leaves.



In another example, peas belong to a large family of legumes called *Fabaceae* (formerly named *Leguminosae*). The edible pea flower is shaped much like the flower of a tree in the same family commonly referred to as redbud (*Cercis canadensis*). All legumes have similar flowers and fruiting structures even though they may be vastly different in form. Other legumes include alfalfa, beans, clover, honeylocust, Kentucky coffee tree, Siberian pea shrub and wisteria.

What do roses have in common with apple trees? They are members of the same family, *Rosaceae*. Their fruits are pomes. Plants in this family share susceptibility to the same diseases. For example, pears and roses are susceptible to fire blight, and both are subject to mildew during humid weather. Other plants in the *Rosaceae* family include cotoneaster, spirea, juneberry, quince and mountain ash.

## Genus

When groups of similar plants are categorized into families, the next lower level of classification is the genus. Plants in the same genus often share similar fruits, flowers, roots, stems, buds and leaves. The genus name is always capitalized and italicized or underlined. Examples:

*Acer* = maple  
*Begonia* = begonia  
*Catharanthus* = vinca  
*Solanum* = tomato  
*Quercus* = oak

## Species

Specific definition comes with the species name, or specific epithet. At this level, marked features that are carried from generation to generation distinguish the group. Specific names are not capitalized, but they are italicized or underlined. Examples:

*Acer rubrum* (red maple)  
*Begonia x semperflorens* (fibrous-rooted begonia)  
*Catharanthus roseus* (vinca)  
*Solanum lycopersicon* (tomato)  
*Quercus alba* (white oak)

## Variety (botanical), subspecies, form

Sometimes the specific name is followed by a botanical variety, subspecific name or form that denotes a fairly consistent, naturally occurring variation within the species. This second specific name is preceded by the abbreviation var., ssp., or forma (f.). Example: *Picea pungens* var. *glauca* (Colorado blue spruce), *Gleditsia triacanthos* var. *inermis* (thornless honeylocust).

## Cultivar (short for cultivated variety)

A cultivar is a group of plants that is clearly distinguished by certain characteristics that may be morphological (structural), physiological (functional), cytological (cellular) or chemical. The differences do not have to be visual for a variation to gain cultivar status — perhaps it is simply more hardy or disease resistant. When a plant is reproduced asexually (by cloning), it retains these distinguishing characteristics.

Cultivar names are always capitalized within single quotes or preceded by the abbreviation cv. In the nursery industry, the cultivar name is recognized as a plant's official name. Examples: *Acer platanoides* 'Crimson King' (Crimson King Norway maple) or *Fraxinus pennsylvanica* cv. Marshall's Seedless (Marshall's Seedless green ash). Along with cultivar designation, recent new cultivars may have other assigned names that are often trademarked (Golden Nugget dwarf Japanese barberry, *Berberis thunbergii* 'Monlars').

### Cultivars

Cultivars, short for cultivated varieties, are variations on plants that originated in cultivation. Cultivar names are even more defining than species names. Some cultivar names are Latinized, and others are not. Cultivars can be confusing because there may be hundreds within one species.

## More plant identification terms

Several more terms may be used to define particular plants or plant groups:

- Strain — A variation within a cultivar. For example, ‘Spur Red Delicious’ apple is a select type of Red Delicious, which is a cultivar of apple.
- Hybrid — The result of natural or deliberate crossbreeding between two or more dissimilar parents is known as a hybrid. Hybrids are denoted by the multiplication sign “×,” placed correctly without a space before the hybrid name. While we find most hybrids at the specific level within a genus, some are intergeneric (result from the cross-breeding of two genera). For example, the hybrid *Forsythia ×intermedia* is from a cross between two species, *Forsythia suspensa* and *Forsythia viridissima*. The intergeneric hybrid ×*Solidaster* (hybrid goldenrod) comes from its parent species, *Solidago* and *Aster*.
- Clone — An individual or individuals that were started by asexual propagation and are genetically identical to each other.
- Line — Plants of uniform appearance grown from seed.
- F<sub>1</sub> hybrid — A cross between two inbred lines.

## Plant identification using plant keys

Dichotomous plant keys are used to identify plants through a series of choices between pairs of alternatives. Each pair refers to a specific plant characteristic such as arrangement of leaves on the stem, type of leaf margin or type of fruit. By selecting the option that accurately describes the plant, you will be led to the next choices until you determine the genus or species.

If a result is ambiguous, final verification can be made by comparison with a known example of that species. In their detailed comparisons, plant taxonomists often use preserved specimens stored in an herbarium.

Reference books for specific types of plants, such as ferns, wildflowers or shrubs, frequently contain their own specialized plant keys. Try to use keys that employ botanical rather than common names. Common names can be confusing for several reasons: one plant may have several common names; the common name for a plant often differs from one region to another; and the same common name can also apply to more than one plant. Botanical names, by contrast, are unique and relatively permanent.

Several major plant keys are available, including the following:

- Bailey, L.H. 1949. *Manual of Cultivated Plants Most Commonly Grown in the Continental United States and Canada*. New York: Macmillan.
- Gleason, Henry A., and A. Cronquist. 1991. *Manual of Vascular Plants of Northeastern United States and Adjacent Canada*. Bronx: New York Botanical Garden.
- Petrides, G.A. 1958. *A Field Guide to Trees and Shrubs*. Boston: Houghton Mifflin.

### Plant “keys”

For successful use of dichotomous “either-or” plant keys, a working familiarity with plant structure and terminology is essential.

## Plant structure

### The plant cell

The plant cell is the basic organizational unit of plants (Figure 1). Each living plant cell contains a nucleus that controls all of the chemical activities in the cell. Within the nucleus, division of the DNA provides the way for the cell to pass on heritable information from one generation of cells to the next.

Cytoplasm is the other main part of the living plant cell. It is composed of many cell structures (organelles), water, pigments, sugar and various minerals. The cytoplasm is bound by a plasma membrane that regulates the flow of water and nutrients into and out of the cell.

The plant's cell wall is one of the fundamental differences between plant and animal cells. The somewhat rigid cell wall is made up of a number of chemical compounds, primarily the carbohydrate cellulose.

The second major difference between plant and animal cells is that many plant cells contain the green pigment chlorophyll. Chlorophyll is contained in chloroplasts, where photosynthesis, the food manufacturing process, takes place. A chloroplast is a type of organelle known as a plastid. There are also plastids that contain pigments other than chlorophyll.

Plant cells can have specialized functions, and there are many cell types. Plant cells are largely made up of water held within the vacuole, which exerts a pressure against the rigid cell wall. This pressure, called turgor pressure, gives the plant shape and structure. When insufficient water is available in the plant to maintain this pressure, the plant begins to droop or wilt.

### Plant tissues

Individual cells work together to form the whole plant. Tissues are organized groups of cells that are similar in appearance and function. An organ is a group of tissues that accomplishes a common function. Plants have two organ systems: roots and shoots. Shoots, in turn, have two main organs: leaves and stems. These organs are made up of various tissues that are called meristematic, which may be dermal or vascular.

Meristematic tissues are sites of cellular activity and division. This is where all of the cell division takes place. Meristematic tissues give rise to the other tissue systems and are named for their location. Animal tissues do not have these specific sites of cell division — rather, all animal cells can divide to create new tissues.

An apical meristem is located at the apex, or tip, of a shoot or root. The lateral meristems exist in the stems and roots of many plants. They help the plant grow in thickness or diameter. The vascular cambium is a lateral meristem that forms new xylem (water-conducting) cells on the inside and new phloem (food-conducting) cells on the outside. Active cambium cells are exposed when the outer skin or bark is peeled away from a dicot stem (monocots usually have no cambium).

### Dermal tissues

There are two types of dermal tissues — epidermis and periderm.

**Epidermis.** The epidermis forms the outer covering of the plant and, in most cases, secretes a waxy coating called cutin, which forms the cuticle. This often shiny coating protects the plant from major water loss and protects the underlying cells. Specialized groups of epidermal cells form pores that allow water, carbon dioxide, oxygen and other gases to pass through to and from the

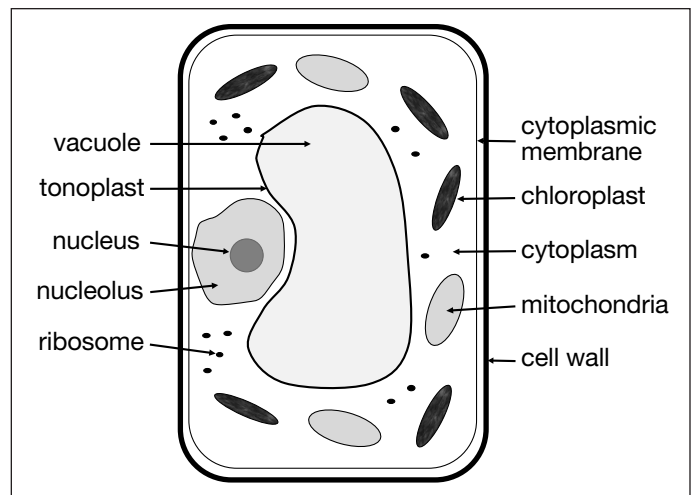


Figure 1. Plant cell.

### Plant tissues

Plant tissues are sometimes classified as either vegetative or reproductive. Vegetative tissues (leaves, roots, stems and leaf buds) are not directly involved in seed production. However, they are often used in asexual or vegetative forms of reproduction such as cuttings.

underlying tissues. These pores, referred to as stomata (singular: stoma), are made up of two guard cells that open and close to regulate the flow of vapors and gases.

**Periderm.** The periderm is created by the cambium and forms the bulk of the bark of woody plants. It is a layer of corky cells that, like the epidermis, prevents water loss and protects the cells beneath. The periderm also has pores to allow gas exchange for underlying tissues. These pores, which are visible to the naked eye, are called lenticels.

## Vascular tissues

Vascular tissues make up the water- and food-conducting system of a plant. They consist of the xylem and phloem.

**Xylem.** The xylem tubes are the water- and mineral-conducting channels and are made up of cells that are shaped into columns that can effectively move water through even a large tree.

**Phloem.** Phloem tubes move food produced by photosynthesis to other parts of the plant.

## Plant organs

Every plant has a unique form and structure and is made up of several distinct organs. All of these influence a plant's overall health and appearance. Gardeners need to consider all parts of the plant and the effects of the environment on these structures, which include roots, stems, buds, leaves, flowers, seeds and seedlings, and fruits.

### Roots

Healthy roots are vital to the well-being and the continued development of most cultivated plants. Roots' structure and growth habits have pronounced effects on the size and vigor of a plant, its ability to adapt to various soil types, and its responses to cultural practices and irrigation. In addition, many plants spread through buds that develop on vigorous roots, and portions of root can be used for vegetative reproduction or propagation. Examples are phlox and lilac (*Syringa*). Roots that store carbohydrates are often used as food for us and for animals. Carrots, beets, sweet potatoes and turnips are examples.

### Types of roots

One or more primary roots originate at the lower end of a seedling or cutting. From here, the root system develops, which is usually characteristic of the plant. Specific soil conditions can cause modifications in roots, however. For example, the taproot of a carrot growing in stony soil will be stunted and branched.

**Taproot.** A taproot is formed when the primary root continues to elongate downward into the soil to become the dominant and most important feature of the root system. Some trees, such as the sassafras and sugar maple, have long taproots with few laterals or fibrous roots. Such trees are difficult to transplant, and they usually grow only in deep, well-drained soil.

If plants that normally develop a taproot are undercut so that the taproot is severed early in the plant's life, the plant will lose its taprooted characteristic and develop a more fibrous root system. In commercial nurseries, this is done so trees that would naturally have taproots will instead develop compact, fibrous root systems. This improves the chances of transplanting success, but when the taproot is undercut in this way, nutritional and moisture conditions must be carefully controlled to maintain healthy topgrowth.

**Lateral roots.** Lateral or secondary roots are side or branch roots that grow from another, larger root.

**Fibrous roots.** A fibrous root system is one in which the primary root either never existed or ceases to elongate. Numerous smaller or lateral roots develop,

### Root functions

The principal functions of roots are to

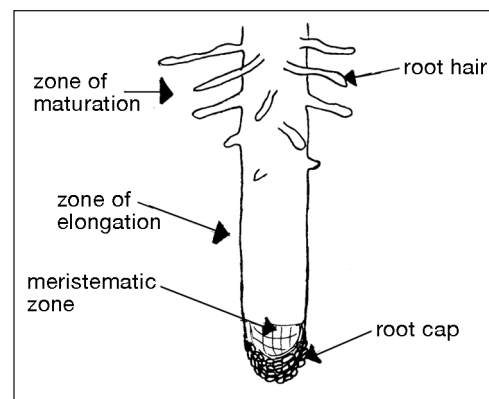
- anchor the plant in the soil,
- absorb nutrients and moisture,
- serve as food storage organs, and
- provide a means of propagation.



branching repeatedly to form the absorptive root system of the plant. Rhododendrons, for example, have shallow, fibrous root systems. By contrast, the tough, vigorous, multiple roots of grasses are capable of penetrating the ground to a depth of several feet. Grasses can, therefore, reach water that is unavailable to the shallower-rooted rhododendron.

**Root hairs.** Root hairs are protrusions of the epidermis that develop on the root just behind the zone of elongation. They perform much of the actual work of water and nutrient absorption.

**Mycorrhizae.** Many plants form a partnership between their root systems and soil fungi called mycorrhizae. These mycorrhizae, literally “fungus roots,” greatly enhance water absorption and the nutrient-acquiring capacities of the roots. Mycorrhizae can be important in plant establishment and survival.



**Figure 2. Longitudinal section of root.**

## Root structure

A root has no nodes and never directly bears leaves or flowers (Figure 2). Lengthwise, it has four main parts:

- **Root cap** — The outermost protective tip of the root. It consists of cells that are sloughed off as the root grows through the soil. The meristem, the area of cell division, is located right behind the root cap and is protected by it.
- **Meristem** — The tip where new cells are manufactured. It is an area of cell division and growth and is protected by a root cap.
- **Zone of elongation** — The area immediately behind the tip. Here, cells increase in size through food and water absorption. These enlarging cells push the root through the soil.
- **Zone of maturation** — The region in which the enlarged cells undergo changes to become the specialized tissues of the epidermis, cortex and vascular system.
  - *Epidermis:* This layer of cells surrounding the root is responsible for absorption of water and minerals dissolved in water.
  - *Cortex:* These cells are involved in food storage and the movement of water from the epidermis.
  - *Vascular system:* This system consists of cells located at the core of the root, whose function it is to conduct food and water.

## More on roots

The quantity and distribution of plant roots are important because these two factors have a major influence on the root’s ability to absorb moisture and nutrients. The depth and spread of the roots depend on the plant’s inherent growth characteristics and on the texture and structure of the soil. Roots will penetrate more deeply into a loose, well-drained soil, where there is adequate soil oxygen, than into a dense, poorly drained soil. A solidly compacted layer in the soil, sometimes called a hardpan, will restrict or terminate root growth.

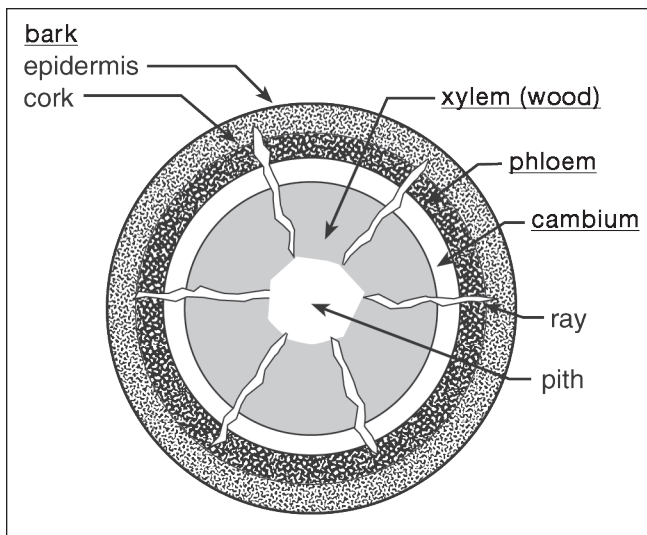
During early development, a seedling plant absorbs nutrients and moisture from the soil within a few inches of the location of the seed from which the plant grew. As plants become well established, the root system develops laterally and usually extends to several times the spread of the branches. The greatest concentration of fibrous roots occurs in the top 12 inches of soil, but significant numbers of laterals may grow downward from these roots to provide an effective absorption system several feet or more underground.

## Stems

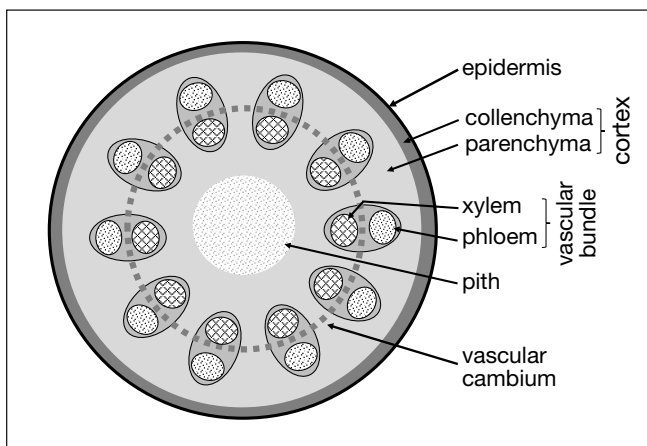
Stems are generally the bulkiest and most obvious part of the plant. They support the leaves, buds, flowers and fruit. Water, nutrients, the products of photosynthesis, and gases pass up and down stems, to and from the roots. In certain plants, stems function as storage organs for food manufactured through photosynthesis. They may spread out and root, making new plants.

### Tuberous roots

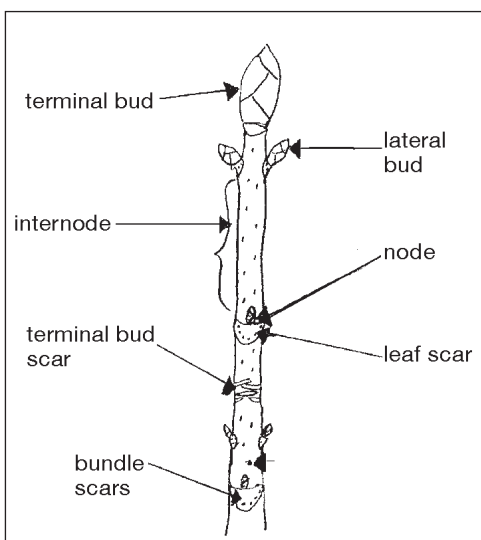
Dahlias and sweet potatoes produce underground storage organs called tuberous roots, which are often confused with bulbs and tubers. However, these are roots, not stems, and have neither nodes nor internodes.



**Figure 3. Cross section of woody plant stem.**



**Figure 4. Cross section of herbaceous dicot stem.**



**Figure 5. Typical woody stem.**

Portions of stem, often called cuttings or slips, are used in vegetative reproduction or propagation. Examples are ivy, blackberry and willow (*Salix*). We commonly use stems as food — examples include asparagus, kohlrabi, broccoli, cauliflower, rhubarb and potatoes.

### Structure of stems

Bark is the external covering of the stem of woody plants. Internally, the stem's three major parts are the xylem, phloem and cambium (Figure 3). The xylem tissue consists of tube-like cells that conduct water and dissolved minerals and gases in the stem, while the phloem tissue conducts food products. Xylem forms the inner rings to become sapwood and heartwood of woody stems. The cambium is dicotyledonous meristematic tissue with cells that divide and enlarge to force the stem to expand outward. New xylem is formed on the inner side of the cambium and new phloem on the outside. The cambium is a thin, actively growing layer that is vulnerable to girdling by wires, weed trimmers and even a tree's own roots.

Herbaceous plants have stems that differ in internal arrangement when compared with woody plants. Although monocots and dicots both contain xylem and phloem, their vascular systems are arranged differently (Figure 4). In the stem of a monocot, the xylem and phloem are paired into bundles that are dispersed throughout the stem. In herbaceous dicots, those vascular bundles are arranged in a circle in the stem.

### External features of stems

Stems grow either above- or belowground. They may be long with large distances between leaves and buds, or they may be compressed with almost no distance between leaves and buds. The location on the stem where a leaf or bud occurs is called a node (Figure 5). It is sometimes difficult to distinguish between stems and roots, but one sure way is to look for nodes. Stems have nodes; roots do not.

The internodes are the regions between nodes. The length of an internode depends on many factors. One of these is genetic — oaks usually have shorter internodes than sycamores. Environment is also a great influence. For example, decreasing fertility will decrease internode length. Early-season growth, which is often the most vigorous, usually results in the greatest internode length. Too little light will cause stems to elongate, resulting in long, spindly growth. Paradoxically, plants that are growing vigorously tend to have longer internodes than weak plants. Internode length will also be affected by competition from surrounding stems or fruits. If the plant's energy (available water and food) is divided between three or four stems, or if fruits (seeds) are also developing on the stem, less energy is available for any one shoot, and internode length is shortened.

Look at the varying internode lengths in a full season's growth of a deciduous tree, such as an oak or an apple. An interesting exercise for a gardener is to look at a stem and then try to identify the conditions that may have affected growth.

## Types of stems

Typical stems are the trunks and branches of shrubs and trees, and the stalks of nonwoody plants. Modified stems can be found both aboveground and belowground.

### Parts of aboveground modified stems

- Crowns — Compressed stems having leaves and flowers on short internodes (strawberries, dandelions, African violets).
- Spurs — Short, stubby, side stems that arise from the main stem and are common on such fruit trees as pears, apples, and cherries where they may bear fruit. If severe pruning cuts close to fruit-bearing spurs, the spurs can revert to become nonfruiting, long stems.
- Thorns — Thorns develop as modified twigs on stems. They may be single (cockspur hawthorn) or branched (honeylocust). Some thorns are modified leaves (cacti).
- Stolons — Horizontal stems that are fleshy or semi-woody that lie along the top of the ground (strawberry runners and bermudagrass).

### Parts of belowground modified stems

- Rhizomes — Similar to stolons, rhizomes generally grow underground rather than above it. Some rhizomes are compressed and fleshy like those of many irises. They can also be slender with elongated internodes, as in quack grass.
- Tubers — Thickened, fleshy underground stems. The eyes of a potato are actually the nodes on the stem: each eye contains a cluster of buds. The tuberous stems of tuberous begonia and cyclamen are shortened, flattened, enlarged and mostly underground. Buds and shoots arise from the top or crown; fibrous roots grow from the bottoms of these tuberous stems.
- Bulbs — Tulips, lilies, daffodils, onions and some irises have shortened, compressed, underground stems surrounded by fleshy scales (modified leaves) that envelop a central bud located at the tip of the stem, which is usually buried deeply and protected by the thickened scales.
- Corms — Solid, swollen stems with dry, scale-like leaves on the outside, as in a gladiolus. A corm is shaped somewhat like a bulb, but without fleshy scales.

## Buds

A bud is an undeveloped shoot from which leaves or flower parts grow. The buds of deciduous trees and shrubs typically are protected by leathery bud scales or, in the case of some evergreens, a resinous covering. Some buds are termed “naked” because they have no covering. Herbaceous plants have naked buds in which the outer leaves are green and somewhat succulent.

Buds may require exposure to a certain number of days below a critical temperature before they will resume growth in the spring. This time period varies for different plants. During rest, dormant buds can withstand low temperatures, but after the rest period, buds become more susceptible to weather conditions and can be damaged easily by cold temperatures or frost.

A leaf bud is composed of a short stem with embryonic leaves and develops into leafy shoots. Leaf buds are often less plump than flower buds. Flower buds are made up of a short stem with embryonic flower parts.

Buds are classified by their location on the stem. Terminal or apical buds are located at the apex or tip of the stem. Lateral or axillary buds are found on the sides of the stem, usually in the leaf axil, the point of leaf attachment to the stem. Adventitious buds arise at other sites, including the internode of the stem, at the edge of a leaf blade, from callus tissue at the cut end of a stem or root, or laterally from the roots of plants.

## Stem functions

The distinguishing feature of stems is that they must have buds or leaves. The principal functions of stems are to

- form the framework that supports leaves, buds, flowers and fruit,
- be a major part of the plant's transport system,
- serve as food storage organs, and
- provide a means of propagation.

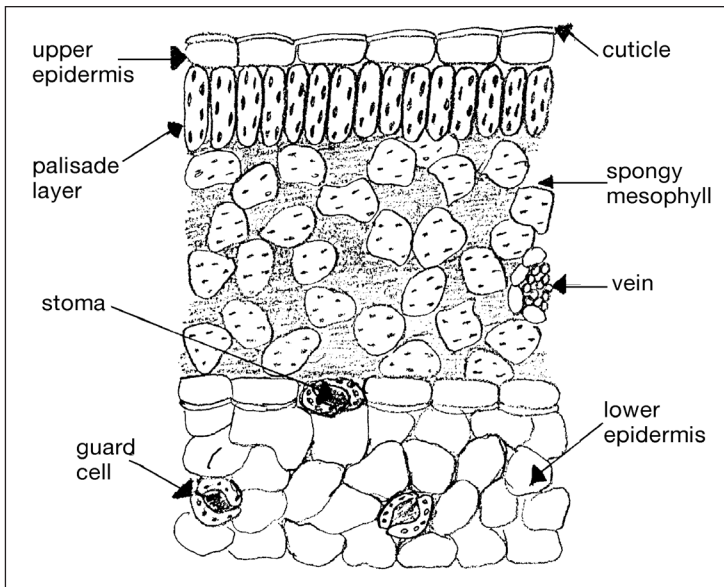


Figure 6. Cross section of dicot leaf.

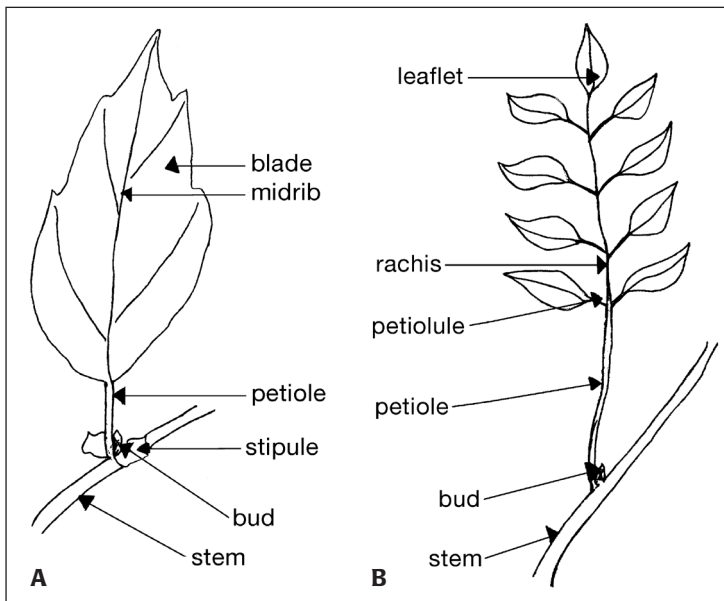


Figure 7. Leaf types: A = simple and B = compound.

## Leaves

The principal function of leaves is to absorb sunlight for the manufacture of plant sugars. This process is called photosynthesis. The typical leaf has a flattened surface to present a large area that efficiently absorbs light energy. In most cases, the leaf is supported by a stemlike appendage called a petiole. The base of the petiole is attached to the stem at the node. The angle formed between the petiole and the stem is called the leaf axil. A bud or cluster of buds is usually located in the axil.

### Structure of leaves

The leaf blade is composed of several layers (Figure 6). On the top and bottom is a layer of small, tough epidermal cells. The primary function of the epidermis is to protect leaf tissues. The arrangement of the cells in the epidermis determines the texture of the leaf surface. Hairs that are present on some leaves are extensions of epidermal cells.

The thickness of the cuticle (the layer of cutin produced by epidermal cells) is a direct response to sunlight. The stronger the light, the thicker the cuticle. For this reason, plants grown in the shade should be moved into full sunlight gradually over a period of a few weeks to allow the cutin layer to build and to protect the leaves from rapid water loss and sunscald.

Cutin repels water and can shed pesticides if spreader/sticker agents or soaps are not used. This is the reason many pesticide manufacturers include some sort of spray additive to adhere to or penetrate the cutin layer.

On the surface of leaves are the stomata. Some plants have stomata on both surfaces; others have them only on the lower surface. Formed from epidermal guard cells that are capable of opening and closing, the stomata regulate the passage of water vapor, oxygen and carbon dioxide into and out of the leaf. The opening and closing of guard

cells is determined by the environment. Conditions that cause large water losses from plants (high temperature, low humidity) stimulate closing, while mild weather conditions leave guard cells open. Guard cells close in the absence of light.

The middle layer of a leaf is known as the mesophyll. This is the location of the chloroplasts that contain the green pigment chlorophyll. Photosynthesis takes place here. In monocot plant leaves, the mesophyll consists of cells and air spaces. In dicot leaves, it is divided into a dense upper layer called the palisade and a lower, spongy layer of cells with air spaces.

### Leaf types

**Simple.** The parts of a simple leaf are the

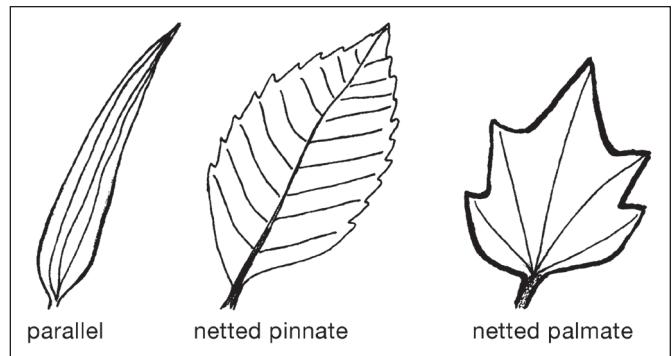
- *Blade:* The expanded thin structure on either side of the midrib (Figure 7A). The blade usually is the largest and most conspicuous part of a leaf.



- *Petiole*: The stalk that supports the leaf blade. It varies in length or may be lacking entirely in cases where the leaf blade is described as sessile or stalkless.
- *Stipule*: One or more small appendages at the base of the petiole, usually in pairs and soon shed.

**Compound.** The parts of a compound leaf are the

- *Leaflet*: Small leaflike structure; several or many leaflets make up one compound leaf (Figure 7B).
- *Petiole*: The stalk that supports each leaflet. It supports the entire compound leaf. Its length varies as for that of the simple leaf’s petiole.
- *Rachis*: This takes the place of the midrib in a simple leaf.



**Figure 8. Leaf venation.**

### Leaf venation

Venation describes the patterns in which the veins are distributed in the blade (Figure 8).

**Parallel-veined.** Numerous veins that run essentially parallel to each other.

Most monocots have parallel venation (corn, tulip, lily).

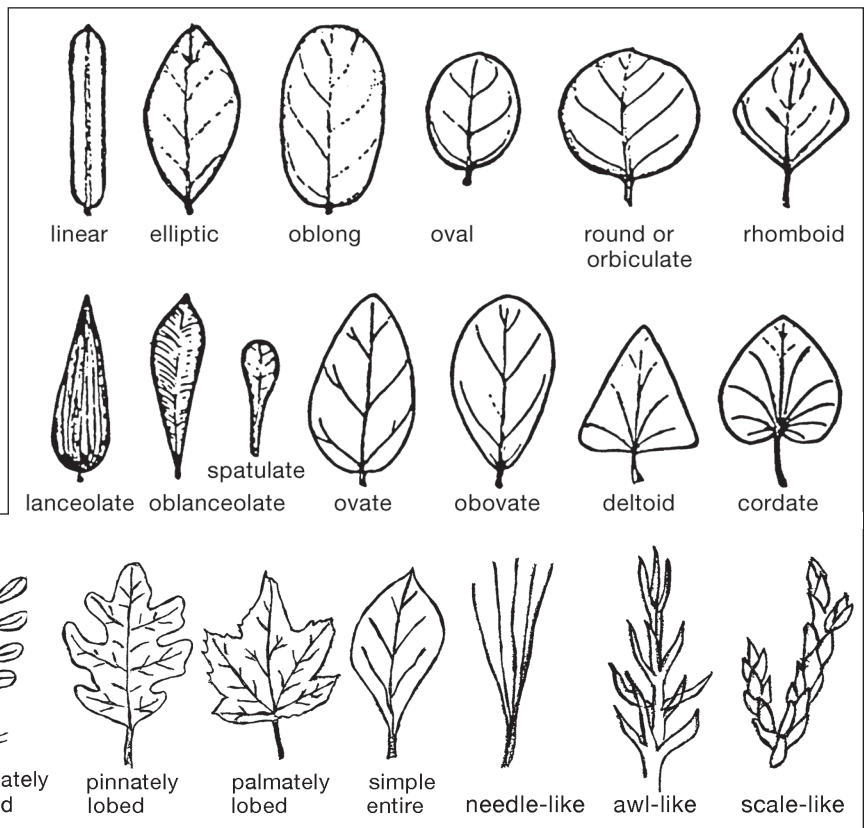
**Net-veined or reticulate-veined.** Veins that branch from the main rib or ribs and then subdivide. These venation patterns may be

- *Pinnate*: A pattern with one main vein or midrib and many lateral veins branching off it (oak and elm).
- *Palmate*: A pattern with three, five or more major veins originating from one point at the base of the blade. Palmate veins extend outwards like fingers from the palm of a hand (maple, English ivy).

### Leaf shapes

The shape of the leaf blade and the type of leaf margin are important

characteristics that help identify plants (Figure 9). Leaf blades vary a great deal. They may be simple (apple, oak) or compound (divided into several smaller leaflike segments, as in honeylocust). The smaller segments are called leaflets and are attached to a stalk (rachis) with a petiolule. Leaflets can also be arranged palmately (horse chestnut) or pinnately (ash). Pinnately compound leaves are said to be odd pinnate (ash) when ending in one leaflet and even pinnate when ending in two leaflets (locust). This terminology is important in identifying plants by their leaves.



**Figure 9. Leaf shapes.**



## Leaf modifications

Leaves have adapted to survive a wide range of environmental conditions. For instance, leaves exposed to strong sunlight are often smaller and have thicker cuticles than leaves of the same plant growing in shade. The reduced surface area and thicker cuticle reduces water loss. Leaves that develop in shade have a larger surface area to absorb light.

Chloroplasts respond to light by exposing as much pigment as possible in low light situations and by exposing less pigment in bright conditions. We see the results: dark green foliage on shade-grown plants and paler green foliage when the same plant grows in a sunnier location. Examples of this include hosta, Norfolk Island pine and weeping fig.

Leaves on plants that grow in dry environments will often be thick or narrow with few intercellular (air) spaces in the mesophyll, while guard cells are sunken below the level of the regular epidermis to minimize water loss. In some desert plants, such as cacti, the foliage leaves may be modified into thorns and photosynthesis occurs in chloroplast-containing cells in the stem.

Plants that grow underwater have just a few widely spaced mesophyll cells and big intercellular spaces for holding gases that are harder to acquire underwater.

Many conifers have leaves adapted for windy or low-moisture conditions. Needlelike leaves on pines have little wind resistance, and the flattened or scalelike leaves of junipers are waxy and well protected from the hot sun.

### Distinct leaf modifications that occur on plants

**Cotyledons.** Also called seed leaves, these are the leaves of the embryonic plant. These commonly serve as storage organs to feed the germinating seedling while true leaves develop.

**Spines and tendrils.** These specialized, modified leaves protect the plant or assist in supporting the stems.

**Storage leaves.** Found in bulbous plants and succulents, these serve as food storage organs containing starch and water.

**Bracts.** These are specialized leaves that are often brightly colored to attract pollinators. The showy structures on dogwoods and poinsettias are bracts, not flower petals.

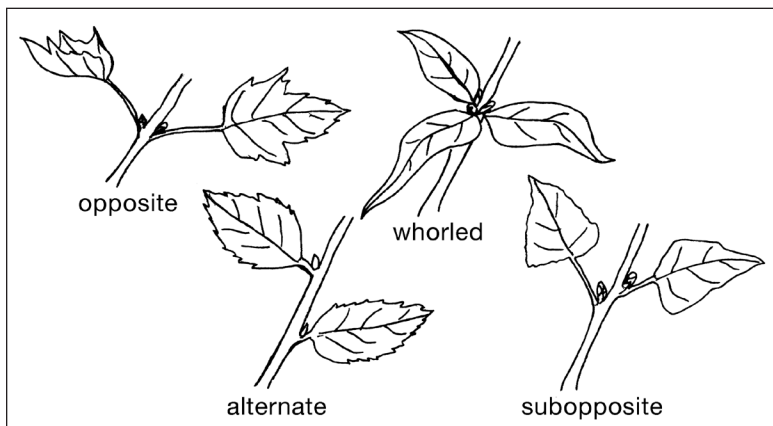


Figure 10. Leaf arrangements.

### Leaf arrangement and attachment

Leaves at the nodes may grow in pairs opposite one another (maple) or alternate (birch) from side to side along the stem (Figure 10).

They also may be whorled, with three or more leaves arising from a node, such as hydrangea. Subopposite leaves are slightly offset from one another; these are relatively rare. An example is the katsura tree, *Cercidiphyllum japonicum*.

## Flowers

Although there are many different kinds of flowers, they are similar in their organization. The function of flowers is sexual reproduction. Thus, flowers often form the showiest part of the plant. Their color and fragrance attract pollinators such as insects or birds to assure the continuance of the species. Flowers that are neither showy nor scented rely on other methods for pollination — wind, for example. Yet all have the same basic structures.

### Parts of flowers

Some plants produce solitary flowers such as a tulip, while others, such as the garden phlox, have clusters of flowers called inflorescences. Each individual flower consists of a stem portion called a receptacle that supports the rest of the flower parts (Figure 11). As the reproductive part of the plant, the flower contains either the male pollen or the female ovules, or both, plus accessory parts such as petals, sepals and nectar glands.

**Perianth.** The perianth consists of all the structures that enclose the reproductive organs, the corolla or petals, and the outermost layer, the calyx or sepals.

- *Sepals:* These are small, leaflike structures at the base of the flower that protect the flower bud. The sepals collectively are called the calyx. Sometimes the sepals are as highly colored and showy as the petals, as in the daylily. These colored sepals are called tepals.
- *Petals:* The highly colored portions of the flower. They may contain volatile fragrant oils and nectar glands. The number of petals on a flower is often used in the identification of plant families and genera. The petals collectively are called the corolla. The calyx and corolla collectively compose the perianth.

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

**Stamen.** The male part of the plant. It consists of a pollen sac called the anther and supporting filament, which holds the anther in position so that pollen from the anther may be disbursed by wind or carried to the stigma by pollinating insects or animals.

### Types of flowers

**Complete.** A complete flower has stamens, pistils, petals and sepals. If one of these parts is missing, the flower is incomplete.

**Perfect.** A perfect flower contains functional stamens and pistils. These are considered the essential parts of a flower and are involved in producing seeds. If either of the essential parts is lacking, the flower is imperfect.

**Pistillate** (female). A flower that possesses a functional pistil or pistils but lack stamens.

**Staminate** (male). A flower that contain stamens but no pistils.

**Dioecious** (literally interpreted “two houses”). Male and female flowers on separate plants. Most holly trees and bittersweet vines are either male (staminate) or female (pistillate) plants. To get berries, it is necessary to grow a female plant and have a male plant nearby to provide pollen.

**Monoecious** (literally interpreted “one house”). Male and female flowers on the same plant, either as bisexual flowers or with separate pistillate and staminate blossoms. Some plants bear only male flowers early in the growing season and later develop both sexes, for example, cucumbers and squash.

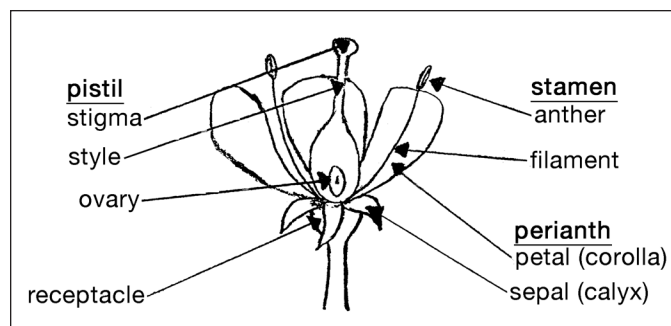


Figure 11. Parts of a typical flower.

### How seeds form

Pollination is the transfer of pollen from an anther to a stigma. This may occur by wind or by pollinators. Wind-pollinated flowers usually lack showy floral parts and nectar since they don't need to attract a pollinator. Flowers are brightly colored or patterned and contain a fragrance or nectar when they must attract insects, animals or birds as pollinators.

Self-pollinated flowers can be fertilized by their own pollen. Some flowers, like varieties of apple, can rarely be fertilized by their own pollen. In these cases, cross-pollination is necessary. With some fruits such as plums that are capable of bearing a crop without the presence of other varieties, cross-pollination will increase the size and quality of the yield.

The stigma contains a chemical that activates a compatible pollen grain, causing it to grow a long tube down the inside of the style to the ovules inside the ovary. The sperm is released by the pollen grain and fertilization occurs. Fertilization is the union of the male sperm nucleus from the pollen grain and the female egg located in the ovary. If fertilization is successful, the ovule will develop into a seed.

## From embryo to seedling

An embryo forms after repeated cell divisions of the zygote — the fertilized ovule. While cells are dividing, distinct parts of the seed are forming. These include the

- *radicle*: contains the root apical meristem and develops into the root system.
- *hypocotyl*: elongates to form the lowest part of the stem.
- *cotyledons* (seed leaves): contain food stored for the newly developing plant.
- *epicotyl*: contains the shoot apical meristem and develops into the shoot system.

Monocots have one cotyledon and dicots have two cotyledons. As the embryo develops, the outer walls that form the seed coat become a tough, protective layer around the seed.

## Seeds and seedlings

### Seeds

The seed or matured ovule is made up of three parts — the embryo, endosperm and seed coat or testa.

**Embryo.** An embryo is a rudimentary plant in an arrested state of development.

**Endosperm.** The endosperm provides a built-in food supply for the embryo. It can be made up of proteins, carbohydrates or fats.

**Seed coat, or testa.** This hard outer covering protects the seed from disease and insects and prevents water from entering the seed and causing germination before the proper time.

### Seedlings

Germination is the resumption of active growth of the embryo. Before anything else, the seed must take up water through the seed coat. In addition, the seed must be in the proper environmental conditions — exposed to oxygen, favorable temperatures and for some, correct light; the seed must be ripe or mature; and dormancy must be broken either physically or chemically. Factors that can limit germination include the time of the year seed was harvested, its age and moisture content, and successful fertilization.

### Fruits

Fruits consist of the fertilized and mature ovules called seeds and the ovary wall which may become fleshy as in the apple or dry and hard as in a maple fruit. The only parts of the fruit that contain genetic material from both the male and female flowers are the seeds. The rest of the fruit is actually part of the maternal plant and is, therefore, genetically identical to it.

The fruit is essentially the structure that protects the seeds as they develop. It also functions as a dispersal mechanism, as in the milkweed pod. A fleshy fruit such as an apple keeps the seeds moist until they are ready to germinate. Some seeds are hard and have a thick seed coat to keep the seed from germinating for months or years (for example, Kentucky coffee tree).

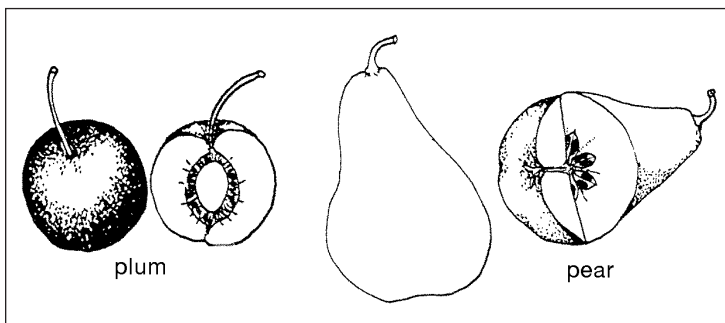


Figure 12. Simple fruits.

### Types of fruits

**Simple.** A simple fruit develops from a single ovary (Figure 12). Simple fruits include plum, cherry and peach (drupes), pears and apples (pomes), and tomatoes (berries). Botanically, tomatoes are a fruit because they develop from a flower, as do squash, cucumbers and eggplant. All of these develop from a single ovary.

**Dry.** Dry fruits are simple fruits in which the fruit wall becomes papery or leathery and hard

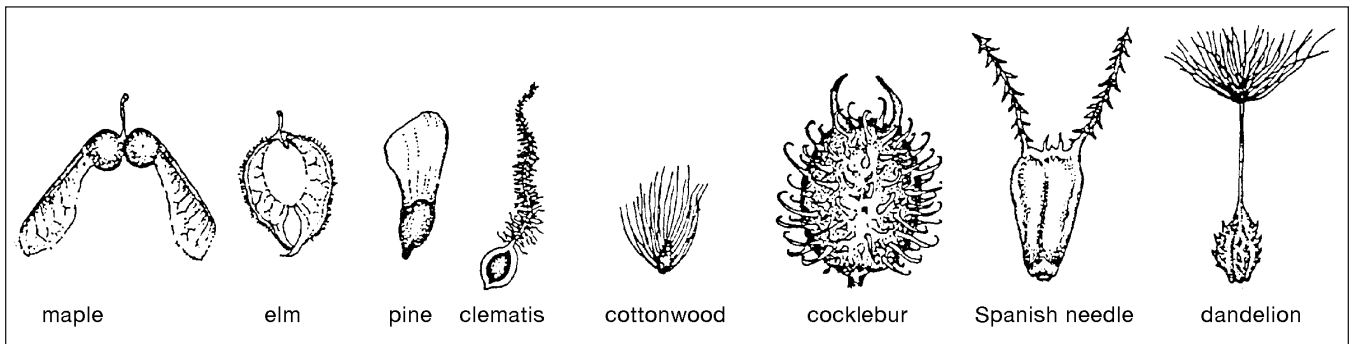


Figure 13. Dry fruits.

(Figure 13), as opposed to the fleshy examples above. Examples are peanut (pod), poppy (capsule), maple (samara) and walnut (nut).

**Aggregate.** Aggregate fruits come from a single flower that has many ovaries (Figure 14). The flower appears as a simple flower with one corolla, one calyx and one stem but with many pistils or ovaries. Examples are strawberry, raspberry and blackberry. The ovaries are fertilized separately and independently. If ovules are not pollinated successfully, the fruit will be misshapen. In the strawberry, the receptacle becomes bright red and fleshy. The small seeds are actually individual one-seeded fruits called achenes.

**Multiple.** Multiple fruits originate from a tight cluster of separate, independent flowers borne on a single structure. Each flower will have its own calyx and corolla. Examples of multiple fruits are corn, pineapple and sunflower.

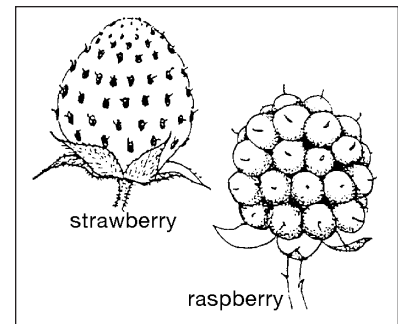


Figure 14. Aggregate fruits.

## Plant processes

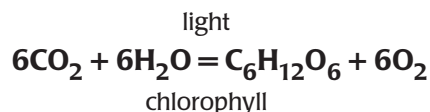
In the world of living things, plants are unique. They can make their own food and, except for plants that depend on insects or animals for pollination, they can exist without any other living creature. We, however, cannot exist without plants because in order to survive, we need what plants produce. Because of this, plants are called primary food producers.

In addition, plants maintain an atmospheric balance between carbon dioxide and oxygen, thus providing a vital buffer against rapid global warming. One further benefit plants offer is that of cleansing, of absorbing pollutants from soil, water and air. Sewage lagoons and enclosed spaces — including offices and homes — benefit from plants' ability to filter out unwanted, organic-based chemicals. All living things depend on photosynthesis for survival.

### Photosynthesis

Photosynthesis is the connecting link between solar energy and the energy required for life on earth. To manufacture its own food, a plant requires energy from the sun, carbon dioxide from the air, and water, usually from the soil. If any of these ingredients is limited or absent, photosynthesis or food production will slow or stop. If any factor is removed for long, the plant will die. Photosynthesis means literally "to put together with light."

The chemical equation below illustrates photosynthesis:



During photosynthesis, chlorophyll harnesses light energy and uses this energy to split water molecules into hydrogen and oxygen. In further reactions, the hydrogen from water is added to carbon dioxide in the manufacture of carbohydrates, the plant's source of energy. Only cells containing chloroplasts in the plant's leaves and stems can manufacture this energy.

The end product, glucose (a sugar), may be used in cellular respiration to provide energy, or it may be converted into other substances such as sucrose (table sugar), starch or cellulose, amino acids and proteins, fats and other compounds. Oxygen is a byproduct of this process.

Generally, as sunlight increases in intensity, photosynthesis increases. This means greater food production. Many garden crops, such as tomatoes, respond best to maximum sunlight. Tomato production is cut drastically as light intensities drop in the autumn. The same can be said for other high-light species such as corn and beans.

The carbon dioxide that is necessary for photosynthesis enters the plant through the stomata. Generally, carbon dioxide is plentiful in the air. However, in a closed greenhouse, plants may use more than can be replenished by outside

### Major plant functions

To understand how plants are able to manufacture their food and live independently, we need a working knowledge of plant growth processes and development. Three major plant functions are the basis of plant growth and development: photosynthesis, respiration and transpiration.

### Differences between photosynthesis and respiration

Photosynthesis	Respiration
1. Produces food	1. Uses food for plant energy
2. Energy is stored	2. Energy is released
3. Occurs in cells' chloroplasts	3. Occurs in all cells
4. Oxygen is released	4. Oxygen is used
5. Water is used	5. Water is produced
6. Carbon dioxide is used	6. Carbon dioxide is produced
7. Occurs in sunlight	7. Occurs in dark as well as light

air movement, and supplemental carbon dioxide can be used to enhance plant growth.

Temperature is also an important factor. In most plants, the optimal range for maximum photosynthetic activity is at temperatures ranging from 65 to 85 degrees F. Higher or lower temperatures may hinder photosynthetic activity. Of the total sunlight energy that falls on the leaf surface, typically only 3 percent is used for photosynthesis, 15 percent is reflected and 5 percent passes through the leaves. The other 70 percent raises the temperature of the leaf. Cooling the leaf takes place through the process of transpiration (water loss).

### Respiration

Carbohydrates made during photosynthesis benefit the plant when they are converted to energy. This energy is used to build new tissues and to help the plant grow. The chemical process by which sugars and starches produced by photosynthesis are converted to energy is called respiration, which is a form of oxidation. The process of respiration is similar to the burning of wood or coal to produce heat. Its byproducts are water and carbon dioxide.

Respiration is essentially the reverse of photosynthesis. Respiration occurs at night as well as during the day. It takes place in all life forms (including animals) and in all living cells. The release of accumulated carbon dioxide and the uptake of oxygen occur at the cellular level. In animals, blood carries both carbon dioxide and oxygen to and from the atmosphere by means of the lungs (or gills in fish). In plants, the oxygen produced during respiration passes by simple diffusion into the open spaces within the leaf and then through the stomata.

### Transpiration

Transpiration is the process by which a plant loses water, primarily through leaf stomata. Transpirational loss accounts for about 90 percent of the water that enters the plant through the roots. The other 10 percent of the water is needed for chemical reactions and expansion of plant tissues.

Transpiration is necessary to transport dissolved minerals from the soil to other plant parts, to cool leaf and stem tissue through evaporation, to move sugars and plant chemicals, and to maintain the turgidity or firmness of plant tissues. The amount of water the plant loses via transpiration depends on environmental factors that include temperature, humidity, and wind or air movement. As temperature or air movement increases, transpiration also increases. As humidity decreases, transpiration increases.

These facts relate to the practical activity of watering. Outdoors, we need to water more often in hot, windy and dry weather. Conversely, when temperatures are cool and relative humidity high, such as in early spring, the need for water decreases because of a decrease in transpiration.

#### For growth

For growth to occur, carbohydrate gains through photosynthesis must be greater than losses through respiration.



## Environmental influences

Plant growth and distribution are influenced by the environment. If any one environmental factor is less than ideal, it will become a limiting factor in plant growth. Such limiting factors greatly influence the geography of plant distribution. For example, only plants adapted to the limited availability of moisture can live in the desert. Most plant problems are associated with one or more environmental factors. The results may be immediate and direct, such as wilting or plant death from lack of water. Indirect results are also seen in apparently healthy plants when they become diseased or decline because they were weakened by flood, drought or some other factor.

Water, light, temperature and air are the four main environmental factors that influence plant growth and development. Understanding how each works can help guide selection of the optimal microclimates for plants.

### Water

Water plays an important role in all plant functions. First, water is necessary to maintain turgor pressure that gives the plant its rigidity and shape (turgor pressure can be compared to air in an inflated balloon). Water is needed for cell division and expansion. It also provides the internal pressure that pushes growing roots through the soil. Water is used during the biochemical process of photosynthesis.

Water also helps in chemical changes that dissolve minerals from the soil — it carries them in solution from the roots to all parts of the plant, where they serve as raw materials in the growth of new plant tissues. During transpiration, moisture is literally pulled through the plant as water evaporates through the leaves and helps stabilize plant temperature.

### Water-related conditions

**Water stress.** If water is in short supply, the plant shows a series of responses. The most common symptom is wilting. However, plants that are water deficient may also show leaf rolling, color changes from deep green to blue-green, leaf browning and foliage losses such as dropping leaves.

During hot, dry summer months, moderate stress can be tolerated by most plants on a daily basis as long as moisture is replenished during the low-stress night period. However, severe or prolonged moisture stress can cause permanent damage to the plant.

**Drought tolerance.** Plants differ greatly in their ability to extract water from the soil and in the absolute amount of water required for normal plant growth. Some plants are considered drought tolerant because they can function well in dry soil (xerophytic) conditions.

Drought tolerance results from one or more of the following factors:

- Deep and well-developed root systems
- Waxy leaf surfaces
- Leaf hairs that minimize water loss by reducing air movement around stomata
- Shiny surfaces that reflect light
- Leaves that fold up or drop under water stress conditions
- Small, thick leaves

**Excess moisture.** Too much water in the root zone can damage plants because of reduced oxygen in the area around root hairs. The objective of proper irrigation is to supply the right amount of water before harmful stress occurs but to avoid keeping the soil so saturated as to limit oxygen availability to the roots.

### Water stress

When adequate moisture is available to the plant, water flows continuously from the root hairs up to the leaves. If inadequate moisture is available in the soil, or if rate of evaporation from the leaves exceeds the rate at which water can move upward, the plant becomes stressed.

The gardener's goal is to reduce the plant's water stress to maintain a quality landscape or a productive garden. This can be done as much through plant selection and placement as by watering.

## Phototropism

Phototropism refers to a plant's tendency to lean and grow toward the light. Seedlings are especially sensitive.

## Light

The principal characteristics of light that affect plant growth are quantity, quality and duration.

### Quantity

The intensity or concentration of sunlight varies with the season of the year. Up to a point, the more sunlight a plant receives, the greater its capacity to produce plant food through photosynthesis. However, if light intensity becomes too high, photosynthesis can actually be reduced. This occurs first in low-light plants such as hosta. Light intensity can be reduced in garden or greenhouse settings by the use of shading materials or by planting in the shade. It can be increased with reflective material around plants, white backgrounds or supplemental lights.

In addition to seasonal variations in light intensity, latitude directly affects how much sunlight reaches us. Energy from sunlight is greatest at and near the equator, diminishing with increasing distance, north or south, from the equator. For example, sunlight in the Missouri Bootheel is slightly more intense than at locations farther north.

### Quality

The color or wavelength reaching the plant surface affects growth. Sunlight can be broken up by a prism into its rainbow colors of red, orange, yellow, green, blue, indigo and violet. Red and blue light have the greatest effect on plant growth because they are the two wavelengths of light most important to the process of photosynthesis. Red light, when combined with blue light, encourages flowering. Green light has least effect on plants as they absorb less of it — they look green to our eyes because they reflect green light rather than use it for growth processes.

Light quality is important as we consider providing artificial light to plants. Cool white fluorescent lights are high in the blue range of light quality, whereas incandescent lights are high in the red or orange range. They generally produce too much heat to be a valuable light source. "Grow lights" have a mix of red and blue colors that imitate sunlight. A similar balance can be achieved with a mixture of warm-white and cool-white fluorescent tubes.

### Duration

Photoperiod is a term that refers to the length of time that a plant is exposed to sunlight or darkness is called photoperiod. The ability of many plants to flower is controlled by photoperiod.

**Short-day or long-night plants.** These plants form flowers only when the day length is less than a certain duration. For these plants, it actually is the length of uninterrupted darkness that accompanies a short day that is critical to trigger the flowering response. If even a flash of light interrupts the dark period, plants will fail to flower. Short-day plants include many fall-flowering plants such as chrysanthemum and poinsettia, whose flowers are initiated naturally when days become shorter.

**Long-day or short-night plants.** These plants form flowers only at day lengths longer than a certain number of hours. They include almost all of the summer-flowering plants, as well as many vegetables, including beet, radish, lettuce, spinach and potato. Flowers are initiated as days become longer in late spring and summer.

**Day-neutral plants.** These plants form flowers regardless of day length. Some plants do not really fit into any category but may respond to combinations of day lengths. For example, petunias will flower regardless of day length, but flower earlier and more profusely under long day lengths.

## Light and flowering

In greenhouses, growers can initiate flowering at any time of the year by regulating light and dark periods. For instance, poinsettias are short-day plants that initiate bloom in response to shorter day lengths. They can be brought into bloom precisely at Christmas by using black curtains to block out sunlight, thus shortening the photoperiod. Other plants can be artificially lit in greenhouses to initiate flowering when outdoor light levels are low.

## Temperature

Temperature affects productivity and growth by affecting the processes carried on in a plant such as photosynthesis and respiration. An individual plant's response depends upon its needs and its adaptability to warm- or cool-season conditions. If temperatures are high and day length is long, cool-season crops such as spinach will flower. Temperatures that are too low for a warm-season crop such as tomato will prevent fruit set. The same problem may be caused by continuous excessive heat. Unfavorable temperatures produce stunted growth and poor quality vegetables. Bitterness in lettuce results from high temperatures. Lupines and delphiniums do not grow well in the lower Midwest because they are not adapted to its hot, humid summers.

Sometimes temperature control is used along with day length to manipulate flowering. The Christmas cactus forms flowers as a result of short days and low temperatures. Temperature alone also influences flowering. Tulips can be forced to flower out of season by putting planted bulbs in cold storage (35–45 degrees F) in October. The cold temperatures encourage flower development and stem elongation as the bulb matures.

Thermoperiod is a term that refers to daily temperature changes. Most plants respond to and achieve maximum growth when daytime temperatures are about 10 to 15 degrees higher than nighttime temperatures. They photosynthesize during optimal daytime temperatures, and their respiration rates slow during the cooler nights. Higher temperatures result in increased respiration, sometimes above the rate of photosynthesis, so products of photosynthesis may be used up more rapidly than they are being produced.

### Optimal temperatures

Plants are adaptable and there are both heat- and cold-tolerant choices for plants that grow best in a given environment. Optimal growing temperatures vary. For example, snapdragons grow best at average nighttime temperatures of 55 degrees F and the poinsettia at 62 degrees F. Florists' cyclamen does well in very cool conditions while many summer annual bedding plants, such as vinca (*Catharanthus*), prefer higher temperatures.

**High temperatures.** Above 86 degrees F, photosynthesis in many plants essentially shuts down and, in some, cell proteins start to be damaged. During the long, hot days of summer, plants often rely on stored energy reserves because there is little photosynthetic activity.

**Low temperatures.** Low temperatures can also result in poor growth. Photosynthesis slows down when it is cold. Since photosynthesis is slow, growth is slow. For harvested crops, this results in lower yields.

**Dormancy.** In some cases, a certain period of time at low temperature is needed by plants in order to break dormancy and to grow properly. This is especially true of crops that originated in cold regions. Apples are a prime example; most varieties require 1,000 to 1,200 hours below 45 degrees F but above 32 degrees F before they will break their rest period and begin growth. Lilies and daffodils need six weeks of temperatures at 33 degrees F before they will bloom.

### Temperature zones

A plant's range — where it will grow naturally — is affected by temperature and other climatic factors. This information can help gardeners select plants and varieties that are suited to local conditions. Maps have been developed that can help you determine the climatic conditions in your area. The websites for these maps are listed on page 24.

**USDA Plant Hardiness Zones Map.** Whether a plant is considered hardy or nonhardy depends on its ability to withstand cold temperatures. This is the basis of the 11 distinct plant hardiness zones for North America, which reflect average minimum winter temperatures for a given area. It does not, however, take into

### Winter injury

Winter injury can occur if midwinter temperatures are too low, or if there are unseasonably low temperatures in early fall or late spring. Winter injury may also occur through desiccation or drying out.

Plant tissues need water during winter. When soil is frozen, water movement in the plant is severely restricted. On windy winter days, evergreens can become water-deficient in a few minutes; leaves or needles soon turn brown. If temperatures drop too low during the winter, entire trees of some species are killed by the freezing and desiccating of plant cells.

On the other hand, unseasonably high winter temperatures can cause premature bud break in some plants; subsequent freezes may kill or severely damage the exposed tissues. Late spring frosts can ruin entire crops.

account temperature fluctuations, adaptation to wet or dry soils, humidity or summer temperatures.

In Missouri, the northern third of the state is mostly in USDA hardiness zone 5 (average winter minimum of -10 to -20 degrees F). The southern two-thirds of the state is zone 6, except for the Bootheel region, which is zone 7 (0 to +10 degrees F).

**American Horticultural Society Heat Zone Map.** The heat zone map depicts 12 heat zones based on the average number of days when temperatures reach or exceed 86 degrees F. Most of Missouri is in heat zone 7, which receives 61–90 days per year of temperatures above 86 degrees F. A small portion of southern Missouri is in heat zone 8 (91–120 days above 86 degrees F) and the north-central part of the state is heat zone 6 (46–60 days above 86 degrees F).

**Sunset Garden Climate Zones Map.** This climate map contains 45 zones, or regions. It takes into account heat, cold, moisture and altitude for specific geographical areas in the United States.

## **Air**

Air contains nitrogen, oxygen and carbon dioxide, plus water vapor or humidity, and a number of other gaseous compounds. Of the three main components, nitrogen is present in the greatest concentration by volume: 79 percent. Oxygen is next, at 20 percent.

Carbon dioxide, or CO<sub>2</sub>, makes up less than 1 percent of the air's volume (about 0.04 percent, or 400 parts per million). Nevertheless, it has great significance in the biological world as one of the ingredients for photosynthesis and for the manufacture of the carbohydrates that enter the food chain.

Land plants rely almost entirely upon carbon dioxide in the atmosphere. A small part of their photosynthetic need is supplied by carbon dioxide from respiration (which never leaves the plant tissues). The rest must enter the plant through the stomata, most of which are located on the undersides of leaves.

## **Soil atmosphere**

Air in the soil usually contains more carbon dioxide than atmospheric air, with concentrations of up to 10 percent or more in some soils. The higher levels of carbon dioxide result from the respiration of many organisms in the soil, including plant roots. In soil with adequate pore space, the concentration of oxygen rarely becomes too low to support aerobic respiration. In wet or flooded soils, oxygen is often too low to fuel aerobic respiration, and anaerobic organisms and processes take over that exist in conditions with very low or no free oxygen.

## **Air pollutants**

Many of the gases that inadvertently and unwantingly get into the air we breathe will affect plants, even in small quantities. For example, tomato plants will respond to small amounts of ethylene by twisting its new growth. Continued exposure will cause leaf curling and death. Ethylene is a byproduct of the incomplete combustion of fossil fuels such as natural gas and oil. Thus, tomato plants are useful indicators where this type of gas is produced. Most ethylene damage to plants occurs in greenhouses equipped with malfunctioning heaters.

Sulfur dioxide and ozone are also damaging to plant tissues. Sulfur dioxide causes dry, dead areas to form at the leaf margins and between veins. Ozone, which enters leaves through the stomata, destroys plant cells by damaging their membranes so they collapse. As a result, the leaves first show a stippled appearance followed by lesions that are white to tan.

Poor plant growth around or downwind from industrial zones may indicate air pollution from these and other chemicals.

## Plant growth and development glossary

**abscission zone** A layer of cells at the base of a leaf petiole, flower or fruit stalk where the organ separates from the plant.

**adventitious** Arising in an unexpected location.

**alternate** Plant parts arranged singly on the main stem or axis.

**annual** A plant completing its life cycle within a single growing season.

**apical** At the tip.

**axil** The angle between the upper leaf surface and the stem to which it is attached.

**bark** All tissues outside the vascular cambium of a woody stem.

**biennial** A plant completing its life cycle within two growing seasons.

**blade** The flattened part of a leaf.

**callus** Undifferentiated tissue developed in response to wounding.

**cambium** A meristematic region giving rise to xylem and phloem.

**chlorophyll** A green plant pigment involved in photosynthesis.

**compound leaf** A leaf in which the blade is divided into leaflets.

**cortex** Tissue in roots and stems immediately inside the epidermis.

**cotyledon** A seed leaf, which is a food storage structure in seeds.

**cross-pollination** Transfer of pollen to a flower from another plant.

**cuticle** Waxy outer layer on leaves, stems and fruits.

**deciduous** Shedding all leaves in one season.

**dicot** Having two cotyledons in the seed.

**dormant, dormancy** A state of reduced cellular activity.

**embryo** Immature plant within a seed.

**epidermis** The outer layer of cells on a herbaceous plant.

**evergreen** A perennial plant bearing leaves throughout the year.

**geotropism** Growth of a plant in response to gravity.

**germination** Beginning of growth of a seed, spore or pollen grain.

**gymnosperm** Class of plants that form seeds in open receptacles, often cones.

**hardiness** Ability to withstand climatic changes.

**herbaceous** Soft, green, nonwoody plant.

**internode** The section of stem between two nodes; it has no buds.

**lateral bud** A bud in a leaf axil, on the side of the stem.

**leaf** The principal organ of photosynthesis, contains a bud at its base.

**leaf scar** The scar left on the plant stem after the leaf has fallen.

**lenticel** Small gas-exchange opening in the cork of a woody stem.

**meristem** A region where cells divide actively.

**mycorrhiza** A type of fungus that forms a partnership with the roots of higher plants; it assists in nutrient and water uptake.

**node** The segment of a stem to which leaves and lateral buds are attached.

**opposite** Arranged directly across from each other.



## For further information

### MU publications

<http://extension.missouri.edu>

G6950 *Steps in Fertilizing Garden Soil: Vegetable and Annual Flowers*

G9112 *Interpreting Missouri Soil Test Reports*

### Related reading and websites

Capon, Brian. 1990. *Botany for Gardeners: An Introduction and Guide*. Portland, Ore.: Timber Press.

Gruelach, Victor A. 1968. *Botany Made Simple*. Garden City, N.Y.: Doubleday and Company.

Harris, James G. and Melinda Woolf Harris. 1994. *Plant Identification Terminology: An Illustrated Glossary*. Spring Lake, Utah: Spring Lake Publishing.

Wilkins, Malcolm. 1988. *Plantwatching: How Plants Remember, Tell Time, Form Relationships, and More*. New York: Facts on File Publications.

U.S. Department of Agriculture. USDA Plant Hardiness Zone Map, <http://planthardiness.ars.usda.gov>

American Horticultural Society. AHS Plant Heat Zone Map, <http://www.ahs.org/gardening-resources/gardening-maps/heat-zone-map>

Sunset. Sunset's Garden Climate Zones Map, <http://www.sunset.com/garden/climate-zones/climate-zones-intro-us-map>

**palisade cell** A photosynthetically active cell directly beneath the upper leaf epidermis.

**palmate venation** Major veins radiate from one point.

**parallel venation** Major veins are parallel to each other, or nearly so.

**parenchyma** Simple, nonspecialized vegetative tissue composed of thin-walled, undifferentiated cells.

**perennial** A plant that lives through several growing seasons.

**pericycle** A root tissue that gives rise to branch roots.

**petiole** Leaf stalk or stem that attaches the blade to the main stem or branch.

**phloem** Food-conducting tissue of plants.

**photoperiodism** Initiation of flowering in response to relative lengths of night and day.

**photosynthesis** Process in which plants use light energy to form sugar from carbon dioxide and water.

**phototropism** Curvature of a plant part in response to light.

**pistil** Female part of a flower, consisting of stigma, style and ovary.

**pollination** Transfer of pollen from an anther to a stigma.

**radicle** Embryonic root.

**respiration** Chemical breakdown of food substances, resulting in liberation of energy.

**rhizome** Underground, horizontal stem.

**root** Underground portion of a plant that anchors it into soil and absorbs water and minerals.

**root cap** Protective covering over root tip.

**root hair** Projection of a root's epidermal cell, which increases surface area for absorption of water and minerals.

**seed** Reproductive structure formed from maturation of an ovule that contains an embryo and stored food.

**seed coat** Protective outer layer of a seed.

**self-pollination** Transfer of pollen from an anther to the stigma of the same flower (or a genetically identical flower).

**senescence** Aging process; breakdown of cellular structures leading to death.

**shoot** Stem that bears leaves.

**sieve tube** A food-conducting cell in the phloem.

**stamen** The male part of a flower, which consists of anther and filament.

**stippled** Covered with white dots or flecks.

**stoma (plural: stomata)** Pore in the epidermis of leaves and herbaceous stems.

**tracheid** Water-conducting cell in gymnosperms.

**transpiration** Loss of water vapor from plants.

**vascular bundle** Strand of food and water-conducting tissue that contains xylem and phloem.

**vein** A strand of xylem and phloem in a leaf blade.

**xylem** Water-conducting tissue of plants.

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