Chapter 4

Basic Plant Physiology: Plant Growth and Development

Bob Polomski, Gary Forrester, and Milton D. Taylor, Ph.D.

Learning Objectives

◆ Understand the process of photosynthesis and respiration.

◆ Know the inputs and outputs of photosynthesis and respiration.

◆ Understand the role of stomata in photosynthesis, respiration, and transpiration.

◆ Understand how photosynthesis and respiration are affected by environmental factors.

◆ Understand the wavelengths of light and their effect on growing plants indoors or in greenhouses.

◆ Understand the concept of photoperiod.

◆ Understand the terms day-neutral, long day, and short day.
Three major plant functions that are the basics for plant growth and development are photosynthesis, respiration, and transpiration.

**Photosynthesis**

One of the major differences between plants and animals is that most plants can make their own food. To do so, a plant requires energy from sunlight in the presence of chlorophyll—the green pigment in plants, carbon dioxide from the air, and water from the soil. If any of these ingredients is lacking, photosynthesis, or food production, will stop. If any ingredient is removed for a long period, the plant will die.

Photosynthesis literally means “to put together with light.” What happens in plants is that light is absorbed by photosynthetic pigments in the chloroplasts of plant cells and used as energy to chemically convert carbon dioxide to sugar and gaseous oxygen. As a result of the photosynthetic process, oxygen is released and sugar is produced in the leaf (Figure 4.1). The sugar molecules formed during photosynthesis serve as a plant’s primary source of food.

The most abundant pigment in plants is chlorophyll, a green pigment found embedded in the membrane of chloroplasts. Chlorophyll $a$ is involved directly in the light reactions of photosynthesis, but plant cells contain other pigments such as chlorophyll $b$, carotenoids, and anthocyanins. The color of the pigment comes from the wavelengths of light reflected (in other words, those not absorbed). The action spectrum of photosynthesis is the relative effectiveness of different wavelengths of light at generating the electrons needed for photosynthesis (Figure 4.2). The absorption spectrum of chlorophyll $b$ peaks at wavelengths where the absorption of chlorophyll $a$ begins to dip. The chlorophylls have minimum absorption in the range of green light and so appear green in color. However, there is some photosynthetic activity even at green wavelengths because of the presence of accessory pigments such as carotenoids. Because each pigment reacts with only a narrow range of the spectrum, there is usually a need for plants to produce several kinds of pigments, each of a different color, to capture more of the sun’s energy. Carotenoids are usually red, orange, or yellow pigments, and include the familiar compound carotene, which gives carrots their color. However, carotenoids cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass their absorbed energy to chlorophyll. For this reason, they are called accessory pigments. The relative abundance of pigments in leaves gives them their color.

Plants store the energy from light in carbohydrates, such as sugars and starches, for use during days when light is limited. Plants can also move these chemicals to the roots. Throughout the plant sugars and starches are converted back to water and carbon dioxide, and the stored energy is released to perform activities necessary for growth. This process is called respiration.

Only cells that have chlorophyll can produce energy. Most of these cells are in the mesophyll layer of plant leaves, located between the upper and lower epidermis (“skin”) of the leaf. This pigment traps light energy of specific wavelengths for use in manufacturing the sugar and starches that serve as the plant’s food supply. Plants are the primary source of food for all other living things, making chlorophyll at least indirectly responsible for supplying food to all living things on Earth. Coupled with the release of the oxygen that all animals depend on to breathe, it becomes almost impossible to overstate the importance of this common plant pigment.
Photosynthesis depends on the availability of light. Plant species vary somewhat in the light levels needed for optimal photosynthesis, but, generally speaking, as sunlight increases in intensity, photosynthesis increases. This means greater food production. Many garden crops, such as tomatoes, respond best to maximum sunlight. Tomato production is cut drastically as light intensity drops. Only a small number of tomato varieties will produce any fruit in greenhouses from late fall to early spring months when sunlight is minimal. Other plants, such as dogwoods, azaleas, hostas, and ferns, can produce sufficient food for optimal growth at lower light levels. Indeed, excessive light levels may harm some shade-loving plants, often indicated by bleaching of the chlorophyll, increased production of other pigments (the red color of anthocyanins), leaf scorching, leaf edge burn, and even bark or stem damage.

Water is also vitally important for photosynthesis in several ways. First, it maintains a plant’s turgor (the firmness or fullness of plant tissue). Turgor pressure in a cell can be compared to air in an inflated tire. Water pressure, or turgor, maintains the plant’s shape and ensures cell growth. Second, as the sun’s energy is absorbed by chlorophyll, water is split into hydrogen and oxygen. Oxygen is released into the atmosphere and the hydrogen is used to make carbohydrates and other energy-storing compounds. Third, water dissolves minerals from the soil and transports them from the roots to the rest of the plant. Certain of these minerals must be present in adequate concentration for photosynthesis to occur efficiently, as they serve as components of the chlorophyll molecules, as catalysts of the process, and as raw materials for growing tissue.

For photosynthesis to occur, the stomata must be open to allow carbon dioxide to enter the leaf. Carbon dioxide in the air is plentiful enough so it is not a limiting factor in plant growth under most circumstances. However, since carbon dioxide is consumed in making sugars, a tightly closed greenhouse in midwinter may not allow enough outside air to enter to maintain an adequate level of carbon dioxide. Under these conditions improved crops of roses, carnations, tomatoes, and others are produced if the carbon dioxide level is raised through adequate venting or
with carbon dioxide generators or, in small greenhouses, dry ice. There are certain types of plants that differ in basic plant morphology, allowing some plants to be more efficient in certain environments. A good example is the difference between cool season grasses and warm season grasses. Physiologically, cool season turfgrasses are called C3 (Calvin cycle) grasses; that is, their photosynthetic pathway involves using carbon dioxide linked to form a series of three-carbon molecules that are directly transformed into glucose, a six-carbon sugar. Warm-season grasses use the more photosynthetically efficient C4 (Hatch and Stack) pathway. Here, carbon is first fixed in a four-carbon intermediary compound before being transformed into glucose, a six-carbon sugar. Warm-season grasses use the more photosynthetically efficient C4 (Hatch and Stack) pathway. Here, carbon is first fixed in a four-carbon intermediary compound before being transformed into glucose, a six-carbon sugar.

Although temperature is not a leading factor in photosynthesis, it is still important. Photosynthesis occurs at its highest rate from 65 to 85°F and decreases with temperatures above or below this range.

**Respiration**

Carbohydrates made during photosynthesis are of value to the plant when they are converted to energy. This energy is used to build new tissues or to keep the plant growing. The chemical process by which sugars and starches produced in photosynthesis are converted to energy is called oxidation. It is similar to the burning of wood or coal to produce heat. Controlled oxidation in a living cell, known as respiration, is shown most simply by this equation:

\[
\text{Sugar} + \text{Oxygen} \rightarrow \text{Carbon dioxide} + \text{Water} + \text{Heat}
\]

This equation is just the opposite of that used to illustrate photosynthesis. However, respiration is accomplished through a complicated series of reactions regulated by enzymes. Complex carbohydrates are broken down into simple carbohydrates, carbon dioxide and water, and the energy released is used in many other cell processes and functions. Therefore, photosynthesis may be called a building process, while respiration is a breaking-down event.

The rate of respiration depends primarily on the temperature, nearly doubling for every 18°F rise between 40 and 96°F, and the availability of oxygen and carbohydrates. At a given temperature, young, rapidly growing tissues have the highest rate of respiration while dormant tissues have the lowest. Respiration occurs at all times in living tissues, even...
in plant parts removed during harvest. Thus, storage conditions for harvested fruits and vegetables are very important.

By now it should be clear that respiration is the reverse of photosynthesis. Unlike photosynthesis, respiration takes place at night as well as during the day. Respiration occurs in all life forms and in all cells. The release of accumulated carbon dioxide and the uptake of oxygen occurs at the cellular level. In animals, blood carries both carbon dioxide and oxygen to and from the atmosphere by means of lungs or gills. In plants, oxygen and carbon dioxide move within the plant from a region of higher concentration of those molecules to a region of lower concentration. This movement of molecules or substances down a gradient is known as diffusion. Gases pass into and out of the leaf through the stomates.

Transpiration

Transpiration is the evaporative loss of water vapor from leaves through the stomata. Stomata are small openings bordered by guard cells in the epidermis of leaves and stems (Figure 4.3). Stomata open when the guard cells take up water and swell, allowing carbon dioxide to enter the leaf for photosynthesis and water vapor to escape.

Water moves along a force/concentration gradient, which is relatively high in the soil and root zone area and relatively low in the air and leaf area (Figure 4.4). As water evaporates from the leaves, a tension develops between the leaves and the roots. The unique properties of water which allows it to be in a long flowing column like a bungee cord allows tension to “pull” it up through the plant. A continuous column of water is maintained in the xylem as long as the stomata are open and water is available in the soil. The upward movement of water from the
“About 98% of the water taken up by a plant passes through it to transport nutrients from the soil to the leaves and mainly to cool the leaves via evapotranspiration. Only about 2% of water or less is actually used for metabolic plant processes.” – Dr. Bill Bauerle, Tree Physiology/Terrestrial Ecosystem Modeling, Clemson University.

roots through the xylem to the uppermost leaves is caused primarily by transpiration. Water loss from the stomates creates a diffusion gradient from the soil through the plant to the atmosphere sufficient to pull the water through the plant.

Transpiration ceases at night in most plant species adapted to temperate climates because their stomata close. Transpiration helps to cool plants on hot days through the cooling effect of evaporation and serves to transport minerals from the soil, organic compounds from the roots, and sugars and plant chemicals to plant cells.

The amount of water lost from the plant through transpiration depends on environmental factors such as temperature, relative humidity, and wind or air movement. As temperature or air movement increases, transpiration increases. As humidity decreases, transpiration increases.

Environmental Factors Affecting Plant Growth

How well a plant grows and how widely it is distributed are affected by its environment. If any environmental condition is less than ideal, it becomes a limiting factor in plant growth. Limiting factors are also responsible for the geography of plant distribution. One example is cacti and succulents, which are adapted to receiving small amounts of water, and so can live in deserts. A less obvious example, but one critical to making plant variety recommendations for the landscape, is the degree of cold or heat tolerance in plant species.

Most plant problems are caused by environmental stresses, either directly or indirectly. Therefore, it is important to understand the environmental factors affecting plant growth. These factors are light, temperature, water, humidity, and nutrition.

Light

Three principal characteristics of light affect plant growth: quantity, quality, and duration. Light quantity refers to the intensity or concentration of sunlight and varies with the season. The maximum is present in the summer and the minimum in winter. The more sunlight a plant receives, up to a point, the better it is able to produce food through photosynthesis. As the sunlight quantity decreases, the photosynthetic process decreases. Light quantity can be decreased in a garden by using overstory trees or shade cloth above the plants or in a greenhouse by using woven shade cloth over the greenhouse structure. Light can be increased by surrounding plants with reflective material, white backgrounds, or supplemental lights.

Light quality refers to the color or wavelength that reaches the plant. Plants are sensitive to almost exactly the same range of light energy as is the human eye; however, human vision and plant use are very different. The natural daylight we see is the visible portion of the spectrum emitted by the sun. When sunlight passes through a prism, white light separates into various colors of differing wavelengths called a spectrum: red, orange, yellow, green, blue, indigo, and violet (Figure 4.5). The shorter the wavelength, the greater the energy. Visible wavelengths range from about 400 nm (violet/blue) to 700 nm (red) (nm stands for nanometer, a unit of length that is one billionth of a meter). Ultraviolet or UV light is shorter than the blue range, and far-red, infrared, and heat are longer than red. All are emitted by the sun, and all have some effect on plant growth.

Humans see best in the yellow/green region, while red and blue are the most effective wavelengths for photosynthesis. The yellow/green region is very photosynthetically inefficient. It takes a

Most of the light energy striking a leaf is absorbed, while some is reflected or transmitted right through the leaf. Only 0.5% to 1.5% of the light energy reaching the leaf is used in photosynthesis.

much greater amount of energy from yellow/green light to drive photosynthesis than it does with either blue or red light.

Changes in light quality can induce physiological, biochemical, and morphological changes in the plant, which allow it to adapt to changes in the environment. The process by which light influences the form of plants is called photomorphogenesis. Studies at Clemson University and other institutions have found that far-red light (invisible to us but “visible” to plants) affects the structure of plants. For example, a plant that becomes shaded by taller-growing, neighboring plants often develops elongated stems and/or larger leaves. By growing taller and producing larger leaves that can capture more sunlight for photosynthesis, the plant can successfully adapt to its environment. These morphological changes are caused not only by a reduction in light quantity but also in the kind of light reaching the plant. Ordinarily, there is less far-red than red in sunlight. However, when red is absorbed or “filtered out” by the upper leaves for photosynthesis, the relative amount of far-red increases in the lower, shaded leaves, which results in a change in plant form.

No artificial light can duplicate the light quality produced by the sun. Incandescent light has a broad range of wavelengths but is low in blue light and emits a large amount of heat. Also, a higher percentage of far-red than red light is emitted, which can cause plants to “stretch.” The intensity of an incandescent light can be increased to a level to drive photosynthesis, but heat then becomes a problem.

Fluorescent light has blue and red light and lacks far-red. However, the light intensity is very low, so it is not effective photosynthetically except when the lights can be placed very close to the plants such as African violets. Fluorescent lights are well-suited for seed germination because red light promotes the germination of many seeds, while far-red inhibits germination. The following kinds of fluorescent tubes are commercially available: “cool white,” “warm white,” and expensive “grow-light” bulbs. Of the three, cool white tubes are the best value for seed-starting. Grow lights produce a spectrum that attempts to mimic sunlight as closely as possible (grow lights have more red light than cool white bulbs). Grow-lights are well-suited for growing flowering plants, but they are costly and considered by some researchers as generally not of any greater value than regular cool white fluorescent lights.

Light duration refers to the amount of time that a plant is exposed to sunlight, or the lack of it, and is called photoperiod. In a natural environment, light duration is equal to the day length (the proportion of light and dark in a 24-hour period). The effects of day length on plant development are known as photoperiodism. When scientists recognized that plants had a photoperiod, they thought that flowering was triggered by the length of the light periods. However, they soon discovered it is not the length of the light period but the length of uninterrupted dark periods that is critical for flower development. The ability of many plants to flower is controlled by their photoperiod.

Depending on their flowering response to the duration of light or darkness, plants can be classified into three categories: short-day, long-day, or day-neutral plants (Table 4.1). Short-day plants are long-night plants requiring a critical period of darkness not interrupted by light to flower (Figure 4.6). Short-day plants include many spring and fall flowering plants such as chrysanthemum and poinsettia.

Long-day plants form flowers only under long-
day (short-night) conditions. They include almost all of the 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. Many of the day-neutral plants have their origins in the equatorial tropics where day-length remains near 12 hours regardless of the time of year.

Some plants do not really fit into any category but may be responsive to combinations of day lengths. Petunias will flower regardless of day length, but they flower earlier and more profusely with long days. Since chrysanthemums flower during the short days of spring or fall, the method for manipulating the plant into experiencing short days is very simple (Figure 4.7). If long days are predominant, black cloth, which keeps out all light and simulates darkness, is drawn over the chrysanthemum for 13 hours daily to block out light until flower buds are initiated and develop to the point where first color begins to show. To bring a long-day plant into flower when sunlight is not longer than 12 hours, artificial light is added to extend day-length to 13 or more hours daily until flower buds are formed and first color shows.

Temperature

Temperature affects a plant’s productivity and growth, depending on whether the plant is a warm- or cool-season crop. If temperatures are high and day length is long, cool-season crops such as spinach will “bolt”, that is, initiate flower development.

Temperatures that are too low for a warm-season crop such as tomato or eggplant will prevent fruit set. Adverse temperatures also cause stunted growth and poor quality vegetables. For example, bitterness in lettuce is caused by high temperatures.

Sometimes temperatures are used in connection with day length to manipulate flowering. Chrysanthemums will flower for a longer period of time if daytime temperatures are 59°F. Christmas cactus forms flowers as a result of short days or low temperatures. Temperatures alone also influence flowering. Daffodils are forced to flower by putting the bulbs in cold storage in October at 35 to 40°F. Besides encouraging rooting, the cold temperatures cause flower stems to elongate. The bulbs are transferred to a warm greenhouse in midwinter where rapid growth begins. In 3 to 4 weeks the flowers are ready for cutting.

Thermoperiod refers to a daily temperature change. Plants respond to and 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 (build up) and respire (break down) during an optimum daytime temperature and to reduce the

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### Table 4.1
A short list of long-day, short-day, and day-neutral plants.

<table>
<thead>
<tr>
<th>Category</th>
<th>Common Name</th>
<th>Scientific name</th>
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<tbody>
<tr>
<td>Long-day</td>
<td>Coneflower</td>
<td><em>Rudbeckia bicolor</em></td>
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<td>Summer phlox</td>
<td><em>Phlox paniculata</em></td>
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<td></td>
<td>Black-eyed Susan</td>
<td><em>Rudbeckia hirta</em></td>
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<td>Radish</td>
<td><em>Raphanus sativus</em></td>
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<td>Dill</td>
<td><em>Anethum graveolens</em></td>
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<td>Ryegrass, perennial</td>
<td><em>Lolium perenne</em></td>
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<td>Sedum</td>
<td><em>Sedum spectabile</em></td>
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<td>Spinach</td>
<td><em>Spinacia oleracea</em></td>
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<td>Short-day</td>
<td>Love-lies-bleeding</td>
<td><em>Amaranthus caudatus</em></td>
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<td>Chrysanthemum</td>
<td><em>Chrysanthemum morifolium</em></td>
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<td>Cosmos</td>
<td><em>Cosmos sulphureus</em></td>
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<td></td>
<td>Kalanchoe</td>
<td><em>Kalanchoe blossfeldiana</em></td>
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<td></td>
<td>Poinsettia</td>
<td><em>Euphorbia pulcherrima</em></td>
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<tr>
<td></td>
<td>Strawberry (June-bearing)</td>
<td><em>Fragaria x ananassa</em></td>
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<tr>
<td>Day-neutral</td>
<td>Bluegrass, annual</td>
<td><em>Poa annua</em></td>
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<td>Gardenia</td>
<td><em>Gardenia angustata</em></td>
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<td></td>
<td>Corn</td>
<td><em>Zea mays</em></td>
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<tr>
<td></td>
<td>Cucumber</td>
<td><em>Cucumis sativa</em></td>
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<tr>
<td></td>
<td>Fruit and nut trees</td>
<td><em>Vitis spp.</em></td>
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<td>Grapes</td>
<td><em>Lycopersicon esculentum</em></td>
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<tr>
<td></td>
<td>Strawberry (everbearing)</td>
<td><em>Viburnum</em></td>
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<tr>
<td></td>
<td>Tomato</td>
<td><em>Viburnum</em></td>
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rate of respiration during a cooler night. Temperatures higher than needed increase respiration, sometimes above the rate of photosynthesis. This means the products of photosynthesis are being used more rapidly than they are being produced. For growth to occur, photosynthesis must be greater than respiration.

Temperatures that are too low can result in poor growth. Photosynthesis is slowed down and, as a result, growth is slowed, producing lower yields. Not all plants grow best in the same temperature range. For example, snapdragons grow best at nighttime temperatures of 55 °F and poinsettias at 62 °F. Cyclamen does well under very cool conditions, whereas many bedding plants prefer a higher temperature.

In some cases, however, a certain number of days with low temperatures are needed by plants to grow properly. This is true of crops growing in cold regions of the country. Peaches are a prime example: most varieties require 700 to 1,000 hours below 45 °F but above 32 °F before they break their rest period and begin growth. Most lilies need 6 weeks of temperatures at 33 °F before they will bloom.

Plants can be classified as either hardy or nonhardy, depending on their ability to withstand cold temperatures. Winter injury can occur to nonhardy plants if temperatures are too low or if unseasonably low temperatures occur early in the fall or late in the spring. Winter injury may also occur because of desiccation or drying out. Plants need water during the winter. When the soil is frozen, the movement of water into the plant is severely restricted. On a windy winter day, broadleaf evergreens can become water-deficient in a few minutes, and their leaves or needles turn brown. On the other hand, periods of above normal temperatures during the winter coupled with rain showers followed by rapidly falling temperatures to below freezing can result in bark-splitting of azaleas, rhododendrons, and Pieris japonica.

Wide variations in winter temperatures can cause premature bud-break in some plants and consequent freeze damage to fruit buds. Late spring frosts can ruin entire peach crops. If temperatures drop too low during the winter, entire trees of some species can be killed by freezing and splitting plant cells and tissue. For many plants, roots are often less temperature hardy than stems and buds.

**Water**

Water is a primary component of photosynthesis. It maintains the turgor pressure or firmness of tissue and transports nutrients throughout the plant. Water is the major constituent of cell protoplasm. Through turgor pressure and other changes in the cell, water regulates the opening and closing of the stomates, thus regulating transpiration. Water also provides the pressure to move a root through the soil.

Among the most critical roles of water is that
of solvent for minerals moving into the plant and for carbohydrates moving to their site of use or storage. Water is also important in bringing about the chemical reactions involved in photosynthesis and respiration. By its gradual evaporation from the leaf surface near the stomates, water helps stabilize a plant’s temperature.

Relative humidity is the ratio of water vapor in the air at a given temperature and pressure to the amount of water the air can hold at that temperature and pressure expressed as a percentage. For example, if a pound of air at 75 °F can hold 4 grams of water vapor and there are only 3 grams of water in the air, then the relative humidity (RH) is calculated as follows: RH = water in air/water that air can hold (at constant temperature and pressure) or RH = \( \frac{3}{4} = 0.75 \) expressed as a percent = 75%.

Warm air can hold more water vapor than cold air. Therefore, if the amount of water in the air stays the same and the temperature increases, the relative humidity decreases.

Water vapor will move from an area of high relative humidity to one of low relative humidity. The greater the difference in humidity, the faster the water will move.

The relative humidity in the air space between the cells within the leaf approaches 100%. When the stomates are open, therefore, water vapor rushes out. As water moves out, a bubble of high humidity is formed around the stomate. This bubble of humidity helps slow down transpiration and cools the leaf. If winds blow the humidity bubble away, transpiration will increase.

**Nutrient Uptake**

Plant growth and development depend on the availability of water and several essential mineral nutrients (see Chapter 1, “Soils and Plant Nutrition.”) These mineral nutrients are used in various processes that include photosynthesis and respiration, and are united with carbohydrates to form important compounds.

Plants obtain all of their water and most of their mineral nutrients from the soil. Most of the water and mineral uptake occurs in roots along the very small fibrous portions of a plant’s root system through a combination of chemical and physical processes. Some of these processes require root cells to expend chemical energy.

Soil water is largely pulled from the soil up through the plant and out of the stomata by transpiration. Some of the plant-essential nutrients are dissolved in the soil water and are transported to the root surface during the process. As discussed in Chapter 1, most nutrient elements are absorbed as charged ions, which may be positively charged cat-
ions or negatively charged anions.

Nutrients also move to the root surface by diffusing along a concentration gradient or by physically intercepting growing root tips. Once nutrients are near the root surface, their uptake by the roots often involves the expenditure of chemical energy.

Water is taken into the plant both passively and actively. Water taken in passively requires no energy output by the plant. It flows through the plant because of differences in concentration between the soil solution and the liquid within the cell. Water that is actively absorbed requires energy from the plant. If no oxygen is available, sugar cannot be metabolized to produce energy; therefore, nutrients cannot be absorbed.

Anything that lowers or prevents the production of sugars in the leaves can lower nutrient absorption. If the plant is under stress because of 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 uptake. Many plants go into a rest or dormancy for part of the year. During this period, few nutrients are absorbed.

Nutrients transported from the roots to living cells by the vascular system move into the cell across a cell membrane. Cells absorb nutrients in three different ways. 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 ion of the pair is pulled into the cell. The other will follow to keep the number of positive and negative charges even. Most anions or 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 one of the same charge. The hydrogen ion (H\(^+\)) is often released from the cell so that the cell can absorb another positive ion, such as the potassium ion (K\(^+\)). Since this is a simple or passive absorption, energy may not be required. Cations or positive ions may be passively absorbed by this method.

Both of these methods of absorption may be passive or active. However, the third method, the carrier system, always involves active absorption, which requires energy. Scientists have discovered specialized chemicals within the cell membrane that act as carriers. A carrier, through chemical changes, attracts an ion outside the cell membrane and releases it inside the cell. Once the ion is inside the cell, it attaches 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 a plant is to grow and be healthy. The factors discussed earlier about absorption by the root are also true for absorption by the cell.

### References and Further Reading

**Technical**


**Gardener Friendly**


**Internet**


1. Briefly describe the process of photosynthesis.

2. What is respiration? How does it differ from photosynthesis?

3. How does water move up from the roots and out from the leaves?

4. What two regions of the visible light spectrum do plants absorb most?

5. What are short-day, long day, and day-neutral plants?