

Water Movement In Trees

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A tree allocates life-energy to survive and thrive in an environment which never has optimal resources. What essential resources are available are usually present in too low, too high, or unavailable concentrations. Trees continue to react to environmental changes with internal adjustments selected for efficient use of tree food while minimizing energy loss to the environment.

The more limiting essential resources are, or the larger energy costs are for a tree for any circumstance, the greater the stress. Trees only have a limited set of responses to any stressful situation as recorded in their genetic material. Trees can only react to stress in genetically pre-set ways. The eventual result of site limitations and stress will be death, but effective management, damage control, and minimizing stress can provide for long tree life.

Essential Water

Of all the resource components of stress impacting tree survival and growth, water stress is the most prevalent. Water is the single most important substance for tree life, comprising 80% of tree substance. All the life processes of a tree take place in water — food making, food transport, food storage, food use, and defense. Water is a reagent in chemical reactions, a chemical bath for other reactions, a transporter, a hydraulic pressure liquid, a coating, buffer, and binder. Water is a universal liquid workbench, chemical scaffold, and biological facilitator.

Water is essential for tree life. As such, it is aggressively gathered, carefully guarded, and allowed to slowly escape in exchange for work energy. The largest single use of water in a tree is for transport of essential materials from roots to leaves. This transport is called the “transpiration stream” and occurs in columns of dead xylem cells within the last few annual rings of the tree. Living cells surrounding this xylem lift system assist with monitoring the water stream. Clearly, water is critical to this basic process.

Pulling Bonds

Because of water’s chemical properties, and their modification when materials are dissolved or suspended, water sticks together and adheres to various surfaces. Water has an affinity for sticking closely to other water molecules. This property is why drops of water placed on a wax (hydrophobic) surface bead-up rather than flattening out and covering the surface. In this case, water would rather stick



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to other water molecules than to the wax surface. Using your finger, you can “pull” water droplets over the waxy surface and consolidate them into larger drops.

Trees utilize water’s special chemical features in many ways, most noticeably in transporting materials into the root and then on to the leaf. Water is pulled in long chains into the root, up through narrow xylem columns or channels, and to the leaf surface where it evaporates into the perpetually dry air. Water evaporates as bonds between molecules are broken by energy concentrated at the liquid water surface.

Sticky Water

As one water molecule is exposed at the wet surface, it is still bound to surrounding water molecules. Because of the temperature (sensible heat or energy) and humidity in the atmosphere, surface water molecules are pulled away from the liquid surface. This pull breaks water connections to other molecules, and at the same time pulls these once-connected neighboring molecules onto the surface. These water molecules, in turn, evaporate into the air generating an evaporative “pull” at the water surface and down through the water column to the roots and into the soil.

One way to consider water in the tree is as a tightly connected stream moving from the soil pores and surfaces, into the root, up the stem, out to the leaf surface and into the air. The water is a continuous line all held together by water’s affinity for sticking to other water molecules. This “stickiness” allows water to be pulled to the top of the tallest of trees against gravity, conduit resistance, and complex pathways.

The faster the evaporation from leaf surfaces, the more energy is exerted to pull the water to the leaf. Too much exertion, and the continuous line of water filled with billions of molecular bonds, is pulled apart. Water column breakage can be catastrophic for the tree because once broken, transport stops. Too much resistance in the soil or too rapid (high energy) evaporation at the leaf, can quickly snap ascending water columns.

Sensing Stress

As water moves from the soil through the roots and into the leaves, it carries with it essential elements, nutrients, and chemical messages. As water and elements move from root to shoot, growth regulators are added by the roots and by neighboring cells along the water columns. Through this chemical communication link, the shoots of the tree can react to the status of the roots. The shoots can then produce their own growth regulator and ship it along living cells to the farthest root tip. The shoots of a tree continually update growth processes in response to root functions, and the tree roots continually modify life processes in response to shoot functions.

In addition to growth regulation signals providing environmental supply and demand information in the tree, leaves have an additional sensor. Leaves are the center of the evaporative load on water columns throughout the tree. Leaves can close or open leaf valves (stomates) for taking in carbon-dioxide gas required in photosynthesis to make food. When the stomates are open, carbon-dioxide can move into the leaf, but water rapidly evaporates and escapes the leaf. For average conditions in a yard tree, 5-10 water molecules evaporate from the leaf for every 1 carbon-dioxide captured. As water availability declines, leaves sense and respond by closing down stomates and photosynthetic processes.

Getting Physical

Water loss in trees is primarily a physical process. There are few points of biological control that override the physical process of water movement. The soil, soil/root interactions, vascular system, and leaf all provide resistance to water movement. Increased resistance to water movement makes water less

available at the leaf. Water movement resistance is based upon the surfaces and structure which water must move through, not biological life functions. The engine that powers water movement in trees is the dryness of the air and the rate of evaporation through the stomates. Anything that effects atmospheric demand for water, and stomate loss rates and control, would affect water movement in the tree.

Water movement and evaporation is a function of temperature and energy in the environment. The evaporative pull from the leaf surfaces move water from around soil particles and into the root. Water is not moved by “pumping,” “suction,” or “capillary action.” Water in trees move by sticking together and being dragged to the leaf surface where evaporation from the stomate (transpiration) generates a “pulling” force on the water columns. Water also evaporates from all tree surfaces – buds, bark, lenticels, fruit, etc. – but the leaves have the only major tree-controlled system for modifying water loss.

Increasing Tension

As water is pulled up to the tree tops and the resistance to soil-water movement increases (uptake slows), a tension or negative pressure develops in the water columns. Water continues to move in the tree from the relatively low tension, easily moved soil water, to the high tension, rapidly evaporating leaf water. As leaf loss continues to exceed root uptake, more tension develops in the water columns. The greater the water tension in the leaf, the less efficient and damaged the photosynthetic support system becomes. As evaporative forces become too great and water tensions too large, leaves will close-down their stomates to prevent damage and conserve water.

The tension in the water columns, even after leaves have closed stomates and are no longer actively evaporating water, still provides energy to pull water into the root and up the stem. When water tensions are reduced enough by roots catching-up to leaf water loss, the stomates may reopen. Water columns can be simply compared to extended rubber bands that are pulled on as leaf evaporation exceeds root uptake of water. The potential energy from the extended rubber band can pull together items, just like a water column under tension can continue to pull in more water after the stomates are closed.

Taking A Break

The consequences of water movement in trees produce two interesting results: siestas and night refilling. During bright, sunny, hot days when the sun is high enough from the horizon to cause the stomates to open, transpiration increases until it out-runs the root’s ability to keep-up. As water column tension increases, a point is reached by mid-day when the tree closes many stomates on many leaves for several hours. The water column tension continues to pull in water from the soil and as tension values decline, stomates begin to reopen. Trees take siestas in the middle of the day to minimize water loss and improve resource efficiency.

As the sun nears the horizon and night approaches, stomates are closed in trees. Water tensions still remain high from the day. Water column tensions continue to pull-in water from the soil over night. Just before dawn, the tree is as rehydrated (water filled) as it will be that day – without rain or irrigation. Trees refill at night.

Stomates

Trees act as conduits through which soil water passes into the atmosphere. Instead of water evaporating at the soil surface using sunlight energy, the tree provides an elevated surface for water evaporation and energy impact. At the junction between tree and atmosphere is the ideal place to position a biological control valve — the stomate. Across the entire water column system, the leaf stomate is the only place actively controlled by the tree to manage water movement.

Stomates are hydraulic valves, usually active only on leaf undersides. By definition, a stomate is the hole in a leaf epidermis initiated by pressure difference between two surrounding guard cells. Generically, stomates are the valve system components taken all together. Some stomates are protected with clumps of trichomes (tree hairs), some are surrounded with layers or deposits of wax, and some are imbedded deep into the leaf away from the surface. Stomates are positioned and designed to take-in carbon-dioxide for food production and minimize water loss at the same time.

Dry Air

When surrounding cells (guard cells) are pumped-up with water, an open gap appears between. The gap produced allows access to the internal portions of the leaf not protected by a cuticle or dead cells. Carbon-dioxide can dissolve into the water-saturated walls and be used in food making. Water from the saturated walls evaporates quickly and escapes from the stomate. The physiological health of the guard cells including supplies of sugars, starch, potassium, and water all influence the opening of the stomate. As water contents decline in a leaf, stomates can not be opened.

The evaporative force to move water through a tree is generated by the dryness of the air. The ability of the air to evaporate water depends upon the water content gradient between the air and leaf surface. At 98% relative humidity (moist!) in the air at 70°F, the air is still 100 times dryer than the inside of the leaf. Trees are always losing water. Only in fog, which is 100% relative humidity, would water not evaporate from the leaf. In addition, temperature provides energy for evaporation. For every 18°F increase in temperature, almost twice the amount of water evaporates from the tree.

Speed

Water movement through a tree is controlled by the tug-of-war between the water availability and movement in the soil versus the water loss from the leaves. The normal seasonal rate of water movement to the top of some trees can be rapid. For example, water movement in feet per hour in ring porous trees are: red oak = 92, ash = 85, hickory = 62, elm = 20; -- in diffuse porous trees: black walnut = 13, willow = 10, yellow poplar = 9, maple = 8, magnolia = 7, beech = 4; -- and, in conifers: pine = 6, hemlock = 3.

Conclusions

Water movement and control in trees can be summarized as a physical process of evaporation – controlled by temperature and humidity – being utilized to move essential materials from root to shoot. This process is partially biologically controlled by opening and closing leaf valves called stomates. Water is the most critical of the site resources trees must gather and control. Stomates help conserve water while allowing for food production. Stomates help convert atmospheric evaporative pull in a supply highway of the tree.
