MASTER GARDENER
COLORADO STATE UNIVERSITY
EXTENSION

CMG GardenNotes #141

Plant Physiology: Photosynthesis, Transpiration, and Respiration

The three major functions that are basic to plant growth and development are:

- **Photosynthesis** – The process of using chlorophyll to capture light energy and convert it to energy stored in sugars. Photosynthesis uses light energy, carbon dioxide (CO2), and water (H2O) to generate glucose with a byproduct of oxygen.
- **Transpiration** – The loss of water vapor through the stomates of leaves.
- **Respiration** – The process of metabolizing (burning) sugars to yield energy for growth, reproduction, and other life processes. Respiration uses glucose and oxygen to generate kinetic energy, with a byproduct of carbon dioxide and water.

Photosynthesis

A primary difference between plants and animals is the plant's ability to manufacture its own food. In photosynthesis, plants use carbon dioxide from air and water in the soil with the sun's energy to generate photosynthates (sugar) releasing oxygen as a byproduct. [**Figure 1**]

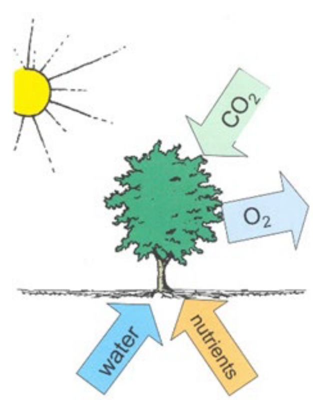


Figure 1. Photosynthesis

Photosynthesis literally means to put together with light. It occurs only in the **chloroplasts**, organelles contained in the cells of leaves and green stems. The chemical equation for photosynthesis is

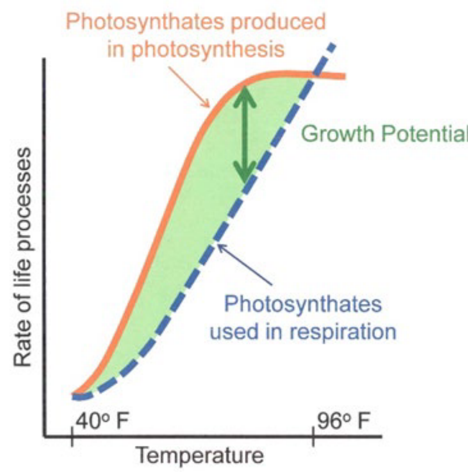
$$\begin{array}{ccccccccc} \text{carbon dioxide} & + & \text{water} & + & \text{light energy} & = & \text{glucose} & + & \text{oxygen} \\ 6CO_2 & + & 6H_2O & + & \text{light energy} & = & C_6H_{12}O_6 & + & 6O_2 \end{array}$$

This process is directly dependent on the supply of water, light, and carbon dioxide. Limiting any one of the factors on the left side of the equation (carbon dioxide, water, or light) can limit photosynthesis regardless of the availability of the other factors. An implication of drought or severe landscape irrigation restrictions result in reduction of photosynthesis and thus a decrease in plant vigor and growth.

In a tightly closed greenhouse, there may be very little fresh air infiltration and carbon dioxide levels can become limiting during the day while photosynthesis is actively occurring, thus limiting plant growth. Large commercial greenhouses may provide supplemental carbon dioxide to stimulate plant growth.

The rate of photosynthesis is temperature dependent. In general, warmer temperatures increase the rates of photosynthesis, but only up to a point. At high temperatures, enzymes used in photosynthesis become less efficient. Furthermore, respiration increases with temperature as well. For example, when temperatures rise above 96 degrees Fahrenheit in tomatoes, the rate of food used by respiration rises above the rate of food manufacture through photosynthesis. Plant growth comes to a stop. Most other plants react similarly. [**Figure 2**]

Figure 2. In the tomato plant, rates of photosynthesis and respiration both increase with increasing temperatures. As the temperature approaches 96°F, the rate of photosynthesis levels off, while the rate of respiration continues to rise.



Transpiration

Water in the roots is pulled through the plant by **transpiration** (loss of water vapor through the stomates of the leaves). Transpiration uses about 90% of the water that enters the plant. The other 10% is used as an ingredient in photosynthesis and cell growth.

Transpiration serves three essential roles:

- **Movement of dissolved nutrients and minerals** up from the roots (via xylem) and sugars (products of photosynthesis) throughout the plant (via phloem). Water serves as both the solvent and the avenue of transport.
- **Cooling**. 80% of the cooling effect of a shade tree is from the evaporative cooling effects of transpiration. This benefits both plants and humans.
- **Turgor Pressure**. Water maintains the turgor pressure in cells much like air inflates a balloon, giving form to the non-woody plant parts. Turgidity is important so the plant can remain stiff, upright, and have a competitive advantage when it comes to light. Turgidity is also important for the functioning of the guard cells that surround the stomates, regulates water loss, and carbon dioxide uptake. Turgidity also is the force that pushes roots through the soil.

Water movement in plants is also mediated by osmotic pressure and capillary action.

Osmotic pressure is defined as water flowing through a permeable membrane in the direction of higher salt concentrations. Water will continue to flow in the direction of the highest salt concentration until the salts have been diluted to the point that the concentrations on both sides of the membrane are equal.

A classic example is pouring salt on a slug. Because the salt concentration outside the slug is highest, the water from inside the slug's body crosses the membrane that is its skin. The slug dehydrates and dies. Envision this same scenario the next time you gargle with salt water to kill the bacteria that are causing your sore throat.

Fertilizer burn and dog urine spots in a lawn are examples of salt problems. In moderately salty soil, the plant can draw water into its roots less efficiently than from soils not affected by salts. In severe cases, the salt level is higher outside the plant than within it, and water is drawn from the plant.

Capillary action relies on the property of water that causes it to form droplets (hydrogen bonding). Water molecules in the soil and in the plant cling to one another and are reluctant to let go. You have observed this as water forms a meniscus on a coin or the lip of a glass. Thus when one molecule is drawn up the plant stem, it pulls another one along with it. These forces that link water molecules together can be overcome by gravity and are more effective in small diameter tubes ("capillaries"), in which water can move opposite gravity to considerable height.

Respiration

In **respiration**, plants (and animals) convert sugars (photosynthates) back into energy for growth and other life processes. The chemical equation for respiration shows that the photosynthates are oxidized, releasing energy, carbon dioxide, and water. Notice that the equation for respiration is the opposite of that for photosynthesis.

$$\text{glucose} + \text{oxygen} = \text{energy} + \text{carbon dioxide} + \text{water}$$
$$C_6H_{12}O_6 + 6O_2 = \text{energy} + 6CO_2 + 6H_2O$$

Chemically speaking, the process is similar to the **oxidation** that occurs as wood is burned, producing heat. When compounds are oxidized, the process is often referred to as "burning." For example, athletes burn energy (sugars) as they exercise; the harder they exercise, the more sugars they burn so they need more oxygen. This is why at full speed they are breathing very fast. Athletes take in oxygen through their lungs.

Plants take up oxygen through the stomates in their leaves and through their roots. Like animals and microorganisms, plants respire to generate the energy they need to live, thus requiring both oxygen and carbon dioxide in order to survive. This is why waterlogged or compacted soils are detrimental to root growth and function, as well as the decomposition processes carried out by microorganisms in the soil, oxygen is not available.

Comparison of Photosynthesis and Respiration

Photosynthesis	←→	**Respiration**
Produces sugars from energy.		Burns sugars for energy.
Energy is stored.		Energy is released.
Occurs only in cells with chloroplasts.		Occurs in all living cells.
Oxygen is produced.		Oxygen is used.
Water is used.		Water is produced.
Carbon dioxide is used.		Carbon dioxide is produced.
Requires light.		Occurs in dark and light.

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