

VIII. PLANTS AND WATER

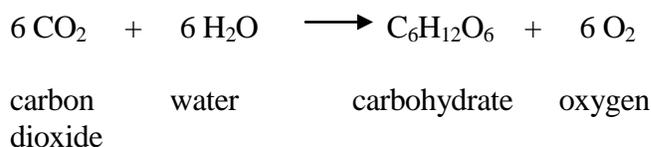
Plants play a large role in the hydrologic cycle. Transpiration, the evaporative loss of water from leaves of natural and cultivated vegetation, returns to the atmosphere about 60 % of the incident precipitation over land surfaces. Another hint of the importance of the interaction between plants and water comes from our review of water use. Agriculture needs large quantities of water for food production. For example, it takes 61 gallons of water to produce a single serving of corn. Thus plants are important in the global circulation of water; and, conversely, water plays many essential roles in plant growth and function. This chapter describes the structural, chemical, and physical, and importance of water in plants and the role of plants in soil water relations.

STRUCTURAL AND CHEMICAL IMPORTANCE AND TRANSPIRATION MECHANISM

Structural role of water in plants. Structurally, the plant cell resembles a water balloon. A young cell is typically 85 % water. Growth occurs as water enters the cell in response to an osmotic driving force, and the pressure of the intracellular water inflates the cellulosic wall which bounds the cell. Proteins, carbohydrates and other metabolites are deposited during growth; but the primary process of volume expansion is driven by water uptake. The structural rigidity of the soft plant tissues is also conferred by water. This can be seen in the wilting of leaves of plants subjected to sudden drought.

On a microscopic scale, most living cells are highly hydrated. The aqueous environment is necessary for the functional shape of many of the important cellular molecules, including the proteins and lipids which are the building blocks of living matter.

Chemical importance of water in plants. Chemically, water is a reactant in photosynthesis, the chemical reaction which is the basis of the food chain. Within the plant chloroplast, energy from sunlight is used to convert carbon dioxide and water into carbohydrate and oxygen. The chemical reaction for photosynthesis is written:

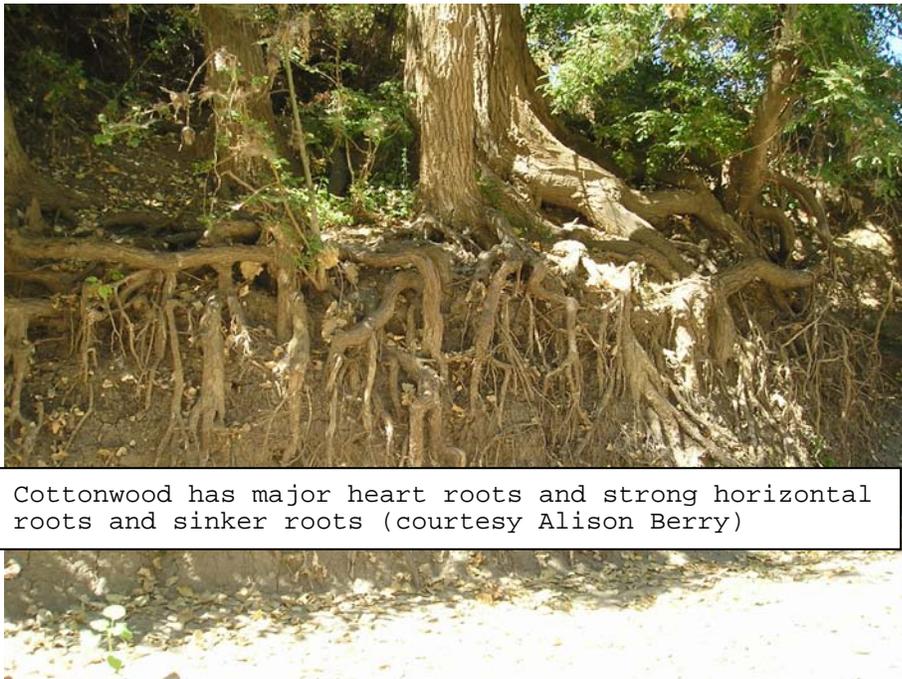


Plants are the only living creatures which can use the energy of sunlight directly to make the carbohydrates to sustain growth and function. Thus plants are called "primary producers." Higher in the food chain, plant-eating animals use the energy-rich chemical compounds (food!), while carnivores consume animals to power their life processes. The food chain is based on plants in both terrestrial and aquatic habitats. In oceans tiny plants called phytoplankton photosynthesize and serve as food for aquatic animals.

Oxygen is the other important product of photosynthesis. Primitive plants had to function for eons of time before the earth's atmosphere had enough oxygen to permit the evolution of respiring animals. Thus the water which is split in photosynthesis provides the oxygen in the air which we breathe.

In addition to its role in photosynthesis, water is essential in many of the chemical reactions of plants and animals.

The pathway for water movement through the plant. Water is absorbed from the soil by roots. Each plant has a vast root system which may contain a highly branched fibrous network (grasses) or system of large woody roots coupled to a branched network of second and third order roots (trees). Root systems take on different shapes under different environmental conditions—roots proliferate in moist and nutrient- rich patches, and root shapes vary with soil hardness. For all root systems water moves from the outer cells of the root around and through cell walls and cytoplasm into xylem elements. The xylem elements, specialized for water conduction, are thick-walled cells that die as they become functional. Xylem elements resemble miniature pipes, and they form a contiguous pipeline which carries water in a continuous liquid column from roots through the stem into the leaves. By holding a leaf up to the light we can see the network of veins which comprise the leaf xylem. Living cells, the bundle sheath cells, often surround the veins of the leaf. Water exists in liquid form in the cell walls of the plant, while in the intercellular air spaces we find water in gaseous form.



The extensive root system of a cottonwood tree mines water from the soil

Cottonwood has major heart roots and strong horizontal roots and sinker roots (courtesy Alison Berry)



The lower leaf surface has many stomata to permit CO₂ uptake for photosynthesis. By regulating stomatal opening, the plant maintains some control over transpiration.

The tradeoff between photosynthesis and transpiration. Chloroplasts are the sites for photosynthesis, and in higher plants they are found primarily in leaves. Leaves are structurally adapted to allow easy diffusion of carbon dioxide into the chloroplast. Openings, the stomata, are formed when specialized structures called guard cells distend in response to light. The open stomata also have a big effect on diffusion of gaseous water molecules out of the leaf--in short, on transpiration. The intercellular spaces of the leaf are saturated with water in gas phase, while the water content of the air outside the leaf is usually much less than saturated. Thus the concentration gradient in water vapor drives water out of the plant into the atmosphere. We can see that as a result of leaf structure, the plant has a tradeoff between acquisition of carbon dioxide and loss of water. This then is the basis of the tremendous transpiration rate of plants. Typically, a crop which weighs 20 tons will contain only five tons of dry matter. But 2000 tons of water will have passed through the roots, stem and leaves of the crop during the growing period.

The cohesion-tension model for transpiration. How does water move to the tops of tall trees? What sort of plant pump drives the large rates of transpiration? During the last century scientists debated whether transpiration is due to vital or purely physical processes. Plant physiologists demonstrated that even when plants were killed by immersion in strong acids, transpiration continued as long as the leaf surface remained intact. Apparently transpiration (unlike photosynthesis which can only occur in living tissue) is physical in nature. The "cohesion-tension" theory of transpiration was proposed. As explained in the section on the pathway for water movement, plants are highly hydrated, and water exists in liquid columns which are continuous from the root into the cell walls of the leaf. Water molecules are strongly attracted to each other by hydrogen bonding. The cohesion of the water molecules in liquid phase implies that when one molecule evaporates out of the liquid phase into the intercellular air space of the leaf, another water molecule is pulled up into the liquid water column. If transpiration is a little faster than absorption, a negative pressure or tension develops. The tension insures that a stream of water is pulled through the plant. Evaporation from the surface of the leaf causes a continuous column of water to be pulled from roots through stem and leaf to atmosphere, just as the base of a piece of string can be pulled by a tug from the top of the string.

The cohesion tension theory of water movement is now pretty well accepted by scientists, and controls on transpiration rate can be understood in terms of the theory. To some extent the plant is like a porous pipe inserted into the soil. Physical factors are important in controlling the rate of transpiration. A rise in temperature causes the transpiration rate to increase. This is due to the effect of temperature on the water vapor content of the intercellular air spaces. The air spaces of the plant are always saturated with water vapor (since the air spaces are adjacent to the liquid water which permeates the neighboring cell walls). The water vapor in the atmosphere is usually much less than saturated. So a gradient in water vapor concentration drives transpiration, and the driving force is greater at higher temperatures. An increase in wind speed also increases the transpiration rate. In contrast, drying of the soil decreases the transpiration rate.

Biological factors also affect the transpiration rate. The most important control is exerted by the guard cells which open the stomata. Ordinarily, light stimulates the opening of the stomata. Photosynthesis begins after sunrise and ends after sunset; often transpiration follows the same diurnal pattern. But if the plant experiences drought, the stomata may close, preventing transpiration and maintaining the plant water status. Thus during dry spells the guard cells act as valves to close the pipeline for water movement through the plant. Other biological factors affecting transpiration are the extent of the rooting system, and the shape and color of the leaves.

B. ROLE OF PLANTS IN SOIL WATER RELATIONS.

Soil water extraction. Plants play an important role in extracting water from soil. To see this, let us consider the water content of a field in Davis. After the rainy season is over, the soil drains to field capacity and may hold, for example, 20% water. After the top layers drain, the hydraulic conductivity is so low that flux is negligible. The field is planted with corn in May, and we can do some simple measurements to measure soil water content as a function of depth. We dig up soil cores and weigh slices of soil. Then we dry the slices and weigh them without water. The difference between the two weighings allows us to calculate the water content of the freshly extracted soil core. At the beginning of the growing season there is uniform soil water content. In June we find that the top layer has much less water. In July the dry layers extend almost one meter below the surface.

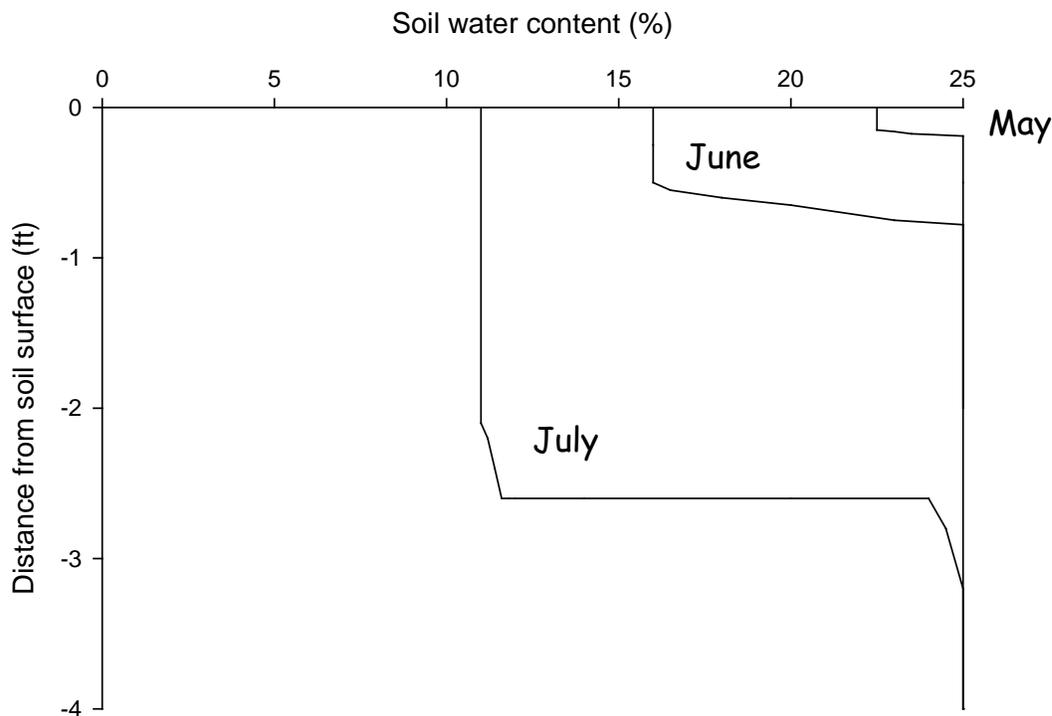


Fig. VIII.1 Soil depth as function of moisture content

Figure VIII.1 shows that even in the absence of irrigation, plant roots extract soil water from progressively deeper layers throughout the growing season. Here is evidence that plants are extremely efficient pumps. Work at Davis has established that plants can extract water that is held in the soil with a tension equivalent to 25 atmospheres! It is surprising to realize that a field of grass may consume as much water as a swimming pool. In the chapter on water use we learned that 80% of the developed water in California is consumed by agricultural plants or native vegetation. Very little of this water is retained in the structure of the plant; most is transpired back to the atmosphere. From studying the water conducting pathway of plants, we now understand how the plant structure facilitates the transpiration which is such an important part of the hydrologic cycle

Prevention of runoff and soil erosion--Plants often prevent runoff and erosion. Runoff from bare soil will be moderately great even during small rains, while a good plant cover will prevent runoff from small and moderate rains. A larger portion of the total water will infiltrate into a good lawn than into a bare patch of soil. However, once enough rain has fallen to saturate the soil, infiltration rate for bare soils is not very different from infiltration rates for planted soils. Thus plants cannot affect catastrophic floods which occur after prolonged rainy or snowy periods.

REFERENCES

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