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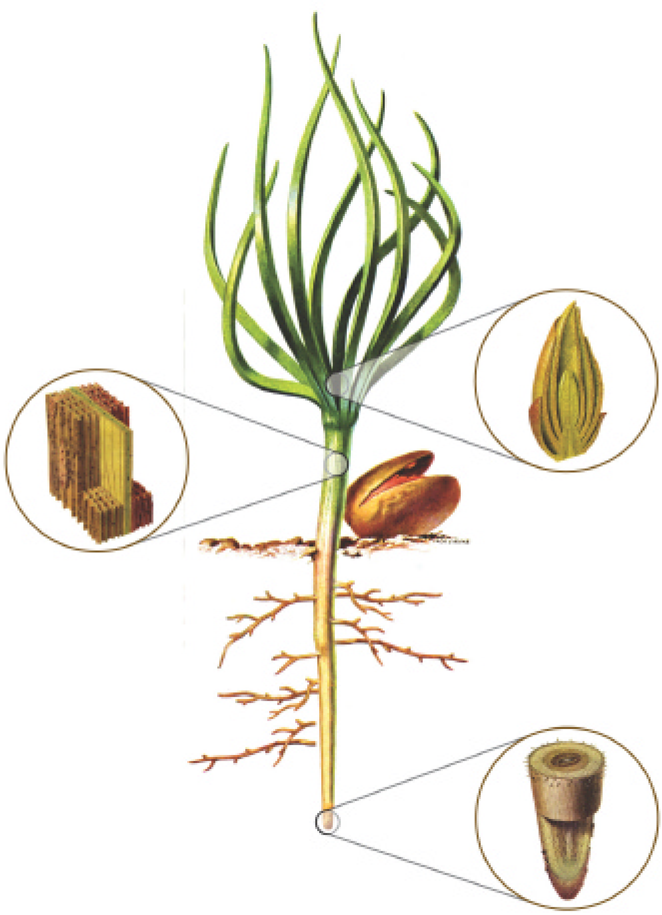
Forest Nursery Notes

Summer 2005



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Reforestation, Nurseries, and Genetic Resources (RNGR) Web Page: <http://www.rngr.net/>

The all new "Directory of Plant Material Providers" is now online and is a combination of three previous hard copy directories:

1) Directory of Forest and Conservation Nurseries
2) Commercial Seed Dealers Directory
3) Native Plant Materials Directory.

As you can probably imagine, it is almost impossible to keep hard copy directories up-to-date because as soon as they are printed, addresses, phone numbers, FAX numbers and E-mail addresses begin to change.

By combining three directories into one, now you can find nurseries, seed dealers, and native plant producers by location, products or services. In addition, suppliers can manage their respective information directly through the RNGR website. For more information on the directory, how to update information, or how to become a part of this powerful tool, please contact:

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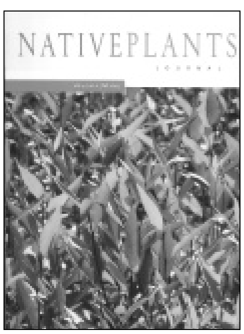
Native Plants Journal



Hopefully, many of you already subscribe to NPJ but, if you don't, you should consider doing so. In a few short years, NPJ has established itself as one of the best journals in horticulture. Not only does it contain a wealth of technical information but the color photographs and illustrations are of the highest quality. Many people think that "native plants" doesn't mean forest trees but NPJ has featured articles on Douglas-fir and longleaf pine as well as ninebark and Nebraska sedge. Many issues also contain focus topics which have ranged from "Nasty Plants" (Poison-oak and stinging nettle) to the Salicaceae family in the latest issue. Each issue also contains a good mix of propagation protocols, nursery equipment, refereed research articles, and outplanting considerations. NPJ is published three times per year (the summer issue includes the Native Plant Materials Directory) and annual subscriptions are a bargain at $42.50 for individuals and $35 for students.

The Native Plants Journal can be ordered from:
Indiana University Press
Journals Department
601 North Morton Street
Bloomington, IN 47404-3797
TEL: 1.800.842.6796
Website: http://iupjournals.org/npj

Nursery Meetings

This section lists upcoming meetings and conferences that would be of interest to nursery, reforestation, and restoration personnel. Please send us any additions or corrections as soon as possible and we will get them into the next issue.

The **Western Forest and Conservation Nursery Association (WFCNA)** will be meeting in Park City, UT on **July 18 to 21 2005**. The theme for this conference is *Watershed Restoration: From Mountain Tops to Wetlands, with People in Between.* For more information please contact:

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34963 Shoreview Road
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Forest Renewal Co-op and the Ontario Ministry of Natural Resources are hosting **The Thin Green Line,** an international symposium on planting stock and stand establishment practices to enhance forest productivity. The symposium will be held in Thunder Bay, Ontario, Canada from **July 26 to 28, 2005**. For registration information please contact:

Sonia Geller
KBM Forestry Consultants
349 Mooney Avenue
Thunder Bay, ON P7B 5L5
CANADA

The **Northeastern Forest and Conservation Nursery Association** has scheduled the next conference at the University Plaza Hotel in Springfield, MO on **August 1 to 4, 2005**. For more information contact:

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PO Box 119
Licking, MO 65542
TEL: 573.674.3229 ext. 22
E-Mail: Greg.Hoss@mdc.mo.gov

The International Union of Forest Research Organizations is planning to hold the **Sixth Meeting of IUFRO Working Party 7.03.04 (Diseases and Insects in Forest Nurseries)** in Uherske Hradiste, Czech Republic **September 9 to 14, 2005**.

For questions and information please contact:

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Editorial - Creating Habitat for Rare Creatures

A couple of recent news releases really buoyed my spirits. The first concerned the recent sightings of an Ivory-billed Woodpecker (*Campephilus principalis*) in Arkansas. The ivory-bill is our largest native woodpecker and, until recently, was thought to be extinct. What is especially disturbing is that we watched them go. The disappearance of the ivory-bill was caused by logging of old growth bottomland forests in the southeastern United States, as well as poaching by professional collectors. The last population of ivory bills were hanging-on in a bottomland hardwood forest in northeastern Louisiana. As this forest was logged, one lone female was last seen in 1944 - that's over 60 years ago. Then, in February of last year, an unusually large, red-crested woodpecker was spotted in the Cache River National Wildlife Refuge, and this sighting was subsequently confirmed by experienced observers. After an initial flurry of interest, the news media dropped the story, and unfortunately, this remarkable event was compared to bigfoot sightings on the TV talk shows

The second story was about the Mount Diablo buckwheat (*Eriogonom truncatum*) that was recently discovered in a California park after being considered extinct for more than 6 decades. Fortunately, this sighting is much easier to confirm because plants, unlike animals, tend to stay in one place. The dozen or so buckwheat plants were found on a property preserved by the conservation group Save Mount Diablo. Seth Adams, director of land programs for the group, echoed my feeling that we've been given another chance: "These stories resonate with people because they show we can set back the clock and do it right".

Both these discoveries are evidence of Nature's resiliency, and emphasize the basic ecological tenet that habitat is crucial to the preservation of all organisms. They are also further ethical justification for ecological restoration. The habitat of the ivory-billed woodpecker is swamp and bottomland hardwood forest, most of which has been logged or drained for agriculture. Fortunately, the Cache River Refuge contains substantial old growth forest and tree planting on both public and private lands is restoring more bottomland hardwoods. These efforts to increase the amount and biodiversity of mature bottomland forest may just be enough to provide Ivory-billed Woodpeckers with suitable habitat. After all, they have proven their mettle and deserve a place to hide. In the case of the Mount Diablo buckwheat, protection will prevent extinction for the time being. However, there is also the opportunity to carefully propagate this plant and re-establish it in other suitable areas.

The role of native plant nurseries in helping preserve and restore threatened and endangered plants and animals is not widely appreciated - possibly because nursery propagation is seen as artificial rather than natural. Succession is inevitable, however, and the lack of widespread disturbance means that protection alone cannot save many critical habitats. Nurseries can produce native plants to recreate any successional sere and provide suitable habitat indefinitely. Hopefully, government agencies and private conservation groups will realize that forest and native plant nurseries are an essential partner in the effort to save and restore rare plants and animals.

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http://nature.org/ivorybill/

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Seedling Quality Tests: Plant Moisture Stress
By Gary Ritchie and Thomas D. Landis

Introduction

This is the fifth installment in our review of seedling quality tests. Here we focus on what is commonly known as “plant moisture stress” or PMS. Although PMS is not routinely used for seedling quality testing *per se*, it is nevertheless the most common physiological measurement made on reforestation stock. This is because the measurement itself is simple and robust, and the equipment needed to perform it is reasonably priced and readily available. However, while measurements of PMS are easily made, their interpretation is not always straightforward. In this article we will discuss the meaning and definition of PMS, how it is measured, how the measurements are interpreted and what, if any, value they have as indicators of “seedling quality.”

What is Plant Moisture Stress?

It is axiomatic that water is essential for plant growth. Without copious quantities of water, plants will cease growing and ultimately die. If plants simply absorbed water from the soil to meet only metabolic needs, water requirements would be quite low. But plants also manufacture food through photosynthesis during which carbon dioxide (CO_2) from the atmosphere diffuses into leaves through tiny pores called stomata. Once inside the leaf, the CO_2 is converted to sugars. Photosynthesis is a “leaky” process, however. While CO_2 is diffusing into the leaves, water is diffusing out – this loss of water is called transpiration. Plants can reduce transpiration and conserve water by closing stomata, but this also impedes photosynthesis. So, in order to grow, plants must also transpire.

Transpiration generates a “stress,” due to water’s high cohesion. This stress is transmitted from the leaf down the stem and into the roots. During daylight, when stomata tend to be open, water loss exceeds the plant’s ability to extract water from the soil. So plants are almost always subjected to some level of water stress during the day. This stress is normal and is not injurious unless it persists at a high level for a prolonged period of time.

In very simple terms, plant moisture stress can be modeled as:

$$PMS = A – T + S$$

Where A is the absorption of water from the soil, T is transpirational loss, and S is storage of water in the plant stem and roots, which is negligible in seedlings but important in large trees. Just as discussed, during daylight, T almost always exceeds A.

Water potential. The fundamental equation that describes the water relations of a plant cell or tissue is:

? $_W$ = ? $_P$ + ? $_O$

where ? $_W$ is the total water potential, a measure of the free energy or chemical potential of water. ? $_W$ in the plant is made up of two component potentials. ? $_P$, the pressure potential, can be either positive or negative, whereas ? $_O$, the osmotic potential, is always negative. Potentials are expressed in units of pressure, and although MegaPascals are the official SI unit, bars are most commonly used in nurseries. By definition, the ? $_W$ of pure water at standard temperature and pressure equals 0 bars. ? $_P$ and ? $_O$ are continually changing as transpiration and osmosis cause water to move across membranes, in and out of cells, and up the transpiration stream. In nursery situations, ? $_W$ is always negative so plants are always under some level of water deficit, or stress.

The interrelationships between ? $_P$ and ? $_O$, and how they affect ? $_W$, are illustrated in a Höfler diagram, named for the German scientist Karl Höfler, who

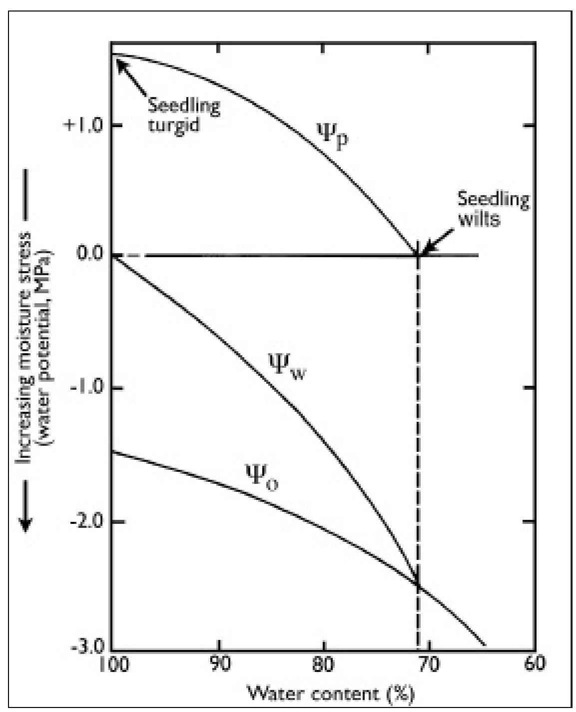

Figure 1- A modified Höfler diagram depicting the interplay of the components of water potential in a plant cell as they change with cell water content (Ritchie 1984).

devised it in the 1920s (Figure 1). The X-axis is the water content of the cell expressed as a percentage and the Y-axis is in units of water potential. This diagram also shows the relationship between potential units and the common nursery terms of turgidity and wilting. At full hydration (100% water content), the positive turgor pressure of the cell walls (? $_{P}$) balances the negative osmotic potential (? $_{O}$) in the cell contents so that ? $_{W}$ = 0 MPa. As the cell loses water, ? $_{P}$ falls and ? $_{O}$ becomes more negative as concentration of solutes in the cell increases. This causes ? $_{W}$ to decrease until ? $_{P}$ reaches 0 MPa and cells collapse. The value of ? $_{W}$ at which this occurs is known as the "zero turgor point" or, as it is more commonly known, the "wilting point."

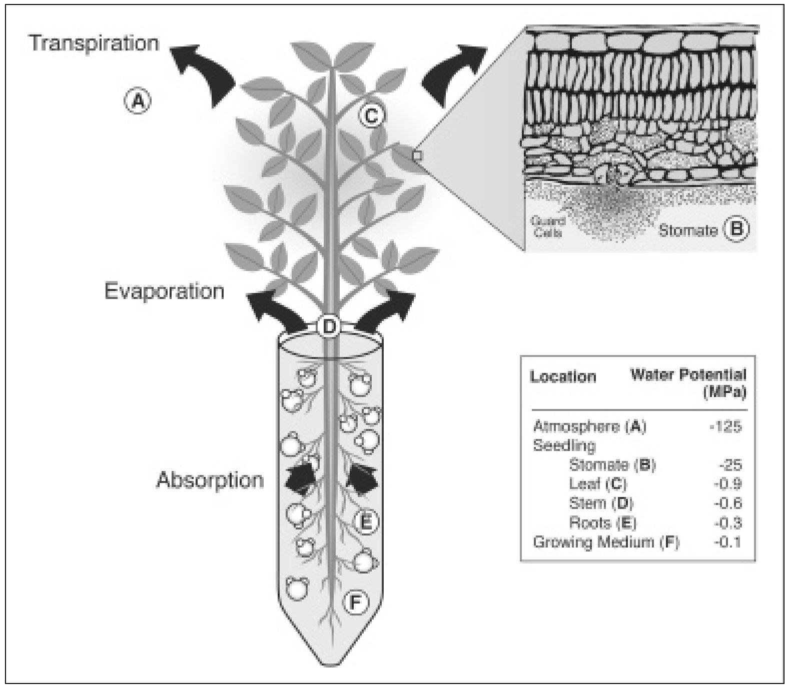

Figure 2 - Water is drawn along a gradient of water potential that is driven by transpirational losses, from higher (less negative) levels in the growing medium, through the seedling to the low (more negative) levels in the atmosphere (Landis and others 1989, modified from MacDonald and Running 1979).

Units of water potential—Thermodynamic water potential terminology (Slatyer 1967) has always been troublesome for growers because negative values are hard to visualize and tricky to manipulate algebraically. Fortunately, someone somewhere had the idea to express water potential as a positive value and call it "Plant Moisture Stress" (PMS). From a

Table 1. Comparison of units and descriptive terms for plant water potential (? $_{W}$) and plant moisture stress (PMS). ? $_{W}$ and PMS have the same value, but ? $_{W}$ is expressed as a negative value whereas PMS values are positive (Landis and others 1989).

Plant water potential (? $_{W}$)				Plant moisture stress (PMS)		
Units*		Relative rating	Relative moisture content	Units*		Relative rating
MPa	Bars			MPa	Bars	
0.0	0.0	High	Wet	0.0	0.0	Low
-0.5	-5.0			0.5	5.0	
-1.0	-10.0	Moderate	Moderate	1.0	10.0	Moderate
-1.5	-15.0			1.5	15.0	
-2.0	-20.0			2.0	20.0	
-2.5	-25.0	Low	Dry	2.5	25.0	High

*? $_{W}$ and PMS are commonly expressed in bars but have been replaced in the published literature by MegaPascals (Mpa) to conform to SI conventions.

practical standpoint, however, water potential terminology is useful because it is consistent from the soil or growing medium through the seedling and into the atmosphere (Figure 2).

Fortunately, water potential and PMS values are directly convertible simply by changing signs. This relationship and some examples are shown in Table 1**.** For example, a PMS value of 10 bars indicates a "moderate" level of stress and is equivalent to ?$_{W}$ of -10.0 bars.

Diurnal changes of plant water potential—As we have already mentioned, ?$_{W}$ is dynamic and this affects its usefulness as an index of seedling quality. Consider, for example, a container seedling whose growing medium is fully saturated with water (Figure 2). During the day, while stomata are open, low humidity (high vapor pressure deficit) draws moisture from the leaves. This creates an imbalance between transpiration and water absorption resulting in the development of PMS (?$_{W}$ decreases). At night, stomata tend to close, relative humidity rises to nearly 100% and transpiration ceases. The negative ?$_{W}$ in the plant pulls water from the growing medium relieving the stress. By early the next

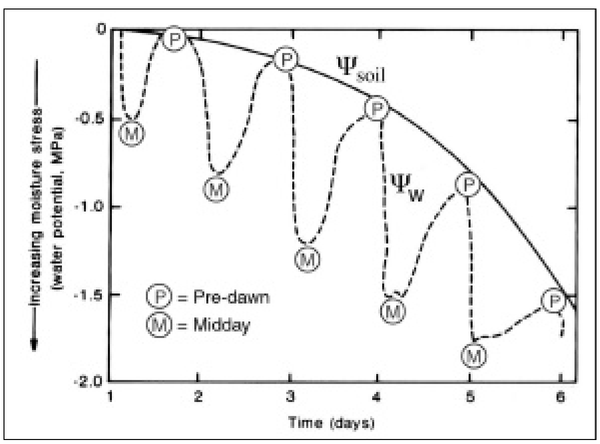

Figure 3 - Changes in plant water potential (?$_{W}$) and growing medium water potential (?$_{soil}$) of a tree seedling growing in a container. The container is initially watered to saturation then allowed to dry (Landis et al 1989, modified from Slatyer 1967).

morning ?$_{W}$ will have reached a dynamic equilibrium with soil moisture potential (?$_{W}$ ~ ?$_{soil}$).
Assume that no water is added to the container so the growing medium is allowed to dry out. As this occurs, the pre-dawn stress and the mid-day plant moisture stress will both increase daily as ?$_{soil}$ decreases (Figure 3). After a few days the seedling will close its stomata during midday to retard transpiration. This can be seen occurring in days 4 and 5 on Figure 3**.** This will result in a moderating of the midday PMS. ?$_{soil}$ will eventually become so negative that the plant will be unable to equilibrate during the night. Throughout this time, the mid-day stress will continue to increase. When re-watered, the system will return to the initial state shown in Day 1.

Note that the ability to track moisture stress levels of both soil and plant in Figure 3 shows the advantage of using water potential units rather than PMS, which reflects only seedling stress.

Measurement of Plant Moisture Stress

Over the years, as plant physiologists labored to understand the dynamics of plant water relations, many attempts were made to develop methods of measuring ?$_{W}$ (Lopushinsky 1990). As far as nursery work goes, the most significant development was when Per Scholander and Howard Hammel at the Scripps Institute of Oceanography invented the "Scholander Pressure Chamber" (Scholander and others 1965). This device was adapted from a glass pressure chamber reported by Dixon (1914) and was further modified for trees and seedlings by Wareing and Cleary (1967), who outlined basic measurement procedures.

The modern pressure chamber consists of a metal pressure vessel that is connected to a nitrogen gas source by way of a pressure regulator (Figure 4**).** To measure PMS, a seedling's stem is cut and inserted through a rubber gasket. The shoot is then sealed into a hole in the chamber lid with the foliage inside the chamber and the cut stem protruding **(**Figure 4). Nitrogen gas is slowly bled into the chamber while the cut stem is closely observed. When a droplet of water appears at the end of the stem the chamber pressure is noted. The gas pressure required to force the drop of water to the surface is equal to the moisture stress of the seedling. For a detailed theoretical description and procedural guide see Ritchie and Hinckley (1975).

The pressure chamber has become the standard technique used for measuring PMS in forest nurseries, ecophysiology laboratories, and other plant research facilities. For example, the JH Stone Nursery in Central Point, OR uses pressure chambers to measure predawn PMS and schedule bareroot seedling irrigation. They are also used to detect dangerous PMS levels during the lifting and packing operations (JH Stone Nursery1996).

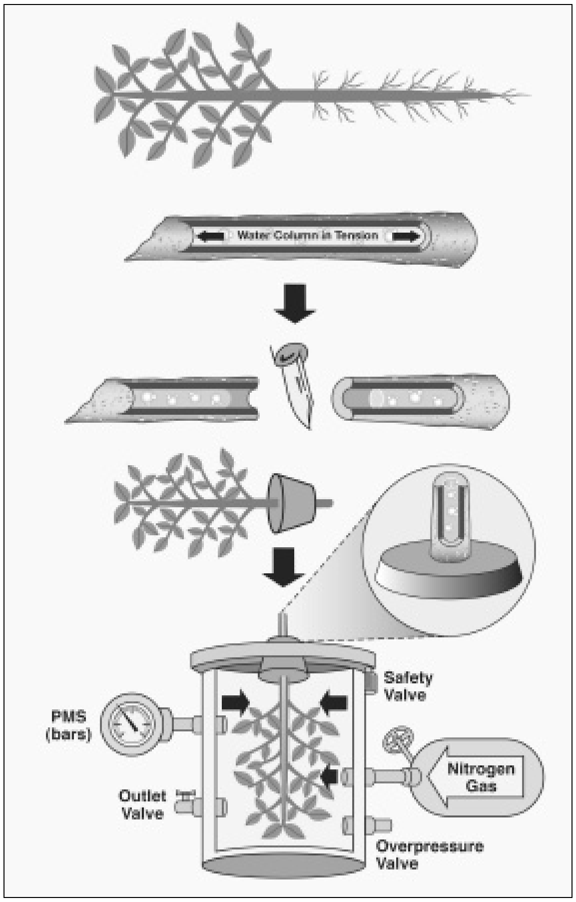

Figure 4 - Diagram showing the steps involved in measuring PMS with a Scholander Pressure Chamber. A stem is severed, and the cut end forced through a hole in the center of a rubber gland, which is then inserted into the lid of the chamber. Nitrogen gas is slowly introduced into the chamber until a drop of water is forced to the surface of the cut stem. The gauge pressure at which this occurs is equal and opposite the forces holding the water in the stem, a.k.a. the plant moisture stress (Landis and others 1989, modified from PMS Instrument Co.).

A variety of pressure chambers and supplies are available from:

PMS Instrument Company
1725 Geary Street SE
Albany, OR 97322 USA
Phone: 541.704.2299
Fax: 541.704.2388
E-mail: info@pmsinstrument.com
Website: http://pmsinstrument.com/

Interpretation of PMS values. The ease and robustness of PMS measurement has led to its extensive use in plant water studies. Interpretation of PMS values, however, is not always as straightforward as one might expect. This is partly because PMS, as an estimate of ? $_{W}$, integrates two variables into one reading and therefore much information is lost. In addition, because the components of water potential change seasonally, a given value of PMS might have a different interpretation if taken in, say, April as opposed to, say, January. For example, Figure 5 shows how the "zero turgor point" changes seasonally in roots and stems of Douglas-fir seedlings (Ritchie and Shula 1984). In April, a stem PMS reading of 25 bars (-2.5 MPa) would be a potentially lethal value because it would be near the zero turgor point. But the same value, if measured in January, would be of little concern. Similarly, root systems with PMS near 20 bars (-2.0 MPa) would be suspect most of the year.

More importantly, there is the issue of diurnal variability. As we show in Figure 3, PMS can vary sharply from day to day and during the day. Typically, the highest values of PMS occur during midday and lowest values in early morning. Daytime PMS values can fluctuate wildly on days with intermittent clouds and sun. So, they often provide only brief "snap shots" of PMS that have little diagnostic value.

Probably the most useful PMS value is what is known as the "pre-dawn PMS." This is the PMS that obtains just before sunrise when ? $_{W}$ is in dynamic equilibrium with ? $_{soil}$ (Figure 3) and provides an estimate of the minimum stress the plant would experience that day. If this minimum value is high, it may be cause for concern. With the above caveats in mind, we present some suggested guidelines for interpretation of pre-dawn PMS measurements as they relate to plant growth and cultural implications (Table 2).

As a footnote, it is not necessary to travel to the field before sunup to take a pre-dawn PMS value. Instead, you can place a dark plastic bag or bucket over a seedling in the evening. This will maintain the relative humidity near 100%. During the night, PMS will reach the pre-dawn value and will tend to hold this value under the high humidity until the covering is removed the following morning.

Is PMS an Indicator of Seedling Quality?

As pointed out by Lopushinsky (1990), the properties of seedlings that are useful as plant quality indicators (root growth potential, cold hardiness, stress resistance, dormancy intensity, carbohydrate content) are not

Table 2. Growth response and cultural implications of inducing moisture stress in conifer seedlings in northwest nurseries (modified from Landis and others 1989).		
Pre-dawn PMS value (bars)	**Moisture stress rating**	**Seedling response/cultural**
0 to 5	Slight	Rapid growth
5 to 10	Moderate	Reduced growth/best for overall hardening
10 to 15	High	Restricted growth/variable hardening results
15 to 25	Severe	Potential for injury
Below 25	Extreme	Injury or mortality

correlated with PMS. Therefore, PMS cannot be used as a proxy indicator of any of these. We should also point out that dead seedlings can exhibit very low PMS values because dead roots retain the ability to absorb water. So, as you can see, low PMS values are not necessarily indicators of healthy stock.

Therefore, the question is: is PMS a useful indicator of seedling quality on its own? In our opinion, PMS indicates seedling quality only when stress is extremely high. For example, nursery seedlings with *pre-dawn* PMS values up in the 15 to 25 bar range should be suspect – especially if these high values persist after irrigation (Table 2). PMS is also operationally used to monitor seedling condition during the lifting-grading-storage process. For example, stock that has a PMS value of, say, 30 bars coming out of storage would certainly be cause for concern.

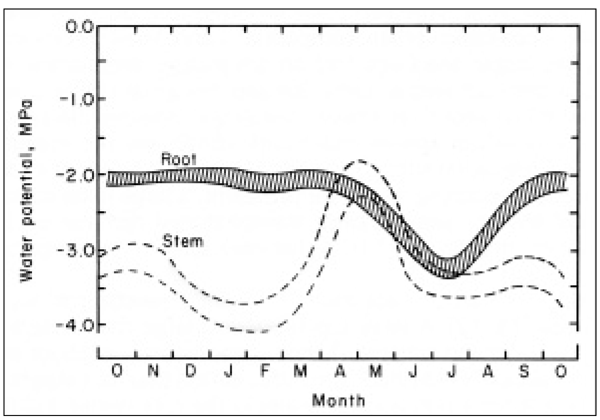

Figure 5 - Seasonal changes in water potential at zero turgor for root systems and stems of Douglas-fir seedlings (Modified from Ritchie and Shula 1984).

Two laboratory procedures exist, however, in which pressure chamber values can be used to measure some aspects of seedling quality:

Pressure-volume (PV) Analysis. PV analysis can be used to generate Höfler diagrams (Figure 1), which are useful for many purposes including identification of seedling water potential at zero turgor. The data in Figure 5 were developed using this technique. But this is a very laborious and difficult procedure and we know of no labs that currently offer it as a service.

Pressure Weight Loss. This pressure chamber technique can be used to identify cold damaged root systems (Ritchie 1990). In this procedure, a seedling root system is submerged in water overnight to assure full hydration. After weighing, it is held in a pressure chamber at 1.5 MPa pressure for 5 minutes. The sample is then removed and re-weighed. Douglas-fir seedlings that lost =7% of their weight had reduced vigor and survival three months later in field and pot trials. It is possible that tests based on this principle could be developed to detect tissue damage in other species and tissues.

PMS as a Snapshot of Seedling Water Status

The fact that PMS is not a good *predictor* of seedling quality should not be interpreted to mean that monitoring PMS is a waste of time. Pressure chambers should be used to check on plant moisture status at several times during nursery tenure. Using pre-dawn PMS readings to fine-tune nursery irrigation practices is a good idea because pressure chamber measurements are the only way to truly know the water status of seedlings at a given time.

PMS measurements during lifting can alert nursery managers to dangerously dry conditions, or excessive seedling exposure. Seedling users can use PMS to check the moisture status of their stock immediately before outplanting. In one recent study, the PMS of Radiata pine (*Pinus radiata*) seedlings was taken immediately after storage and a very strong relationship was found between moisture stress and root growth after outplanting (Mena-Petite and others 2001). They concluded that post-storage water potentials below 1.5 MPa reduced root growth by 90% (Figure 6).

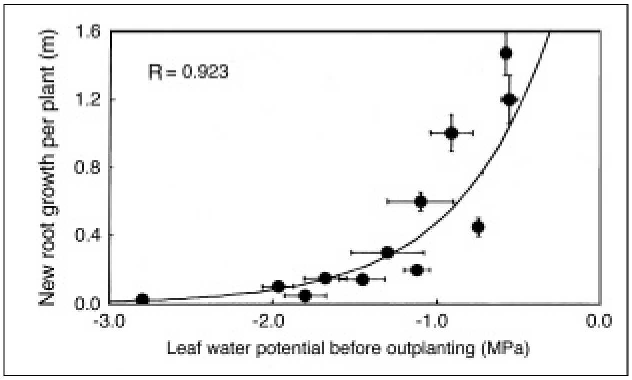

Figure 6 - A strong correlation was found between PMS readings taken after storage and new root growth after outplanting (Mena-Petite and others 2001).

Conclusions and Recommendations

Plants normally lose water more rapidly through transpiration than they absorb from the soil, so they are almost always under some level of water stress. This is often called plant moisture stress (PMS). PMS is numerically equal to, but differs in sign from, plant water potential (? $_W$). PMS shows strong diurnal variations as transpiration rates change in response to changes in temperature, vapor pressure deficit and stomatal aperture. The most useful value of PMS is that which occurs just before dawn, when ? $_W$ is near equilibrium with ? $_{soil}$. This is called the pre-dawn PMS. The Scholander pressure chamber remains the most robust and useful method for measuring PMS. Here, a stem is severed from a plant and sealed in a pressure chamber with the cut end protruding from a hole in the chamber lid. Gas pressure is introduced into the chamber until a water drop forms at the base of the stem. The pressure at which this occurs is equal and opposite to the forces holding the water in the stem and provides an estimate of PMS. Although there are seasonal variations in critical PMS values, readings in the range of 5 to 15 bars are normal whereas those above 15 bars are cause for concern.

PMS is not directly correlated with any of the classical seedling quality indicators (root growth potential, cold hardiness, stress resistance, dormancy intensity and carbohydrate concentration). Therefore its use as a seedling quality indicator is limited to only a couple of laboratory procedures, neither of which are currently available commercially. PMS readings, however should still be used as a snapshot of overall seedling water status.

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Top Pruning

By Thomas D. Landis

Controlling plant height is always a challenge because shoot growth is stimulated in modern nursery environments (Figure 1). To further aggravate the problem, economics forces nurseries to grow their stock at high densities and so plants want to outgrow their neighbors. Inducing mild stresses helps to slow height growth but this has only limited application. Chemical treatments like paclobutrazol have proven effective with floral crops, but have not found wide application in forest and conservation nurseries. Therefore, many growers resort to top pruning which is also called top mowing or clipping.

*Figure 1 - Top pruning is often the only option for crops like quaking aspen (*Populus tremuloides*) that produce tall shoots with minimal fertilization.*

Top pruning has become a routine cultural practice in many bareroot conifer nurseries. Over 90% of bareroot pine growers in the Southeast routinely prune their stock (Duryea 1986) and, in a survey of Pacific Northwest nurseries, 92% top pruned Douglas-fir (Duryea 1984). Since these surveys, top pruning has gained wider acceptance with bareroot conifers and hardwood nurseries. Container growers have been slower to adopt top pruning although controlling shoot height is much more difficult in greenhouses. Much of the concern comes from foresters and other seedling users who believe that top pruning causes forked or multiple stems. Let's consider the evidence.

Crop Growth Patterns

Position of Shoot Meristem and Type of Tissue. With top pruning, the location of the shoot meristem and whether the crop produces woody or nonwoody tissue is the first thing to think about. Grasses, sedges and other non-woody plants have their growing point at ground level and never produce woody tissue. So, these crops can be pruned regularly without any problems. Meristems of woody plants, however, are located at the tips of the terminal shoot and branches, and so shoot pruning is more problematic.

Types of Woody Plant Shoot Growth. In the temperature zones, woody plants exhibit either determinate or indeterminate growth. Pine, spruce, hickory and oaks exhibit determinate shoot growth in which foliar buds break in the spring, and shoots expand before setting another bud in mid- to late summer. In nurseries, determinate species sometimes produce another late growth spurt known as lammas growth. On the other hand, shoots of indeterminate species such as western redcedar, junipers, and elm do not have true dormant buds and produce several growth spurts during the summer. In general, top pruning of indeterminate species poses few problems whereas there is a narrow window for determinate plants.

Reasons for Top Pruning

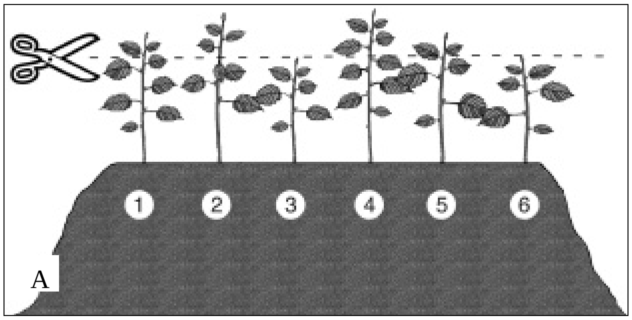
Growers top prune their stock for several reasons:

To Control Shoot Height. This is the most obvious and common reason to top prune, and over half of southeastern nurseries gave this as their primary reason in a 1986 survey (Duryea 1986). Removing the newest shoot tissue temporarily slows shoot production and allows more photosynthate to be diverted to stem and root growth.

To Achieve a Uniform Crop Size. This was the second most common reason to top prune in the southern survey (Duryea 1986). Due to differences in seed germination timing and initial growth rates, nursery crops do not grow uniformly. At the high growing densities in seedbeds and multiple cell containers, plants that get a slow start are typically overtopped and end-up as culls. Top pruning during the growing season is an ideal way to temporarily slow the faster growing plants and allow slower ones to catch-up (Figure 2). The result would be higher seed-use efficiency and more shippable plants. Dierhauf (1976) was the first to note that top pruning "released" small seedlings, but subsequent trials had mixed results.

To Decrease Shoot-to-Root Ratio. Many foresters and restorationists request plants with short, stubby shoots and a large, fibrous root system for their harsher sites. Top pruning is a cost-effective way to produce these target stock types, and is one of the main reasons why southern nursery managers use this practice.

To Increase Stem Diameter. It would seem logical that top pruning would increase stem diameter because more



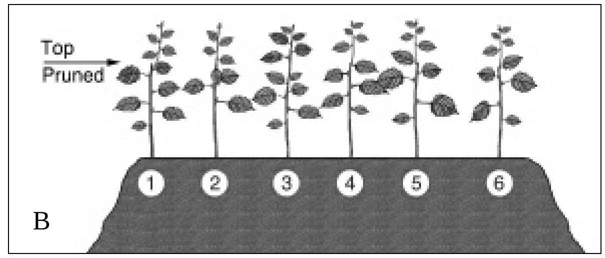


Figure 2 - One of the reasons to top prune nursery stock is that it produces plants of a more uniform size. At the time of top pruning, only the taller plants (1,2,4, & 5) will be clipped (A). The shorter plants (3 & 6) will be released from competition for light and hopefully catch-up with their neighbors (B).

photosynthate would be available. However, several studies have shown the opposite effect.

To Facilitate Seedling Handling During Transplanting and Outplanting. Nurseries producing transplant stock typically top prune their seedlings to make them easier to handle during the transplanting process. Top-pruned plants are also more hardy and resistant to moisture stress and growth checking after transplanting. With some species, top pruning is used to reduce shoot height and make plants easier to harvest, handle, store, and ship. In a general review, South (1996) found that top-pruning hardwood seedlings to a target height is a standard nursery practice.

Implementing Top Pruning

Types of Equipment. Bareroot nurseries use a variety of tractor-drawn implements to top prune their stock. In the southeastern survey, most nurseries used rotary mowers (Figure 3A) that can be easily adjusted for height. Sickle-bar mowers feature a reciprocating sickle mounted within a sidebar. Flail mowers have swinging pyramid-shaped flail blades which rotate from a horizontal cylinder. Sources for top pruning equipment can be found in the Bareroot Nursery Equipment Catalong (Lowman and others 1992).

Ornamental growers have been top pruning their container stock for years, either manually or with homemade equipment such as lawnmowers (Figure 3B). Hedge trimmers have also been used but must be cleaned regularly when pruning pines and other conifers because of their sticky resin.

Timing. With most crops, one top pruning in early summer when shoots are still succulent is recommended. In the southeastern states, loblolly and other southern pines are often top pruned several times throughout the summer to keep seedlings within target specifications.

During Crop Cycle—In my experience, timing is the primary reason for poor top pruning results, but this varies with nursery climate and plant species. Woody plants in tropical or semitropical climates show continuous bursts of shoot growth whenever

Figure 3 - Top pruning with rotary mowers is a routine practice in many bareroot conifer nurseries (A). Ornamental container growers have modified lawnmowers to top prune their stock (B).

environmental conditions, especially moisture, are favorable. This is the main reason why controlling shoot growth is so difficult in nurseries in these climates.

Trees and shrubs with indeterminate growth habit have a wide pruning window and can be pruned almost anytime during active shoot growth. Determinate woody species should be top pruned when the terminal shoot is expanding and before it becomes woody. In pines, this is often called the "pinfeather" stage because the new emerging needling look like the pinfeathers on a duck (Figure 4).

Proper timing is critical for developing wound callus tissue and forming new buds. Pruning wounds made during the early-summer flush heal better than those made at other times of the year. Pruning too late in the season can cause plants to flush again which can lead to fall frost injury. So, the best time to top prune cannot be scheduled by the calendar but instead must be determined by phenological development which will be different from nursery to nursery and year to year.

At Harvest—Hardwoods and other broadleaved nursery stock are sometimes top pruned with paper cutters as part of the lift-and-pack process. Because they are dormant and without foliage, this does not appear harmful but greatly facilitates handling, storage, and shipping. This practice should not be attempted with conifer stock which must be stored because the injured foliage would certainly attract gray mold (*Botrytis cinerea)* and other foliar pathogens.

Concerns About Top Pruning. As already mentioned, some growers have reservations about top pruning their crops and the possibility of producing seedlings with forked stems or increasing disease are the major concerns.

Stem Forking—The possibility of creating multiple shoots is the most common reason that growers are afraid to try top pruning. In one of the few comprehensive research studies, top pruning increased the number of Douglas-fir bareroot seedlings with multiple leaders from 10 to 38% at time of harvest but that percentage dropped two years after outplanting (Duryea and Omi 1987). With loblolly pine, outplanting trials found no forked seedlings after 3 years (Dierhauf 1976).

Of course, the objectives of the seedling user would determine whether initially forked plants would be a problem. Foresters are concerned about producing trees with straight boles but forking would not be important for nursery stock used for restoration or other non-commercial objectives. In the final analysis, experience has shown most young plants exhibit strong apical dominance so forking does not persist for long.

Figure 4 - Trees and shrubs with indeterminate growth should be top pruned before the expanding terminal shoot becomes woody; in pines, this is called the "pinfeather" stage.

Disease—This is one of the oldest fears about top pruning. Toumey (1916) was concerned that the wounds from top pruning would allow access for fungal pathogens. This is certainly a possiblity and so growers should keep their pruning equipment sharp and mowers should be steam-cleaned regularly. Brown-spot needle blight, caused by *Scirrhia acicola*, is the only documented disease to be spread by top pruning but experience has shown that spreading fungal disease has not been a problem in bareroot nurseries. In container nurseries, the greatest risk is from *Botrytis* because this fungus is omnipresent and quickly colonizes wounded tissue. Therefore, the presence of foliar disease should be surveyed before top pruning and pruned shoots should be promptly raked immediately afterwards.

Effects on Outplanting Performance

Most published research has been with southern pines, and several studies have shown that top pruning usually improves survival of loblolly pine by around 6% (South 1998). Longleaf pine is a particularly challenging species and needle clipping just before outplanting increased field survival of seedlings from four separate nurseries. For Douglas-fir, outplanting survival and growth of pruned seedlings was not better than the controls (Duryea and Omi 1987). With hardwood tree crops, many trials show no significant effect on survival after outplanting but South (1996) found that this differed with harshness of the outplanting sites. On hotter and drier sites, top pruned seedlings performed better probably due to their better balance between shoots and roots.

Top pruning has been shown to improve the survival and growth of oak and other broadleafed seedlings. With blue oak (*Quercus douglasii*), McCreasy and Tecklin (1993) report that top-pruned container seedlings had greater height and stem growth after two growing seasons. They recommend top pruning for all nursery stock that has grown overly tall with an out-of-balance shoot:root ratio. With bareroot water oaks (*Quercus nigra*), top-pruned seedlings were not only growing faster after outplanting but also appeared to be more vigorous (Adams 1985).

Conclusions and Recommendations

Although the published research contains contradictory and confusing results, top pruning is a valuable cultural procedure that helps nursery managers control shoot height and achieve crop-size uniformity. Timing is critical and seedlings should be pruned when actively growing in early summer to ensure the proper development of terminal buds. In the southeastern states, loblolly and other southern pines are often top pruned several times throughout the summer. Pruned shoots should be removed immediately after pruning to reduce chances of disease. Although pruning is an effective alternative for excessively tall stock, nursery managers should always make small tests before implementing this practice operationally.

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Sideslit or Airslit Containers

By Thomas D. Landis

Spiraling and other types of root deformation have been one of the biggest challenges for container growers. Chemical root pruning with copper coatings was the first innovation and is still being used in some nurseries. Concerns about copper leaching, toxicity, and induced deficiencies of other micronutrients have limited their use, however. The next feature to help control roots was the sideslit or airslit container which was introduced by Carl Whitcomb in the late 1980's. The original RootMakers® were single containers and large in volume, but multicell trays came out in 1996. In the early 1990s, the Accelerator® was developed which featured round, removable sideslit containers that fit in a rack. Since then, a number of companies have developed containers that featured air slits on their sides (Table 1).

The basic principle behind the sideslit container is simple. Just like when plant roots "air prune" when they hit the bottom drainage hole (Figure 1A), they stop growing and form suberized tips when they hit the lateral slits when in sideslit containers (Figure 1B). When they first came out, many nurseries bought a few of these new sideslit containers and set them out in the greenhouse with their regular containers. It soon became apparent, however, that these containers dried-out much quicker than solid wall containers and so quickly fell out of fashion. Growing a few new containers in the midst of another container type is not a fair comparison, but few growers wanted to gamble on converting over completely. The nurseries that tested sideslit containers found two drawbacks: 1) roots sometimes bridged between containers, and 2) seedlings in sideslit containers dried out much faster than in those with solid walls. The bridging was minimized by increasing the taper of the cells and staggering the location of the airslits. The drying was most rapid around the perimeter of the block and so containers on the perimeter of the growing area dried-out much faster than those in the middle.

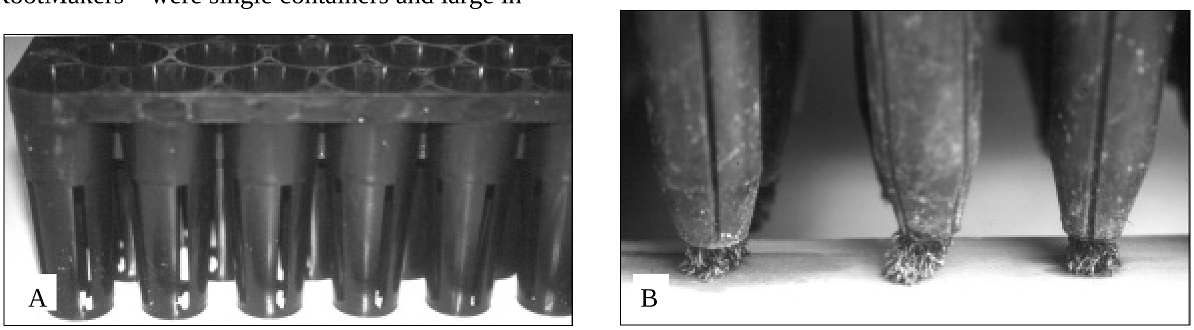

Figure 1 - Using the concept of "air pruning" (A), the lateral slits in sideslit containers (B) control spiraling and other root deformities.

Table 1. Types of slideslit containers for forestry and conservation nurseries.

Company	Container	Range in Cell Volumes		Features
		in^3	ml	
Accelerator®	APL2	13.7	225	Soft plastic round cells, removable
BCC™	Sideslit	3.4 to 7.3	55 to 120	Hard plastic blocks, square cells
Hiko™	V Series	3.1 to 9.2	50 to 150	Hard plastic blocks, round or square cells
Lannen™	Plantek®	3.1 to 16.8	50 to 275	Hard plastic blocks, square cells
Panth™	Starpot©	3.0 to 7.3	50 to 120	Hard plastic blocks, round cells
IPL	Rigi-Pots™	4.9	80 to 350	Hard plastic blocks, square cells
RootMaker®	RootMaker I & II	6 to 930	98 to 15.31	Hard plastic trays and containers, round or square

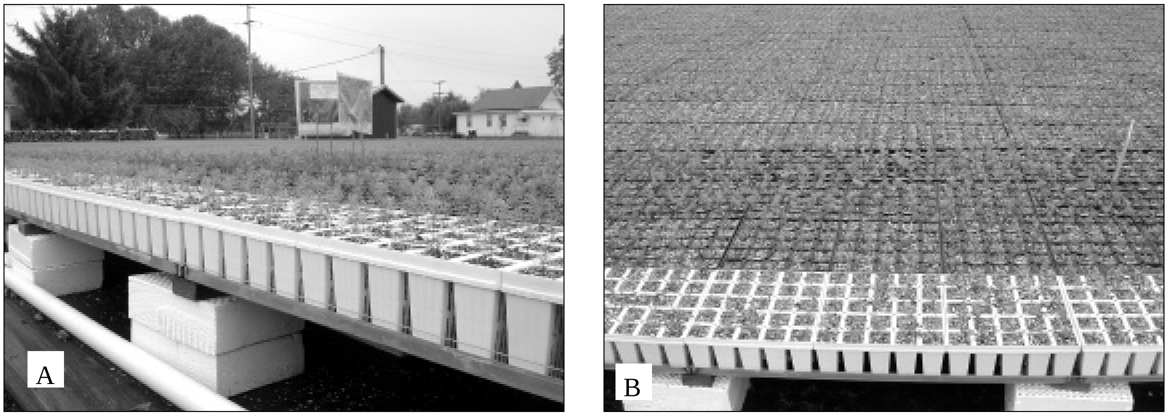

Figure 2 - IPL solved the problem of excessive perimeter drying (A) by manufacturing special white RigiPot™ 25-350 containers without air slits on the outer sides (B).

The challenge was to create a container that would not dry out the root system but still enable air pruning. IPL took an innovative approach: change the design of the perimeter containers. They created RigiPot™ 25-350 block containers without side slits on the outside walls (Figure 2A). This new "perimeter tray" is constructed of white plastic to differentiate it from the black "inside trays" with slits on all four sides. The white perimeter containers also prevent root damage from direct sunlight. This new innovative container system is currently being used operationally at Microseed Nursery in Ridgefield, WA (Figure 2B).

Sideslit containers are extensively used in Quebec, Canada due to their innovative nursery research. They have dealt with the more rapid drying by adapting a soil moisture monitoring instrument that is based on time domain reflectometery (TDR). Sensor probes are inserted through the sideslits of the containers and gives an instantaneous, non-destructive measurement of percent moisture in the growing media. With this technology, growers can quickly and accurately adjust their irrigation from germination through the hardening phase (Figure 3). This not only saves water but decreases fertilizer leaching.

Summary

Sideslits or airslits are the most recent design feature to help control root spiraling in containers and develop a multi-branched and fibrous root system. Before testing these containers, growers must realize that they need to grow them together in a area where the irrigation can be managed separately from other container types. Containers around the perimeter of the growing area will dry out much quicker than those in the interior.

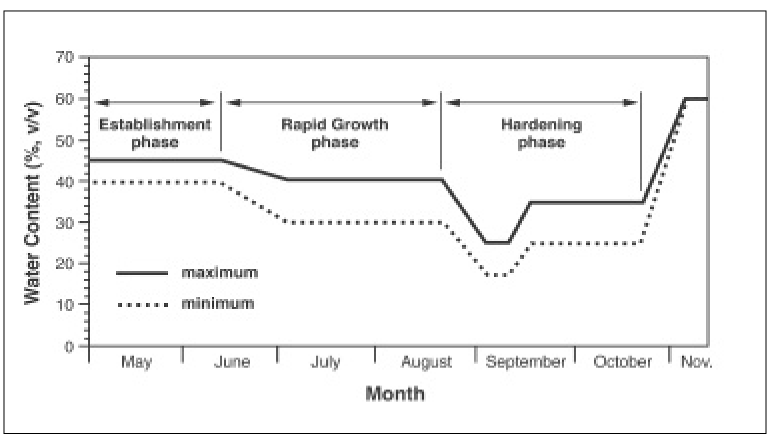

Figure 3 - Quick and precise monitoring of the water content in the growing media allows container growers in Quebec to regulate seedling growing and development throughout the growing season (Lamhamedi and others 2001).

If you would like to try sideslit containers, the best single source of information is Eric Stuewe and his staff at Stuewe and Sons:

Stuewe & Sons Inc
2290 SE Kiger Island Drive
Corvallis, OR 97333-9461
TEL: 541.757.7798
FAX: 541.754.6617
E-MAIL: eric@stuewe.com
WEBSITE: www.stuewe.com

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Cooling with Shade

By Thomas D. Landis

Using shade to reduce the sunlight and resultant heat reaching nursery crops is a time-honored cultural practice. Shading seedbeds was standard practice in early bareroot nurseries and two types of shade were employed. Shadeframes (Figure 1A) were also known as “low shade” to distinguish them from the “high shade” that was used to allow use of machinery in the seedbeds (Figure 1B). Back then, the primary objective of shading was to reduce the undesirable increase in temperature and resultant transpiration from direct sunlight. When modern irrigation practices were installed in nurseries, however, it was discovered that shade was really not necessary if adequate soil moisture was present.

Horticultural Uses of Shading

Shadeframes are rarely seen in modern bareroot nurseries, and today, shading is primarily used in container nurseries. Shadecloth or fixed lath can be used to produce permanent shade, and some container nurseries use special lath houses to both shade and protect seedlings during the hardening phase and for overwinter storage. Standard shadeframes are made from snowfence, which consists of strips of wooden lath connected by wires with alternate open spaces that produce 42% shade. Although some container nurseries produce seedlings in shadehouses, this amount of shade is generally considered to be too high for most species.

Over the years, I have seen many nurseries with shadehouses or with shadecloth covering greenhouses and, in my opinion, shading is often used incorrectly. So, let’s review the practice.

Decrease Light Intensity for Shade-loving Species. Shading is rarely used with crops of commercial conifers, and even “shade-tolerant” species like western hemlock (*Tsuga heterophylla*) can be germinated and grown in full sunlight. Growers have found that many species tend to grow excessively in height (“stretch”) under heavy shade which contributes to poor shoot-to-root ratios.

Shade is used to grow other native plants, especially if the species is shade loving and will be outplanted underneath an existing plant canopy (Table 1). Seedlings that will be outplanted into full sun conditions should receive minimal or no shading, including during the Hardening Phase. In fact, excessive shade has been shown to delay hardening.

Cooling in High Sunlight Environments. Keeping greenhouses and other propagation structures cool is the biggest environmental challenge facing container growers, especially at lower latitudes and in climates with few cloudy days. Growers can choose from three options:

Ventilation—This is the most common method of cooling but greenhouses must be properly designed for it to be effective. Natural ventilation feature roof and side vents whereas mechanical systems use a staged sequence of vent openings and fan speeds.

Evaporative cooling—Evaporative pads and exhaust fans use the latent heat of evaporation to cool incoming air. Cooling is especially problematic, however, in humid climates where natural ventilation and evaporative cooling are ineffective. Fog systems use high pressure nozzles to produce a fine mist which cools the air and plants as it evaporates. Good quality water is required to prevent plugging nozzles and avoiding spots on foliage and surfaces.

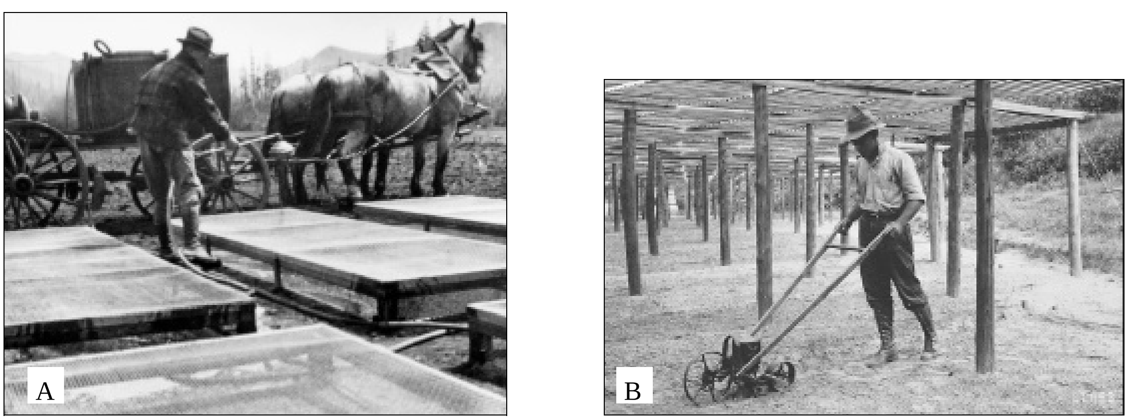

Figure 1 - Historically, shadeframes over seedbeds were standard procedure (A) and “high shade” allowed equipment access (B).

Table 1. Native plant species commonly grown under full sun or shade, along with species which grow under either condition (Courtesy of T Luna)				
Species	**Common Name**	**Sun Requiring**	**Shade Requiring**	**Sun or Shade**
Artemisia tridentata	big sagebrush	X		
Carex aquatilis	water sedge	X		
Prunus virginiana	chokecherry	X		
Dryopteris filis-mas	male fern		X	
Chimaphila umbellata	pippesisiwa		X	
Gymnocarpium dryopteris	oak fern		X	
Ceanothus sanguineus	redstem ceanothus			X
Rubus parviflorus	thimbleberry			X
Pteridium aquilinum	bracken fern			X

Shading—The basic concept is to reduce the amount of incoming solar radiation that converts to heat inside the propagation structure. Historically, growers with glass greenhouses applied whitewash paint during the summer so that the white color would reflect sunlight and thereby cool the interior of the structures. With the newer types of greenhouse glazing, whitewash is uncommon and shadecloth is used instead. Whether shadecloth is effective in cooling depends on two things: 1) the color and composition of the shadecloth, and 2) how it is installed.

On a sunny summer day, a 30 x 100 ft greenhouse can capture about 3.2 million BTU of solar heat, which is the same as burning 32 gallons of fuel oil. (Bartok 2001)

Types and Colors of Shadecloth

Since black woven shadecloth was introduced in the 1960s, many growers have installed it over their greenhouses for cooling during the heat of summer (Figure 2). This is one tradition that needs to be re-examined.

Shadecloth composition. Many different types of shadecloth are available and there are several dconsiderations before purchase including durability, fire resistance, shrinkage, percentage shade, and method of manufacturing:

- Polypropylene is strong, resistant to abrasion and will only shrink about 1%.
- Saran is fireproof but, because it can shrink about 3%, should be installed with a slight sag.
- Knitted polyethylene is strong, ultraviolet resistant, and will not fray when cut or ripped.
- Polyester fabrics are fire resistant and can be interwoven with aluminum strips.

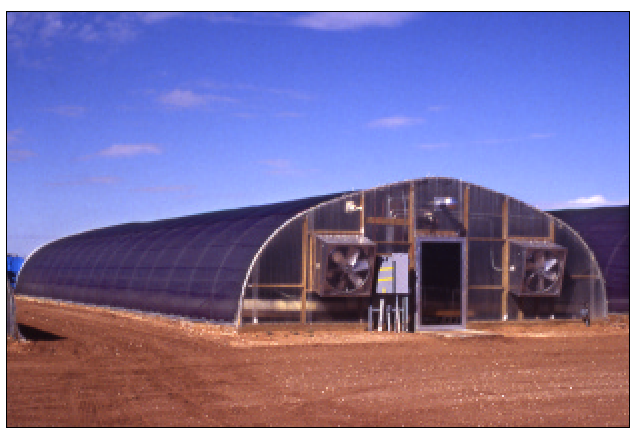

Figure 2 - Black mesh shadecloth has traditionally been installed directly over greenhouses but is not the most effective application (see Figure 3A).

Aluminet® keeps a greenhouse 8 to 10 °F cooler than standard black shadecloth, but is twice as expensive

Shadecloth color. As already mentioned, black is the traditional color for shadecloth (Figure 2). It may seem logical that, because black shadecloth reduces the amount of light reaching the crop, it is also a good way to cool plants. That's not necessarily the case, however. If you remember your physics, "black bodies" absorb visible light and reradiate it as heat whereas white objects reflect light.

White shadecloth absorbs much less heat than black and other colors are intermediate. New "aluminized" fabrics do a great job of reflecting incoming sunlight. For example, Aluminet® is a special knitted fabric made from high density polyethylene strips laminated with aluminum. It is available in several shading levels and is lighter in weight than standard shadecloth.

Surprisingly enough, published data about inside temperatures with different types and colors of shadecloth is hard to find, especially in high sunlight environments. However, the temperatures in Table 2 illustrate the physics involved. Solar radiation is converted to heat only when it is absorbed, and air temperatures only heat up when greenhouse surfaces and plants reradiate this heat. Therefore, although the air temperatures are very different, the white shadecloth reflected more sunlight and therefore kept the growing medium significantly cooler. For your crop, this would be reflected in less transpirational water loss.

Shadecloth Installations

The installation method is just as important as the type of shading material. In the typical case, growers just install the shadecloth directly on top of the covering. This is less effective for cooling, however, because sunlight is absorbed by the shadecloth and then conducted and reradiated into the propagation area (Figure 3A). Improperly installed shadecloth can also interfere with proper ventilation and further add to the heat load.

The best way to install shadecloth is to support it above the covering leaving a layer of air underneath. This is more effective because the absorbed heat cannot be conducted through the covering but rather exhausted with natural ventilation (Figure 3B).

One innovative way to increase the cooling effect is to install irrigation lines with mist nozzles over the shadecloth. The resultant evaporative cooling can be very effective if the water is free from soluble salts.

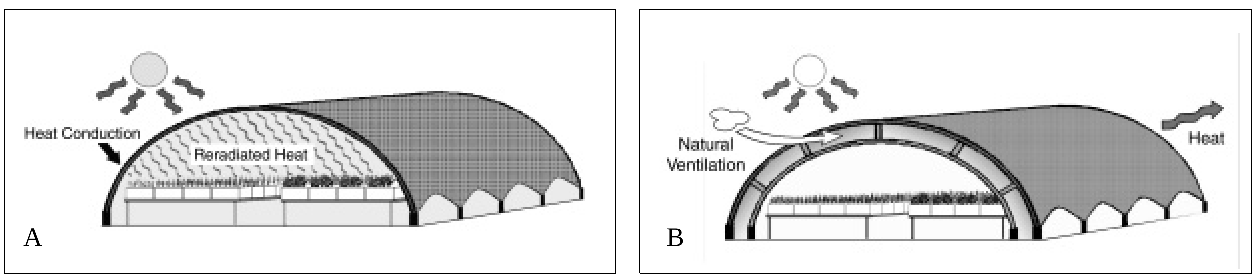

Figure 3 - Black shadecloth absorbs sunlight which is converted to heat which is conducted and reradiated into the greenhouse (A). Instead, shadecloth should be mounted above the greenhouse covering so that heat can be ventilated outside (B).

Table 2. Comparison of temperatures (F°) inside a greenhouse with different types of shadecloth in Northern Oregon in September (modified from Svenson 2000).

Shading Material	Air Temperature (F°)	Growing Medium (F°)
None	88	118
Black shadecloth—30% shade	88	115
Black shadecloth—63% shade	90	108
White shadecloth—50% shade	89	92

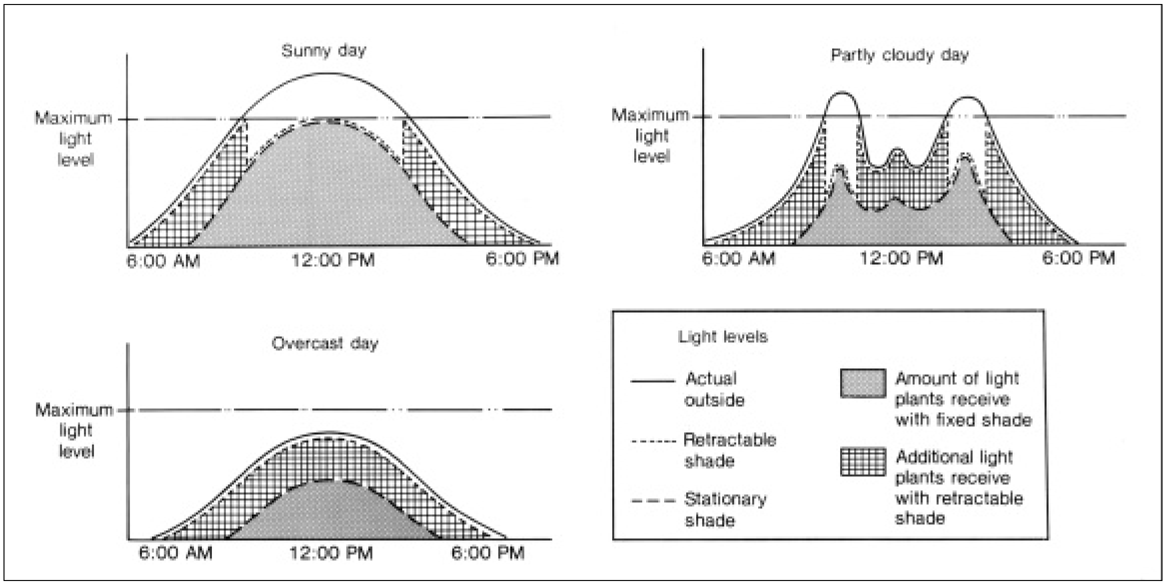

Figure 4 - Retractable shadecloth allow plants to receive more sunlight than "fixed" installations, especially early in the morning, late in the afternoon, and on days with variable clouds (Landis and others 1992).

Retractable Shading

Sunlight intensity changes during the day with the angle of the sun and the degree of cloud cover. Because of the labor involved, however, it is uneconomical to adjust the shadecloth manually to prevailing light conditions. With the advent of automatic retractable shading systems, however, container growers have the option of adjusting the light intensity within the growing area to maximize photosynthesis or lower temperature several times a day. Although relatively expensive, automatic shading systems can greatly increase the amount of sunlight reaching the crop and therefore increasing seedling growth rates (Figure 4). In an operational greenhouse trial, an automated shading system allowed the crop to receive 50% more hours of PAR than the crop in a house with permanent shade (Vollebregt 1990). A novel type of shade curtain with alternating bands of aluminized and clear material has the added advantage of actually reflecting diffuse light back into the greenhouse while reflecting away unwanted thermal radiation. Garzoli (1988) considered these reflective shade screens invaluable for cooling greenhouses across Australia.

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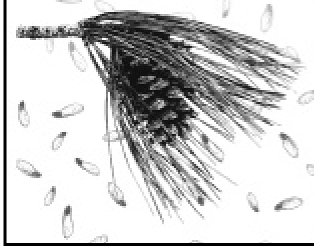
Horticultural Humor

"It's so lovely out here you wonder why they have it so far from the city."

Tom and CTNM Seven

"Finish it? Why would I want to finish it?"



New Nursery Literature

Copies of the following journal articles or publications are free and can be ordered using the Literature Order Form on the last page of this section. Just write in the appropriate number or letter on the form and return it to us. Note that there are three restrictions:

1. Limit in the Number of Free Articles: In an effort to reduce mailing costs, we are limiting the number of free articles that can be ordered through the FNN literature service. All subscribers will be restricted to 25 free articles per issue.

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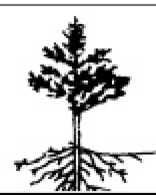
Bareroot Production



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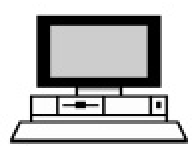
Business Management



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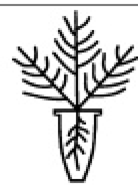
SO. Models for designing the production-distribution system in supply chains of the Finnish nursery industry. Rantala, J. Finnish Forest Research Institute, Research Papers 936. 215 p. 2005. ORDER FROM: The Finnish Forest Research Institute, Library, P.O. Box 18, FIN-01301 Vantaa, Finland. E-mail: kirjasto@metla.fi.

Container Production



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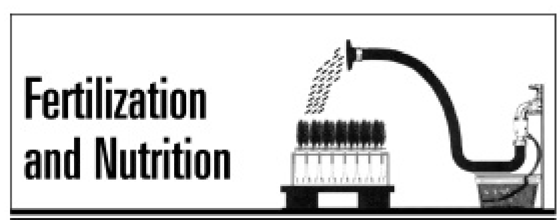

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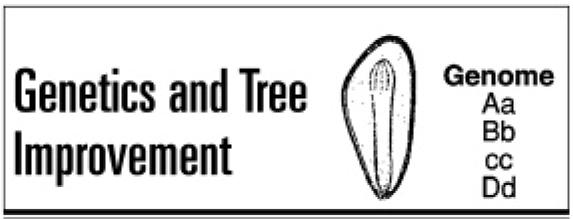

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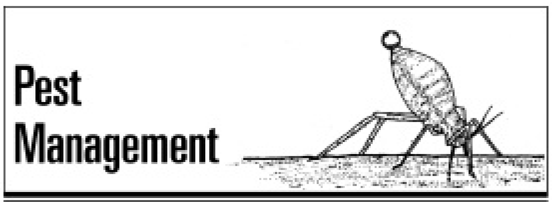

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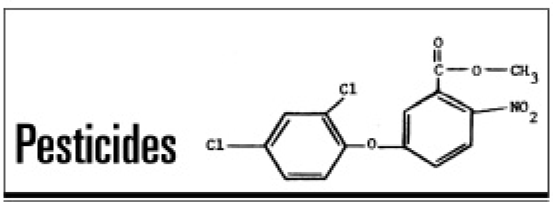

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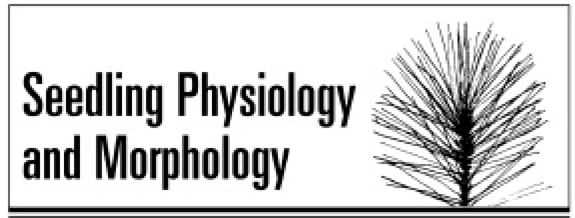

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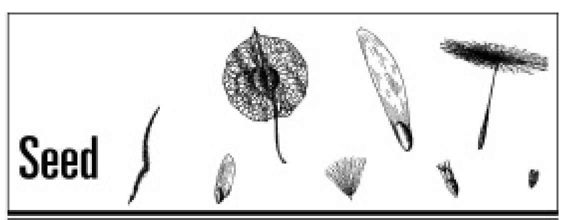

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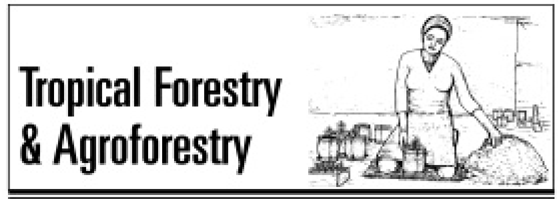

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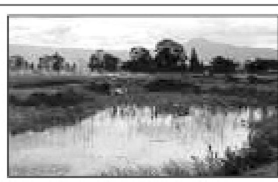

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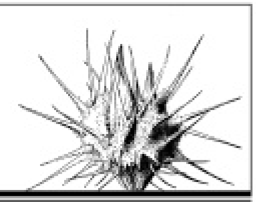

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Nursery Directory Form

The Reforestation, Nurseries, and Genetic Resources (RNGR) Home Page (http://www.rngr.net) contains a state-by-state directory of forest and conservation nurseries. There is also a list of nurseries that specialize in native plants in the Native Plant Network section. Use the following form to add your nursery to the directory, or update your listing. Note that we can list your E-mail and WWW home page address so that customers can contact you directly. Send this form back with your literature order form or fax it to: 541.858.6110.

Example:

Utah	**Updated: December, 1999**			
Nursery Name & Address	Ownership Type	Stock Type	Current Season Seedling Distribution	Potential Seedling Distribution
WWW:http://www.nr.state.ut.us/slf/lonepeak/home.htm Lone Peak Conservation Center 271 West Bitterbrush Lane Draper, UT 87020-9599 TEL: 801.571.0900 FAX: 801.571.0468 E-mail: nrslf.szeidler@state.ut.us		Bareroot	400,000	800,000
		Container	200,000	210,000

Your Nursery:

Your State	**Updated:**			
Nursery Name & Address	Ownership Type	Stock Type	Current Season Seedling Distribution	Potential Seedling Distribution

RNGR Contacts

Contact Information for Reforestation, Nurseries, and Genetic Resources (RNGR) Team

Technology Transfer Services	Region of Responsibility	Who To Contact
Technical Assistance about Forest and Conservation Nurseries	Western US	To Be Determined
National Nursery Specialist Forest Nursery Notes Container Tree Nursery Manual Proceedings of Nursery Meetings Native Plants Journal	US and International	Kas Dumroese USDA Forest Service 1221 S. Main Street Moscow, ID 83843 TEL: 208.883.2324 FAX: 208.885.2318 E-Mail: kdumroese@fs.fed.us
Technical Assistance about Tree Improvement and Genetic Resources Technical Assistance about Forest and Conservation Nurseries	Southeastern US	George Hernandez USDA Forest Service Cooperative Forestry 1720 Peachtree Road NW, Suite 811N Atlanta, GA 30367 TEL: 404.347.3554 FAX: 404.347.2776 E-Mail: ghernandez@fs.fed.us
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