about 20 pounds of water a day; when 77–114 days pregnant they consume about 30 pounds a day. The water consumption of mature pullets is about 3 to 4 gallons for each 100 birds; 100 laying hens need 5 to 7 gallons a day.

The other major factor that may affect the intake of water is environmental temperature. Considerable work has been done at the California and Missouri Agricultural Experiment Stations on the effects of temperature on consumption of water and the related physiological alterations in dairy cattle, swine, and chickens. The experiments showed that as external temperature increases from about 50° to 100° F., the amount of moisture lost by evaporation from the body surfaces also steadily increases. Moisture loss by evaporation has the effect of enabling the animal to withstand better the effects of increased temperatures, because it can get rid of large amounts of heat efficiently. This mechanism whereby heat is lost reaches a high development in horses, which sweat profusely. It has a limited effect in most domestic animals, which sweat less. Increased evaporative loss, on the other hand, raises the need for water in order to keep the water balance of the tissues.

In all the experiments, consumption of water increased as the temperature went up. At the highest temperatures, however, no further increase in consumption occurred; in some instances it declined. At those temperatures, feed consumption, milk production, and egg production fell and body temperature increased. The observations indicate that increased water consumption as a means of combating high environmental temperatures has its limitations.

So we see that the water needs of livestock fluctuate widely—particularly the needs of ruminants, whose rations may vary a great deal in composition and water content.

Data on water consumption of livestock and poultry are given in tables on page 17. The values given for poultry and hogs will be applicable generally and will actually approximate the water requirements, because the feeds usually given them contain little water and do not vary widely in composition. The figures given for cattle and sheep cover the maximum requirements, but because data on consumption on pasture or range are lacking and because the water content of rations varies widely, the minimum amounts cannot be stated accurately.

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The Needs and Uses of Water by Plants

Leon Bernstein

Most actively growing plants or plant parts contain more water than solids.

The water is not inert material or "filler"—the water in plants, as in all living matter, contributes as much to the essential properties of life as do the more complex proteins, the fatty compounds, carbohydrates, and minerals.

Many people believe that life originated in the sea. The relationship of primordial life to water therefore was direct and relatively simple. When the terrestrial forms developed, water supply became a critical factor, and plants underwent profound changes in structure during the long process of adapting themselves to living on land.

The cell is the unit of living matter. The structure of plants can be understood only in terms of the cells that constitute them. Plant cells are diverse in size, form, and composition, but their basic structure is much the same.

The average plant cell measures only about one one-thousandth of an inch in diameter.

A LEAF CELL, such as is found in the interior of the leaves of most plant species, consists of a relatively rigid outer wall and its contents. The cell wall surrounds and is in close contact with the protoplasm, the viscous fluid that is the living matter of the cell. Cell walls—familiar to us in the form of natural fibers such as cotton and hemp, and in aggregate form as wood—consist largely of complex carbohydrates built up by the combination of numerous sugar units. The cell wall, because of its rigidity, determines the shape of cells. Large numbers of cells adhering at points of contact determine the shape and form of the plant.

Chemically, the protoplasm inside the cell wall is complex. Next to water, proteins are present in greatest abundance; more than any other class of constituents, they are responsible for the unique properties of living matter. The properties of proteins that make them the principal building material of living matter and the substances that control most of the life processes are actually properties of protein solutions in water. The distinction may be illustrated by comparing the obvious properties of a protein, such as egg white, in the fresh and dehydrated forms.

Water, proteins, and the other constituents of protoplasm, including the fatty materials, sugars, salts, and many other derivatives, thus compose a complex system, no part of which can be omitted without fundamentally altering the potentialities of protoplasm.

The protoplasm contains a number of distinct structures, which regulate or perform specific cellular functions. The nucleus carries the heritable factors, or genes, which transmit certain characteristics from generation to generation and control the development of the individual cells in conformity with the inherited potentialities. In green tissues, chloroplasts (in which the green pigment, chlorophyll, is localized) act as the centers in which light energy is absorbed to convert carbon dioxide and water to sugars.

The protoplast, or the unit of protoplasm in a cell, also contains one or more vacuoles, which are droplets of a watery solution of various salts, sugars, and other materials, completely surrounded by protoplasm. In the water relationships of cells, each part, the cell wall, the protoplasm, and the vacuole, has a necessary and distinct function. The cell wall permits the free passage of water and most dissolved materials, but the protoplasm limits the passage of the latter.

Before we can consider the manner in which the distinctive properties of the cell wall and protoplasm regulate the water relationships of the cell, we must understand some of the properties of solutions.

THE COMPONENT PARTICLES of solid matter occupy relatively fixed positions, but the particles of gases, liquids, and solids in solution move about freely and at random. All parts of a solution therefore tend to achieve equal concentration. An example: A lump of sugar dropped into a tumbler of water dissolves, and the sugar particles begin to disperse throughout the water as they become detached from the lump.

As a final result of this process of diffusion, the number of sugar particles in any given volume of water anywhere in the tumbler eventually becomes equalized. Diffusion affects the water in the tumbler as well as the sugar; the water particles likewise tend to become evenly distributed throughout the tumbler, as a result of their random motion.

Let us consider a single plant cell immersed in a droplet of rainwater.

The water bathing the cell contains

little dissolved material. The water inside the cell contains sugars, salts, and various other compounds in solution. The dissolved materials tend to move out of the cell, and water tends to move into the cell by the process of diffusion, each material tending to equalize its concentration in the water-droplet-cell system. The protoplasm restricts the movement of most dissolved materials much more than that of water, however, so that, in effect, the water moves into the cell while the dissolved materials in the cell are largely retained within it. The water accumulates in the vacuole of the cell and builds up a pressure, which forces the protoplasm against the cell wall and keeps it fully distended. A cell in this condition is said to be turgid. The diffusion pressure of water in the cell, which is a measure of the tendency of water to move out of the cell, increases as the turgidity of the cell increases. At equilibrium, the turgor of the cell sufficiently increases the diffusion pressure of water in the cell to compensate for the lower concentration of water due to the presence of dissolved materials.

If the droplet of rainwater is replaced by a moderately strong sugar or salt solution (so that the water is in greater abundance in proportion to dissolved materials inside the cell than outside) water begins to move out of the cell. The pressure inside the cell is relieved, and if the outward movement of water continues, the cell loses its turgor and becomes flaccid. The movement of water across a membrane such as the protoplasm, which is more permeable to water than to the materials dissolved in it, is called osmosis.

The basis for the osmotic movement of water is the difference in permeability of the protoplasm to water and to substances in solution in the water. If the protoplasm is injured or killed, as by excessive heat or poisons, it loses its property of differential permeability, and dissolved substances diffuse out of the cell. A piece of red beet tissue loses very little of its water-soluble red pigment if immersed in tapwater, but if the water is heated enough to injure or kill the beet cells, or if some poison is added to the water, the red pigment rapidly diffuses into the water. The tissue becomes flaccid as it loses the ability to retain dissolved materials.

A Leaf Cell

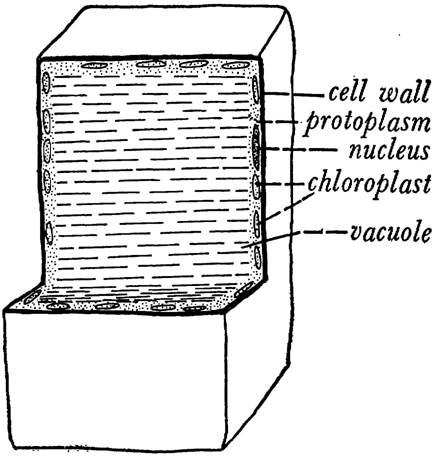


Diagram of a leaf cell, a part of which has been cut away to show the relationships of cell wall, protoplasm, and vacuole.

PLANT CELLS tend to absorb water by another process, which is characteristic of many finely divided or dispersed materials. Water is strongly attracted by the large surfaces exposed by such materials and is held with considerable force. Proteins and carbohydrates, such as the cellulose of the cell wall, represent a high proportion of the solids in plant cells, and some of the water in the cell is held by the attractive force they exert. Dry wood, largely cellulose, will take up water and swell or warp. The process of water uptake by such materials is called imbibition and is largely responsible for the initial water uptake by dry seeds.

We can now appreciate more fully the advantageous position of aquatic plantlife with respect to its water supply. The protoplasts need only maintain the ability to retain the dissolved substances which the cell manufactures or absorbs, and (if the bathing medium is not too concentrated) the plant cells will obtain water by simple diffusion, or osmosis.

WITH THE DEVELOPMENT of land forms, the parts of the plant that are exposed to the air became subject to desiccation by the evaporation of water from the cells. The evaporative loss of water from plants is called transpiration. By far the greatest portion of the water taken up by the roots of a plant is lost by transpiration.

For every pound of dry matter in a plant, we commonly find about 5 or 10 pounds of water, but for each pound of dry matter produced, the plant must absorb several hundred pounds of water; the difference between the 5 or 10 pounds and the several hundred pounds represents water lost by transpiration. By contrast, the aquatic plant has to absorb only the water required for its growth; that is, the 10 pounds or so per pound of dry matter constituting the plant body. It is evident, therefore, that land plants must have efficient means for absorbing water, for distributing it throughout the plant, and for controlling water loss as much as possible.

THE CHARACTERISTICS of land plants which have made possible their survival and extensive development in an environment so demanding with respect to water supply are represented in the drawing on the next page. Because most of the water used by land plants must be absorbed from the soil in which they grow, root systems must be extensively developed. The underground parts of most land plants permeate a volume of soil as large as—or even larger than—the space occupied by the aboveground parts, and the finely divided root system presents an enormous surface area for water absorption. That large absorbing surface is augmented by the development of numerous fine root hairs on the young, growing roots. The total length of the roots developed by a single grain plant, such as wheat, may be tens of miles, and many millions of root hairs may increase the already large absorbing surface by as much as ten times or more.

The conduction of water is facilitated by the development of specialized, greatly elongated cells in the roots, stems, and leaves of land plants. After the cells have grown, the protoplasts degenerate and disappear, leaving a long, hollow tube, or tracheid, which presents a minimum of resistance to the movement of water. The end walls of the cells in many species are digested away as the cells mature, and resistance to the flow of water is reduced further. Such units are called vessels. Vessels and tracheids and the cells that remain alive form the xylem tissue or wood, most extensively developed in woody plants.

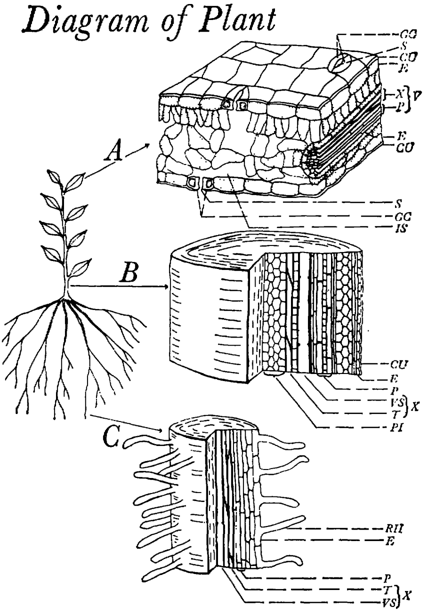
The xylem affords a continuous system of hollow tubes from near the tip of the root, through the root and stem, and into the leaf, where it is part of the familiar leaf-vein network. The woody tissue of stems and roots also performs other functions in a land plant, notably anchorage and mechanical support. Adaptation to a terrestrial habitat resulted in modifications of the plant body with respect to many features, and the discussion of water relationships is not intended to minimize the importance of the other features.

The leaves of plants typically are flattened structures, which present a maximum surface for the absorption of light energy and the interchange of gases with the environment. These are necessary features for photosynthesis, the process whereby green plant tissue manufactures sugars from the carbon dioxide absorbed from the air and water obtained from the soil. Oxygen also is produced in the process.

A leaf is constructed of a number of specialized cell types. The interior of the leaf is made up largely of the green, or chloroplast-containing cells loosely arranged, with continuous but irregular airspaces between the cells. The airspaces are interconnected and lead to the exterior atmosphere through numerous minute pores—stomates—in the surface of the leaf. Thus, as the green cells take up carbon dioxide, more of this gas enters the leaf by diffusion from the surrounding air, while the oxygen produced by the cell moves out of the leaf by the same process. The cell walls inside the leaf are saturated with water, which evaporates from their surfaces and also diffuses into the surrounding air. Most of the water lost by the plant passes through the stomates as water vapor by transpiration.

The plant has to conserve water, but it cannot completely exclude the surrounding air, with which it must maintain necessary exchanges of gases. Transpiration, however, is restricted by the presence of a waxy covering, or cuticle, on the outer surfaces of leaves and young stems. Comparatively little water is lost through the cuticle. With older, woody stems, whose growth in diameter results in the rupture of the cuticle, water loss is controlled by the development of a layer of cork cells, whose thick, impervious walls restrict loss of water. Small areas of spongy, loosely arranged cells, the lenticels, permit gaseous exchange through the cork layer, or outer bark.

Associated with the stomates are pairs of specialized cells, the guard cells. The pore, or stomate, is the space between a pair of guard cells. If the guard cells are fully turgid, the stomate is open to its fullest extent. As the guard cells lose turgor, they approach each other, closing the stomate. These movements in the guard cells, which control the stomatal opening, are brought about by differential thickness of the cell walls. The walls next to the stomate commonly are thicker than those on the opposite side of the guard cells. An increase in turgor forces out the thinner walls and pulls the two guard cells apart, opening the stomate. If the leaf loses water faster than it can be replaced, the leaf



A diagram which shows the relationships of the parts of a plant that are concerned with absorption, conduction, conservation, and loss of water. A, is an enlarged portion of leaf cut away to show internal structure; B, enlarged segment of stem; C, enlarged segment of young root. Sectors have been removed to expose cells in the interior. GC is a guard cell; S, stomate; CU, cuticle; E, epidermal cell; X, xylem; P, phloem; V, vein; IS, intercellular space; VS, vessel; T, tracheid; PI, pith; RH, root hair.

cells become less turgid, and as the guard cells lose turgor, they begin to close, eventually reducing water loss by the closure of the stomates.

The movement of guard cells is also conditioned by light. Photosynthesis is initiated in the presence of light. That lowers the acidity of the guard cells and favors the conversion of starch into sugar. The increase in sugar, resulting from these processes, increases water absorption from adjacent cells, so that turgor increases and the stomates open. Those processes are reversed in the dark; respiration produces carbon dioxide and sugars are converted into insoluble starch in the chloroplasts. The changes lower the sugar content of the guard cells, they lose water to adjacent cells, and the stomates close.

Because most of the water absorbed by land plants is lost by transpiration, the rate of water uptake must depend largely on the rate of transpiration. The mechanics underlying this relationship are fairly simple. Some of the cells of the leaf are directly in contact with the water-conducting elements of the leaf veins. Others have indirect contact through other cells. When water is lost by transpiration, the turgor of the leaf cells decreases, and they tend to absorb water from the water-conducting tissues with increasing force. Thus the loss of water from the leaf means that more water is pulled into the leaf. That, in turn, causes more water to move along the water-conducting elements from the root cells, thereby increasing the intensity of water absorption by the root cells in contact with the soil moisture. The whole process is therefore a chain reaction, in which the controlling element is the rate of water loss by transpiration.

According to this theory, the water in the xylem elements should be under tension, because of the pull exerted by the leaf cells. That has been demonstrated by cutting into the xylem cells of the stem while the part to be cut is immersed in a dye solution. The flashlike movement of the dye into the cut xylem elements supports the view that the water in these elements is actually under tension when transpiration is rapid. On the other hand, when transpiration is very slow, and soil moisture is adequate, appreciable positive pressures may build up in the xylem elements. Under such conditions, cutting into the xylem results in "bleeding." The volume of water made available to the plants by this process is, however, small when compared with the volumes lost during rapid transpiration.

SINCE TRANSPIRATION is the key process in the utilization of water by plants, the factors governing it are important. Transpiration involves the evaporation of water in the airspaces in the leaf and its diffusion out into the surrounding atmosphere. Within the leaf, the airspaces are nearly saturated with water vapor. Diffusion into the surrounding air, which is primarily through the stomates, is proportional to the difference in concentration of water vapor between the leaf spaces and the air around the leaf. Other factors being equal, therefore, the lower the water vapor content, or relative humidity, of the air, the more rapidly will water be transpired.

As leaves absorb solar radiation, they tend to become warmer than the air, the temperature difference being frequently as much as 5° to 10° F. The amount of water that can be held by saturated air increases as the temperature increases. Warming of the leaf by the sun's rays, therefore, increases the concentration of water vapor in the leaf and favors more rapid water loss.

It is not surprising, therefore, that the rate of transpiration follows a daily cycle that tends to parallel light intensity. By far the greater portion of water is lost during the daylight hours, and the rate of loss is most rapid during the middle of the day.

Transpiration tends to increase the concentration of water vapor in the air around the leaves. That would tend to decrease further loss of water from the plant. Air currents, by blowing away the accumulated water vapor, counteract the tendency.

CONTINUED TRANSPIRATION is possible only if the plant has a continuing supply of available moisture. If the supply becomes depleted or if loss of water exceeds the rate of water uptake, the plant eventually wilts, the stomates close, and transpiration is curtailed. While such control by the plant may prevent or delay serious injury or death, it is not without cost to the plant. Turgor, the distended condition of the plant cells, is necessary for continued plant growth, and a decrease in turgor, or wilting, is reflected in retardation or inhibition of growth.

A severely wilted plant, which has

closed stomates, cannot carry on photosynthesis effectively because the necessary exchange of gases with the surrounding air is impaired. Water is also one of the raw materials in photosynthesis, being the substance which is acted upon in the light to produce hydrogen, the basic reaction in photosynthesis. The amounts of water used in photosynthesis are small compared to those lost, however, and even in a severely wilted plant, the decrease in photosynthesis results from a limited supply of carbon dioxide or injury to the protoplasm as a result of desiccation, rather than deficiency of water as a raw material for photosynthesis.

Although excessive transpiration may injure plants and reduce yields, very little can be done to control it under field conditions because factors such as temperature, light, and wind are difficult to modify.

We can, however, attempt to maintain an adequate water supply for the plant by providing soil conditions that permit the maximum development and activity of the roots. A healthy, active root system and an adequate water supply are the only practical answers to the problem of transpiration.

Although transpiration appears to be an unavoidable evil in the functioning of plants, some effects of transpiration tend to be beneficial. Plants function best in a relatively narrow range of temperature. Excessively high temperatures may be injurious or deadly. Since transpiration cools the plant tissues, especially the leaves, it contributes to the control of temperature. Other physical processes, such as conduction and reradiation of heat, however, are usually more effective than transpiration in cooling leaves.

In higher forms of plantlife, certain functions are restricted largely to specific organs, which are modified to perform the functions most efficiently. The roots absorb water and minerals for the whole plant. The leaves manufacture foods. The stem supports the whole unit in the most favorable position for its component parts. Of primary importance is the movement of materials, originating in or absorbed by a specific organ, to the other plant parts where they are needed.

Water is essential for all transport in plants, as the transported materials move along as solutions. Sugars and other complex compounds move down from the leaves, where they are synthesized, to the stem and roots in the bark tissue, known as phloem. Minerals largely move in the xylem or wood elements, where they are carried upward from the roots to the stem and leaves. Transpiration, by accelerating the movement of the stream of water in the xylem, tends to hasten the transport of materials—but that is of dubious value because the supply of minerals in the leaves is adequate even when the transpiration rate is low.

EVEN THE HIGHLY specialized structures characteristic of plants in humid regions would not be enough to insure growth in the arid or subarid regions. There the native vegetation has undergone further modification to enable its survival. Some species, rather similar to those in the humid areas, are annuals, which complete their life cycle in a brief period and can use to advantage the limited rainfall in certain areas. The profuse blooming of plants in some deserts after spring rains often is due to them. After that burst of life, the plants die, and only the seeds remain to carry on the species in another year.

In plants that survive the year around, profound modifications of the plant body safeguard it against desiccation in the dry months. Leaves are characteristically reduced to scaly or spiny appendages or may be entirely absent. The stem takes over the functions of leaves. This reduction in exposed surface reduces transpiration.

Further reduction in surface may result from an increase in diameter of stems, as in the cylindrical or globular bodies of cacti, whose fleshy stems store large amounts of water. Their cells are rich in mucilages, gums, and other materials that have a high affinity for water.

Other plant forms, such as shrubs and grasses, survive without those obvious modifications in their structure. They may have extensive and well developed root systems and relatively limited top growth. This affords a greater water-absorbing system in relation to the transpiring surface. The shrubs usually have small leaves. In some species a profuse growth of hairs shields the stomates and sometimes reduces evaporation by retarding the loss of vapor from the surface of the plant.

Rows of specialized cells in the upper epidermis of many grasses are sensitive to reduced supply of water. As the cells lose turgor, they cause the entire leaf to roll up and so shield the stomates and reduce a further transpiration. Thicker cuticles may be produced, and frequently stomates are depressed, the guard cells being recessed below the general surface of the leaf.

THE EFFECTIVENESS of the modifications depends on the fact that—in the whole chain of processes governing the movement of water into, through, and out of the plant—the greatest pressures controlling the flow are those that govern the movement of water from the airspaces in the plant into the surrounding air. The pressures governing diffusion of water vapor out of the leaves even in moderately moist air tend to be about 100 times greater than those governing water movement into and through the plant. Effective control of transpiration is most readily obtained by a partial blocking of the pathway along which diffusion into the external atmosphere occurs.

Thus it is apparent that plants have evolved diverse adjustments in response to dry environments. Regardless of the nature of the modifications of structure and function, these plants are generally characterized by limited growth, especially of the aboveground parts. Growth and yields can usually be increased markedly if water is supplied in greater abundance.

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Water and the Micro-organisms

Paul R. Miller and Francis E. Clark

Without water there would be no micro-organisms, those myriad, minute, living forms whose bodies consist largely of water in which other vital materials are combined or dissolved.

Nearly every substance is a substrate, or foundation, on which some one of these microscopic forms may feed and grow. Some of the organisms are beneficial. Others cause a great deal of trouble. Some grow in water, and some in soil. Some live on dead or decaying vegetable or animal matter.

Some—the pathogenic micro-organisms—may invade the tissues of living plants or animals or human beings, in which they cause disease.

We first take up the water require-