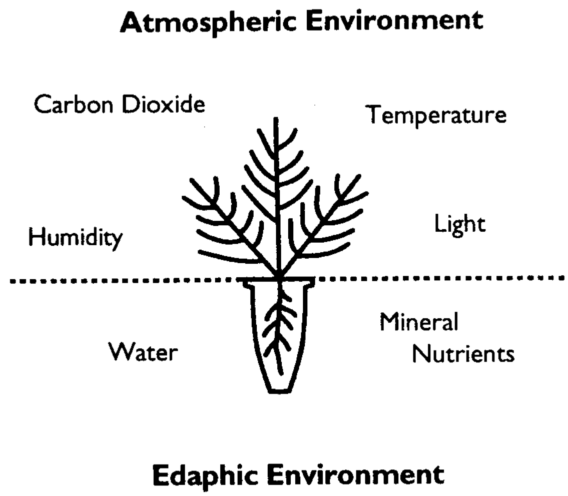

Figure A. Factors limiting seedling growth.

Limiting Factors--Water

As we have been discussing in past issues of FNN, plants need six different "limiting" factors for good growth. Four are found in the ambient environment (light, temperature, humidity, and carbon dioxide) and two (mineral nutrients and water) are supplied from the soil or growing medium *(Figure A).* We have covered everything except water and so, in this issue, we will take a look at how seedlings use water and how growers supply it to their crops.

Water is one of the most important growth-limiting factors in natural terrestrial ecosystems.

The ecological importance of water is matched by its physiological importance because almost every process in plants is directly or indirectly affected by water:

1. Water is a major constituent of plants, composing 80-90 % of fresh weight.

2. Water is the "universal solvent", and the medium for mineral nutrient transport within the plant.

3. Water is a biochemical reactant in many critical physiological processes, including photosynthesis *(Figure B).*

4. Water is essential for maintaining turgidity in plant cells, promoting cell expansion and seedling growth.

Biophysics of water in containers

The best way to describe seedling water status is in terms of water potential because the basic principles and units remain the same throughout the nursery system. Water is drawn along a water potential gradient that is driven by

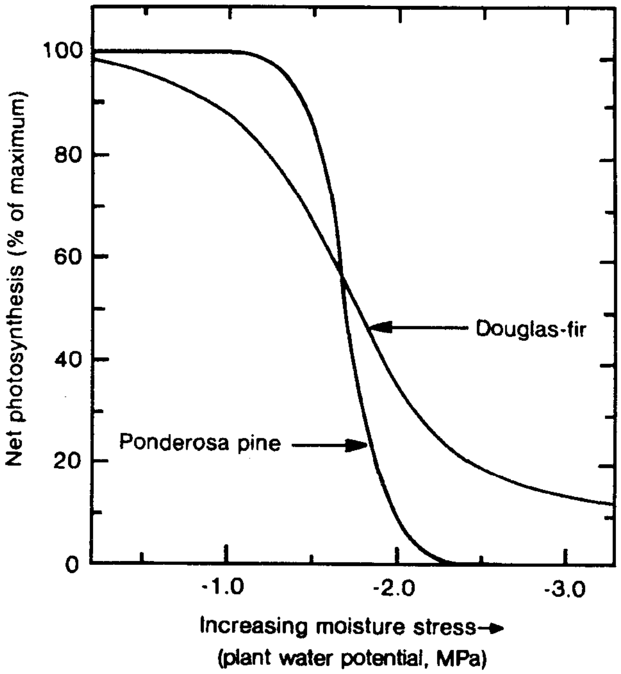

Figure B. Increasing moisture stress, as measured by more negative plant water potential, reduces photosynthesis of tree seedlings at different rates, depending on species characteristics.

evapotranspirational losses: from higher levels in the growing medium, through the seedling, and into the lower levels in the atmosphere.

Growing medium water potential is composed of two parts. The matric potential represents the energy with which water is held in the pores of the growing medium. The porosity of the growing medium affects water availability because seedlings are able to extract water easier from larger pores than from smaller ones. Water in containers behaves very differently than in an unconfined soil. Because of the air beneath a container, a layer of saturated growing medium always exists at the bottom *(Figure C).* Although the actual thickness of the layer is determined by the type of growing medium, the relative depth of this saturated layer is always greater in shorter containers.

The osmotic potential is the second component of the growing medium water potential and reflects the influence of dissolved salts, including fertilizers. The osmotic potential of the growing medium solution increases as the soil water content decreases due to evapotranspiration - a reduction of 50% water content will approximately double the salinity. Heavy fertilization produces a significant osmotic potential, which increases as the medium dries out. When the osmotic potential becomes significant, fertilizer "burn" results.

Seedling Water Relations

Plant water potential (PWP) also contains two components: osmotic potential and pressure potential, which change in relationship to one another as the seedling loses water from turgidity to the wilting point. PWP changes in a typical daily pattern, the absolute value of which depend on soil moisture levels and atmospheric demand. Nursery managers and foresters are more familiar with the term plant moisture stress (PMS). The two terms are identical in absolute value; PWP is always expressed in negative terms, whereas PMS is always a positive number (see Monitoring Seedling Water Use section for sample readings).

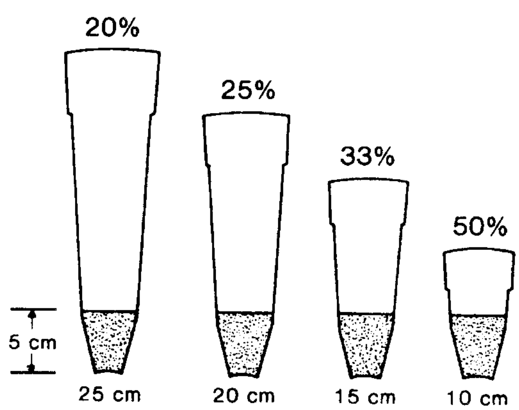

Figure C. The depth of the saturated growing medium layer at the bottom of the container is proportionately greater in shorter containers, given the same type of growin medium.

Water Quality

The definition of water quality is determined by its intended use. Water that would be entirely suitable for domestic or industrial purposes can be severely damaging to plants. For nursery purposes, irrigation water quality is determined by two factors: suspended sediments or pests, and dissolved salts.

Suspended sediments - Inorganic materials such as clay, silt, and even very fine sand particles are small enough to remain suspended in irrigation water. Suspended sediments are abrasive and can quickly wear out water pumps, fertilizer injectors, and sprinklers. The source of the irrigation water determines what types of suspended materials it may contain. Municipal water usually has been filtered to remove particulate matter, although this should be checked. Surface water often contains suspended silt or clay particles, especially after a heavy rain, and depending on the characteristics of the aquifer and type of casing, even well water may contain sand. Organic sediments can be harmless but pests, such as weed seeds and fungal or algal spores, are also be suspended in water. Water from surface sources, especially ponds in agricultural areas, can contain propagules of potential nursery pests, which include weed seeds and spores of fungi, algae, mosses, and liverworts.

Specially-designed filters can remove the larger waterborne pests including weed seeds, algae, and some fungal spores, but the cost of the filters increases as the minimum pore size decreases. Domestic water sources are normally well-filtered and so these pests should not be a problem. Chlorination is the traditional way to eliminate pathogenic fungi, bacteria, algae, and liverworts in irrigation water.

Dissolved salts - Many different mineral ions can be dissolved in potential irrigation water, but even perfectly clear water can contain harmful salts. In coastal areas, potential nursery sites can have

Table 1 - Salinity standards for forest nurseries

Water Quality Index	*Do Not Exceed Limit**	
Salinity (Electrical Conductivity)	1500 uS/cm (umhos/cm)	
Toxic Ions		
Sodium (Na^+)	50 ppm	2.2 meq
Chloride (Cl^-)	70 ppm	2.0 meq
Boron (B)	0.75 ppm	N/A
Accessory Ions		
Calcium (Ca^{2+})	100 ppm	5.0 meq
Magnesium (Mg^{2+})	50 ppm	4.3 meq
Sulfate (SO_4^{2-})	250 ppm	5.2 meq
Foliar Staining Ions		
Bicarbonate (HCO_3^-)	60 ppm	1.0 meq
Total Hardness (Ca+Mg)	206 ppm	----------

* = These values assume a porous and free draining growing medium. Water with much lower salt concentrations can cause serious problems if poor drainage or irrigation practices allow salts to accumulate. 1 part per million (ppm) = 1 milligram per liter (mg/l): the conversion between milliequivalents (meq) and ppm varies with the atomic weight and electrical charge of the ion. Boron has several different ionic forms in irrigation water and therefore a specific conversion cannot be made.

groundwater that is contaminated by saltwater intrusion. Some salt ions, such as the calcium and magnesium that are found in "hard" water, can be either troublesome or beneficial depending on their concentrations. Moderate levels of calcium and magnesium can be beneficial because they are plant nutrients and are often difficult to formulate into liquid fertilizer solutions. Higher concentrations cause deposits ("scale") on irrigation nozzles and other surfaces. Other ions, especially boron, can be toxic to tree crops at concentrations of less than 1 part per million *(Table 1).*

Types of Irrigation Systems

Although several types of irrigation are used for other nursery crops, sprinkler irrigation is still the norm for the propagation of both bareroot and container stock in forest and conservation nurseries. A typical sprinkler irrigation system consists of a pump, pressure tank, pipes, and sprinkler heads. Fixed rotary sprinklers are standard in bareroot nurseries and are laid out on a grid with the irrigation lines running along the paths between the seedbeds. In container nurseries, either fixed sprinklers or mobile booms are commonly used.

Uniform water application in a fixed sprinkler irrigation system is determined by five factors:

1. nozzle design and function
2. size of the orifice
3. water pressure at the nozzle
4. spacing and pattern of the heads
5. wind direction and speed.

Because of the centrifugal force caused by the rotary motion, all fixed sprinkler irrigation systems create water distribution patterns resembling a "doughnut" *(Figure D).* Engineers design irrigation systems to compensate for this inherent defect by insuring that nozzles have enough overlap. Irrigation uniformity is measured as the

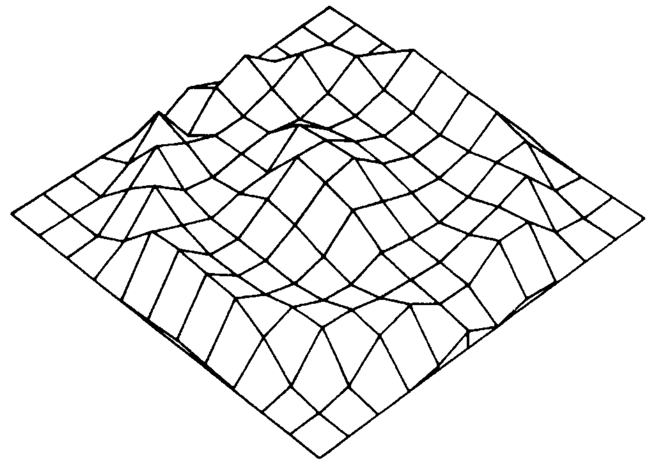

Figure D. Sprinkler distribution patterns can be modeled on computers, using cup test data. This three-dimensional graph illustrates a common problem encountered with fixed overhead sprinkler systems: a "doughnut" patter, resulting from low water pressure at a single nozzle.

coefficient of uniformity and the standard target is around 85%. Actual irrigation efficiencies are probably less in actual practice. Most growers tend to overirrigate because water is inexpensive and excess water quickly soaks out of sight in bareroot nurseries. Samples from a container nursery with a fixed overhead irrigation system, however, show that irrigation waste can be as high as 80%.

Although they are more expensive, mobile irrigation booms are becoming more common in container nurseries because they apply water evenly and only to the propagation areas - not to the aisles and border areas. Reducing runoff and possible discharge of fertilizer or pesticide pollutants is becoming a major consideration in irrigation system design. Sampling with boom systems have shown them to be significantly better in water distribution and runoff compared to fixed irrigation.

Most nurseries control irrigation duration with a time clock which regulates a series of solenoid valves that turn the water on and off in each irrigation line or zone. These controllers can be programmed to time the duration of irrigation in each zone, which allows the irrigator to adjust the amount of water applied to the demands of each crop. Controllers make irrigation at night and on weekends possible, but have the disadvantage that the same amount of water is applied each time regardless of climate or crop condition. Fully-controlled container nurseries use environmental computers with "on-demand" control systems to regulate irrigation by monitoring accumulated light, vapor pressure deficit, or evaporative demand. While these new computer systems offer new possibilities, personal monitoring of irrigation is still recommended. Irrigation is such a critical part of nursery culture and seedling water use can change so rapidly that reliance on a fully-automated control system is not advised without regular supervision.

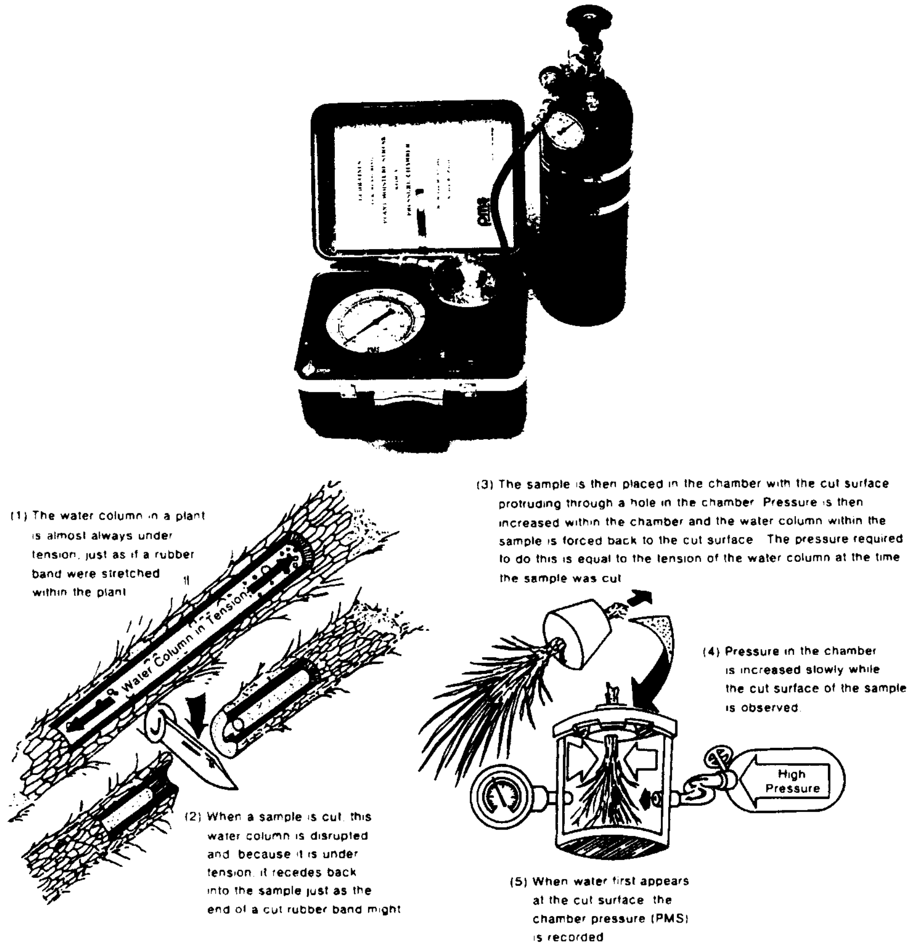

Figure E. The pressure chamber offers a direct measure of plant water potential or plant water stress (courtesy of PMS Instrument Company, Corvallis, OR).

Monitoring Seedling Water Use

Growers can monitor water in the soil or growing medium, and in the seedlings themselves. Irrigators in bareroot nurseries generally rely on the feel or appearance of the soil, the weather, and seedling vigor to determine water requirements. Tensiometers or gypsum blocks are sometimes installed at permanent locations within the seedbed to give the grower an indication of soil moisture conditions. There is just no surefire way to accurately monitor soil moisture levels in bareroot nurseries, however, but experienced irrigators are able to keep soils in the ideal moisture range without too much trouble.

Container growers have a few more options, although the typical small capacity containers provide seedlings with minimal water reserves. Measuring container weight is the most popular and practical way to monitor seedling water use. The basic principle is simple - because water is a significant component of container weight, monitoring the weight change of sample containers provides a nondestructive way to measure water loss. The only piece of equipment needed is an accurate scale that can be moved through the productions areas to weigh the sample containers. Although weights vary with many factors and have to be adjusted for seedling size, growers construct easy-to-use tables of irrigation weights as a percentage of their wet weight.

Table 2 - Guidelines for monitoring plant moisture stress

Plant Water Potential (Predawn)		*Relative Stress Rating*	*Seedling Response/ Cultural Implications*
MPa	*Bars*		
0.0 to - 0.5	0 to 5	Slight	Rapid Growth
- 0.5 to - 1.0	5 to 10	Moderate	Reduced Growth Best for Hardening
- 1.0 to - 1.5	10 to 15	High	Restricted Growth Variable Hardening
-1.5 to - 2.5	15 to 25	Severe	Increasing Injury
< - 2.5	> 25	Extreme	Injury or Death

Plant water potential readings are the most accurate way to monitor seedling water status and predawn readings with a pressure chamber give the most useful information *(Figure E).* Pressure chambers can be used during the growing season to schedule irrigation, as well as during the hardening phase to monitor induced moisture stress *(Table* 2). In bareroot nurseries, pressure chambers are also sometimes used during dry periods in the lifting season to determine when supplemental irrigation is required.

Water has such an overriding importance to seedling culture that growers must know the quality of their irrigation sources and carefully manage the amount of irrigation that they supply to their crops. The proper amount of irrigation is becoming a political as well as a biological concern as the question of what happens to nursery runoff comes under increasing scrutiny.

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