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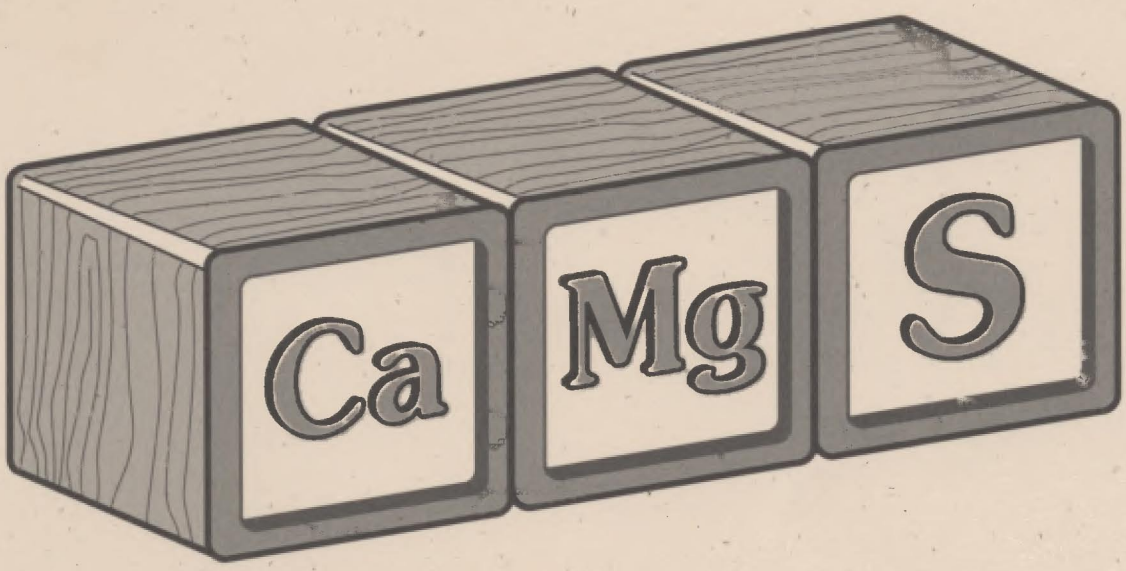

Alternative Sources of Secondary Macronutrients

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A New Western Nursery Specialist

Hello, my name is Gabriela Buamscha and since last March I am Tom Landis' successor as the Western Nursery Specialist for the USDA Forest Service. I work in State and Private Forestry and am based at the Regional Office in downtown Portland, Oregon. The main duties of my job include technical assistance and technology transfer to native plant nurseries in 17 Western U.S. states and the Pacific Islands. I am also a member of the Reforestation, Nurseries, and Genetic Resources (RNGR) Team. This is a national team whose members are George Hernandez, Kas Dumroese, Jeremy Pinto, Ron Overton, and Bob Karrfalt. One of the unique attributes of the RNGR Team is the ability to share expertise across Forest Service deputy areas.

The intention of this update is to let you know how I spent my time in the last four months and some of the projects I will be working on during 2008. So far, I have visited State, Federal, and private nurseries in Oregon, Washington, California, Nevada, Idaho, and Montana. I attended the Westside Greenhouse Growers, Northeast Forest & Conservation Nursery Association, and the Intertribal Nursery Meetings. In the coming months, I will visit tribal nurseries in Washington, Oregon, and California. I am hoping to bring along Jeremy Pinto, our Native American Nursery Specialist. My short-term goal is to visit nurseries throughout my assigned territory, get acquainted with the people I will be assisting, and assess needs. I am also getting acquainted with research peers working in nursery production, plant pathology, reforestation, restoration, and forest genetics. I am planning on building a strong and efficient network of collaborators.

During my previous tours, several people showed interest in strategies to save energy costs at their nursery. Others have requested information on alternative energies for operating greenhouses and other nursery structures and equipment. As a consequence, I am in the initial stages of a project whose objectives are to: (1) compile available information on technology and practices to reduce energy costs in a nursery using conventional energy sources; (2) identify nurseries that have implemented alternative energies (solar, wind, geothermal, etc.), as well as universities and government agencies conducting research on the subject; and (3) gather information on sources of grant money specific to private, tribal, and state nurseries. The final outcome of this project will be a workshop on energy efficiency and alternative energies for nurseries. Current project collaborators include the Washington State University Energy Program, Missoula Technology Development Center, and agricultural engineers. Nevertheless, I welcome anyone who would like to offer ideas and suggestions. Any ideas on speakers for the energy workshop would be more than appreciated.

And, that is just the beginning! I'll be updating you in future FNN issues. Please do not hesitate to contact me if you have any questions or suggestions.

Cheers, Gabriela

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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 57th Annual Meeting of the **Eastern Region of the International Plant Proagators' Society** takes place at the Hyatt Regency Montreal, Montreal, Quebec on **September 16 to September 19, 2007.** The meeting theme is **Look to the Future: Trends, Challenges and Opportunities.** For more information contact:

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URL: http://www.ipps.org/EasternNA/meeting.htm

The Forest Nursery Association of British Columbia (FNABC) will host a joint conference with the Western Forest and Conservation Nursery Association (WFCNA) on **September 17 to September 19, 2007.** The conference will take place in Sydney, BC at the Mary Winspear Centre (http://www.sanscha.com). For more information please contact:

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The Society for Ecological Restoration Northwest Chapter (SERNW) and the Society for Wetland Scientists Pacific Northwest Chapter (SWS) will be holding a joint Annual Meeting at the Yakima Convention Center, Yakima, WA on **September 25 to September 28, 2007.** Sessions will feature an array of topics pertinent to restoration of plant communities in the Pacific Northwest. For information on submission of titles for presentations or posters or for additional information about the meeting, contact:

Jim Hansen (SERNW)
TEL: 509.454.6573
Email: jimbobtoo@aol.com
or
Jim Wiggins (SWS)
Tel: 360.856.2139
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The meeting agenda will be available at a later date on the web:
http://www.ser.org/sernw/calendar.asp

The 48th Annual Meeting of the Western Region **International Plant Propagators' Society** will be held at the new Salem Conference Center in **Salem, Oregon** on **October 17 to October 20, 2007.** "It's a Jungle Out There, Let's Propagate It!" is the meeting theme. For more information contact:

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The Southern Region of the **International Plant Propagators' Society** will hold their 32nd Annual Meeting **October 29 to October 31, 2007** at the Chattanooga Mariott in **Chattanooga, Tennessee.** For registration and other information write or call:

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On **November 7, 2007,** the **Forest Seedling Quality Workshop** is being presented by the Nursery Technology Cooperative of Oregon State University in Corvallis, OR. This hands-on workshop will cover several areas of forest seedling quality assessment including cold hardiness, root growth potential, mineral nutrition, bud development, plant moisture stress, and seedling morphology. Participants will have a rare opportunity to see these techniques first-hand, and to learn about their application in the nursery or on the outplanting site. Registration will be limited. For further information, contact:

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The **Fourth Pacific Northwest Native Plants Conference** will be held on **November 28 to 29, 2007** at the Hilton Conference Center in Eugene, OR. This event is hosted every three years by the Nursery Technology Cooperative at Oregon State University and the Western Forestry and Conservation Association. It will consist of two days of presentations covering the full gamut of propagation, restoration, genetics, invasive plants, landscaping, and more. For further information, contact either:

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Establishing, Culturing, and Harvesting Stooling Beds

Thomas D. Landis and Tara Luna

This is the second article of a two-part series. "New Stock Types and Species from Stooling Beds" was published in the Winter, 2007 issue of FNN, and discussed the advantages of stooling beds, the types of plant materials they can produce, and which plant species can be successfully stooled. In this article, we finish up with how to establish stooling beds, culture them, and harvest the cuttings.

Installing Stooling Beds.

Planning - Stooling beds may take 2 or more years to produce significant numbers of harvestable cuttings, depending on species, clone, management practices, and length of growing season. In Colorado, 2 acres of stooling beds of *Salix* (willow) and *Populus* (cottonwood) yield 100,000 to 200,000 cuttings each year (Grubb 2007). In Saskatchewan, one acre of hybric poplar stooling beds can produce anywhere from 154,000 to 348,000 cuttings per year. The beds remain productive for 4 to 8 years, after which vigor and productivity start to decline, and new mother plants should be established (Saskatchewan Forest Centre 2003). Other conservation nurseries have maintained stooling beds of *Salix* and *Populus* clones for **12** to **15** years without losses in vigor.

Factors that must be considered when selecting an area of the nursery for stooling beds include soil conditions, species characteristics, type of plant material, and whether the beds will be maintained manually or with tractor-drawn equipment. The literature states that "nursery soils must be fertile and well drained" but stooling beds are much less demanding than other nursery crops. Productive stooling beds of cottonwood and willow have been established on silt, clay, or rocky soils that are unsuitable for raising seedlings and, as long as irrigation is provided, stooling beds will also do well on sandy soils. A major consideration when planning stooling beds is access during the winter harvesting season. If the cuttings will be harvested mechanically then soils should be well drained to allow tractor access. This is less of a concern in northern climates, where soils remain frozen and can easily support machinery. Where stooling beds will be harvested by hand, row spacing can be much closer and beds can even be established on slopes.

Species growth characteristics must also be considered during the planning process. With dioecious plants including willow and cottowood, it is important to collect cuttings from both male and female plants in the field to ensure good sexual diversity in the stooling beds (Landis and others 2003).

The growth habits of some willow and cottonwood limit their use in stooling bed propagation. For instance, coyote willow *(S. exigua)* produces aggressive lateral suckers and so cannot be cultured in standard rows. The Colorado State Forest Service Nursery grows this species in two 0.5-acre fields in which plants grow freely. The plants grow for 2 years before the first harvest to all allow the cuttings to reach shippable size. Then the fields are harvested every other year.

Figure 1 - The design of stooling beds depends on several factors including the type of plant material desired, and whether machinery will be used for culturing and harvesting. For typical cuttings, single rows and wide aisles allow mechanical harvest from the sides (A). For larger poles, blocks consist of rows of plants in wider blocks (B). Photo A courtesy of Big Sioux Nursery.

Narrowleaf cottonwood *(Populus angustifolia)* is also not grown in typical stooling beds. Production blocks consist of rows of 3 to 6 inch (8 to14 cm) trees which are 10 to 16 ft (3 to 5 m) tall. The tree branches and terminal shoots are manually cut back to the stem each winter during dormancy to harvest hardwood cuttings; this type of culture is very similar to pollarding (Grubb 2007).

The type of cutting to be harvested will also affect the design of stooling bed blocks. For typical hardwood cuttings, plants are grown in single rows and spaced so that harvesting can be done from all sides (Figure 1A). Specialty products like poles of tree willows and cottonwoods require wider blocks of more closely-spaced rows (Figure 1B).

Before planting a stooling bed, soils are usually prepared well in advance. Soil for stooling beds should be ripped to break-up hardpan layers and then roto-tilled to break up clods. In some cases, it may be necessary to apply herbicides the year before establishment to kill stubborn weeds and lower the weed seed reservoir in the soil.

Row and Plant Spacing - For willows and cottonwoods, stooling beds are usually established with nonrooted hardwood cuttings but seedlings or rooted container cuttings would also work. The best season for planting stooling beds is early spring to minimize transplant shock, although with proper care, they could be established throughout the growing season. Approximately 1,000 hybrid poplar cuttings were needed per acre when planting stooling beds on a 3 **x** 12 ft (0.9 x 3.6 m) spacing (Saskatchewan Forest Centre 2003).

Table 1—Information for installing stooling beds of native woody plants of the Pacific Northwest

Plant Species		Spacing of Cuttings within Rows (ft)***	Growth Rate of Sprouts	Height and Width of Established Plants (ft)
Scientific name	**Common Name**			
Baccharis pilularis	Coyote brush	1 to 2	Moderate	6 by 4
Cornus sericea	Red-osier dogwood	2 to 4	Fast	16 by 10
Oemleria cerastiformis	Indian plum	2 to 4	Moderate	16 by 10
Physocarpus capitatus	Pacific ninebark	2 to 4	Moderate to Fast	14 by 8
Philadelphus lewisii	Lewis mock orange	2 to 3	Moderate	10 by 8
Populus trichocarpa	Black cottonwood	3 to 4	Very Fast	150 by 30
Rosa woodsii	Woods' rose	2 to 3	Moderate to Fast	8 by **
Salix amygdaloides	Peachleaf willow	3 to 4	Very Fast	50 by 20
Salix exigua	Coyote willow	3 to 4	Fast	26 by**
Salix lasiolepus	Arroyo willow	3 to 4	Very Fast	35 by 25
Salix scouleriana	Scouler's willow	3 to 4	Very Fast	25 by 16
Spirea douglasii	Douglas spirea	2 to 3	Fast	7 by**
Symphoricarpos albus	Snowberry	2 to 3	Fast	5 by**

*=modified from Crowder and Danis (1999)
**=species that spread laterally by underground shoots or rhizomes
***=lft = 30cm

Many nurseries use a single row system for stooling beds and the spacing of rows and plants within rows varies by species. The spacing between rows will depend on the size of established plants and whether tractor access is desired. If all culturing and harvesting will be done by hand, then rows can be much closer together. The widths and heights for a variety of plant species is provided in Table 1 along with suggested in-row spacings. Mark the beginning and end of each stooling bed with permanent markers and develop detailed maps as you go along. It's a good idea to separate stooling beds of similar appearing clones or ecotypes to avoid possible confusion during mid-winter harvesting (Morgenson 1992).

With some difficult-to-root species such as redstem dogwood *(Corn us sericea),* it may be beneficial to use a rooting hormone to assist in root establishment (Dirr and Heuser 1987). Most *Salix* and *Populus* species have pre-formed root initials present in the stem tissues and will root to high percentages (90% or greater) without hormones. In South Dakota, however, some ecotypes of *Populus deltoides* do not root well (Larson 2007).

Culturing Stooling Beds

Irrigation - Newly established stooling beds must be irrigated frequently to keep the newly transplanted plants or cuttings from drying, and to stimulate production on new roots. Use of a black plastic row covering will help maintain soil moisture and increase the speed of rooting. Established stooling beds of riparian species like willows and cottonwood require very frequent irrigation for optimal growth. Sprinkler irrigation will work but sprinkler heads will need extensions to keep above the height of the rapidly growing plants. For willow stooling beds in Ontario, 1 to 2 inches (25 to 50 mm) of sprinkler irrigation is required per week (Mathers 2003). Drip or flood irrigation is a more water efficient way to irrigate stooling beds.

Fertilization - Nitrogen (N) is the most important mineral nutrient for achieving rapid establishment and growth but should be applied in a balanced fertilizer to avoid excessive vegetative growth (Morgenson 1992). Where soil tests have shown that fertility is naturally high, no fertilizer is usually applied until the newly established plants have put on 4 to 6 inches (10 to 15 cm) of top growth (Mathers 2003). For established stooling beds, fertilization should be based on annual soil testing, and many nurseries apply a balanced fertilizer twice per season. In New Mexico, stooling beds are fertilized twice at a rate of 50 to 75 lb/acre (56 to 84 kg/ha) N and 25 to 50 lb/acre (28 to 56 kg/ha) **P** (Dreesen 2007). Recent research indicates that early spring N provides little benefit and should be delayed until late spring. Foliar applications of N as urea (3% spray) in September have shown to be beneficial and, unlike fall soil N applications, do not delay dormancy nor increase the risk of damage from an early frost (Saskatchewan Forest Centre 2003).

Pest Management - Monitoring for pests on a regular basis is especially important. Both willows and cottonwoods are very susceptible to the stem fungus *Cytospora chrysosperma.* The fungus infects the bark and causes blackstem disease, which can lead to severe losses of cuttings in stooling beds. If infected cuttings are harvested, then the disease can spread during storage. The severity of blackstem diseases increase with the age of the stooling blocks, so it is suggested that stooling blocks not be used for more than 4 to 5 years (University of Illinois 2007).

Populus species are susceptible to cottonwood leaf beetle which can be heavy defoliators. In Colorado, leaf beetles are treated with one application of an imidacloprid insecticide. The difficultly in controlling this insect is that the egg stage appears to be resistant to insecticide treatments. Adults and egg stages of beetle development may be present at the same time and on the same leaf. A new crop of adults will emerge 1 to 3 weeks after initial treatment (Grubb 2007). Both willows and cottonwood are susceptible to leaf rusts and must be treated with fungicides on a regular schedule. Weeds are managed with pre-emergent herbicides, by spot treating with contact herbicides, and regular manual cultivation.

Roguing and Pruning - Unhealthy or diseased plants should be rogued from stooling beds and, if necessary, replaced with vigorous plants. Stooling beds must be cut back every winter, including the first year of establishment, to approximately 4 inches (10 cm) above ground (Figure 2). With some species, pruning too low to the ground will generate shoots the following spring that are prostrate in habit and are difficult to harvest with mechanical equipment (Saskatchewan Forest Centre 2003). Following pruning, some nurseries cover the root crowns with soil or mulch to stimulate more shoots the following season.

Some plants spread laterally by underground stems or rhizomes which can become a management problem. With these species, it may be necessary to laterally prune the edges of the stooling beds with a coulter or vertical blade.

Figure 2 - Stooling beds are harvested by hand or with machinery during the winter dormant period. The Big Sioux Nursery bundles whips together before cutting (A) and then transports the bundles in wooden boxes (B). Lincoln-Oakes Nursery uses a side-mounted harvester that is powered by a tractor (C). Photos A&B by Big Sioux Nursery and C by Greg Morgenson.

Harvesting and Processing

Timing - Hardwood cuttings are harvested from stooling beds when they are fully dormant, which usually means December through early March. Harvesting cuttings early in the dormant period ensures that carbohydrate levels are at their highest, and also allows adequate time for buds to fulfill their chilling requirement. Harvesting early also reduces the chances for winter desiccation, which can seriously reduce rooting percentages (Vanstone and others 1986). Fall watering of woody plants, especially in arid environments, is recommended to alleviate winter desiccation, and should improve the performance of the harvested cuttings.

Harvest Methods - Harvesting is done with everything from simple hand tools to custom fabricated equipment. However they are harvested, special care must be taken to preserve the natural polarity of the cuttings. Some nurseries cut the bottoms of the whips at an angle which establishes the polarity whereas other nurseries mark the tops or bottoms with paint.

Manual harvesting is accomplished with hand pruners, pruning shears, pruning saws, lopping shears, or tractor-mounted sickle bar mowers. After pruning, the whips are placed on trailers and transported to the packing shed for processing. The Big Sioux Nursery in South Dakota has developed an innovative way to speed-up harvesting (Larson 2007). They trap the whips together into tight bunches (Figure 2A) which makes them easier to cut and transport (Figure 2B).

Lincoln-Oakes Nursery in North Dakota has developed a side-mounted mechanical harvester powered by the PTO on a tractor (Morgenson 1992). Whips are severed with a rotating blade and then transported by belts to a person who catches them and places them in large box (Figure 2C).

Once harvested, the whips transported back to an unheated processing area or packing shed. Processing depends on the type of product desired. For propagation cuttings and live stakes, side branches are pruned off the whips that are bunched together and cut to the desired length with a band saw. Care should be taken to select healthy, vigorous material with plenty of vegetative buds. For propagation cuttings, the top ends are usually cut flat (90 degree angle) while the basal end is cut at an angle (45 degrees or less) for easier sticking in the field or greenhouse. The terminal portions of the whips are discarded because they contain flower buds and root poorly. All cutting tools should be sterilized frequently to prevent the spread of diseases, and some nurseries spray or dip the bundles in a Benlate/Thiram solution to prevent storage molds (Morgenson 1992). Finally, the cuttings are collected into bundles and bound with twine, string or even large rubber bands. Be sure to label bundles of cutting with permanent tags that won't fade or be damaged by moisture.

The bundles of cuttings are stored in outdoor heeling-in beds or indoor cooler storage to maintain dormancy until they will be used at the nursery or shipped. Because they can become desiccated, cuttings should be soaked in water for 2 to 3 days to encourage the root initials in the stems to swell (Mathers 2003).

Summary

Stooling beds are an effective way to produce a large number of healthy, vigorous cuttings for use in the nursery or for sale to clients. Compared to field collection, stooling beds ensure that all cuttings will be collected at the proper time and will be of the proper species and genetic source. When properly established and cultured, stooling beds can remain productive for many years.

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Biofumigation - A New Potential Option in Nursery Pest Management

Thomas D. Landis and Nabil Khadduri

We recently became aware of several technical articles on a new technology that might have real applications in both container and bareroot nurseries. A naturally-occurring fungus species *(Muscodor albus)* was recently discovered on a cinnamon tree in a botanical garden in Honduras (Strobel 2006). Another member of the genus *(M roseus)* has also been identified. Clinical trials demonstrate that cultures of these fungi generate a gaseous mixture of bioactive volatile organic compounds (VOCs). These VOCs have been shown to be lethal to a wide variety of plant and human pathogenic fungi (Table 1), as well as some bacteria, nematodes, and insects Although the fungi tested may not be the same species that attack nursery crops, they are very closely related to common nursery pathogens (Figure 1A).

Biofumigation

The term "mycofumigation" is being used to describe the process of inoculating soil and growing media with the beneficial fungus for the purpose of eliminating potential pathogens prior to sowing. Of course, a promising application of this technology would be replace methyl bromide fumigation as a means to control soilborne plant diseases (Figure 1B).

Initial trials with agronomic crops have shown promise in both field and greenhouse applications. AgraQuest is a biotech company from Davis, California is developing and commercializing *M albus* for a variety of agricultural applications. AgraQuest received a conditional U. S – EPA registration for *M albus* products for use in greenhouse soils, agricultural soils and post-harvest decay control in 2005. In recent experiments with sugar beet *(Beta vulgaris)* and eggplant *(Solanum melongena)* seedlings, soil inoculated with several pathogenic fungi was mycofumigated with *M roseus* and *M albus.* After several weeks, the transplanted seedlings were comparable to those growing in autoclaved soil (Stinson and others 2003).

Biofumigation with *M albus* has some exciting advantages but also some challenges. It is an interesting fungus because it produces a white sterile mycelium with no asexual or sexual spores or other reproductive structures such as chlamydospores or sclerotia. This is ideal for a biocontrol agent because the fungus dies as soon as it uses up its food sources, and its VOCs dissipate quickly. On the other hand, one ongoing goal is to optimize delivery of the fungus to nursery seedbeds of container plants to maximize its effectiveness in the root zone.

Trials at Webster Nursery

The Washington State Webster Nursery tentatively plans to test *M albus* as a pre-plant fumigant as part of an alternatives to methyl bromide trial scheduled for 2008. Measurements on 1+0 and 1+1 coastal Douglas-fir *(Pseudotsuga menziesii)* will include pre-and post-fumigation soil pathogen loads, seedling mortality, seedling shoot and root volumes, and shippable seedlings per bed foot.

Summary

Biofumigation with *M albus* is certainly an exciting new development in nursery pest management. It will be interesting to follow the operational nursery trials and I'll keep my eyes open for any new published literature.

Table I—Effects of volative organic compounds of the fungus *(Muscodor albus)* on common fungal pathogens (modified from Strobel 2006)

Fungus	Type of Disease	Viability After 3 Day Exposure	Mycelial Growth After 2 day Exposure *(%)*
Pvthium ultimum	Damping-off; root rot	Dead	0
Phytophthora cinnamomi	Root rot	Dead	0
Rhizoctonia solani	Damping-off; root rot	Dead	0
Fusarium solani	Damping-off; root rot	Alive	19.4
Cercospora beticola	Leaf spot	Alive	17.5

Sources

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Figure 1 - Biofumigation has real potential as an environmentally friendly way to control common nursery diseases such as damping-off (A), and the ultimate application could be to replace the hazardous chemicals used for soil fumigation (B).

Alternative Sources of Secondary Macronutrients

Thomas D. Landis

Conventional fertilization is mainly concerned with the "Big Three" macronutrients - nitrogen, phosphorus, and potassium which together comprise over 75% of the mineral nutrients found in typical plant tissue. So, it's easy to forget about the importance of the "secondary macronutrients" - calcium, magnesium, and sulfur. To make matters worse, the symptoms for these mineral nutrients are not particularly diagnostic. For example, native plant seedlings do not exhibit visible calcium deficiency symptoms such as "blossom end rot" of tomatoes and peppers. In fact, I'm embarrassed to admit that these symptoms in my vegetable garden this spring brought the importance of these nutrients to my attention. After all, I'm supposed to know something about growing plants!

This experience caused me to reevaluate the options for supplying calcium, magnesium and sulfur as fertilizers and, in particular, look for new options for nurseries.

Calcium is seldom in the spotlight in conifer seedling culture because it is found in all but the most acid soils, and also is commonly present in irrigation water. The "lime" that has traditionally been added to nursery soils and incorporated into growing media to raise pH is an excellent source of calcium and magnesium so growers feel that they don't need to worry about this critical nutrient.

Calcium has several critical functions in plant metabolism and structure. Calcium pectate acts as a physical barrier to fungal hyphae penetration and high calcium levels inhibit the polygalacturonase enzyme which fungi, such as *Fusarium* and *Pythium* spp., manufacture to invade plant tissue. This means that young germinating plants should have an immediate source of calcium to ward off disease. In addition, calcium pectate is needed for strong cell walls and so calcium nutrition becomes particularly important during hardening.

Calcium deficiencies can reach severe levels before they are noticed because they occur first in the meristems which are not readily visible - buds are cloaked within other tissues and root tips are buried in the soil (Figure 1A). In the case of root tips, a problem with calcium supply results in a complete cessation of root extension within only a few hours (Figure 1B).

Although magnesium is most well-known as the only metallic constituent of the chlorophyll molecule, this macronutrient has many other physiological functions in plants. Magnesium is found naturally in many bareroot soils and is also common

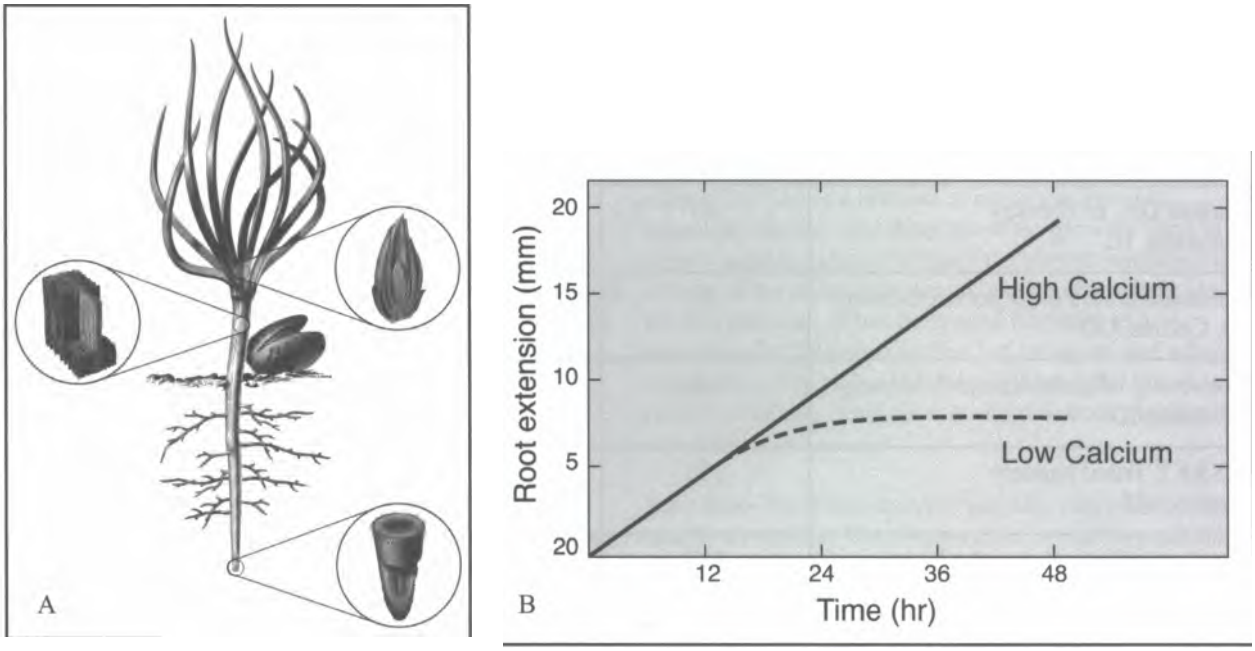

Figure 1- In trees and other native plants, calcium deficiency affects the meristems (A) which are not visible. In the case of root tips, a problem with calcium supply results in a complete cessation of root extension within only a few hours ***(B).***

in irrigation water. In the sandy soils favored for bareroot nurseries, however, heavy rainfall and frequent irrigation can leach the magnesium ions out of the root zone. Because it is a chemical constituent of vermiculite, magnesium is found at low levels in some artificial growing media. However, this is not enough to supply the needs of rapidly growing seedlings.

Foliar chlorosis is the typical symptom of magnesium deficiency, but the position, pattern and timing of the symptoms are not diagnostic in native plants. Because magnesium is mobile within plant tissue, translocation from older to younger foliage will occur, causing deficiencies to show in older tissue first. Note that visual symptoms do not develop until the magnesium deficiency is severe, by then, serious growth loss has already occurred.

Sulfur is rarely applied as a fertilizer in traditional agriculture because it is commonly found in soil minerals and is also supplied in rain and irrigation water. Because sulfur is found in both available and unavailable forms in the soil and the concentrations of these form varies over time, bareroot nurseries shoulc have their soils tested for sulfur on an annual basis to determine if fertilization is warranted. Artificial growing media components like peat moss, vermiculite and perlite contain essentially no available sulfur.

The fact that sulfate is an anion affects its availability in 2 ways: first, elemental sulfur must be oxidized before it can become absorbed, and second, sulfate anions are not strongly held in the soil or growing medium. So, unlike calcium and magnesium which can accumulate on the cation exchange sites in the soil, sulfur leaches readily form the root zone and so must be regularly supplied to a growing crop.

Ways to Supply the Secondary Macronutrients

Irrigation Water - As previously mentioned, irrigation water often contains enough calcium, magnesium, and sulfur to supply plant needs. However, their concentrations vary considerably from nursery to nursery depending on the source of the water and the local geology (Table 1). Because it has had less time to dissolve soluble minerals in the soil, irrigation water that is obtained from surface sources such as streams and ponds will usually have lower soluble salt levels than water from underground sources. The water at many places in the western US is called "hard" because it contains high levels of calcium and magnesium that cause scale to accumulate in pipes and also leaves deposits.

Nurseries with moderately hard water are fortunate because it often supplies all or most of the calcium and magnesium requirements. As you can see in Table 1,

Table 1 - Irrigation water can be a significant source of the secondary macronutrients but the amounts vary considerably from nursery to nursery

Nursery	Total Salts - Electrical Conductivity (msm/cm)	Calcium (ppm)	Magnesium (ppm)	Sulfate - Sulfur (ppm)
Hawaii Div. of Forestry Kamuela, **HI**	40	1	1	1
Colorado State Forest Service Nursery Ft. Collins, CO	58	7	1	11
University of Idaho Research Nursery Moscow, ID	240	25	10	4
CS&KT Tribal Nursery Ronan, MT	280	35	14	1
Los Lunas Plant Materials Center Los Lunas, NM	520	17	5	31
California Div. of Forestry Davis, CA	1610	66	113	315
Target Ranges	**0 to 500**	**40 to 80**	**20 to 40**	**30 to 80**

Figure 2 - Fertigation is the only way to ensure that each container receives the same amount of fertilizers (A). Bareroot nurseries are starting to apply the lessons learned from container culture and applying soluble fertilizers to their fields (B).

however, the base levels of these 2 mineral nutrients in irrigation water varies considerably. The amount of sulfur in irrigation water also varies widely: a recent survey from across the US found that 4% of the water samples contained no sulfur, and another 65% contained less than 10 ppm. Compared to a target level of around 60 ppm, this is too low to supply the needs of rapidly growing seedlings.

Traditional Sources

Dolomitic Limestone in Bareroot and Container Nurseries - This has been the best choice for supplying both calcium and magnesium in both bareroot and container nurseries. In addition, the carbonate ions raise the pH of the soil or growing medium so dolomite is applied to bareroot nursery soils prior to sowing or incorporated into growing media. This practice is effective in bareroot nurseries where plant roots have access to larger soil volumes. Small container plants, however, only have access to a very limited volume of growing medium and problems in even distribution of the dolomite can cause variable growth patterns.

Fertigation in Container Nurseries - Injecting soluble fertilizers is the only way to ensure that calcium and magnesium will be available at the proper concentration and ratio. Custom-mixed fertigation solutions should contain a target concentration of around 80 ppm calcium and 40 **ppm** magnesium with a Ca to Mg ratio between 2:1 and 3:1. Be aware that most commercial soluble and slow-release fertilizers do not contain calcium or magnesium due to problems with solubility in concentrated stock solutions.

Soluble, Readily-available Sources

Progressive nursery managers are realizing that, next to proper irrigation, custom fertilization is the most effective way of increasing the growth rate and quality of their stock. Injecting soluble fertilizers in the irrigation system ("fertigation") ensures that the same amount of soluble fertilizer is applied to each container (Figure 2A). Some progressive bareroot nurseries are starting to apply soluble fertilizers to their crops to ensure that the nutrients are readily available to small, rapidly growing seedlings early in the growing season (Figure 2B).

Compared to the other mineral nutrients, there are fewer soluble options for the secondary macronutrients (Table 2). However, calcium, magnesium, and sulfur can be supplied with only 2 fertilizers: calcium chloride ($CaC1_2$) and epsom salts ($MgSO_4$). Calcium is the most difficult mineral nutrient to supply through fertigation because only two soluble forms are available. Calcium nitrate($CaNO_3$) is a favorite of container growers especially during hardening but often growers want to supply soluble calcium without the growth stimulating effects of the added nitrogen. Calcium chloride is ideal for this purpose. **It** has been used for years as a treatment for "blossom end rot" of tomatoes and other vegetables (Figure 3). Ordinary epsom salts is a cheap, readily available fertilizer that supplies both magnesium and sulfur.

Both these fertilizers are very soluble, inexpensive, and readily available. The only caution is that they should not be tank-mixed because of solubility problems.

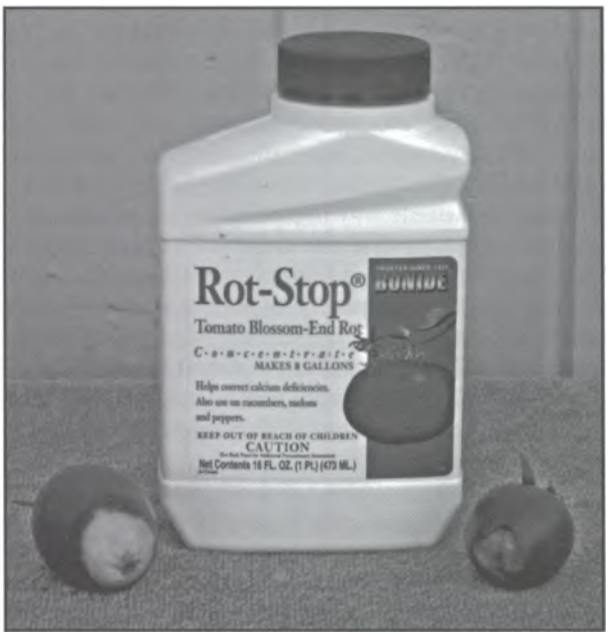

Figure 3 - Calcium chloride is widely used as a foliar treatment for the physiological disease known as "blossom end rot" of tomatoes, but this fertilizer is not commonly used in native plant nurseries.

Summary

Because they are often found in irrigation water, the secondary macronutrients are often overlooked by nursery managers. Adequate supplies of calcium, magnesium, and sulfur should be made available to young developing seedlings. In particular, a ready source of calcium is needed for new root growth and also inhibits damping-off and other root rot fungi. Fortunately, all 3 secondary macronutrients can be easily supplied to both bareroot and container crops through fertigation with calcium chloride and epsom salts.

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Testing Irrigation Sprinkler Systems

Thomas D. Landis and Ron Overton

Overhead sprinklers are the most common irrigation method in both bareroot and container nurseries. Bareroot nurseries typically use rotary sprinklers that are spaced in some regular geometric pattern. Fixed sprinkler systems are also commin container nurseries, although some have mobile irrigation booms. The spacing of the individual sprinkler heads is determined by the engineering specifications of the nozzle, the water pressure at the head, and anticipated wind speed and direction.

Fixed sprinkler systems have a couple of inherent flaws. All sprinkler heads apply water in a circular area, but there is always some amount of variation from the center of the head out to the outer edge of the circle (Figure 1A). Irrigation equipment manufacturers try to compensate for this by equipping their nozzles with spinners, wobblers, pin points, and so on to their heads to help break up and spread the flow of water. In spite of these engineering features, variation in water application always occurs with the circular application area.

Secondly, both bareroot and container nurseries are divided into rectangular zones or bays that are controlled by a valve. This means, you are attempting to irrigate a rectangular area with a bunch of circles. To demonstrate the difficulty of getting uniform irrigation onto your zones try drawing a bunch of circles within a rectangle so that the surface of the rectangle is covered but no circle overlaps the other (Figure 1B).

Both new and existing irrigation systems should be tested periodically to see if they are performing properly. Many nursery managers assume that a new system will perform according to the engineering specifications, but this should be checked under normal operating conditions. Fischer (1987) found that theoretical irrigation patterns differed from operational patterns and attributes this discrepancy to 2 factors:

1. The theoretical patterns assume that the water pressure will be identical at each nozzle, which is impossible because of pressure losses within the lateral distribution lines.

2. Droplet collision between adjacent sprinklers will affect distribution.

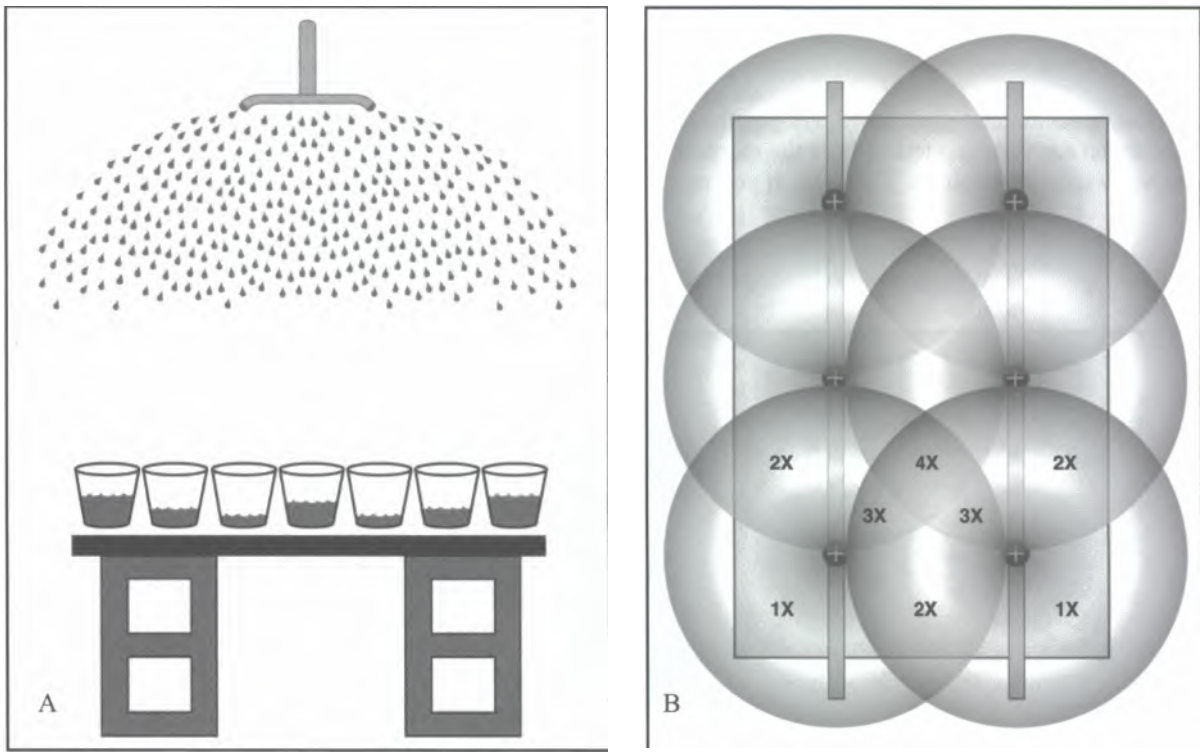

Figure 1—Because all sprinklers apply water irregularly (A), they are installed with considerable overlap which creates application rates up to 4 times as much as normal (B).

Table 1—Target values for measures of sprinkler irrigation uniformity (Savory 2006)

Statistic	Container Nursery	Bareroot Nursery
Coefficient of Uniformity	>90%	>85%
Distribution Uniformity	>85%	>75%
Scheduling Coefficient	1.1	<1.3

Existing irrigation systems need to be checked every few months because nozzles can become plugged or worn down to the point that they are no longer operating properly.

The "Cup Test" - This simple but effective procedure involves measuring the depth of water caught in a series of cups or cans laid out on a regular grid system throughout the growing area (Figure 2). Containers for cup tests should have a circular opening that has a narrow rim; the shape of the container below the opening is not important as long as the cup is stable and deep enough to hold several centimeters of water without any splashing losses. Paper or plastic "Dixie" cups will work but will need to weighted down to keep them in place. Use a standard sized weight like a large metal washer so you don't have to remove the weight before measuring water depth.

Of course, wind direction and speed will greatly affect the results so run your cup test early in the morning or whenever winds are minimal. However, if you must irrigate **during** windy periods, then it will be helpful to run another cup test at the standard irrigation time. Once your grid of cups is laid out, run the irrigation system for a predetermined length of time. Measure the depth of water within each cup and record the values on a chart showing cup placement within the grid (Figure 2B).

Analysis of Cup Test Data

The amount of water collected can be converted to water application rate in inches per hour by the following formula (Furuta 1978):

$P = (C \times 3000)i\ (D^2 \times T)$

Where:
P = irrigation water applied per hour in inches
C = average water "caught" in cup (milliliters)
D = inside diameter of cup opening in millimeters
T = time of irrigation period (minutes).

Analysis of irrigation efficiency can be high-tech or

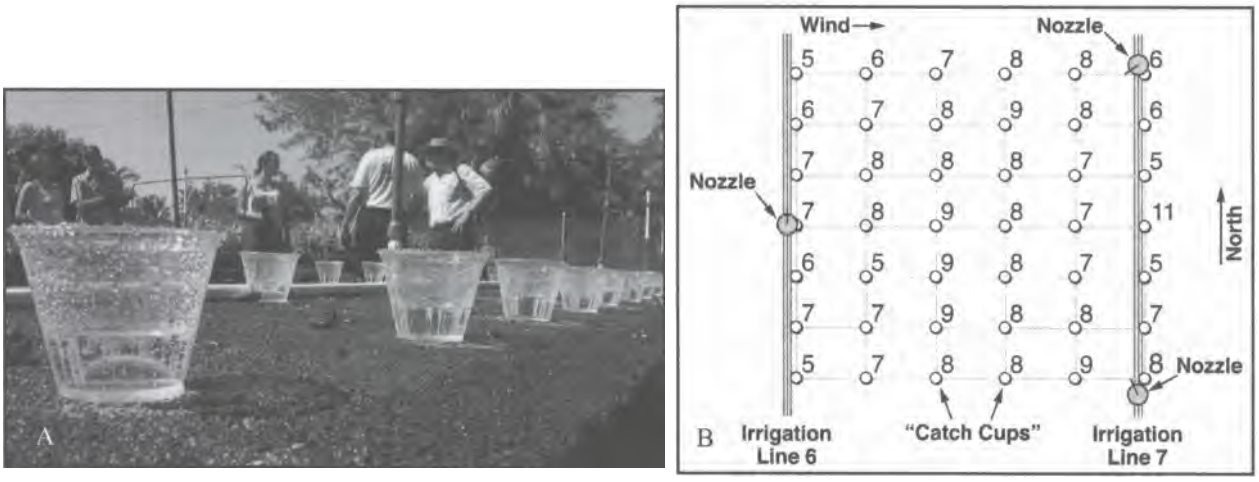

Figure 2—The best way to test irrigation sprinkler efficiency is the "cup test" (A), a regular grid where the depths or volumes of water are measured at each point (B). Photo A by Kim Wilkinson

low-tech. Just looking at the raw collection data will show you where you are over-watering or under-watering. You should also run the cup test values through the standard indices of irrigation efficiency. Target values are provided in Table 1.

Coefficient of Uniformity (CU) - This test, which was originally called Christiansen's coefficient of uniformity, is the most widely used method to evaluate sprinkler efficiency. It is based upon actual measurement of the amount of water collected (the "catch") in the cup test. The CU is a statistical representation of the catch pattern expressed as a percentage, and expresses the average catch minus the average deviation from the average catch to the average catch. Most people measure the depth of water in each cup and calculate the CU as follows:

CU % = 100 (1 - Average Deviation / Average Depth)

Unfortunately, the CU is not a straight-forward measure of the variation within the irrigated area. Because the deviation from the average catch and the catch are both averaged, the full range of deviation between sample individual sample points is not accurately expressed by the CU. This means, if you have a CU of 85%, you can't just increase your watering cycle by 15% to bring the irrigation of the driest points up to the desired level of irrigation. The CU is most useful for evaluating different types of irrigation systems rather than measuring irrigation efficiency.

Distribution Uniformity (DU) - Another common measure of the efficiency of an irrigation system is called the distribution uniformity, and is expressed as a percentage between 0 and 100%. The DU is calculated by dividing the average water depth in the lowest 25% of the cups from the cup test by the average water depth: :

DU % = 100 (Average of Low One-Quarter Readings / Average Depth)

The Distribution Uniformity test can be misleading if the lowest application rates are uniformly spread over the total area.

Scheduling Coefficient (SC) - The scheduling coefficient gives a measure of the additional time required at the area of lowest application (usually measured over 5% of the area) to achieve the average application rate.

A Real World Example

The information in Table 2 is the actual results from a nursery that converted to a new irrigation system. Converting to the new system reduced water application rate and increased irrigation application uniformity in both the greenhouse and the shadehouse. Converting the application rates to yearly water use shows that upgrading your irrigation system can result in substantial savings in water as well as the energy used to pump it. An added side benefit was the reduced amount of water runoff that had to be managed (Messina 2006).

Where to Get Help

Several websites offer help in evaluating irrigation systems. Some offer programs where you can input your cup test data and they will calculate the CU or DU values.

A computer program called SPACE (Sprinkler Profile And Coverage Evaluation) is offered by the Center for Irrigation Technology (CIT) **in** Fresno, California. CIT conducts irrigation equipment testing and evaluation for both public agencies and private businesses and also offer seminars, workshops, study tours and customized training programs for domestic and international clients. Fees for projects are negotiated individually, depending on the type of service and contracting agency. For more information:

Center for Irrigation Technology
California State University Fresno
5370 N. Chestnut Ave.
Fresno, CA 93740-0018
Phone: (559) 278-2066
Fax: (559) 278-6033
Website: http://cati.csufresno.edu/cit

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Successful Trial With Innovative Cold NSure Test on Douglas-fir Seedlings

Monique F. van Wordragen, Peter Balk,
and Diane Haase

Forest tree nurseries rely on a tight scheduling of operations to be able to deliver vigorous seedlings to the planting site. Refrigerated storage is used to maintain planting stock in an inactive condition and to ensure adequate stock availability for geographically distinct planting sites. Cooler and freezer storage has therefore become common practice, but can present challenges. Lifting and storage of insufficiently hardened plants reduces vitality and may lead to cold damage, dehydration, and fungal infection. To prevent this kind of damage, and its adverse economic effects on nurseries and their customers, it is of vital importance to be able to accurately determine seedlings' peak physiological condition for harvesting, storage, or shipping to the field.

The NSure Cold Hardiness Assay

Last year, a new method to measure cold tolerance was introduced by NSure, a spin-off company from Wageningen University in the Netherlands. The test is based on measuring the level of activity of a carefully selected set of genes. Because all physiological responses are started and orchestrated by genes switching on or off, this method can be highly accurate and reliable. In fact, a comparable technology has been used in medical diagnostics for some time now, predominantly for making complex diagnoses such as tumour typing. NSure developed a sampling procedure that enabled the application of this technique in agro-production, because no lab is required.

In the Summer 2006 issue of FNN, an article described this new technology. At that time, NSure had tests available for Scots pine *(Pinus sylvestris),* Norway spruce *(Picea abies),* and European beech *(Fagus sylvatica).* The assay is based on the relative activity of 3 indicator genes that together provide enough information to give an estimate of the cold hardiness stage of the seedling. The corresponding genes dominate

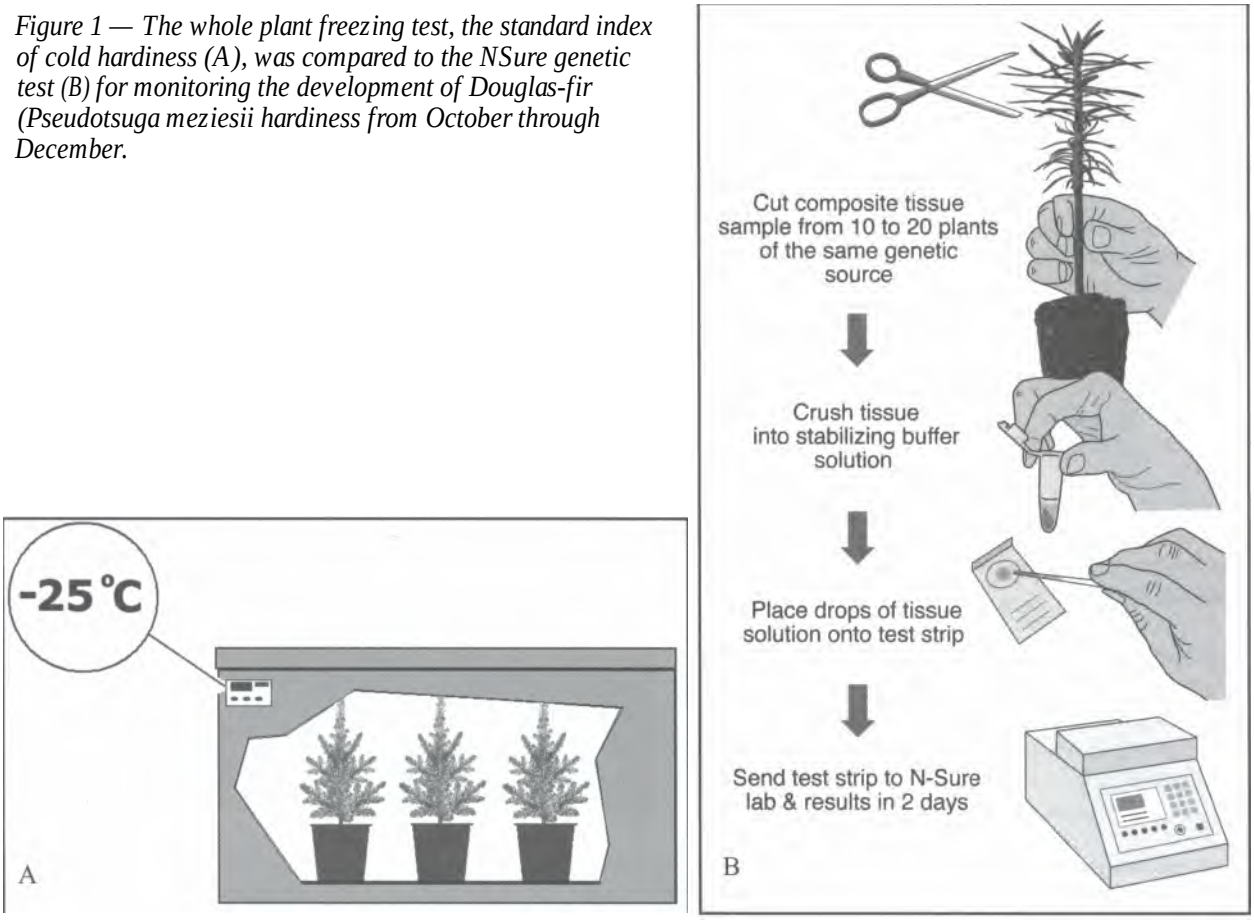

Figure 1 — The whole plant freezing test, the standard index of cold hardiness (A), was compared to the NSure genetic test (B) for monitoring the development of Douglas-fir (Pseudotsuga meziesii hardiness from October through December.

the process of hardiness development in all provenances studied and have a strong positive correlation with shoot electrolyte leakage (SEL) cold hardiness tests. The activity of three of these indicators (2 differentially regulated dehydrin gene family members and one control gene) is measured in the cold hardiness test implemented by the company NSure.

Testing Douglas-fir

Because nurseries from the Pacific Northwest region were interested in this technology, NSure developed a new assay aimed at one of the economically most important species in this region: Douglas-fir *(Pseudotsuga menziesii).* The NSure test was been examined during the 2006-07 season as part of a larger cold hardiness project with the Nursery Technology Cooperative (Dept. of Forest Science, Oregon State University).

Cold hardiness at time of lifting was compared between the Whole Plant Freezer Test (WPFT) and the NSure test across 5 dates (October through December, 2006) for 6 different Douglas-fir seed lots. For the WPFT, seedlings were placed into a programmable chest freezer at 4 target temperatures (Figure **1A).** After freezing, seedlings were placed into a greenhouse with optimal growth conditions for 6 days and then assessed for foliar, bud, and cambial damage to estimate the LT_{10} or LT_{50} (lethal temperature to 10% or 50 % of the seedlings, respectively).

The NSure test was conducted on needles and buds collected from the same seedlings used for the WPFT test. The tissue was processed according to the sampling protocol provided with the Nsure sampling kit. Samples were then sent to The Netherlands for analyses. NSure measured the level of expression of 6 indicator genes and calculated the corresponding hardiness status using models derived from *P. sylvestris and P. abies.*

Results

The results indicate a typical development of cold tolerance as the autumn proceeded as well as differences between seed lots derived from different elevations. The stages of frost tolerance that are distinguished by the NSure method corresponded to different levels of frost tolerance as measured using the WPFT technology.

The NSure assay distinguished 3 stages of frost tolerance. These phases were shown to correlate very well with the **LT** values from the whole plant freezing test (Table 1).

When needles were used, however, the correlation was poor. In contrast to previous findings with Norway spruce and Scots pine, this study indicates that *Pseudotsuga* needles may not be as reliable as test material.

Based on these results the NSure method seems to be a good alternative for cold hardiness assay. The big advantage of the NSure test is that seedlings do not have to be transported to a test laboratory. The samples can be taken and stabilized on site. Any physiological changes occurring in response to transport conditions will therefore not hamper the outcome of the test.

Future Testing

NSure would like to extend the present dataset with samples from the 2007-08 season. Nurseries growing Douglas-fir are therefore encouraged to try the ColdNSure assay this year at a considerably reduced price. A 50% reduction is offered to nurseries that are willing to share information on batch quality with NSure. Especially results of alternative cold hardiness measurements performed on the same batch would be very valuable to NSure.

Table I—Comparison of the NSure assay of Douglas-fir buds and the whole plant freezing test for cold hardiness

NSure Phase	Cold Hardiness from WPFT Measured by LT50	Nursery Application
0	No frost tolerance observed	Seedlings are not hardy
1	23 and 14 °F (-5 and **-10** °C)	Developing hardiness—adequate for short-term cold storage: 33° to 36°F (**1**° to 2°C)
2	Below 14 °F (-10 °C)	Developing hardiness—adequate for long-term freezer storage: 30° to 25 °F (-2° to -4°C)

At present, NSure test facilities are located in Sweden and The Netherlands. Samples must be sent to one of these locations for analyses which will lengthen the response time. NSure is looking for partners, however, to set up a local test lab that will be able to generate a result report within 1 or 2 days after receipt of the sample.

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Horticultural Humor

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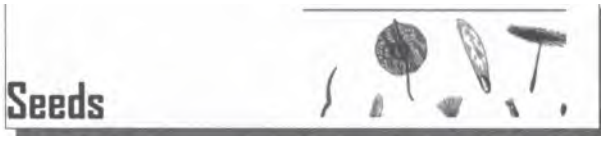

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