Optimizing the Water Relations of Cuttings During Propagation©

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SO, HOW DO CUTTINGS GAIN AND LOSE WATER?

It is important to remember that water is the universal solvent. It brings minerals from the roots for biosynthesis within the leaf. About 1%-2% of water utilized is needed for photosynthesis and plant growth, while the remaining 98% of water is lost to transpiration and the subsequent cooling of leaves. Evaporative cooling occurs during transpiration as water passes from a liquid to gaseous phase (vapor). Transpiration is the "engine" that pulls (lifts) water up from the roots. Unlike people, who can move and find a more comfortable location, a plant lacks mobility, so it needs to do its best to reduce the heat load, which it does through transpiration. There is tremendous pressure (tension) that occurs in the top of a 100 m (300 ft) redwood tree *(Sequoia)* in the movement of water from the roots into the tops of these tall trees. The pressure in the xylem (part of the plumbing system of the plant) can exceed 250 psi, which is some 18 times greater than atmospheric pressure. The lifting of water occurs through transpiration and the process of cohesion with the hydrogen bonding of water molecules. This gives a column of water tremendous tinsel strength, i.e., as strong as metal.

ENVIRONMENTAL FACTORS AFFECTING TRANSPIRATION

There are three environmental factors that effect transpiration: light, temperature, and humidity.

Light causes plants to transpire more rapidly, stimulates the opening of the stomata (Fig. 1) and warms the leaf. Temperature increases transpiration since water evaporates more quickly. A 20 "F (10 "C) increase in temperature will cause a 3-fold increase in transpiration. Humidity affects the diffusion of water as a vapor from the leaf through the stomata into the surrounding drier air. Water travels from a high potential (saturated internal leaf cavities) to a lower potential (unsaturated, drier) surrounding air outside the leaf (Fig. 1).

VAPOR PRESSURE DEFICIT (VPD)

Vapor pressure is determined by temperature and relative humidity (RH). The vapor pressure deficit (VPD) is the gradient measured as difference between the

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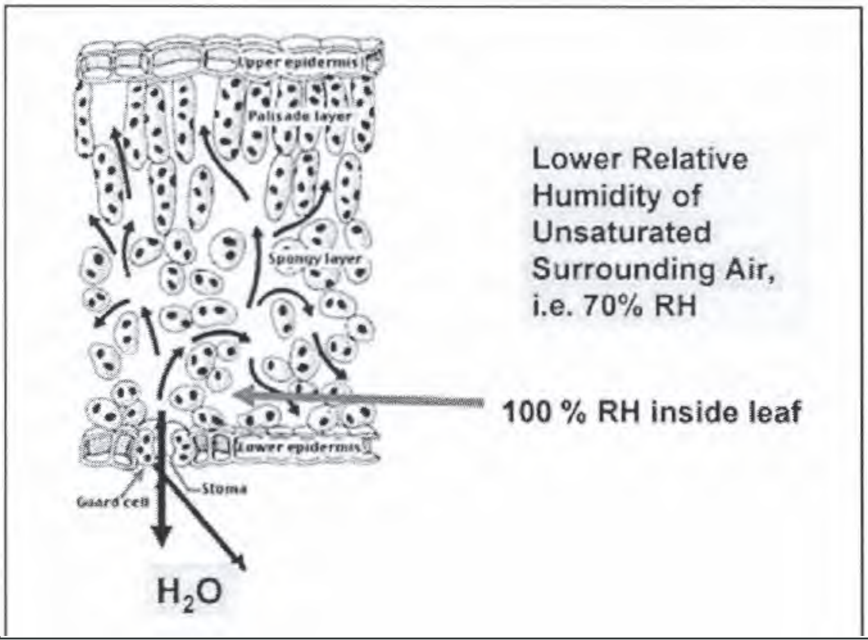

Figure 1. Water vapor travels from the saturated leaf cavity to surrounding unsaturated air.

water vapor pressure in leaves (V_{im}) and surrounding air (V_{air}). At 85 °F (29 °C) the air inside the leaf is saturated at 100% RH and has a vapor pressure of 0.60 psi. If the drier air surrounding the leaf has 75% RH, then its vapor pressure is 0.45 psi. Hence, the VPD is 0.60 psi — 0.45 psi = 0.15 psi. The goal in controlling the water relations of cuttings is to reduce the VPD (Hartmann, et al, 2002; Loach, 1988).

WATER RELATIONS OF CUTTINGS

The water relations of cuttings is a balance between transpirational losses and the uptake of water. Water travels from the soil (propagation medium) through the roots into the stems and into the leaves where photosynthesis and transpiration occurs. Cells must maintain adequate turgor for growth and for initiation and development of adventitious roots. Root meristematic areas also produce a phytohormone, abscisic acid (ABA), which is a chemical signal for drought. As the surrounding soil (medium) dries, ABA travels through the xylem from the roots to leaves and causes the guard cells to collapse, which closes the stomata and helps to regulate the loss of water.

THE PROBLEM

Since cuttings initially do not have roots, they can't produce ABA to control water loss and lack effective organs to replace transpired water lost. Cuttings take up water poorly through the base of the stem — until adventitious roots are formed. The cutting base and any foliage immersed in the propagation medium are main entry points of water until adventitious roots form (Loach, 1988).

Water absorption through leaves is not a major source/contributor of water balance. Water uptake in cuttings and tissue relative water content (RWC) [helps de-

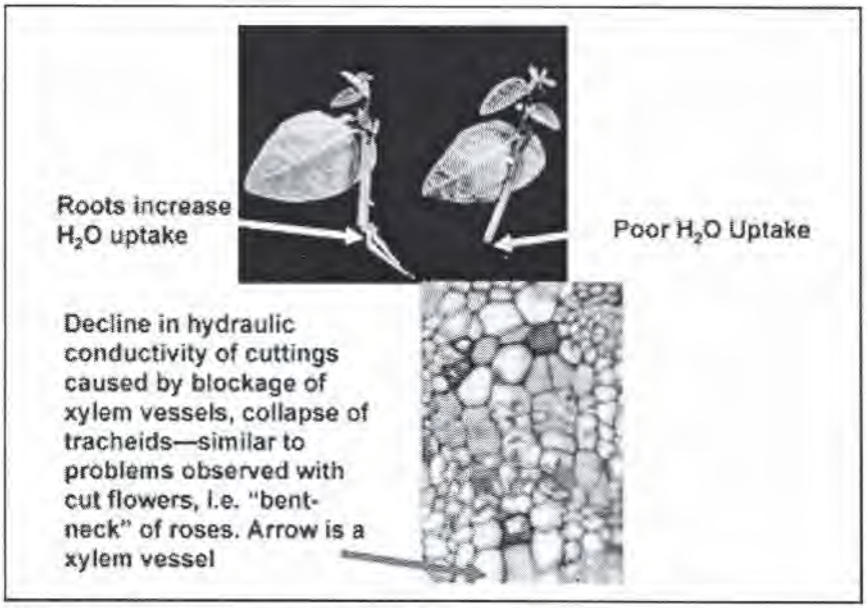

Figure 2. New adventitious roots increase water uptake.

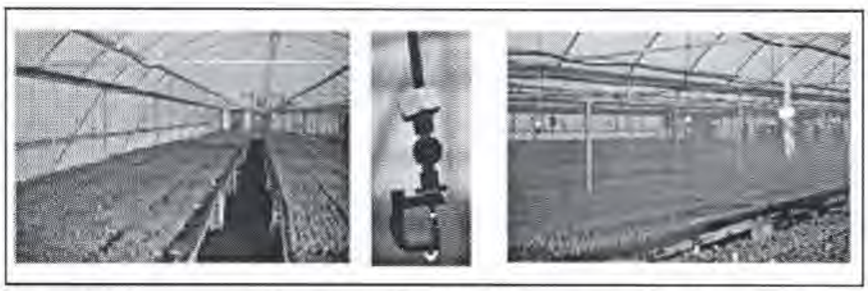

Figure 3. Intermittent mist forms water droplets with an average size > 50 µm and a range of 50 to 100 µm. Water from mist condenses and forms a film of water on leaf surface. Water evaporates from the leaf surface rather than from internal water in the tissue.

termine actual water in tissue] declines after cuttings are initially inserted into the propagation medium. There can also be a decline in hydraulic conductivity of cuttings caused by blockage of the xylem vessels and a collapse of tracheids (part of the plumbing system of the plant). This is similar to blockage problems that occur in cut flowers, i.e., "bent-neck" of roses (Fig. 2).

It is important to maintain hydraulic contact between the cutting base and propagation media — thus improving water uptake of cuttings. Wounding increases the contact area between cutting base and propagation medium for more optimum water uptake of cuttings.

CONTROL OF WATER LOSS IN CUTTINGS

Intermittent mist is the most common system for propagating cuttings (Fig. 3). Mist is composed of water droplets that average >50 and have a size range of 50

Figure 4. Fog systems form fine water droplets with an average size of 15 Fog has a high surface: volume ratio, which helps water remain suspended in air as a vapor (gas) to maximize evaporation. Fog does not condense, avoids over-saturation of media and foliar leaching, which occurs with mist.

to 100 µm. The mist condenses and forms a film of water on the leaf surface. Water evaporates from the leaf surface rather than from internal water in leaf tissue.

Mist decreases V_{leaf} by reducing leaf temperature and causes a modest increase in V_{air}, by increasing the RH. Mist lowers the leaf to air VPD or vapor pressure gradient and slows down transpiration of the cutting leaf surface.

There are some inherent problems with intermittent mist. Mist rapidly leaches cuttings of nutrients such as nitrogen, phosphorus, potassium, and magnesium, with losses as high as 60% or more within the first week (Hartmann et al., 2002). Water condenses from mist, which can saturate the propagation medium, reducing aeration and creating an anaerobic condition that can lead to poor rooting and death of cuttings. The evaporative cooling of mist can also lead to suboptimal propagation medium temperatures, which is why bottom heat is sometimes used in indoor and outdoor mist propagation systems.

FOG SYSTEMS

Fog produces fine water droplets that average around 15 pm (Fig. 4). Fog has a high surface to volume ratio that allows it to remain suspended in air as a vapor (gas) to maximize evaporation. Fog does not condense, which avoids the over-saturation of medium and foliar leaching that occurs with mist.

Fog maximizes the V_{air} by increasing the RH of the surrounding air. Fog also decreases V_{leaf} by decreasing leaf and air temperature. It lowers the leaf to air VPD and slows down transpiration.

Figure 5. Contact systems and nonmisted enclosures reduce water loss from foliage. Condensation increases the relative humidity of the air. They are simple, inexpensive and cost-effective. Minimal condensing occurs and over-saturation of media and foliar saturation of media and leaching is avoided, which occurs with mist. Temperature control is critical.

Problems with fog systems include high costs and high maintenance requirements — including clogging and wearing out of nozzles. Filtration/deionizing systems are required to remove any salts from the water supply.

CONTACT SYSTEMS/NONMISTED ENCLOSURES

Contact systems and nonmisted enclosures reduce water loss from foliage, and the condensation increases the relative humidity of the air (Fig. 5). These systems are simple, inexpensive, and cost-effective. There is minimal condensing, which avoids the over-saturation of media and foliar leaching that occurs with mist. This system works well with hardwood and semihardwood cuttings of difficult-to-root species that require longer propagation times.

Contact systems/nonmisted enclosures maximize V_{air} by preventing the escape of water vapor. The system predominately uses humidification since only V_{air} is affected. The V_{lea}f is somewhat affected, particularly when the leaf temperature is cooler with the condensation that occurs in the contact poly system. It lowers the leaf to air VPD and slows down transpiration. While inherently cheaper, there are problems with contact systems/nonmisted enclosures. It is critical to control irradiance and subsequent heat load via shade and temperature control. The system easily traps heat via light irradiance, which can adversely increase the VPD by reducing RH of air and increasing the air and leaf temperature.

STATIC MIST CONTROL SYSTEMS

Static mist systems are the most common way of controlling mist. They are relatively inexpensive, easily installed, and rely on clocks and timers (Fig. 6). However, they are unable to automatically respond to daily fluctuations in light irradiance, cloud cover, RH, temperature, or stage of root development. Under moderate conditions they reduce evaporative demand by reducing VPD. However under cloudy days when solar radiation is low, too much mist is applied. Conversely, on very sunny, windy days when net radiation is high, too little mist is applied.

Figure 6. Static mist control systems rely on clocks and timers. They are unable to automatically respond to daily fluctuations in light irradiance, cloud cover, relative humidity, temperature, or stage of root development.

Figure 7. Dynamic mist control systems respond to changes in the environment affecting vapor pressure deficit. Evapotranspiration-based mist control systems (dynamic control) can respond to changes in air temperature, time interval between misting and calculated vapor pressure deficits between the leaf and surrounding air.

DYNAMIC MIST CONTROL SYSTEMS

Dynamic mist control systems respond to changes in the environment affecting VPD (Fig. 7). There are evapotranspiration-based mist control systems of dynamic control, which are based on air temperature, the time interval between misting, and calculated VPD al.r(Hartmann et al., 2002; Wilkerson et al., 2005). These systems can also be regulated by net solar radiation and relative humidity. They are much more responsive to the changing environmental conditions.

IDEAL PROPAGATION MEDIUM

The ideal propagation medium has an air filled porosity of 15%-40%, with 20%-25% considered to be optimal. The ideal water holding capacity (WHC) has a range of 20%-60%, after gravitational drainage. Nonetheless there is no one universal commercial propagation medium. It is important to have good water drainage for sufficient aeration and sufficient WHC to maintain adequate hydraulic contact between the cutting base and propagation medium.

Figure 8. It is important to maintain the plant's momentum by collecting during optimum seasonal rooting and early in the day before plants become stressed. Storage under low light, high RH and cooler temperatures helps to alleviate vapor pressure deficit.

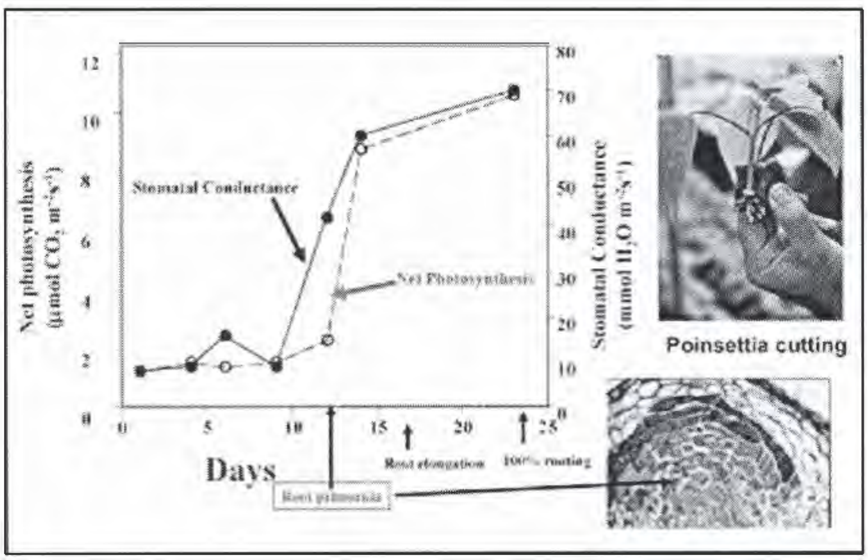

Figure 9. Keep light levels low until cuttings start to show visible roots (Svenson et al., 1995).

STOCK PLANT MAINTENANCE AND MAINTAINING THE PLANT'S MOMENTUM

It is important to maintain stock plants that are nutritionally fit and under optimal irrigation regimes. It is also important to maintain the plant's momentum by harvesting cuttings during the season of the year when maximum rooting occurs, to reduce the propagation time under mist.

Cuttings should also be collected early in the day when plant water status is optimum to minimize any stress to the cuttings, i.e., low VPD (Fig. 8). Storage under low light., high RH, and cooler temperatures helps to control VPD.

During the initial week or two of cutting propagation, it is not necessary to maintain high light conditions under mist. In a study with poinsettia, relative water content, xylem water potential, net photosynthesis, and stomatal conductance were initially low with u Prooted cuttings (Svenson, et al., 1995). Only when cuttings started to form root primordia and adventitious roots first became visible did stomatal conductance and net photosynthesis start to increase (Fig. 9). The take home message is that prior to visible roots — keep light levels low to reduce VPD. When roots start to form, increase the light. so plants can take advantage of higher photosynthetic rates to improve root development and production of rooted liners.

SUMMARY OF OPTIMIZING WATER RELATIONS OF CUTTINGS

- Maintain the plant's momentum by propagating during optimum rooting periods, collecting cuttings early in the day and minimizing plant stress.
- Control stress — light, temperature, and humidity (RH) — to reduce VPD, i.e., an atmosphere of low evaporative demand decreases transpirational losses from cuttings.
- Don't increase light until cuttings start to form adventitious roots.
- Apply just enough mist to form a thin film of water on leaf surface.
- Use a loose propagation medium for proper aeration.
- Group cuttings in propagation by species requirement for moisture, i.e., zelkova and Chinese elm have a lower tolerance for mist and saturated propagation medium than river birch (Johnson, 2004).

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