TwoOldGuys™ Study Guides
BI114 Biological Concepts for Teachers
Chapter 7. Anatomy, Plant & Animal
7.1. Plant organization

Based on Indiana's Academic Standards, Science, as adopted by the Indiana State Board of Education, Nov 2000.

Numbers refer to the age-appropriate grade-level for the content.

Review

Plants (Botany)

Plant Anatomy

grades 3: to 5:

Plants have four basic parts:

- roots
- stems
- leaves
- flowers

roots

The roots are usually below the ground, and attach the plant to the ground. Roots also absorb water and nutrients (minerals) from soil.

stems

The stems are the primary above ground part of the plant. Their function is to support the other above ground parts.

leaves

For most plants, the leaves are the green parts of the plant. The green color absorbs sunlight to make sugar (as syrup, or sap) which flows through the stems to the rest of the plant.

flowers

Flowers are used for seed production. Some flowers are large and colorful, in order to attract animals to pollinate the flower so it can produce seeds. Bees are the most familiar of the pollinating insects, but many other insects, such as butterflies and flies, also pollinate some flowers. Other flowers are pollinated by birds, such as hummingbirds. Many seeds form in edible fruit to encourage animals to eat the fruit and discard the seeds far from the parent plant. Other seeds have parachutes and are carried by the wind beyond the area where the parent plant grew.

However, not all plants have flowers. Pine trees, for example, have cones instead of flowers, while ferns have no flowers or cones.

grades 6: to 8:, secondary: to college:

Flowering plants have two basic systems

All of the parts of flowering plants can be grouped into two basic systems: the root system and the shoot system. The primary difference between the root system and shoot system is the part of the plant embryo from which the structures are produced. There are also some anatomical details that can be used to determine which of the two systems produced the structure.

Plant growth takes place in a relatively small region of actively dividing cells called a meristem. In most cases the meristem will be a terminal apical meristem, or located at, or near, the growing tip [apex] of the root or stem. Immediately behind the apical [primary] meristem, there is a [secondary] lateral meristem which is responsible or growth in diameter. The lateral meristem will continue up to the entire length of the root or stem, where growth in diameter continues for the life of the plant. The stem apical meristem ceases growth in length when the plant reaches its mature height, although branch apical meristems continue to grow for the life of the plant unless they overtop the primary stem.

root system

The root system may consist of a primary root with an apical meristem and lateral meristems, branch roots, and adventitious roots. The primary root grows directly from the embryo, and when present in the adult plant, is a tap root. The most familiar of tap roots are carrots [the part that you eat] and dandelion roots, which may grow as long as tens of feet. Some tap roots form branch roots from the lateral meristem. In some plants, such as most trees, the branch roots further branch, usually dichotomously [meaning that they form Y-shapes at the branch point, where the apical meristem splits in two]. This pattern of branching is normally accompanied by lateral meristems which run the entire length of the branch. In other plants, such as grasses and many weedy flowers, the short primary root gives rise to numerous branches [called a fibrous root system]. These branches have an apical meristem, but a very short lateral meristem, so tend to be long and skinny. The remaining root type is the adventitious root which grows from a adventitious root bud on the shoot system rather than from the embryonic root.

The entire root system grows from the hypocotyl (embryonic root) of the embryo plant [in the seed]. Vascular plants without seeds [ferns] do not form true roots, but instead have rhizomes which resemble underground, horizontal stems (often including bark), with rhizoids as the absorbing structures. Non-vascular plants [mosses] have only rhizoids for "roots." Rhizoids are hair-like, but unlike root hairs [which are cell extensions] are cellular, consisting of one or more complete cells.

Anatomically, the root system has the conducting tissue reversed from the condition in the shoot system. The xylem, or water-conducting tissue, is near the surface of the root; while the phloem, or sap-conducting tissue is toward the center of the root. Roots, and branch roots, have the growing tip covered by a rootcap. The rootcap is a very hard, dome-shaped structure which protects the underlying growing region [meristem] from damage as the root grows through the ground, and even through rocks. Most roots are believed to enter the rock at a crack, but then crumble the rock to fine gravel (or even dirt) as the root continues to grow.

- anchor and stabilize the plant

Typically the root system will be below ground, but there are exceptions, such as prop roots which can form a cone-shaped system of supports which can protect a tree from being toppled by high winds (up to about 100 mph or 160 km/hr, including category 1 and 2 hurricanes). Trees without prop roots can sustain winds up to about 80 mph or 130 km/hr (minimal hurricane), provided they have an elaborate system of horizontal, near ground-surface branch roots in unsaturated (with water) soils.

Another exception to the generalization that root systems are below ground are the "knees" of the bald cypress tree of the Gulf Coast bayous. These bends in the horizontal roots rise about the ground surface, and have been speculated to provide oxygen to the rest of the root system which will be below the water line. This assertion has never been confirmed. An alternate (unconfirmed) hypothesis is that the cypress knees may serve the function of prop roots since the Gulf Coast is very prone to hurricanes.

- absorb water and minerals

The epidermis (outermost layer) of the small branch roots [analogous to twigs in the shoot system] has cellular extensions called root hairs. While not hairs in the usual sense, they superficially resemble fine hairs. The root hairs are the primary [if not only] structures adapted to absorb water, and dissolved minerals, from the soil moisture. They are extremely delicate and easily damaged during transplanting. It has been suggested in horticultural literature that root hair damage is the cause of 'transplant shock.' The damage can be avoided by transplanting the plant with a root ball [most of the root system with the original soil still surrounding the root system]. This works sufficiently well to allow us to have confidence that the hypothesis is valid. It does, however, not rule out the possibility that the new soil is sufficiently different in mineral content from the original soil to contribute to the transplant shock.

- often store energy as starch

The most familiar examples of root system starch storage are potatoes and carrots. Most perennial plant roots will have numerous starch grains in their central cells by the end of the growing season, and are believed to be the primary site of starch storage to supply the energy needs of the plant at the beginning of the next growing season.

Shoot system

The entire shoot system grows from the epicotyl (embryonic stem) of the seed plants, or from the protonema [analogous to an embryo, but without recognizable embryonic structures] of the non-seed plants. The primary stem grows directly from the embryo, and the branches grow from lateral buds produced by the lateral meristem. Each lateral bud has an apical meristem. Branches normally branch repeatedly, ultimately producing twigs. It has been suggested that leaves are modified stems, and therefore part of the shoot system. Flowers and cones are generally believed to be modified branch systems.

Anatomically, the shoot system has its vascular, or conducting system, organized into a ring around the interior of the shoot. Woody species have a continuous ring of vascular tissue, while herbaceous species have bundles of vascular tissue arranged loosely into a ring. The sap-conducting phloem is closest to the epidermis or bark (when bark is present), and the water-conducting xylem is toward the center. Most woody perennial plants have annual rings in the xylem, with only the more recent rings still alive and functioning for water conduction. The older, more central xylem becomes more woody by depositing lignin (a protein) in the cells walls, then dying. The age of a woody perennial plant can be determined by counting the rings in the wood.

Often, older woody plants will have considerable deposits of crystallized toxins 'stored' in the wood. Since plants do not have excretory systems, the toxins are disposed of by hiding them as crystals in the central non-living portion of the plant. A few woody plants store small amounts of starch in the newer xylem, while most perennial non-woody, or herbaceous, species store more starch in the pith which is central to the xylem. Pith consists of large, relatively soft (for a plant) cells at the center of the shoots. Most roots have little pith, except in the case of tubers (for example, potatoes). Annual herbaceous species do not store starch at all, since they live for only one growing season.

- stems support above ground parts

Stems proper provide support to hold the leaves where they get adequate sunlight to manufacture sugar as the energy source for all the living portions of the plant, although to a limited extent the leaves [or other green parts] can derive energy directly from sunlight. Sugar is also the substrate from which starch and oils are made as the long term energy storage compounds in plants.

In a few species of trees (Pines and Maples growing as isolated specimens) which have been studied to determine the geometry of branch placement, the lower branches are just low enough below the next higher branch so that the cone-shaped umbra, or dark shadow, ends above the lower branch. This arrangement would minimize the amount of shade on each of the lower branches and maximize the amount of photosynthesis in the leaves of the branch. In most, but not all, plants with secondary stems [branches], the secondary stems are arranged in a spiral up the primary stem. There is no pattern to the direction of the spiral [clockwise or counter-clockwise; counter-clockwise may be more common], although clones of the original plant [from cuttings or natural asexual reproduction] will probably rotate the same direction as the parent. Several species of perennial plants have short, vertical, underground primary stems and annual secondary shoots which die back at the end of the growing season. All known plants of this type have spirally arranged secondary shoots. Many, or most, of them have woody primary stems, but herbaceous secondary shoots.

The vascular tissue in the stems of many species of woody plants spirals up the trunk [primary stem]. We hypothesize that all woody species probably do this. Few herbaceous [non-woody] species have been examined to see if the vascular tissue spirals in them too.

- leaves

All leaves have complex internal structure, sandwiched between the upper and lower epidermis. The upper epidermis typically has a thick cuticle, often composed of waxes, for protection of the soft underlying tissues. The lower epidermis may have a thin cuticle, or more often a covering of hairs to protect the soft internal tissues. There are numerous openings, called stomata, in the lower epidermis through which the plant exchanges gases with the atmosphere. Surrounding the stomatal opening are guard cells which can change from banana-shape to tube-shape to open or close the stomata, as a means of regulating the exchange of gases, including carbon dioxide, oxygen and water vapor. The evaporation of water through the stomata has been shown (by inserting microscopic temperature sensors into a leaf, and in the air adjacent to the leaf) to lower the internal temperature of Aspen [Cottonwood family] leaves on hot summer days. Above the lower epidermis is a loose tissue, called spongy mesophyll, of green, photosynthetic cells with large empty (air-filled) spaces among them. Thicker leaves also have a tissue, called palisade mesophyll, consisting of one or two layers of densely packed, columnar cells. The palisade mesophyll, when present, lies directly below the upper epidermis.

Embedded in the mesophyll there are bundles of vascular tissue. When both mesophyll layers are present, the vascular tissue lies at the boundary between the spongy and palisade mesophylls. These bundles branch similar to shoots. The vascular bundles have their xylem toward the upper epidermis, and the phloem toward the lower epidermis. This suggests that a vascular bundle from the shoot to which the leaf is attached turned from the vascular cylinder of the shoot and curved outward into the leaf, implying that the lower epidermis is an extension of the shoot epidermis. The hypothesis that the leaf midvein came from a vascular bundle in the shoot is also based on the observation that above the vein entering the leaf, there is a gap in the vascular cylinder of the shoot. The similarity of the leaf vascular bundles within the leaf to the vascular bundles in the shoot, plus the continuity of the shoot vascular cylinder and the leaf midvein, suggests that the leaf itself is a modified, branched shoot system which has been flattened with tissue development between the branches.

- flowers

Flower parts are arranged spirally on a receptacle, which is considered to be a modified stem. One of the interpretations of the flower is that it is a modified shoot system, with each part being a separate branch from the receptacle. The parts of the flower from the apex down the receptacle are as follows:

  - pistil, with female gametophyte and egg inside
  - stamens, which make pollen (male gametophyte and sperm nucleus)
  - petals, usually large and showy
  - sepals, normally smaller and green
  - bracts, sometimes present as persistent covers of the flower bud.

The flower includes all the organs of sexual reproduction, with the egg produced internally in the pistil and the sperm nuclei produced externally in the pollen grains. Pollen is transported by wind or by animals from the flower where it was produced to another flower. At the destination flower, the sperm nucleus migrates through the pistil to the egg and fertilizes it [in most species, the pollen from the same flower will not grow on the pistil of that flower]. The resulting zygote, with one allele for each trait from each parent, develops into an embryo, while the rest of the female gametophyte becomes the seed coat. The rest of the fruit surrounding the seed grows from various flower parts (mostly pistil).

In spite of having this elaborate method for sexual reproduction, most plants reproduce more frequently by asexual means than by sexual ones.

Plant Physiology

grades 6: to 8:, secondary: to college:

Chemical (hormone) control of growth and responses

We have long known that the nervous system of animals is involved in the response of the animal to its environment, and that plants do not have apparent nervous systems. At one time, we speculated that the absence of a nervous system ought to limit the ability of plants to respond to their environment. However, it also has been known since at least 1880 that plants do respond to their environment (C. Darwin & F. Darwin, 1880). The oldest paper, which discusses plant responses to the environment, cited by the Darwins was published in 1837. Plant responses to the environment are grouped into three categories: tropisms, photoperiodism, and nastic movement.

Tropisms are directed responses which either turn in the direction of the stimulus, or turn away from the stimulus. Probably the most familiar tropism is phototropism, in which the shoots will turn toward light. This can be demonstrated, in the classroom, by placing a potted plant near the windows. Over time, the shoots will grow toward the window. To confirm that this is happening, after the plant has clearly grow toward the window, rotate the pot about a quarter of a turn and then watch it grow toward the window again. You can even produce bonsai-like trees this way. Also, to keep indoor potted plants growing straight, you must rotate them at least once a week. Another well known tropism is gravitropism, in which the roots grow toward gravity, and shoots grow away from gravity. This can be demonstrated, in the classroom, by placing a potted plant on its side. Over time, the roots will grow downward (toward gravity) and the shoots will grow upward (away from gravity).

Tropisms are caused by two [or more] plant hormones. Shoot apical meristems produce the hormone auxin, and root apical meristems produce giberellin. Auxin stimulates the growth of the lateral meristem to produce growth in length, but auxin is broken down by sunlight. Therefore, the shady side of a shoot will grow faster than the sunny side, causing the shoot to curve toward the light. In sunflowers, this causes the flower to "follow the sun." In addition, gravity will pull the auxin down in shoots that are not vertical. This causes the lower side to grow faster than the upper side, and the shoot curves upward. Giberellin suppresses the growth in length by the root lateral meristem. If the root is not vertical, this causes the lower side to grow less than the upper side, so the root curves downward. When the root is vertical, the giberellin is pulled back into the apical meristem, which is not suppressed by the giberellin, so growth occurs equally around the root.

Photoperiodism is the mechanism by which plants determine the day of the year. Plants living in those portions of North America where winter occurs [roughly north of the Ohio River valley, and north of the Missouri Ozarks] delay the growth of leaves until spring should have arrived, ignoring the warm periods [the 'mid-winter thaw']. These same plants must also drop their leaves before the return of winter. Plants accomplish this by measuring the length of the night using phytochrome which is continually converted from the inactive form to the active form by the plant, while direct sunlight converts phytochrome back to the inactive form. From the winter solstice to the summer solstice, the length of the daylight hours increases; and from the summer solstice to the winter solstice, the length of the daylight hours decreases. Because sunlight breaks down the active form of phytochrome, the amount of active phytochrome decreases from the winter solstice to the summer solstice and increases from the summer solstice to the winter solstice. Essentially, the amount of active phytochrome indicates the day of the year. Leaves do not grow until the active phytochrome decreases to the 'correct' amount for the species, and leaves change color and fall off as soon as the active phytochrome increases to the 'correct' amount for the species. This has been confirmed by transplanting plants from Indianapolis to Gary, Indiana [and vice versa]. The transplanted plants grow leaves and drop leaves at the correct time for the region from which they were transplanted, not the correct time for the region into which they were transplanted.

Nastic movement refers to those movements of plant parts that are not clearly directional. Morning Glory flowers open in the early morning and close after sunset, so they are open only when the insects that pollinate them are active. Sensitive Plant leaves wilt when brushed by animals [why is not known]. Cottonwood family trees (cottonwood, willow, aspen) fan themselves during the hottest part of the day by waving their leaves back and forth, which produces a cooling effect. Venus flytraps close their 'bear-trap' shaped leaves when insects land on the leaf, then apparently eat the insect.

Works Cited

Charles Darwin & Francis Darwin, 1880. *The Power of Movement in Plants*.
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