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Robert B. Wylie
*University of Iowa*

# PLANTS AND THE SURFACE FILM OF WATER

ROBERT B. WYLIE

The plant's uses of water are many. As a solvent water permits the absorption of raw materials of all kinds taken in by the plant. Within the plant body water performs many functions, some of it even entering into the constitution of the protoplasm itself. In leaving the plant in the form of vapor its evaporation cools the tissues when otherwise they might at times be injured by the radiant energy of the sun to which extensive portions of the plant must be exposed for photosynthesis. The familiar root-shoot type of land vegetation is the form-response of plants to the contrasting conditions of light and dryness on the one hand and darkness with moisture on the other.

Denied for the most part ability to endure dessication the living tissues of higher plants must be kept moist at all times. With their lack of locomotion and limited capacity for water storage seed plants must maintain practically uninterrupted contact with sources of external water during their entire period of active life. While the amount of water needed is less during the rest period, especially if accompanied by leaf fall, excessive water loss even for deciduous trees is usually fatal. Much of our so-called "winter-killing" is due to this cause.

This paper makes brief reference to the relations of plants to contiguous liquid water, with special reference to the physical fact of the surface-film. No account is taken at this time of the presence of water vapor about the plant or within its open spaces though obviously these relations are of the greatest importance. The escape of water from the plant as vapor is, however, from a film covering the most exposed of the plant's noncutinized cells which usually lie adjacent to the intercellular spaces. It need only be remarked in passing that the maintenance of this exposed film of water is one of the most serious of the problems of land plants. The literature relative to transpiration has become one of the most extensive of any branch of experimental botany.

Turning first to the root portion of the plant one notes that its strategy is to maintain uninterrupted contact with a permanent supply of liquid water. For the average land plant this is secured by thrusting absorbing organs deeply into the soil, which organs contribute also to the anchorage of the plant. Absorption is not mainly from the saturated soil, however. Since its spaces both large and small are filled with water to the exclusion of gases, except such as are in solution, the oxygen content is too low to permit favorable root activity.

The roots get their water supply primarily from those volumes of soil with more or less interrupted water content. These zones lie above the region of gravitational water, where there is complete saturation, though it is from the latter region, of course, that their supply is renewed. The moisture of the overlying soil levels is held in both capillary and hygroscopic form. The former fills the smaller soil spaces to such height above the gravitational level as it may be sustained by the surface tension of water. The latter or hygroscopic water occupies the soil adjacent to that filled by capillarity and is characterized by open and gas-filled spaces with films of water about the individual soil particles. Of great importance is the fact that liquid water can be brought up by capillarity and also can move in and through the film of hygroscopic moisture about the soil particles, thus permitting the absorbing areas of the plant to secure water which otherwise would be wholly unavailable. While the plant can not absorb the film itself it may remove water from the film if this is renewable from terrestrial reservoirs within the deeper layers of soil.

Soil texture thus plays an important part since both capillary and hygroscopic water are dependent upon the surface tension for expression. The finer the soil particles the more efficient the surface film and the higher the capillary rise. Similarly the smaller particles afford greater superficial surface and a correspondingly increased amount of hygroscopic water per given volume of soil. Fortunately, increasing fineness of soil texture leads to a complementary development of both the capillary and hygroscopic water upon which the plant is so fully dependent. The surface film, therefore, largely determines the capacity of a given soil for the absorption and retention of water; further, it operates in lifting water upward from the gravitational level in response to the plant's withdrawal of moisture, and thus becomes an efficient agent in the raising of mineral salts as well. In brief the phenomena of soil moisture as related to plants are primarily dependent upon the physical fact of a surface film.

Turning to the aerial portion of the plant the **surface tension** of water here operates as an inhibitor of the transfer of liquid water through cortical openings. While gases, including water vapor, pass freely through the stomatal and lenticel openings in either direction, according to the diffusion pressure of the given gas at the moment, these tiny apertures are barriers to the movement of liquid water into the air-spaces of the plant. The stomatal openings are so small that the surface film bridges across from one cutinized lip to the other when there is gas on one side and liquid water on the other side of the opening. It would require a tremendous pressure to force liquid water through such microscopic openings in non-wettable surfaces. Guttation, or the giving off of liquid water by the uninjured plant, is possible through enlarged openings where the wider span lessens the breaking strength of the surface film. So, while rains and dews moisten the outside of leaves and stems, but little if any liquid water enters through stomata and lenticels. It might be added that the water passing in through cutinized walls, the reverse of cuticular transpiration, is probably slight in amount because the living epidermal cells are already saturated with water. The aerial portions of the plant, therefore, are adapted to exclude liquid water. Doubtless natural selection has operated in keeping the cortical apertures for gaseous exchange to such size as to be safely guarded by the surface film. If liquid water should once completely infiltrate the space system of a leaf, death of tissues would probably soon result from suffocation.

Students of aquatic life have been interested in the evident use of the surface film by organisms in aquaria, or out of doors in lakes and streams. Any who have read Needham's (1) interesting pages in this connection have doubtless wished that he would expand them into a chapter or better still into a volume dealing with this neglected field of aquatic biology. Many plants and animals living in water display evident adaptations to the surface film, using it in various ways to further their movement, support, respiration and reproduction. The nature of the surface film makes it a more important factor in smaller areas than over larger stretches of open water. It is, therefore, in the shallower water, where the stems and flowering spikes of rooted plants retard wave action and give support to the film that it is most potent in the lives of aquatic organisms. Under favorable conditions it exercises a marked influence in building up definite associations of animals and plants, the organization of the group developing progressively as the emergent parts of larger plants break up the open areas and afford favorable conditions for the expression of the film. A common instance of this is the change in shallower bays following the blooming of submerged seed-plants which send up flower stalks and thus break up the open areas of water.

With only passing reference to animals whose use of the surface film is most striking in many ways, it might be of interest to give examples of the more common ways by which the aquatic plants utilize the surface film of water. These involve both habits and structures, some of them highly specialized, suggestive of long association with aquatic conditions.

*Buoyancy.* — Through the formation of bubbles which remain attached to submersed parts, and partly, of course, through volumes of gas imprisoned within their spaces, many plants achieve the lightness necessary to bring them to the surface of the water. Algal clots quickly form such gas bubbles under favorable conditions of temperature and illumination, and the rapid disappearance of such forms with the coming of colder weather is often merely submergence due to lack of these supporting bubbles.

*Salvinia,* one of the smaller aquatic ferns, bears on the dorsal side of its floating leaves a number of strong trichomes some of which are branched. If the plant is submerged the surface film is held out from the epidermis by these plant hairs and a considerable quantity of air is enclosed which adds greatly to the buoyancy; upon release the plant darts to the surface without its upper epidermis having been even touched by the water. The floating leaves of aquatic plants, such as certain species of *Potamogeton,* while lacking trichomes possess a waxy surface which repels water. This operates to keep the surface of the leaf dry, as it instantly drains following emergence. It also favors buoyancy since the leaf will displace more than its volume of water if depressed slightly below the level of the surface. *Potamogeton americanus* has often a marked ridge of water held back by the surface film, along the margins of its leaves, which otherwise would be covered by water to a greater or less degree.

*Support.* — A striking instance of the influence of the surface tension of water is often noted along lake shores where the film frequently carries considerable quantities of dry sand probably for great distances. Animals are frequently seen moving or resting upon the surface film, their weight entirely sustained by its tenacity. Familiar are the water striders whose elongated and outspread appendages distribute their weight over a considerable portion of the film and enable them to walk on the water. The writer knows of no plant in vegetative condition which rests entirely upon the film without any pendant parts in contact with the liquid water beneath. But pollen grains of various water plants and dry seeds, especially those possessing pappus of the right consistency, are often supported by the film.

The detached staminate flowers of *Vallisneria spiralis,* noted below, are entirely above the film and of course adherent to it, in which situation they are freely moved along by currents of air.

*Anchorage.* — Reference is here made to those tiny organisms which live entirely submerged but are anchored to the film along its under side. The observed instances of this habit are usually limited to smaller enclosed areas of water where the film is proportionately stronger. A great many animals enjoy this relation fastening themselves to the film and moving with it or actually swimming about still adherent to this surface layer. Plants seldom achieve this position, partly because of their size and also because of their lesser motility. The most common examples are sporelings of various algae which grow for a time attached to the under side of the film, having gained this position through the earlier anchorage of motile zoöspores which are sensitive to contact. With larger growth these plants soon become free in the water.

*Equilibrium.* — A great many floating plants of smaller size are kept in position largely through the assistance of the film. Familiar examples are seen in *Ricciocarpus natans, Lemna, Sprirodela, Azolla,* and *Salvinia.* The under sides of these plants are noncutinized and are freely wetted by the water. Any attempt to invert them, or to lift them from the water, results in pulling up a fold of the surface film which encloses and raises a considerable volume of water. Both the elasticity of the film and the weight of the displaced water operate to pull the plant back to its original position. This force is considerably aided by the submerged ventral organs possessed by many of these forms. Structures such as the scales of *Ricciocarpus,* the roots of *Lemna* and the submerged leaves of *Salvinia* engage the surface film as the plant is lifted or partly over-turned, and aid backward pull of the film by giving it favorable anchorage.

*Respiration.* — Multitudes of small aquatic animals, such as rotifers and copepods, are favored in their respiration by climbing up the stems of submerged plants and raising the film above them. This position favors the intake of oxygen and perhaps gives greater safety from attack. Many larvae fasten themselves to the film and breathe through organs that reach through it to the outer air. Water plants do not so conspicuously employ the film for respiration probably because of their fixed position. The adhering bubbles of oxygen, released from submerged plants during the hours of sunshine, might be partly resorbed during the succeeding period of darkness.

Capillary water is often drawn up into clots of filamentous algae that emerge from the water. One often finds mats of *Vaucheria, Cladophora,* or *Enteromorpha* well above the water level about them, a position favorable to gaseous exchange.

*Reproduction.* — A number of the submerged seed plants employ the surface film in their pollination, and it is probable that a careful study would show its use to be more common than has been appreciated. Field observations suggest that *Myriophyllum spicatum* and various species of *Potamogeton* probably are pollinated largely by microspores floating upon the water. With wave action the film is made to rise and fall around the emergent spikes of flowers offering pollen to all adhering surfaces.

The writer (2) called attention some time ago to the influence of this factor in the pollination of *Elodea canadensis.* In this species the elongated pistillate flower opens upon reaching the surface and its weight resting upon the recurved stigmas and sepals, which are not wetted by the water, produces a slight depression of the film. Floating pollen grains, moved by air currents, may fall into these depressions and make contact with the stigmas. It can readily be proved that the pollen grains of this species are really heavier than water. Their buoyancy is due to multitudes of tiny blunted spines which cover the exine; these hold back the film and include sufficient air to keep the spores afloat. If the film is broken the pollen grains sink at once to the bottom.

Perhaps the most remarkable plant in the degree of adaptation of its flowers to the surface film is *Vallisneria spiralis,* the "Wild Celery" of our lakes and slow moving streams. In this plant both of the dioecious flowers employ the film in order to bring about pollination (3). When the long stalked pistillate flower opens at the surface it produces a distinct depression in the film as in the case of *Elodea,* but in this instance the cup is much larger and deeper. The staminate flowers, after detachment from the flowering axis at the bottom of the water, rise slowly as tiny ovals to the surface. As they open floating on the water there is first thrust out the smaller sepal which fastens to the film and orients the flower permitting the pair of larger sepals to spread out with their convex surfaces downward. These sepals now anchor the flower to the film so completely that they may be picked up by thrusting a pencil into the water and slowly withdrawing it, thus bringing up the film on its sides with great numbers of the flowers fastened firmly to it. However, these tiny flowers, each with its pollinium held aloft, are blown lightly along by the winds, riding the waves with ease and rarely meeting disaster by overturning. They bank like snowdrifts along the leeward side of open waters where plants are abundant. Any accidentally reaching the depression about a pistillate flower drop into the cup, and the earlier arrivals thus come to lie with their pollinia against the coiled stigmas. Further depression of the seed-bearing flower, resulting from a passing wave or tension of the scape, deepens the cup, causing the flowers to tip still more sharply inward. If it is carried much further the film yields laterally, shutting some of the now completely overturned staminate flowers tightly against the receptive stigmas, in which relation the flower group, locked in the bubble of air, is slowly drawn downward as the scape coils. It should be noted that the whole plan of pollination is related to the surface film and that only through its assistance could the transfer of pollen be accomplished. Such highly specialized relations suggest an age-long association with liquid water; back of that lies the still longer period as a land plant necessary for the attainment of the seed-habit.

DEPARTMENT OF BOTANY,
UNIVERSITY OF IOWA.

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