Chapter 1

Basic Botany, Physiology and Environmental Effects on Plant Growth

Gymnosperms and Angiosperms 1

Life Cycles 2

Principal Parts of Vascular Plants 2

- Roots 2
  - Types of Roots 2
  - Parts of a Root 3
  - Roots as Food 4
- Stems
  - Texture and Growth of Stems 5
  - Diversified Stem Development 5
  - Stem Use 6
- Leaves 7
  - Parts of a Leaf 7
  - Types of Leaves 8
  - Venation of Leaves 8
  - Leaves as a Means of Identifying Plants 8
  - Shape of the Leaf Blade 9
  - Shape of the Blade Ends 9
  - Leaf Margins 9
  - Leaf Arrangement Along a Stem 10
  - Leaves as Food 10
- Buds 10
  - Buds as Food 11
- Flowers 11
  - Parts of the Flower 11
  - Types of Flowers 11
  - Flowers and Plant Classification 11
- How Seeds Form 12
- Types of Inflorescences 12
- Fruit 12
  - Parts of Fruit 12
  - Types of Fruit 13
- Seed 13

Physiology: Plant Growth and Development 15

- Photosynthesis 15
- Respiration 16
- Transpiration 16

Environmental Factors That Affect Plant Growth 17

- Light 17
- Temperature 18
  - Review of How Temperature Affects Plant Processes: 18
- Water 19

Plant Nutrition 20

- Macronutrient Outline 21
- Micronutrient Outline 23

References 24

CHAPTER 1

Basic Botany, Physiology, and Environmental Effects on Plant Growth

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In order to gain a working knowledge of horticulture, it is necessary to understand the life cycles of plants, their various structures and how they function, and how plants develop in reaction to the environment.

Gymnosperms and Angiosperms

Nearly all of the plants we use in horticulture are vascular plants. Vascular plants contain tissues which transport water and dissolved materials. The vascular system may be likened to the circulatory system in animals, or the plumbing in your house.

A few of these plants, like ferns and horsetails, do not produce seed. They reproduce by spores. The vast majority of vascular plants do produce true seed; these can be further divided into two large groups: **gymnosperms** and **angiosperms**.

Gymnosperms and angiosperms are similar in many ways: they photosynthesize, or produce sugars; they have vascular systems to transport water, minerals and other materials; and they reproduce by seed. But they vary in some important ways.

Gymnosperms do not have true flowers, and although they produce seeds, the seeds are not enclosed in fruits. Most of the gymnosperms we use in horticulture produce their seeds in cones. Examples are pine, spruce, cedar and juniper. A surprising member of this group is the ginkgo. Angiosperms produce flowers and develop fruits that contain seeds. This group can be further divided into **monocotyledons** (monocots) and **dicotyledons** (dicots). Monocots and dicots differ in a number of ways:

1. **Monocots produce one cotyledon,** or seed leaf, when they emerge from seeds while **dicots produce two cotyledons**;
2. Monocot flower parts are generally in multiples of three (for example, tulips have six "petals") while dicot flower parts are generally in multiples of four or five (for example, a rose has petals in multiples of five).
3. Monocot leaves are long and narrow with **parallel veins** (for example, corn and bermuda grass) while dicots have variously shaped leaves with **netted veins** (as found in maples and cucumbers).
4. The internal root, leaf, and stem structures vary significantly between monocots and dicots (see section on stems).

In this introductory chapter, we are focusing on Angiosperms, or flowering plants.

Life Cycles

Flowering plants can be classified by the number of growing seasons required to complete their life cycle. **Annuals** pass through their entire life cycle from seed germination to seed production in one growing season, and then die. Examples include marigold, zinnia, calendula, cucumber and tomato. Some annuals like pansy are called winter annuals, because they germinate in fall, overwinter, produce seed in spring, and then die. Plants like impatiens are perennial in their native tropical habitats, but we can use them in colder regions as if they were annuals.

Biennials are plants which start from seeds and produce vegetative structures (usually only foliage) and food storage organs (roots) the first season. During the first winter, the plant is **vernalized**. That is, it is stimulated to produce reproductive structures during the following growing season. In the second season, flowers, fruit, and seeds develop to complete the life cycle, and the plant dies. Carrots, beets, cabbage, celery, onions, hollyhock, foxglove, and sweet william are all biennials.

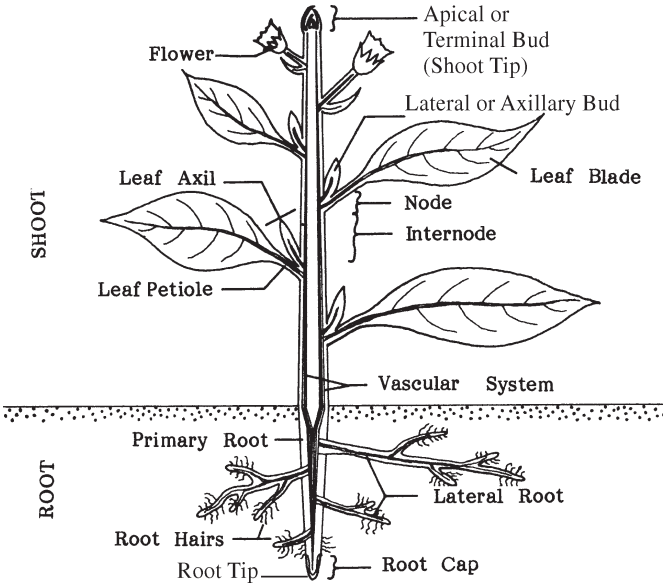
Plants which are botanically classified as biennials may, in some cases, complete their life cycle in only one growing season. This situation occurs when drought, variations in temperature, or other climatic conditions cause the plant to physiologically pass through the equivalent of two growing seasons, in a single growing season. This phenomenon is referred to as **bolting**. Also, some specific biennials, like 'Foxy' foxglove, act as annuals because they have been specifically bred to do so.

Perennial plants live for three or more years. Once they reach maturity, they generally produce flowers and seeds each year. Perennials are called herbaceous if their top dies back to the ground each winter and new stems grow from the roots each spring. Most of our flower garden perennials are herbaceous. Trees and shrubs are classified as woody perennials, since their top growth persists and develops woody tissue.

Principal Parts of Vascular Plants

The parts of a plant can be divided into two groups; **vegetative parts** and **sexual reproductive parts**. The vegetative parts include the stems, leaves, leaf buds and roots. Sexual reproductive parts are those involved in the production of seed: flower buds, flowers, fruits, and seeds.

Principle Parts of a Vascular Plant



Roots

A thorough knowledge of plant root systems is essential in order to understand plant growth, flowering, and fruiting. The structure and growth habits of roots have a pronounced effect on the size and vigor of plants, method of propagation, adaptation to certain soil types, and response to cultural practices and irrigation.

Roots typically form the below-ground portion of a plant. They are characterized by the presence of a **root cap**, and the absence of nodes, internodes, buds, leaves and flowers. The principal functions of roots are to **absorb nutrients and water**, to **anchor the plant** in the soil, to furnish **physical support** for the stem, and to serve as **food storage** organs. In some plants, they are used for propagation.

Types of Roots

The **radicle**, or seedling embryo root, develops into one of two major types of root systems: **taproot** or **fibrous**. In taprooted plants, the radicle develops into a central, often fleshy root which continues to elongate downward into the soil. A taproot becomes the central and most important feature of such a root system, with a rather limited amount of

secondary branching. Some trees, especially nut trees like pecan, have a long taproot with very few lateral or fibrous roots. This makes them difficult to transplant and necessitates planting only in deep, well-drained soil. Taproots are the principal edible parts of carrot, parsnip and salsify. Most herbaceous dicots have taproots, often with many branching lateral roots. One factor which causes shrubs and dwarf trees to remain smaller than standard trees is the lower activity of the cambium tissue in the lateral roots.

If plants that normally develop a taproot are undercut so that the taproot is severed early in the plant's life, the root loses its taproot characteristic and develops a lateral root system. This is done commercially in nurseries so that trees, which naturally have taproots, will develop a compact, root system. This allows a higher rate of transplanting success.

A fibrous root system develops on plants whose primary root ceases to elongate, leading to the development of numerous secondary roots, which branch repeatedly and form a wide-spreading root system. Most herbaceous monocots (like grasses) have fibrous root systems. Fibrous roots remain small in diameter because of a lack of cambial activity.

Taproot of Carrot



Fibrous Root of Grass



The quantity and distribution of plant roots influence a plant's absorption of moisture and nutrients. The depth and spread of roots depends on the inherent growth characteristics of the plant and physical characteristics of the soil. Roots penetrate much deeper in a loose, well-drained soil than in a heavy, poorly-drained soil. A dense, compacted layer in the soil restricts or even stops root growth.

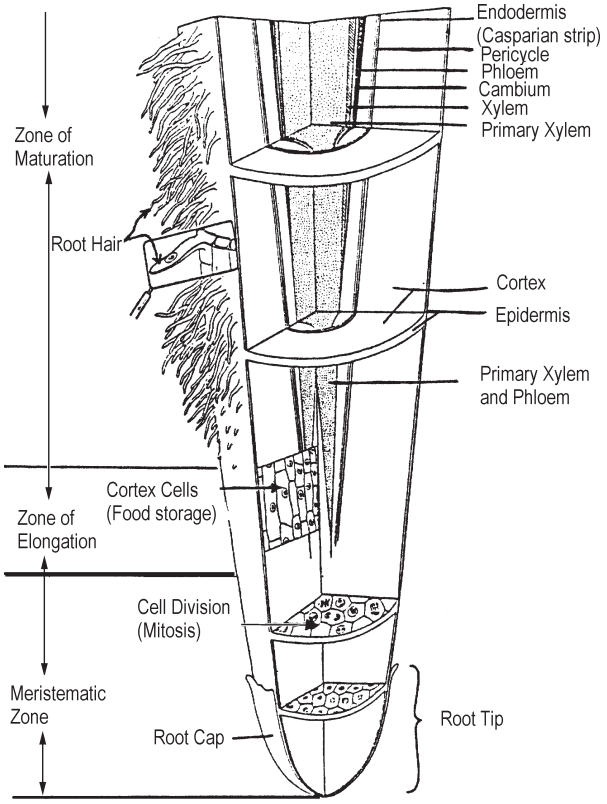
During early development, a seedling absorbs nutrients and moisture from just the few inches of soil surrounding it. Therefore, the early growth of most horticultural crops which are seeded in rows benefits from band applications of fertilizer, placed a few inches to each side and slightly below the seeds, and irrigation in the zone immediately around the young plant.

As plants become established, lateral or feeder root systems develop laterally and usually extend far beyond the spread of the branches. For most cultivated crops, roots meet and overlap between the rows. The greatest concentration of feeder roots occurs in the top 12 inches of soil, but significant numbers of lateral roots may grow downward from these roots to provide an effective absorption and anchoring system several feet deep.

Parts of a Root

A growing root has four major sections: the **root cap**, the root tip or **meristem**, the **zone of elongation** and the **maturation zone**. The root cap, outside the very tip of the root, consists of cells that are sloughed off as the root grows through the soil. The root cap covers and protects the meristem (root tip), which manufactures new cells. The meristem is an area of cell division and growth. Behind it is the zone of elongation, in which cells increase in size through food and water absorption. These cells, by increasing in size, push the root through the soil. In the maturation zone, cells change into specific tissues such as epidermis, cortex, and vascular tissue. The epidermis, or outermost layer of cells surrounding the root, is responsible for taking up water and minerals. **Root hairs** are specialized epidermal cells which perform much of the water and nutrient uptake. **Cortex cells** move water from the epidermis into the middle of the root, and also serve as a site of food storage. **Vascular tissue**, located in the center of the root, conducts water and nutrients upward, and synthates downward.

Root Structure



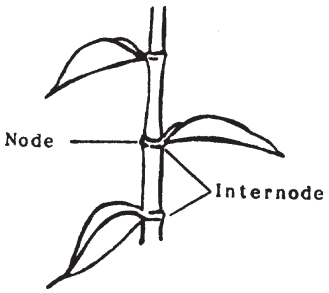
Roots as Food

Some plants such as dahlia and the sweet potato produce underground storage organs called **tuberous roots**. They are true roots, not stems, and have neither nodes or internodes.
Carrot, parsnip, salsify, and radish are elongated taproots.

Stems

A stem is the main axis of a plant. Stems generally extend upward, and often produce secondary stems called branches. In some plants, stems are horizontal at ground level, and some plants even produce underground stems. A stem can be differentiated from a root because all stems have **nodes** and **internodes**, while roots do not. A node is the region of stem where leaves are attached. The region between two nodes is called an internode.

Parts of a Stem



The length of an internode depends on many factors. Decreasing fertility can decrease internode length. Too little light can result in a long internode, creating a "spindly" plant. This situation is known as **etiolation**. Growth produced early in the season has the greatest internode length. Internode length decreases as the growing season nears its end. Vigorously growing plants tend to have greater internode lengths than less vigorous plants. Internode length varies with competition from surrounding stems or developing fruit. If the energy for a stem has to be divided among three or four stems, or if the energy is diverted into fruit growth, internode length is shortened.

Stems help us define a plant's habit. A tree is a perennial woody plant, generally with one main stem called a trunk, and generally over 25 feet tall at maturity. A shrub is a perennial woody plant with one or more main stem, generally less than 25 feet tall at maturity. Vines, which may be annual or perennial, develop long, trailing stems that grow along the ground unless they are supported by another plant or structure. Some twining vines circle their support clockwise (hops and honeysuckle) while others circle counter-clockwise (pole beans and Dutchman's pipe vine). Climbing vines support themselves with aerial roots (English ivy and poison ivy), slender tendrils which encircle the supporting object (cucumber, gourds, grapes, and passion-flowers), or tendrils with adhesive tips (Virginia creeper and Japanese creeper).

In addition to giving plants their characteristic form (upright, prostrate, shrubby, etc.), stems support buds and leaves, and serve as conduits for carrying water, minerals, and sugars. Inside the stem is the vascular system, which transports food, water and minerals and offers skeletal support for the plant. The vascular system is composed of two types of complex tissue - xylem and phloem. Xylem tissue conducts water and minerals up from the roots, while phloem conducts synthates manufactured in the plant to wherever they are needed.

In monocots, the vascular tissues form individual bundles of paired xylem and phloem. These bundles are scattered throughout the simple, undifferentiated ground tissue that fills the stem.

In dicots, individual bundles are arranged in a ring, with xylem towards the inside and phloem towards the outside. In young dicots, the individual bundles are still discreet. In older plants, the bundles merge to form continuous bands of xylem and phloem.

The central core of a dicot stem is filled with simple pith tissue. The space between the epidermis and the vascular bundles is filled with simple cortex tissue.

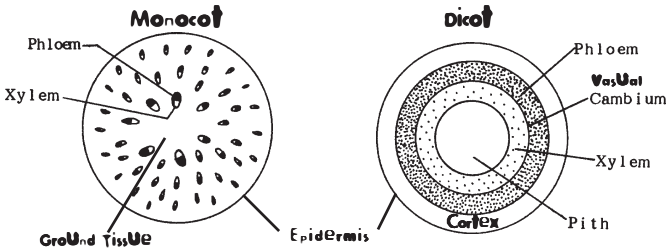
In older dicot stems, the bands of xylem and phloem are separated by a thin band of cells known as the vascular cambium. This is a lateral meristem (site of cell division and active growth), and is responsible for the increase in stem girth in woody dicots.

Towards the inside of the vascular cambium, new xylem (or wood) cells are formed each year, contributing to the formation of countable "rings" in the cross-section of a tree. Towards the outside of the vascular cambium, new phloem cells are formed each year, but these layers are very thin and cannot be easily distinguished as rings.

As a woody plant ages, the oldest phloem mingles with cork and bark and may eventually be removed from the tree. The oldest xylem becomes the central heartwood of the tree.

This difference in vascular systems is of practical interest to horticulturists because certain herbicides are specific to either monocots or dicots. An example is 2,4-D, which kills dicots but not monocots.

Cross-section of a Stem



Texture and Growth of Stems

Many **woody** stems have a central region called **pith.** Surrounding this pith, most of the girth of woody stems is called wood, which is composed of rings of dead xylem tissue. Generally, one ring of xylem is added to the wood per year; by counting the rings we can estimate the age of a woody stem. Fruit trees and ornamental trees and shrubs are examples of plants with woody stems.

A cane is a stem which has a relatively large pith, and usually lives only one or two years. Examples of plants with canes include rose, grape, and raspberry.

While the potential for cambial activity in many herbaceous dicots does exist, those annuals and perennials that are sensitive to cold temperatures will not experience any increase in stem girth. Their above-ground vegetative parts are destroyed every fall and new herbaceous shoots must develop each spring. Of the angiosperms, only woody dicots (trees and shrubs) grow in stem diameter.

Monocots, however, have no vascular cambium at all and; therefore, no potential for increased girth or "woodiness". They are always herbaceous.

Stems may be long, with great distances between nodes (branches of trees, runners on strawberries), or compressed, with short distances between nodes (fruit spurs, crowns of strawberry plants, dandelions). Stems can be above the ground like most stems with which we are familiar, or below the ground (potato tubers, Siberian iris rhizomes). All of these various stems have one thing in common: they have nodes divided by internodes.

Diversified Stem Development

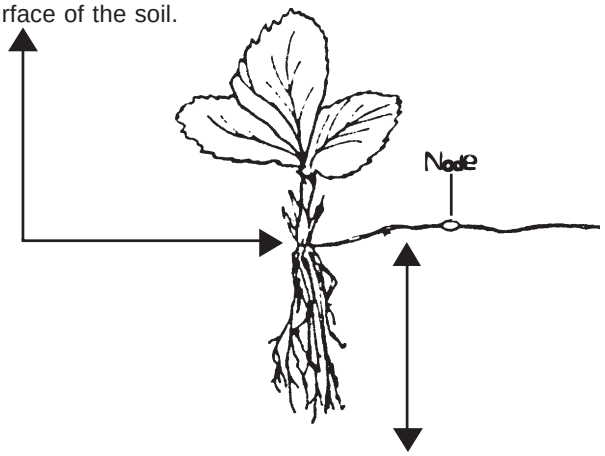
Modified Stems. Although typical stems are above-ground trunks and branches, modified stems can be found both above and below ground. The above-ground modified stems are crowns, stolons, and spurs. Below-ground stems include bulbs, corms, rhizomes, and tubers.

Above-ground stem modifications:

Crowns (strawberries, dandelions, African violets) are compressed stems with short internodes.

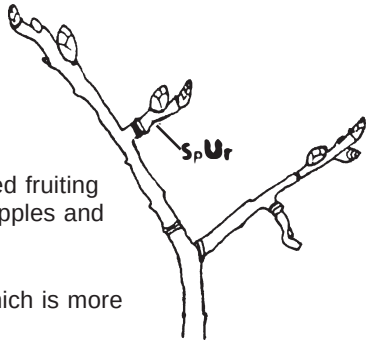
A **stolon** is a horizontal stem that lies along the top of the ground. Strawberries and spider plants have runners, or stolons. The leaves on strawberry runners are small, but are located at the nodes, which are easy to see.

A **crown**, found on many herbaceous perennials, is a region of compressed stem tissue from which new shoots are produced, generally found near the surface of the soil.



A **runner**, or stolon, is a specialized stem at soil surface that forms a new plant at one or more of its nodes.

Spurs are 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 is done close to fruit-bearing spurs, the spurs can develop into long, non-fruiting stems.



A spur is a compressed fruiting branch, as found on apples and pear.

A branch is a stem which is more than one year old.

Below-ground stems:

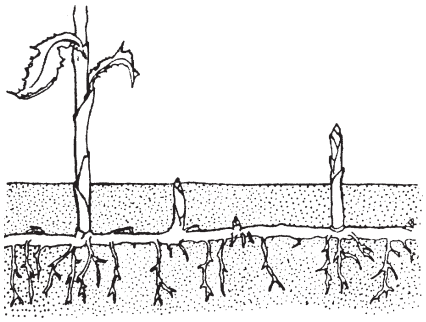
The **tuber**, like any other stem, has nodes that produce buds. The eyes of potato are actually the nodes on the stem. Each eye contains a cluster of buds.



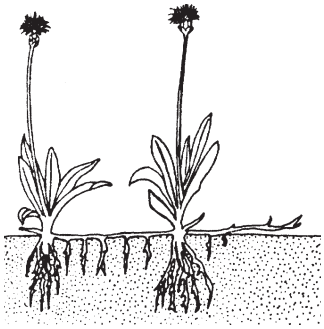
A tuber is an enlarged portion of an underground stem.

Rhizomes are specialized stems which grow horizontally at or just below the soil surface. Some rhizomes are compressed and fleshy such as those of iris; they can also be slender with elongated internodes such as quackgrass. Quackgrass, or witchgrass, is a noxious weed principally because of the spreading capability of its rhizomes.

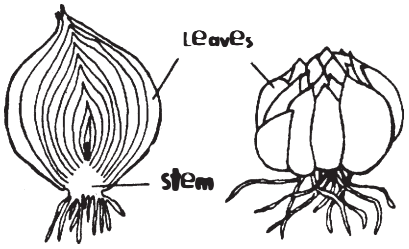
Rhizome



Stolon

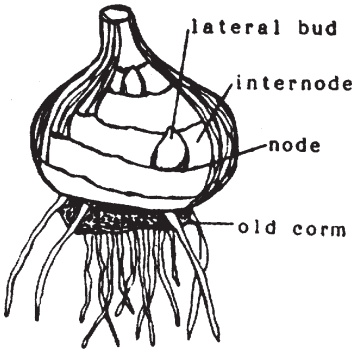


Tulips, lilies, daffodils, and onions produce bulbs: shortened, compressed, underground stems surrounded by fleshy scales (leaves) that envelop a central bud located at the tip of the stem. If you cut through the center of a tulip or daffodil bulb in late fall, you can see all the flower parts in miniature within the bulb. Many bulbs require a period of low-temperature exposure before they begin to send up new growth. Both the temperature and length of this treatment are critical.



A bulb is composed of a short stem plate, closely spaced buds and fleshy leaves. Lilies and onions are bulbs.

Corms are somewhat similar to bulbs, but do not have fleshy scales. A corm is a solid, swollen stem whose scales have been reduced to a dry, leaf-like covering.



A corm, as in gladiolus and crocus, is compressed stem with reduced scaly leaves.

Stem Use

Stems can be used for **plant propagation.** Above-ground stems can be divided into sections with internodes and nodes. These sections are called **stem cuttings**; they produce roots to form a new plant when treated properly. Below-ground stems are also good propagative tissues: rhizomes can be divided into sections; small bulblets form at the base of mature bulbs; cormels form under mature corms; and tubers can be cut into pieces containing eyes, or nodes with buds.

Stems are used as **food**. The edible portions of asparagus and kohlrabi are stem tissue. The edible parts of broccoli are composed of stem tissue, flower buds, and small leaves. The edible part of white potato is a fleshy underground tuber. Although the name suggests otherwise, the edible part of the cauliflower is proliferated stem tissue.

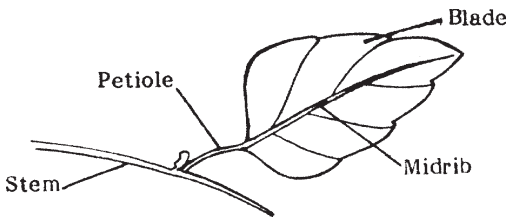
Leaves

The primary function of leaves is to photosynthesize, or capture energy from the sun and convert it to sugars for later use. Leaves are green because they contain chlorophyll, the green pigment involved in photosynthesis. They are generally broad, to intercept a maximum amount of sunlight.

Parts of a Leaf

The blade of a leaf is the expanded, thin structure on either side of the **midrib** or main vein. The **blade** is usually the largest and most conspicuous part of a leaf. The **petiole** is the stalk which supports the leaf blade. The base of the petiole is attached to the stem at a **node**. The small angle formed between the petiole and the stem is called the l**eaf axil**. A bud or cluster of buds is usually located in the axil. The petiole is absent in some leaves, in which case the leaf is described as **sessile**, and is attached directly to the stem.

Broadleaf



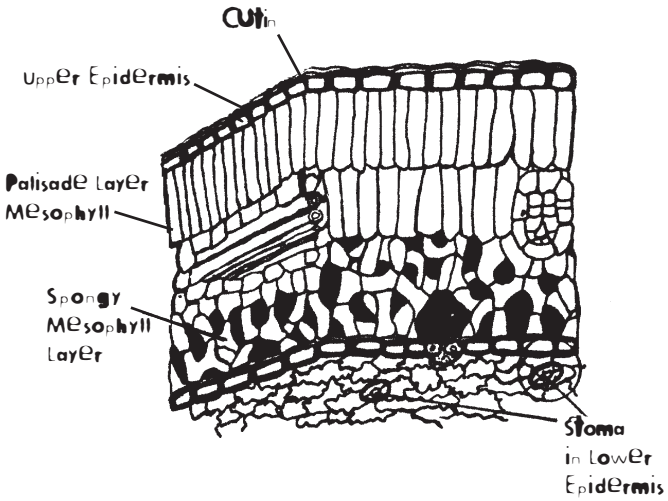
The leaf blade is composed of several layers. On the top and bottom is a layer of protective cells called the **epidermis**. Some leaves have **hairs** that are an extension of epidermal cells. The African violet has so many hairs that the leaf feels velvety.

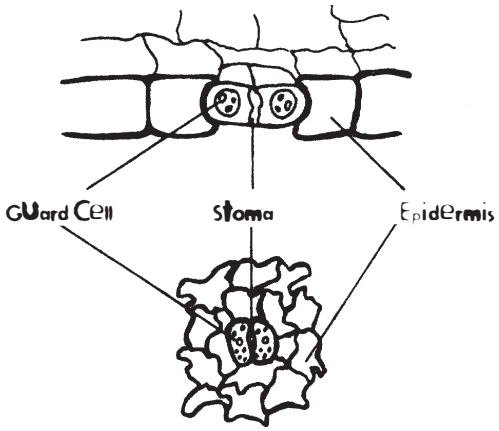
Covering the epidermis is the **cuticle**, which is composed of a waxy substance called **cutin** that protects the leaf from dehydration and prevents penetration of some diseases. Leaves grown in higher light intensity have a thicker layer of cuticle than leaves grown in less light. When plants are moved from shade to sun, they should be moved gradually in order to allow more cuticle to develop, to protect the leaves from the shock of rapid water loss or sun scald. The waxy cuticle also repels water and can shed pesticides if spreader-sticker agents are not used (many pesticide formulations contain an additive that promotes the product's penetration of the cuticle).

On the underside of leaves, some pairs of epidermal cells surround openings to the interior of the leaf. These **guard cells** regulate the passage of water, oxygen, and carbon dioxide through the leaf through the openings, called **stomates**. The opening and closing of stomates is determined mostly by the weather. Conditions that cause large water losses from plants (high temperature, low humidity) stimulate guard cells to close. Mild weather conditions promote opening of stomates.

The middle layer of the leaf, the **mesophyll**, is located between the upper and lower epidermis. This is the layer in which photosynthesis occurs. The mesophyll is divided into a dense upper layer, called the **palisade**, and a lower layer, called the **spongy** layer, that contains much air space. The cells in these two layers contain chloroplasts which are the actual site of the photosynthetic process.

Leaf Parts





Types of Leaves

A number of rather distinct types of leaves occur on plants. Leaves, commonly referred to as foliage, are the most common and conspicuous and, as previously stated, serve as the manufacturing centers where the photosynthetic activity of the plant occurs. Scale leaves are found on rhizomes and are also the small, leathery, protective leaves which enclose and protect buds. Seed leaves, or **cotyledons**, are modified leaves which are found on embryonic plants in seeds, and commonly serve as storage organs. **Spines** and **tendrils**, as found on barberry and pea respectively, are specially modified leaves which protect the plant or assist in supporting the stems. Storage leaves, found in bulbs and succulents, serve as food storage organs. Other specialized leaves include **bracts**, which are often brightly colored. The showy structures on dogwoods and poinsettias are actually bracts, not petals.

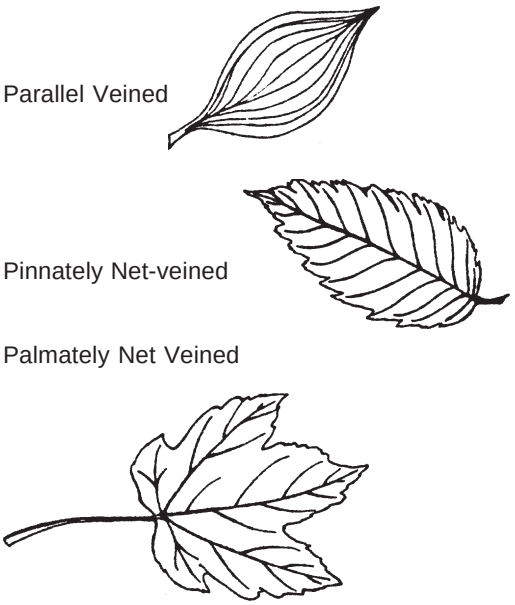
Venation of Leaves

The vascular bundles from the stem extend through the petiole and spread out into the blade. The term **venation** refers to the patterns in which veins are distributed in the blade. Two principal types of venation are **parallel-veined** and **net-veined**.

Parallel-veined leaves are those in which numerous veins run essentially parallel to each other. The most familiar type of parallel veining found in plants of the grass family where the veins run from the base to the apex of the leaf. Another type of parallel-venation is found in plants such as banana, calla, and pickerel-weed, in which the parallel veins run laterally from the midrib. **All of these parallel-veined plants are monocots.**

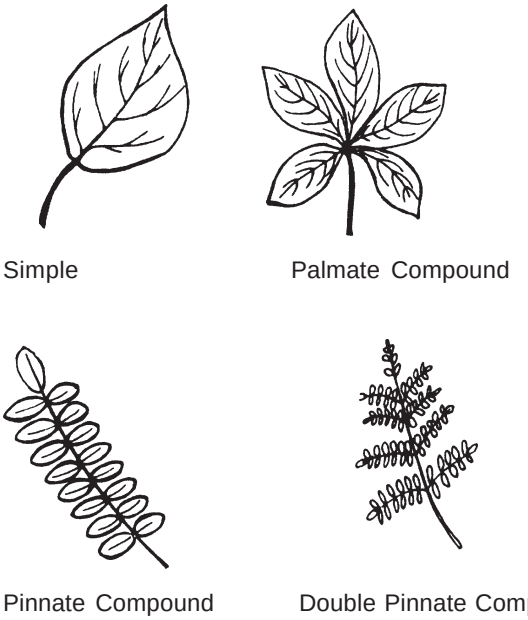
Net-veined leaves, also called reticulate-veined, have veins which branch from the main rib and subdivide into finer veinlets which spread in a complicated network. This system of veins gives the leaf more resistance to tearing than most parallel-veined leaves. Net-venation may be either pinnate or palmate. In pinnate (feather-like) venation, the veins extend laterally from the midrib to the edge, as in apple, cherry and peach. In palmate venation, like grape and maple leaves, the principal veins extend outward like the fingers of a hand from the base of the leaf blade. **Net-veined leaves occur in dicots.**

Types of Venation



Leaves as a Means of Identifying Plants

Leaves are useful in identifying species and varieties of horticultural plants. The shape of the leaf blade and the type of margin are important as identifying characteristics. Simple leaves have one single blade. Compound leaves have several separate blades, called leaflets, arising from the same petiole.



A deeply lobed leaf may appear to be a compound leaf, but if the leaflets are connected by narrow bands of blade tissue, it is classified as a simple leaf (for example, marigold, dahlia and tomato). If the leaflets have separate stalks and, particularly, if these stalks are jointed at the point of union with

the main leaf-stalk, the leaf is called compound (for example, honey locust and pea shrub). Some leaves may be doubly compound, with the leaflets divided into secondary leaflets.

Leaflets do not have axillary buds at the base of their stalks. Only leaf petioles have axillary buds. If axillary buds are not present, you are probably looking at a leaflet - not a leaf.

Shape of the Leaf Blade

The following are some common shapes which are found in leaves and leaflets.

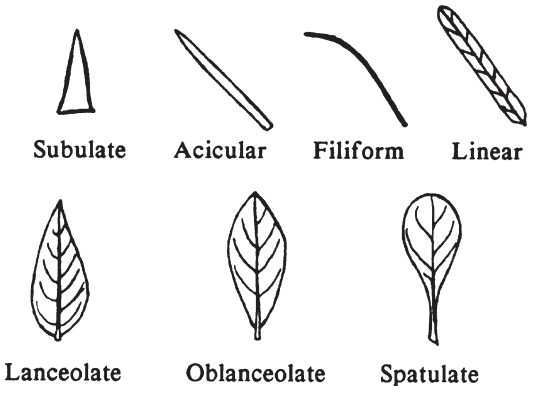
Linear: Narrow; several times longer than wide; approximately the same width throughout.

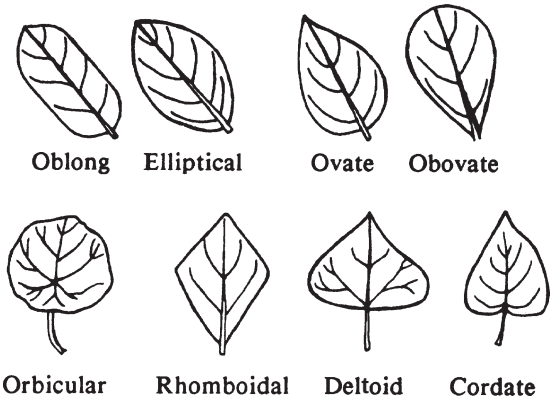
Lanceolate: Longer than wide; tapering toward the apex and base.

Elliptical: 2 or 3 times longer than wide; tapering to an acute or rounded apex and base.

Ovate: Egg-shaped; basal portion wide; tapering toward the apex.

Cordate: Heart-shaped; tapering to an acute apex, with the base turning in and forming a notch where the petiole is attached.





Shape of the Blade Ends

The following are common shapes of the leaf tip (apex) and leaf base (point where leaf joins to petiole).

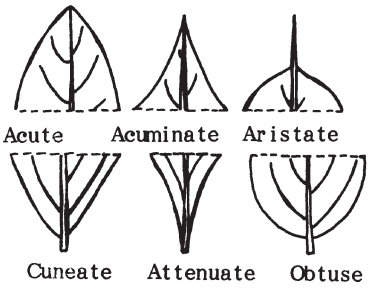
Acuminate: Tapering to a long, narrow point.

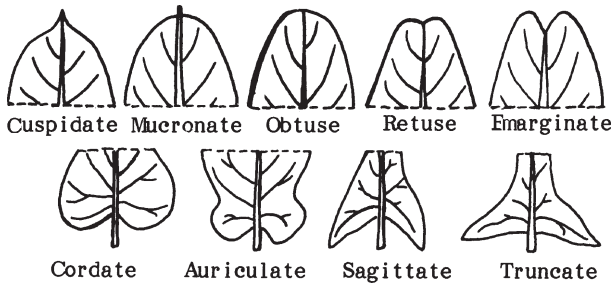
Acute: Ending in an acute angle, with a sharp, but not acuminate, point.

Obtuse: Tapering to a rounded edge.

Sagittate: Arrowhead-shaped, with two pointed lower lobes.

Truncate: Having a relatively square end.





Leaf Margins

Variations in leaf margins help in distinguishing closely related plants.

Entire: Smooth, with no teeth or notches.

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

Dentate: Having teeth ending in an acute angle, pointing outward.

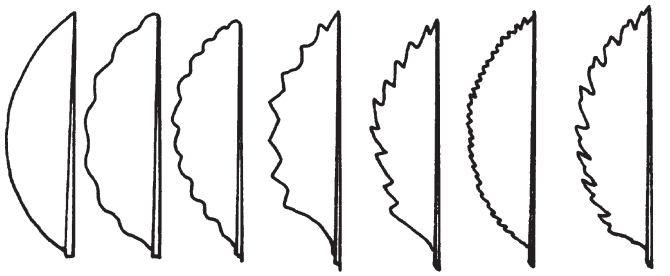
Crenate: Having rounded teeth.

Sinuate: Having a pronounced sinuous or wavy margin.

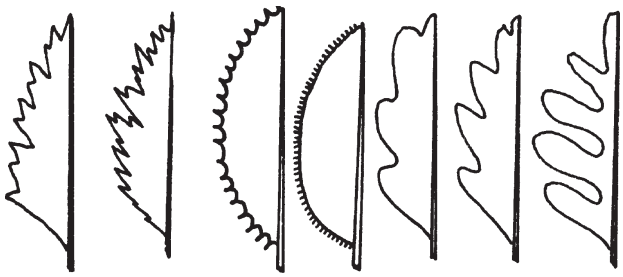
Incised: Having sharp, deep irregular teeth or incisions.

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

Cleft: Having incisions that extend more than halfway to the midrib.



Entire Sinuate Crenate Dentate Serrate Serrulate Double serrate

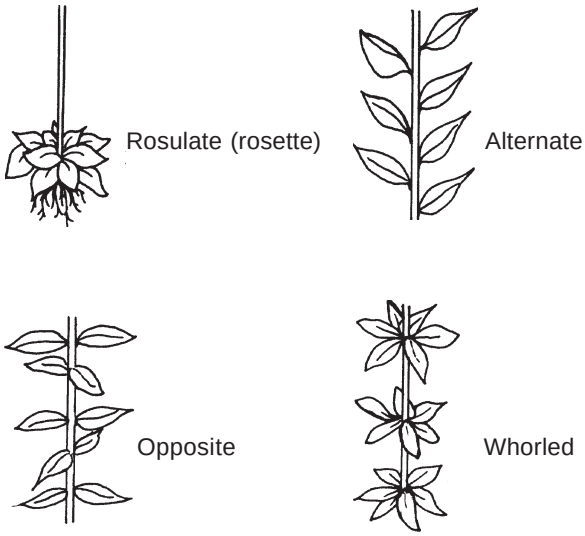


Incised Lacerate Pectinate Ciliate Lobed Cleft Parted

Leaf Arrangement Along a Stem

The various ways leaves are arranged along a stem are also used to help identify plants. A rosulate arrangement is one in which the basal leaves form a rosette around the stem with extremely short nodes. Opposite leaves are positioned across the stem from each other, two leaves at each node. Alternate or spiral leaves are arranged in alternate steps along the stem with only one leaf at each node. Whorled leaves are arranged in circles along the stem, with three or more leaves at each node.

Types of Leaf Arrangement



Leaves as Food

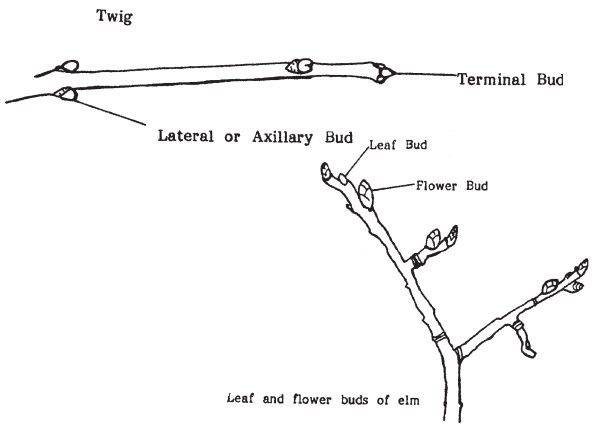
The leaf blade is the principal edible part of several horticultural crops including chive, collard, dandelion, endive, kale, lettuce, cabbage, parsley, spinach, and Swiss chard. The edible parts of leek and Florence fennel are clusters of fleshy leaf bases. The edible bulbs of onions and scallions are primarily leaf tissue. The leaf petiole is the edible portion of celery and rhubarb.

Buds

A bud is an undeveloped shoot from which embryonic leaves or flower parts arise. Our temperate zone trees and shrubs typically develop a protective outer layer of small, leathery, bud scales on those buds that overwinter, while our annuals and herbaceous perennials have naked buds in which the outer leaves are green and somewhat succulent.

Overwintering buds of many perennial plants require exposure to a certain number of days below a critical temperature before they can resume growth in the spring. This dormancy period varies for different plants. The flower buds of forsythia require a relatively short cold period, and resume growth in early spring. Many peach varieties require from 700 to 1,000 hours of temperatures below 45 degrees F (7 degrees C) before they resume growth. During this dormancy period, fully dormant buds can withstand very low temperatures, but after the dormancy requirement is satisfied, buds become more susceptible to weather.

Lateral buds are located on the sides of the stem. Most lateral buds arise in leaf axils, and are called **axillary buds**. In some instances, more than one bud is formed. Adventitious buds are those which arise at sites other than the stem apex or leaf axil. Adventitious buds may develop at stem internodes; at the edge of leaf blades; from callus tissue at the cut end of stems or roots; or in a plant's root system.



Buds as Food

Enlarged buds or parts of buds form the edible portion of some horticultural crops. Cabbage and head lettuce are examples of unusually large terminal buds. Succulent axillary buds are the edible parts of Brussels sprouts. In the case of globe artichoke, the fleshy basal portion of the bracts of the flower bud are eaten along with the solid stem portion of the bud. Broccoli is the most important horticultural plant in which edible flower buds are consumed (along with portions of the stem and small leaves).

Flowers

Flowers, generally the showiest parts of plants, are important in sexual reproduction. Plants that are pollinated by insects, bats and other animals are often ornamental and fragrant in order to attract pollinators. Plants that are pollinated by wind or rain are generally not as showy (for example, corn).

Parts of the Flower

As the reproductive part of the plant, the flower contains the **male pollen grains** and/or the **female ovules**, plus accessory parts such as **petals, sepals, and nectar glands**.

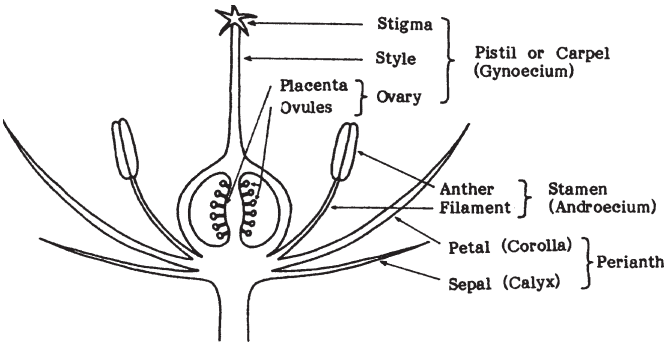
The **perianth** is composed of the **calyx** and the **corolla**. The calyx is divided into **sepals**, which are small, often green, leaf-like structures at the base of the flower. Sepals protect the flower when in bud.

The corolla is divided into petals, which are often highly colored. The shape, arrangement and number of flower petals is useful in identifying plants. Flowers of dicots typically have sepals and/or petals in multiples of four or five. Monocot flowers typically have these parts in multiples of three.

The **pistil** is the female part of the plant. It is in the center of the flower, and consists of the **stigma**, **style**, and **ovary**. The stigma, a sticky structure located at the top of the pistil, receives pollen during pollination. The pollen then grows down through the tubelike style to the ovary, which contains the ovules, or eggs.

The **stamen** is the male reproductive organ. It consists of an **anther** (pollen sac) on top of a threadlike **filament**, which holds the anther in position so the pollen it contains may be dispersed by wind or carried to the stigma by insects or other pollinators.

Parts of the Flower



Types of Flowers

Flowers that have a stamen, pistils, petals, and sepals are called **complete** flowers. If any of these parts are missing, the flowers are designated **incomplete**. For example, anemones do not have petals (the showy parts are actually sepals), and are called incomplete flowers.

Most flowers have functional stamens and pistils, and are referred to as **perfect** flowers. Flowers lacking either stamens or pistils are called **imperfect**. In other words, perfect flowers are both male and female, while imperfect flowers are either male or female. **Pistillate** (female) flowers possess a functional pistil but lack stamens. **Staminate** (male) flowers have stamens but no pistil. Plants in which pistillate and staminate flowers occur on the same plant are called **monoecious**; examples are begonia and corn. Plants in which pistillate and staminate flowers occur on separate plants are called **dioecious**; examples are holly and yew. Since hollies are dioecious, and both male pollen and female ovules are required to produce the berry fruits, both a male holly and a female holly must be planted into a landscape in order to obtain fruit. Some plants bear only male flowers at the beginning of the growing season, but later develop flowers of both sexes; examples are cucumbers and squash.

Flowers and Plant Classification

Plants can be placed in a hierarchy based on how closely they are botanically related. This relatedness is based primarily on flower structures; this explains why flowers are so useful in identifying plants. We know many plants by common names, but in order to communicate with plant professionals around the world, we use the scientific language of plant nomenclature. Each plant is identified by a unique botanical Latin name. The system of binomial nomenclature provides a double name for plants, called its **genus** and **species**. The first, or generic name, is followed by a descriptive, or specific, name.

Modern plant classification, or **taxonomy**, is based on a system of binomial nomenclature developed in the 1700's by the Swedish physician, Carl von Linne (remembered today by his Latin name, Linnaeus). Prior to Linnaeus, people had tried to classify plants by leaf shape, plant size, flower color, etc. None of these systems proved workable. Linnaeus's revolutionary approach based classification on the flowers and/or reproductive parts of a plant. This has proven to be the most reliable system, since flowers are the plant part least influenced by environmental changes. For this reason, a knowledge of the flower and its parts is essential to plant identification.

How Seeds Form

Pollination is the transfer of pollen from an anther to a stigma. This may occur by wind or rain, or by pollinators such as bats, birds and insects. Wind-pollinated flowers lack showy floral parts and nectar, since they do not need to attract a pollinator. Many flowers that are brightly colored or patterned and contain a fragrance or nectar must attract pollinating insects, birds, or bats. In the process of searching for food, these pollinators transfer pollen from anther to stigma, and from one flower to another.

The stigma contains a chemical which excites the pollen, causing it to grow a long tube down through the style, to the ovules inside the ovary. After breaking through the ovule, the pollen grain releases two sperm nuclei: one combines with the female egg cell to form an **embryo**, and the other combines with polar nuclei in the embryo sac to form the **endosperm** (food storage tissue). This process is called **double fertilization**. If the fertilization process is successful, the embryo and endosperm and surrounding protective tissues develop into a seed.

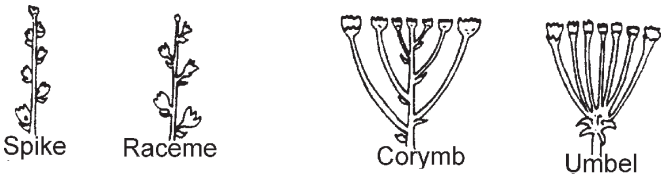
Some plants are **self-fertile**; that is, the pollen and ovules of a single plant can unite to form seeds containing viable embryos. Most plants, even those that are self-fertile, can be **cross pollinated**; this process combines genetic material from more than one plant, and produces stronger seed and more vigorous offspring. Consequently, more plants reproduce by cross-pollination than self-pollination.

Types of Inflorescences

Some plants bear only one flower per stem; these are called **solitary flowers**. Other plants produce an **inflorescence**, a term which refers to a cluster of flowers and how they are arranged on a floral stem.

Some examples of inflorescences are **spike, raceme, corymb, umbel**, and **head**. A spike has many stemless florets, each attached to an elongated flower stem; an example is gladiolus. A raceme is similar to a spike except the florets are on small stems (pedicels) attached to the central axis; an example is snapdragon. A corymb's florets are on stalks, called pedicels, and are arranged at random along the peduncle in such a way that the florets create a flat, round top; an example is yarrow. An umbel is similar except that the pedicels all arise from one point on the peduncle; an example is dill. A head, or composite, inflorescence is composed of two distinct types of stemless florets. Usually, fertile disk florets crowd the central button and are surrounded by generally sterile, strap-like ray florets, often wrongly referred to as "petals".

Some types of Inflorescences



Fruit

Botanically, the true fruit is the enlarged ovary around the newly developed seeds. But in practical horticulture, we often refer to fruits as the accessory tissues of the flower which develop around the true fruit.

Parts of Fruit

The only parts of a fruit which are genetically representative of both the male and female flowers are the seeds (mature ovules). The rest of the fruit arises from the maternal plant, and is therefore genetically identical to that female parent. This explains why a pumpkin can be cross-pollinated by a squash and still produce a predictable-tasting pumpkin, yet the seeds of that pumpkin will produce a new plant that is a hybrid between the pumpkin and the squash.

Types of Fruit

Just as flowers are useful in identifying plants, fruits are also characteristic of specific plants. Fruits can be classified as **simple fruits, aggregate fruits**, or **multiple fruits**. Simple fruits are those which develop from a single ovary. These include cherries and peaches (called drupes), pears and apples (called pomes), and tomatoes (called berries). Tomatoes are a botanical fruit since they develop from the flower, as do squash, cucumbers, and eggplant. All of these fruits develop from a single ovary. Some types of simple fruit are dry, with papery, leathery or hard tissue. Examples are peanut (an example of a fruit type called legumes), poppy (typical of fruits called capsules), maple (a samara), and acorn (a true nut).

Aggregate fruits, such as raspberries, come from a single flower which has many ovaries. The flower appears as a simple flower, with one corolla, one calyx, and one stem, but with many pistils (and therefore many ovaries). The ovaries are fertilized separately and independently. Incomplete pollination can produce misshapen fruit. Strawberry and blackberry are aggregate fruits born on an edible, enlarged receptacle, which is fused to the fruits and eaten as part of them. We sometimes call these "accessory" or "false" fruits, since the fleshy, juicy part is not the biological fruit, or ripened ovary itself.

Aggregate/Accessory Fruit

Strawberry



Achene-like fruits imbedded in fleshy receptacle

Multiple Fruit

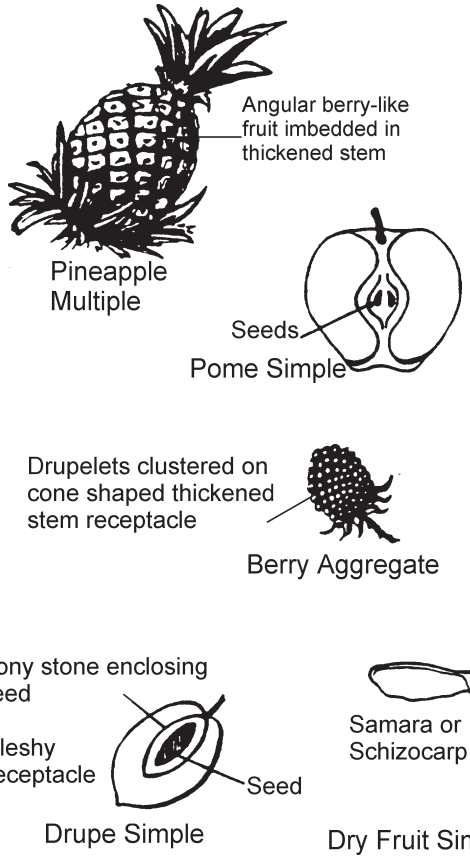
Fig



Numerous achene-like fruits develop from flowers which bloom within fleshy covering

Multiple fruits are derived from a tight cluster of separate, independent flowers borne on a single structure. Each flower has its own calyx and corolla. Examples of multiple fruits are pineapple, fig and beet.

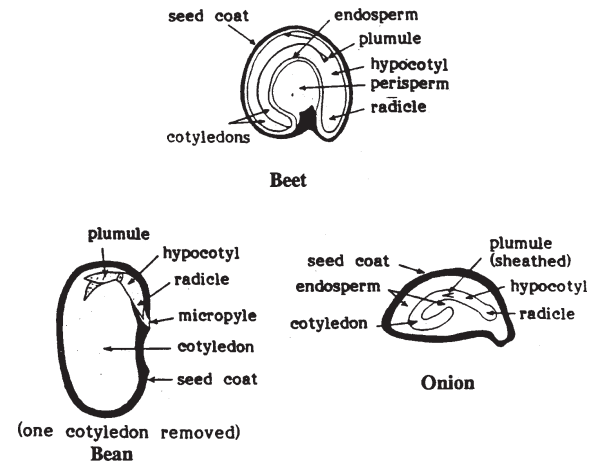
Kinds of Fruit



Seed

The seed, or matured ovule, has three parts. The **embryo** is a miniature plant in an arrested state of development. Most seeds contain a built-in food supply called the **endosperm** (orchid is an exception). The endosperm can be made up of proteins, carbohydrates, or fats. The third part is the hard outer covering, called a **seed coat**, which protects the seed from disease and insects and prevents water from entering the seed (this would initiate the germination process before the proper time).

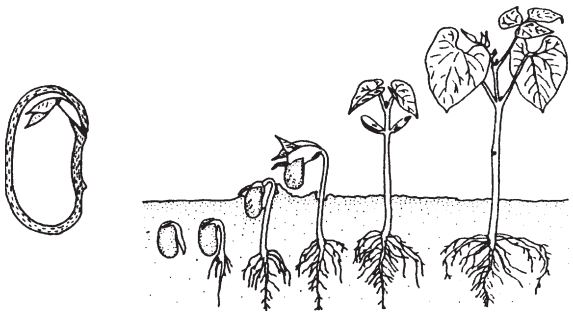
Parts of a Seed



Germination begins when the seed absorbs water through the **seed coat**, and ends when the green plant begins photosynthesis. Successful germination requires the proper environmental conditions: favorable **temperatures**, correct **light** levels, and adequate **moisture** and **aeration**. The absorbed water activates hormones and enzymes which convert stored food into simpler food materials, and activate essential growth processes. The embryo begins to grow through cell division and enlargement, causing the young seedling to burst from the seed, sending its **radicle** downward to develop into a root system, and its **plumule** upward to develop into the stem and leaves. With uptake of water from the soil by the young root system and photosynthesis by the young green tissue, germination is complete.

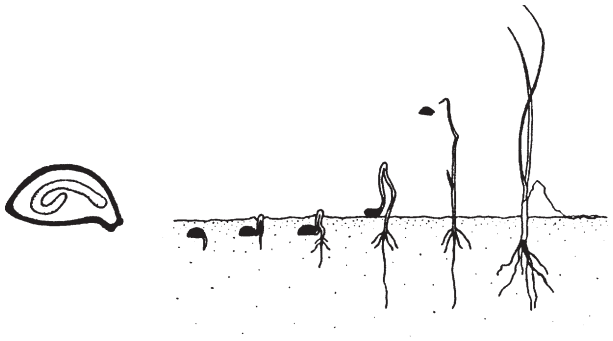
In many plants, the **cotyledons** (seed leaves) are the first structures to emerge above ground. Monocots have one cotyledon while dicots have two cotyledons. The cotyledons of many plants are similar, while their true leaves can vary greatly.

Germination of a Dicot



Bean

Germination of a Monocot



Onion

Physiology: Plant Growth and Development

Three major plant functions that are essential for plant growth and development are photosynthesis, respiration, and transpiration.

Photosynthesis

One of the major differences between plants and animals is the ability of plants to internally manufacture their own food. For this process of photosynthesis, a plant requires **chlorophyll** within its tissue, energy from **light**, **carbon dioxide** from the air, and **water** from the soil. If any of these ingredients is lacking, photosynthesis cannot proceed. Photosynthesis literally means "to put together with light."

Photosynthesis

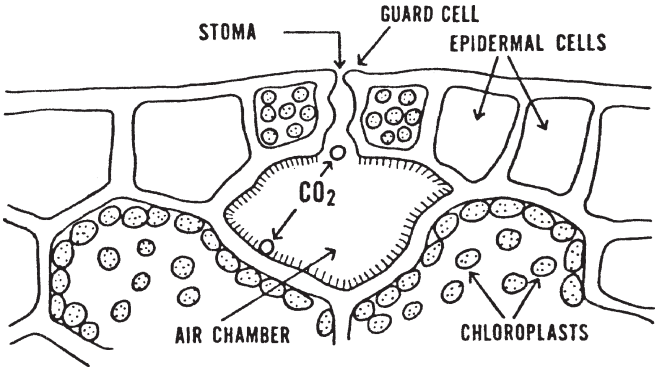
$$\text{CARBON DIOXIDE + WATER} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{SUGAR + OXYGEN + WATER}$$

$$6\ CO_2 + 12\ H_20 \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}0_6 + 6\ 0_2 + 6\ H_20$$

Plants store the energy from light first in **simple sugars**, such as glucose. This food may be converted back to water and carbon dioxide, releasing the stored energy through the process called **respiration**. This energy is required for all living processes and growth. Simple sugars can also be converted to more complex sugars and starches (carbohydrates) which may be transported to the stems and roots for use or storage, or they may be used as building blocks for other synthates, such as oils, pigments, proteins, and cell walls.

Any green plant tissue can photosynthesize. **Chloroplasts** in these cells contain the green pigment, chlorophyll, which traps the light energy. Leaves are the primary site of photosynthesis due to their special structure. The internal tissue (mesophyll) contains cells with abundant chloroplasts in an arrangement that promotes easy movement of water and air. The protective upper and lower epidermal layers of the leaf include many stomates that regulate movement of the gases involved in photosynthesis into and out of the leaf.

Leaf Cross Section



Photosynthesis is dependent on the availability of light. Generally, as sunlight increases in intensity, photosynthesis increases. This results in greater production. Many garden crops, such as tomatoes, respond best to maximum sunlight. Tomato production is greatly reduced as light intensities drop. Only a few "greenhouse" tomatoes produce fruit when sunlight is minimal in late fall and early spring.

Water plays an important role in plants in several ways. First, it maintains a plant's **turgor**, or the firmness of plant tissue. Turgor pressure in a cell can be compared to air in an inflated balloon. Water pressure or turgor is needed by plant cells to maintain shape and ensure cell growth. Second, water is split into hydrogen and oxygen by the energy of the sun that is absorbed by the chlorophyll in plant leaves. This oxygen is released into the atmosphere while the hydrogen is used in carbohydrate synthesis. Third, water dissolves minerals from the soil and transports them up from the roots and throughout the plant, where they serve as raw materials in the development of new plant tissues. The soil surrounding plants must provide adequate water to be pulled into the plant by **transpiration** (evaporation of water from the leaves' stomates).

Photosynthesis also requires carbon dioxide (CO_2) which enters the plant through the stomates. Carbon and oxygen are used in the manufacture of carbohydrates. Carbon dioxide in the air is plentiful enough so that it does not limit plant growth outdoors. However, since carbon dioxide is consumed in making sugars and is not replenished by plants at a rapid rate, a tightly closed greenhouse in midwinter may not let in enough outside air to maintain an adequate carbon dioxide level. Under such conditions, production of roses, carnations, tomatoes, and many other crops can be increased by adding carbon dioxide to the growing area.

Temperature affects photosynthesis rates. Photosynthesis occurs at its highest rate in the temperature range 65 to 85 degrees F (18 to 27 degrees C) and decreases when temperatures are above or below this range.

Respiration

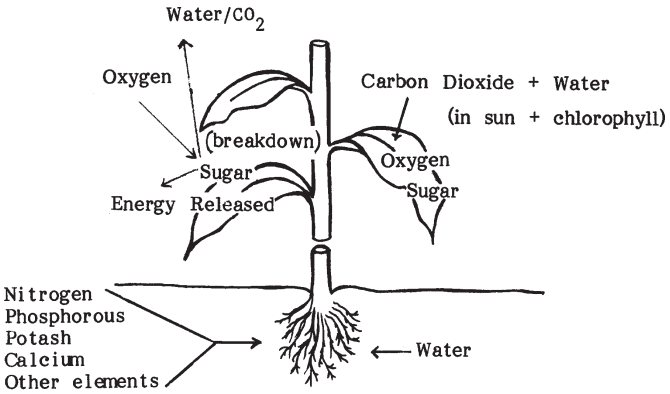
Carbohydrates made during photosynthesis are of value to the plant when they are converted into energy, which is used for other plant processes like plant growth. The process by which sugars and starches are slowly oxidized to release energy is called respiration. It is similar to the burning of wood or coal to produce heat (energy).

Respiration

$$C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2O + \text{Energy}$$

This equation is precisely the opposite of that used to illustrate photosynthesis, although more is involved than just reversing the reaction. However, it is appropriate to consider photosynthesis to be a building process, and respiration to be a breaking-down process.

Respiration **Photosynthesis**



The differences and similarities between photosynthesis and respiration can be summarized as follows:

Photosynthesis

1. Produces food.
2. Captures energy.
3. Occurs in cells containing chloroplasts.
4. Releases oxygen.
5. Uses and produces water.
6. Uses carbon dioxide.
7. Rate is dependent on light.

Respiration

1. Uses food for plant energy/growth.
2. Releases energy.
3. Occurs in all cells.
4. Uses oxygen.
5. Uses and produces water.
6. Produces carbon dioxide.
7. Rate is independent of light.

Transpiration

Transpiration is the process by which a plant loses water, primarily through leaf stomates. The amount of water lost through transpiration depends on several environmental factors such as temperature, humidity, and wind or air movement. Transpiration is a necessary process by which about 90% of the water that enters plant roots is lost through the stomates. The remaining 10% of water is used in chemical reactions and in plant tissues.
Transpiration is not simply water loss; it is the process by which water is pulled up into plants. The water in a plant's xylem forms a continuous column. As water evaporates through leaf stomates, more water is drawn into plant roots. The process of transpiration provides for **mineral transport** from the soil into the plant, cooling of plant parts through evaporation, translocating sugars and plant chemicals, and maintaining turgor pressure.

Environmental Factors That Affect Plant Growth

Plant growth and distribution are limited by the environment. Any one environmental factor that is less than ideal becomes a limiting factor in plant growth. For example, only plants adapted to limited amounts of water can live in deserts.

Many plant problems are caused by environmental stress, either directly or indirectly. Therefore, it is important to understand the environmental aspects that affect plant growth. These factors include **light**, **temperature**, **water**, **humidity**, and **nutrition**.

Light

Light has three principal characteristics that affect plant growth: **quantity**, **quality**, and **duration**.

Light quantity refers to the **intensity** or concentration of light. It varies with the season of the year. Maximum light occurs in the summer; minimum light in winter. The more light a plant receives (up to a point), the better it is able to photosynthesize (capture energy). As light quantity decreases, the photosynthetic process decreases. If light quantity is too high, it can be decreased in a garden or greenhouse by using cheesecloth or lath shading above the plants. Low light quantities can be increased by surrounding plants with white reflective material, or with artificial lights.

Light quality refers to the color or **wavelength** reaching plant surfaces. Sunlight can be separated into red, orange, yellow, green, blue, indigo, and violet light. Red and blue light have the greatest effect on plant growth because they are the best qualities of light for photosynthesis. In addition, red light affects flowering. Green light is least effective to plants, which appear green because they reflect green light. Among artificial lights, a combination of cool white and warm white fluorescent tubes provide excellent quality light for green growth, and are excellent for starting seedlings indoors. Fluorescent "grow lights" provide a mixture of red and blue light that imitates sunlight quite closely, but they are costly and generally not of any greater value than regular fluorescent lights. Incandescent bulbs produce high levels of red light, but generally produce too much heat to be a valuable light source for plants.

Light duration, or photoperiod, refers to the **amount of time** per day that a plant is exposed to sunlight. Some plants' flowering process is controlled by photoperiod, and plants are classified into three categories, depending on their exact response. These are **short-day, long-day**, and **day-neutral**. When the photoperiod concept was first recognized in the 1920's, it was thought that the length of light periods triggered flowering in some plants, so the various categories of responses were named according to the light period's length. It was later discovered that it is not the length of the light period but the length of uninterrupted dark period that is critical to floral development. The categories of responses retain their early names, making it somewhat confusing at first.

Short-day plants (actually long-night plants) form their flowers only when the day length is less than a critical length, generally about 12 hours. Short-day plants include many spring- and fall-flowering plants such as chrysanthemum and poinsettia. Long-day plants (actually short-night plants) form flowers only when day lengths exceed 12 hours. They include many summer-flowering plants, such as rudbeckia and California poppy, as well as many vegetables including beet, radish, lettuce, spinach, and potato. Day-neutral plants form flowers regardless of day length. Some plants do not really fit into any category but may respond to combinations of day lengths. The petunia flowers regardless of day length, but flowers earlier and more profusely under long days.

This concept is important in manipulating those plants that respond to day length. For example, chrysanthemums are easily scheduled throughout the year. They produce leaves and stems under long-day (short-night) conditions. Such conditions occur naturally in summer, and can be created in winter by breaking up the long winter night with light (greenhouse growers set timers to turn on lights for a few hours in the middle of each night, creating two "short nights"). The plants produce flowers naturally under the short-day conditions of winter, and they can be forced to flower in summer by artificially providing short-day conditions (greenhouse grower pull black shade cloths over chrysanthemums at the end of the work day, and remove the cloths in the morning; this creates a "long night").

Temperature

Temperature affects plant productivity and growth. Many plant processes proceed faster in warm conditions, and slow down in cool conditions. Plants generally tolerate the coolest temperatures when they are dormant (well below freezing in many cases), the warmest temperatures as young seedlings (generally 60-80 degrees F), and temperatures somewhat cooler than seedling temperatures when they are actively growing, mature plants.

Incorrect temperatures, both high and low, can produce undesirable effects. Under high temperatures and long days, cool-season crops such as spinach bolt (produce undesirable flowers) rather than producing the desired leaves. Temperatures that are too low for a warm-season crop such as tomato prevent fruit set. Adverse temperatures also cause stunted growth and poor quality; for example, lettuce grown at high temperatures becomes bitter.

Sometimes temperatures are used in connection with day length to manipulate the flowering of plants. Chrysanthemums flower for the longest period of time if daylight temperatures remain at 59 degrees F (15 degrees C). Christmas cacti form flowers in response to short days and cool temperatures. Daffodils flower if the bulbs are placed in cold storage (35 to 40 degrees F (2 to 4 degrees C)) beginning in October, to promote bulb maturation. The bulbs are transferred to a cool greenhouse in midwinter where top growth begins, and the flowers are ready for cutting in 3 to 4 weeks.

Thermoperiod refers to daily temperature change. Plants produce maximum growth when exposed to a day temperature that is about 10 to 15 degrees higher than the night temperature. This allows the plant to photosynthesize and respire at optimum rates in the day, and to slow the rate of respiration during the cooler night. High temperatures increase the respiration rate, sometimes above the rate of photosynthesis. In such a situation, the products of photosynthesis would be used more rapidly than they were produced, and the plant would not grow. **For growth to occur, photosynthesis must exceed respiration.**

Temperatures lower than optimum for specific plants result in poor growth. Photosynthesis is slowed by low temperatures. When photosynthesis is slowed, growth is slowed, resulting in lower yields. Not all plants grow best in the same temperature range. For example, snapdragons grow best when nighttime temperatures are 55 degrees F (12 degrees C), while poinsettias prefer 62 degrees F (17 degrees C). Cyclamens do well under very cool conditions, while many bedding plants prefer warmer temperatures. Knowing the specific temperature preferences of crops allows more efficient production; for example, peas are far more productive in the cool spring than in summer.

Winter temperatures determine how far north (and south) plants can grow. Perennial plants are classified as either hardy or nonhardy, depending upon their ability to withstand cold temperatures. Cold New England winters prevent the growth of many plants altogether. Other plants may be slightly injured in some winters when unseasonably low temperatures occur early in the fall or late spring. After a plant's winter dormancy is met, early spring thaws can cause premature bud break in some plants; this may be followed by freezing damage if temperatures drop again. Late spring frosts often destroy entire peach crops in Northern New England.

Review of How Temperature Affects Plant Processes:

Photosynthesis:	Increases somewhat within a range of temperatures.
Respiration:	Rapidly increases as temperature rises.
Transpiration:	Increases with temperature.
Flowering:	Is partially triggered by temperature in some plants.
Sugar storage:	Low temperatures reduce energy use and increase sugar storage.
Dormancy:	Is fulfilled by cold temperatures.
Bud Development In Spring:	May occur too early in a spring thaw.

Water

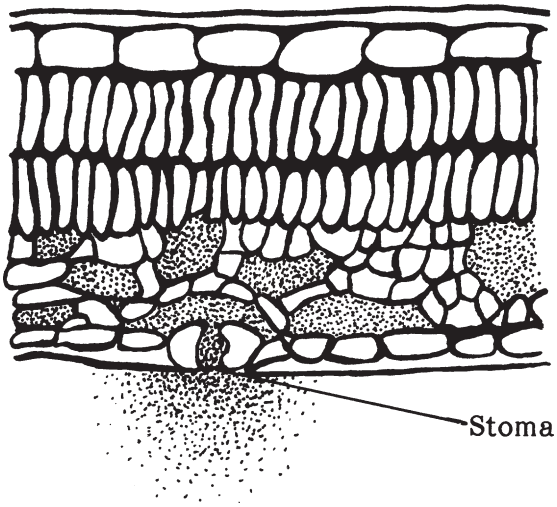
Water is a major component of plants, composing as much as 95% of some plant tissues. It serves many roles in plants. Water is responsible for maintaining the **turgor** pressure (firmness) of tissue; water is involved in the **opening and closing of stomates**, thus regulating transpiration; water's evaporation from plant surfaces helps **regulate plant temperatures**; water accounts for much of the **cell growth in root tips** that moves roots outward into new soil; water acts as the **solvent for minerals** moving upward in the xylem, and for carbohydrates moving through the phloem to their site of use or storage; and water is an essential raw **material for photosynthesis**.

Water is important to plants not only as liquid, but also as vapor. **Relative humidity** is the percentage of water vapor in the air compared to the total amount of water the air could hold at a given temperature and pressure. For example, if a pound of air at 75 degrees F holds 3 grams of water as vapor, while it could hold a total of 4 grams of water vapor, then the relative humidity (RH) is :

RH = (3 g / 4 g) x 100% = 75% RH

Warm air can hold more water vapor than cold air. That means that if the amount of water vapor in the air remains constant, then as the temperature increases, the relative humidity decreases. Also, as the temperature decreases, the relative humidity increases until it reaches 100%, at which time the air can hold no more. If the temperature continues to drop, water condenses and falls out of the air (in nature, we call this precipitation).

Water vapor moves from a place of high relative humidity to one of low relative humidity. The greater the difference in humidity, the faster water moves. This is an important concept in transpiration. The spaces between plant cells (intercellular space) can be occupied by air and water vapor. When the relative humidity in the intercellular space near stomates approaches 100%, and the stomates open, water vapor leaves the plant (if the relative humidity outside the leaf were also 100%, the stomates would not open). As the vapor moves out, a cloud of high humidity is formed around the stomate. This cloud of humidity helps slow transpiration and cool the leaf. If air movement blows the humid cloud away, transpiration increases as the stomates keep opening to balance the humidity. This is why plants exposed to windy environments may experience water stress.



Dots represent Relative Humidity

Plant Nutrition

Many people confuse plant nutrition with plant fertilization. Plant nutrition refers to the needs and uses of the basic chemical elements in the plant. Fertilization is the term used when these materials are supplied to the environment around the plant. A lot must happen before a chemical element supplied in a fertilizer can be taken up and used by the plant.

Plants need 17 elements for normal growth. Carbon, hydrogen, and oxygen are found in air and water. Nitrogen, potassium, magnesium, calcium, phosphorous, and sulfur are found in the soil. The latter six elements are used in relatively large amounts by the plant and are called macro-nutrients. There are eight other elements that are used in much smaller amounts; these are called micronutrients or trace elements. The micronutrients, which are found in the soil, are iron, zinc, molybdenum, manganese, boron, copper, cobalt, and chlorine. All 17 elements, both macro-nutrients and micro-nutrients, are essential for plant growth.

Most of the nutrients that a plant needs are dissolved in water and then absorbed by the roots. Ninety-eight percent of these plant nutrients are absorbed from the soil solution and only about 2% are actually extracted from the soil particles by the root. Most of the nutrient elements are absorbed as charged ions, or pieces of molecules (which are the smallest particle of a substance that can exist and still retain the characteristics of the substance). Ions may be positively charged cations or negatively charged anions. Positive and negative are equally paired so that there is no overall charge. For example, nitrogen may be absorbed as nitrate (NO_3^-) which is an anion with one negative charge. The potassium ion (K^+) is a cation with one positive charge. Potassium nitrate ($K^+NO_3^-$) would be one nitrate ion and one potassium ion. However, calcium nitrate ($Ca^{++}\ NO_3^-)_2$) would have two nitrate ions and one calcium ion because the calcium cation has two positive charges.

The balance of ions in the soil is very important. Just as ions having opposite charges attract each other, ions having similar charges compete for chemical interactions and reactions in the environment. Some ions are more active than others or can compete better. For example, both calcium (Ca^{++}) and magnesium (Mg^{++}) are cations with two charges, but magnesium is more active. If both are in competition to be absorbed, the magnesium will be absorbed.

This explains why the results of a soil test may indicate that, while there is sufficient calcium in the soil, the plant may still exhibit a calcium deficiency because of an excess of the more active magnesium. What may be expressed as a deficiency in one micronutrient may really be caused by an excess of another.

In order for the ions to be easily absorbed, they must first be dissolved in the soil solution. Some combinations of ions are easily dissolved, such as potassium nitrate. When other ions combine, they may precipitate or fall out of solution and thus become unavailable to the plant. Many of the micronutrients form complex combinations with phosphorous and calcium and precipitate out of the soil solution so the nutrients cannot be easily taken up by the plant. The pH, which is a measurement of acidity or alkalinity, greatly affects these chemical reactions. If the soil pH is extremely high (alkaline), many of the micronutrients precipitate out of the solution and are unavailable to the plant. When the soil pH is extremely low (acid), some of the micronutrients become extremely soluble and ion levels may become high enough to injure the plant. The effect of pH varies with the ion, the types of ions in the soil, and the type of soil. Therefore, not only is the amount of the nutrient important, but also the soil pH.

Adequate water and oxygen must be available in the soil. Water is required for nutrient movement into and throughout the roots. Oxygen is required because the mineral ions must be moved into the root cells across their membranes. This is an active absorption process, utilizing energy from respiration. Without adequate oxygen from the soil, there is no energy for nutrient absorption.

Anything that lowers or prevents the production of sugars in the leaves can lower nutrient absorption. If the plant is under stress due to low light or extremes in temperature, nutrient deficiency problems may develop. The stage of growth or how actively the plant is growing may also affect the amount of nutrients absorbed. Many plants go into a rest period, or dormancy, during part of the year. During this dormancy, few nutrients are absorbed. Plants may also absorb different nutrients just as flower buds begin to develop.

Nutrients transported from the root to the cell by the vascular system move into the cell through a cell membrane. There are three different ways this happens. First, an entire molecule or ion pair may move through the membrane. If the cell is using

energy or active transport to absorb the ions, then only one of the ions in the pair is pulled into the cell. The other will follow to keep the number of positive and negative charges even. Most anions (negative ions) are actively absorbed.

The second way of keeping the charges inside the cell balanced and absorbing a new ion is to exchange one charged ion for another ion with the same charge. A hydrogen ion (H^+) is often released so that the cell can absorb another positive ion such as potassium (K^+). Since this is a simple, passive exchange, absorption energy may not be required. Cations may be absorbed by this passive method.

Both of the methods mentioned above may be passive or active. However, the third method, the carrier system, is always active absorption, requiring energy. Scientists have discovered that within the cell membrane there are specialized chemicals that act as carriers. The carrier, through chemical changes, attracts an ion from outside the cell membrane and releases it inside the cell. Once the ion is inside the cell, it is attached to other ions so that it does not move out of the cell. Complex chemical reactions are involved in the entire process. Although nutrients can be absorbed passively, research has shown that active absorption must take place if the plant is to grow and be healthy. The factors we discussed earlier about absorption by the root are also true for absorption by the cell. A quick review of some of the factors that affect nutrient absorption: type of ion, soil pH, solubility of ion pairs, water, soil oxygen, sugar supply, plant stress, and temperature.

Foliar Absorption: A Special Case. Under normal growing conditions, plants absorb most nutrients, except carbon, hydrogen, and oxygen, from the soil. However, some nutrients can also be absorbed by the leaves if they are sprayed with a dilute solution. The factors that affect absorption by the cell are still important because the nutrient must enter the cell to be used by the plant. Care must be taken that the concentration of the nutrient is not too high or the leaf will be injured. Also, the leaf is covered by a thin layer of wax called the cuticle that the nutrient must get around or through before it can enter the cell.

Macronutrient Outline

Nitrogen (N)

Absorbed as NO_3^-, NH_4^+.
Leaches from soil, especially NO_3^-
Mobile in plant.

- Nitrogen excess:
  Succulent growth, dark green color, weak spindly growth, few fruits, may cause brittle growth especially under high temperatures.
- Nitrogen deficiency:
  Reduced growth, yellowing (chlorosis), reds and purples may intensify with some plants, reduced lateral breaks. Symptoms appear first on older growth.
- Action notes:
  In general, the best NH_4^+/NH_3^- ratio is 1/1.
  High NH_4^+ under low sugar conditions (low light) can cause leaf curl.
  Uptake inhibited by high P levels.
  N/K ration extremely important.
  Indoors, best N/K ration is 1/1 unless light is extremely high.
  In soils with high CHO/N ratio more N should be applied.

Phosphorus (P)

Absorbed as $H_2PO_4^-$, HPO_4^-
Does not leach from soil readily.
Mobile in plant.

- Phosphorus excess:
  Shows up as micronutrient deficiency of Zn, Fe, or Co.
- Phosphorus deficiency:
  Reduced growth, color may intensify, browning or purpling in foliage in some plants, thin stems, reduced lateral breaks, loss of lower leaves, reduced flowering.
- Action notes:
  Rapidly "fixed" on soil particles when applied under acid conditions fixed with Fe, Mg and Al.

  Under alkaline conditions fixed with Ca. Important for young plant and seedling growth. High P interferes with micronutrient absorption and N absorption. Used in relatively small amounts when compared to N and K. May leach from soil high in bark or peat.

Potassium (K)

Absorbed as K^+ Leaches from soil.
Mobile in plant.

- Potassium excess:
  Causes N deficiency in plant and may affect the uptake of other positive ions.
- Potassium deficiency:
  Reduced growth, shortened internodes, marginal burn or scorch (brown leaf edges), necrotic (dead) spots in the leaf, reduction of lateral breaks and tendency to wilt readily.
- Action notes:
  N/K balance is important.
  High N/low K favors vegetative growth; low N/high K promotes reproductive growth (flower, fruit).

Magnesium (Mg)

Absorbed as Mg^{++}
Leaches from soil.
Mobile in plant.

- Magnesium excess:
  Interferes with Ca uptake.
- Magnesium deficiency:
  Reduction in growth, marginal chlorosis, interveinal chlorosis (yellow between the veins) in some species. May occur with middle or lower leaves, reduction in seed production, cupped leaves.
- Action notes:
  Mg is commonly deficient in foliage plants because it is leached and not replaced. Epsom salts at a rate of 1 teaspoon per gallon may be used 2 times a year. Mg can also be absorbed by leaves if sprayed in a weak solution. Dolomitic limestone can be applied in outdoor situations to rectify a deficiency.

Calcium (Ca)

Absorbed as Ca^{++}, moderately leachable.
Limited mobility in plant.

- Calcium excess:
  Interferes with Mg absorption. High Ca usually causes high pH which then precipitates many of the micronutrients so that they become unavailable to the plant.
- Calcium deficiency:
  Inhibition of bud growth, death of root tips, cupping of maturing leaves, weak growth, blossom end rot of many fruits, pits on root vegetables.
- Action notes:
  Ca is important to pH control and is rarely deficient if the correct pH is maintained. Water stress, too much or too little, can affect Ca relationships within the plant causing deficiency in the location where Ca was needed at the time of stress.

Sulfur (S)

Absorbed as SO_4^-.
Leachable. Not mobile.

- Sulfur excess:
  Sulfur excess is usually in the form of air pollution.
- Sulfur deficiency:
  S is often a carrier or impurity in fertilizers and rarely deficient. It may be also absorbed from the air and is a by-product of combustion. Symptoms are a general yellowing of the affected leaves or the entire plant.
- Action notes:
  Sulfur excess is difficult to control.

Micronutrient Outline

The majority of the micronutrients are not mobile; thus, deficiency symptoms are usually found on new growth. Their availability in the soil is highly dependent upon the pH and the presence of other ions. The proper balance between the ions present is important, as many micronutrients are antagonistic to each other. This is especially true of the heavy metals where an excess of one element may show up as a deficiency of another. If the pH is maintained at the proper level and a fertilizer which contains micronutrients is used once a year, deficiency symptoms (with the exception of iron deficiency symptoms) are rarely found on indoor plants. Many of the micronutrients are enzyme activators.

Iron (Fe)

Absorbed as Fe^{++}, Fe^{+++}.

- Iron deficiency:
  Interveinal chlorosis primarily on young tissue, which may become white.
  Fe deficiency may be found under the following conditions even if Fe is in the soil:
  Soil high in Ca, poorly drained soil, soil high in Mn, high pH, high P, soil high in heavy metals (Cu, Zn), oxygen deficient soils or when nematodes attack the roots.
  Fe should be added in the chelated form; the type of chelate needed depends upon the soil pH.
- Iron toxicity:
  Rare except on flooded soils.

Boron (B)

Absorbed as BO_3^-.

- Boron excess:
  Blackening or death of tissue between veins.
- Boron deficiency:
  Failure to set seed, internal breakdown, death of apical buds.

Zinc (Zn)

Absorbed as Zn^{++}.

- Zinc excess:
  Appears as Fe deficiency. Interferes with Mg.
- Zinc deficiency:
  "Little leaf," reduction in size of leaves, short internodes, distorted or puckered leaf margins, interveinal chlorosis.

Copper (Cu)

Absorbed as Cu^{++}, Cu^{+}.

- Copper excess:
  Can occur at low pH. Shows up as Fe deficiency.
- Copper deficiency:
  New growth small, misshapen, wilted. May be found in some peat soils.

Manganese (Mn)

Absorbed as Mn^{++}.

- Manganese excess:
  Reduction in growth, brown spotting on leaves. Shows up as Fe deficiency. Found under acid conditions.
- Manganese deficiency:
  Interveinal chlorosis of leaves followed by brown spots producing a checkered red effect.

Molybdenum (Mo)

Absorbed as MoO_4^-.

- Molybdenum deficiency:
  Interveinal chlorosis on lower or midstem leaves, twisted leaves (whiptail).

Chlorine (Cl)

Absorbed as Cl^-.

- Chlorine deficiency:
  Wilted leaves which become bronze then chlorotic then die; club roots.
- Chlorine toxicity:
  Salt injury, leaf burn, may increase succulence.

Cobalt (Co)

Absorbed as Co^{++}.
Needed by plants recently established.
Essential for Nitrogen fixation.
Little is known about its deficiency or toxicity symptoms.

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