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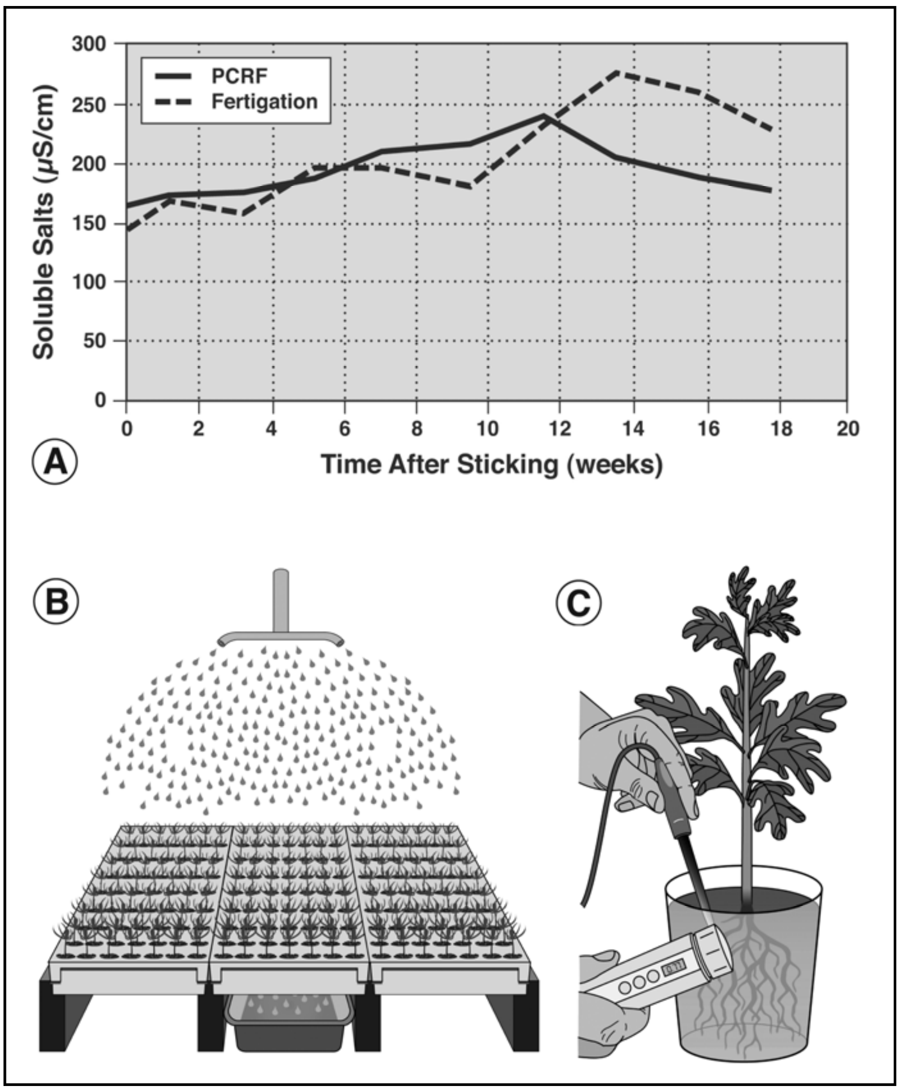

Please send address changes to Rae Watson. You may use the Literature Order Form at the end of the New Nursery Literature section.

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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.

Innovation and New Horizons in tree Nursery Stock Production and Forest Restoration—From Research to Business. This is the title of an International Scientific Conference, organized within the EU FP6 project "Pre-Forest", that will be held in **Rome, Italy from March 12 to March 14, 2009.** This conference is organized in co-operation between Vivai Torsanlorenzo Group, University of Tuscia, Dalarna University and National Agricultural Research Foundation and IUFRO. For more information please contact:

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The USDI Bureau of Land Management and USDA Rocky Mountain Research Station are sponsoring a Workshop: Developing a Successful Native Plant Program on **April 1 to April 2, 2009,** at the Four Rivers Cultural Center, in **Ontario, Oregon.** The program will emphasize native plant materials for the Great Basin and surrounding areas plus seeding equipment and strategies. A complete agenda and lodging information are available at the following website:

http://www.fs.fed.us/rm/boise/research/shrub/projects/Native.pdf

Note: There are no registration fees, but pre-registration is required as space is limited to 150 registrants.

Vegetative propagation and deployment of varieties - the scope for Europe. **Liverpool, England, April 21 to April 23, 2009** Join tree breeders and foresters from across Europe and beyond in what promises to be ***the*** definitive workshop considering the state of play of clonal forestry currently being practiced around the world. Some of the leading practitioners in their field from New Zealand, Canada, USA and at home in Europe - working on both conifer and hardwood species - will outline what they do to make clonal forestry work. The indoor meeting will be held over 3 days. There will be a visit to Delamere Nursery on Day 2 to see large scale production of rooted cuttings from selected full-sibling families.

Please find attached a link to our website giving all the necessary details of the meeting - location, cost and speakers: http://www.forestresearch.gov.uk/fr/INFD-7KHHFW**.** E-mail your registration form (downloadable from the website) to: evelyn.hall@forestry.gsi.gov.uk

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The 7th meeting of the IUFRO Working Group (7.03.04) Disease and Insects in Forest Nurseries will meet in **Hilo, Hawaii, July 10 to July 17, 2009.** Registration and requirements for submission of papers can be found at these websites:

http://www.westernforestry.org/
http://www.iufro.org/auth/science/divisions/division-7/70000/70300/70304/activities/unit/7.03.04/

A joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Grower's Association, and the Intertribal Nursery Council will be held in **Moscow, Idaho, July 14 to July 16, 2009.** For more information please contact:

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Using Polymer-coated Controlled-release Fertilizers in the Nursery and After Outplanting
by Thomas D. Landis and R. Kasten Dumroese

Controlled-release fertilizers (CRF) are the newest and most technically advanced way of supplying mineral nutrients to nursery crops. Compared to conventional fertilizers, their gradual pattern of nutrient release better meets plant needs, minimizes leaching, and therefore improves fertilizer use efficiency. In our review of the literature, we found many terms used interchangeably with controlled-release, such as slow-release, but in this article, we will simply refer to all of them as controlled-release fertilizers (CRF). CRF can be divided into 3 categories based on their coating and nutrient composition:

1. Uncoated, nitrogen-based fertilizers – This oldest class of CRF consists of chemically-bound urea and the release rate is determined by particle size, available water, and microbial decomposition (Goertz 1993). Ureaform and IBDU are examples of uncoated, nitrogen-based fertilizers. With the exception of Agriform® tablets, which have been used at outplanting, this class of CRF is rarely used in forest, conservation, and native plant nurseries.

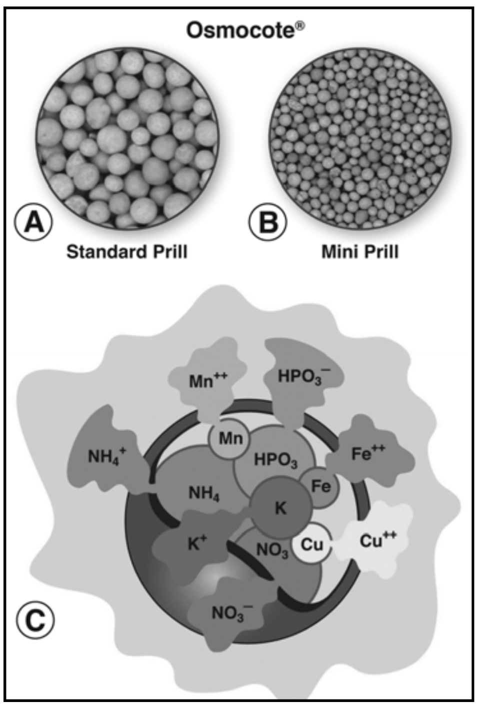

Figure 1 - The individual particles of polymer-coated controlled release fertilizers (PCRF) are called "prills" and consist of soluble fertilizers inside a thin plastic shell (A-B). After water penetrates the prills, soluble nutrient ions move outwards into the soil or growing medium along an osmotic gradient (C). (A and B courtesy of Scott-Sierra®.)

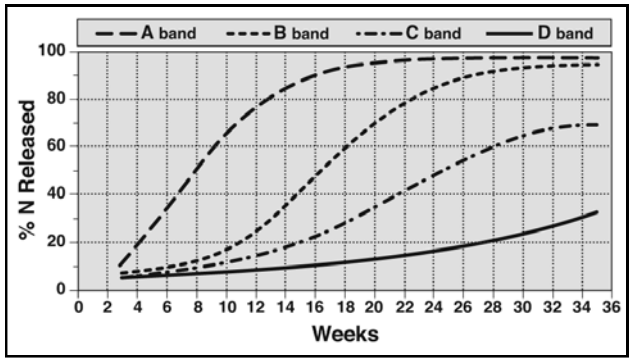

Figure 2 - Nutrient release patterns vary between fertilizer brands and formulations. For example, the nutrients in Osmocote® can be formulated in bands to release faster or slower during the growing season (modified from Hulme and Buchheit 2007).

2. Coated, nitrogen-based fertilizers – Sulfur-coated urea was one of the first CRF and nitrogen release is controlled by the thickness of the sulfur coating (Goertz 1993). Although still used in agriculture, sulfur-coated urea is rarely used in forest, conservation, and native plant nurseries.

3. Polymer-coated multi-nutrient fertilizers – Polymer-coated CRF (PCRF) are the newest and most technically sophisticated fertilizers being used in horticultural plant production, and consist of a core of soluble nutrients surrounded by a polymer coating. Each polymer-coated fertilizer particle is known as a prill" (Figure 1A-B), and nutrient release is precisely controlled by the chemical composition and thickness of the polymer coating. Compared to the previous categories that only supply nitrogen, PCRF supply all 3 "fertilizer elements" (nitrogen [N], phosphorus [P], and potassium [K]), and many formulations include calcium, magnesium, sulfur, and micronutrients. The defining characteristic of PCRF, however, is the sophisticated polymer coatings that gradually release nutrients over extended periods; release rates can be as short as 3 months or as long as 18 months.

Nutrient release from PCRF prills occurs by diffusion through a semi-permeable membrane. The process occurs in 2 stages (Gambash and others 1990). First, when prills are exposed to moisture in the soil or growing medium, water vapor infiltrates into the prill and condenses on the soluble fertilizer salts, creating an increase in osmotic pressure. Second, this elevated pressure within the prill causes the fertilizer ions to diffuse outward into the surrounding medium (Figure 1C) .

Types of Polymer-Coated Controlled-Release Fertilizers

Several different brands of PCRF have been used in forest and conservation nurseries in North America, and they can be categorized by nutrient content, release pattern, and longevity (Jacobs and others 2005).

Osmocote® (Scott-Sierra, Marysville, OH) is one of the oldest PCRF and its coating is classified as a polymeric resin. The coating is applied in several layers, and the relative thickness determines the speed and pattern of nutrient release at 70 °F (21 °C). Osmocote fertilizers are available with release periods from as short as 3 to 4 months to as long as 14 to 16 months (Table 1). One recent innovation is called "patterned nutrient release", which uses specialized formulations called bands to offer specific release patterns (Figure 2). A wide variety of Osmocote PCRF is available for different crops and production cycles including a "miniprill" formulation (Figure 1B) for small volume containers and miniplugs (Scotts Horticulture 2008). Although more expensive, the smaller miniprills improved distribution between containers by 5-fold and reduced problems with uneven growth (Drahn 2007).

Apex® (J.R. Simplot, Boise, ID) uses the Polyon® Reactive Layers Coating (RLC™) process that applies 2 reactive monomers over the fertilizer core in a continuous coating drum, resulting in an ultrathin polyurethane membrane coating. The result is a PCRF that delivers nutrients through a solute concentration gradient permeation process that is unaffected by soil moisture, microbial activity, or pH levels. A variety of Apex formulations are available to meet the specific needs of conifers, woody plants, and native plants (Table 1). One formulation, Apex Native, is specially formulated for plants that are sensitive to high rates of P, and therefore aids in the colonization of mycorhizal fungi (Simplot 2008).

Multicote® and **Nutricote**® (Sun Gro Horticulture, Bellevue, WA) uses thermoplastic resin coatings blended with special release-controlling agents to determine the nutrient release rate and longevity. Sun Gro markets 2 brands of PCRF—Multicote® in the U.S. and Canada, and Nutricote®, which is only available in the western U.S. (Sun Gro Horticulture 2008). Multicote® is available in a wide variety of nutrient formulations with release rates from 4 to 16 months (Table 1).

Diffusion® (Green Valley Agricultural, Caledonia, MI) PCRF are customized for different temperature zones, and come in many nutrient formulations with longevities from 3 to 9 months (Green Valley Agricultural 2008).

Table 1 - Macro nutrient composition (N-P-K) and longevity of polymer-coated controlled release fertilizers commonly used in forest and native plant nurseries *

Longevity at 70 °F (21 °C)	Osmocote Classic®	Apex®	Multicote®	Diffusion ®
3 to 4 mos	14-14-14 19-6-12		15-7-15	17-6-17 18-6-18 22-2-3
5 to 6 mos			15-7-15	17-6-17 18-5-18 22-4-9
8 to 10 mos	13-13-13 19-6-12	13-13-13 16-8-16 18-6-12 19-8-12 21-2-11	15-7-15 17-7-14 20-6-12	17-6-17 18-4-18 22-4-8
12 to 14 mos	19-6-12	17-6-12	14-7-14 17-6-14 20-5-12	
14 to 16 mos	19-6-12	16-5-11	14-7-14 17-5-14 20-5-10	

* = modified from www.scottsprohort.com, www.simplot.com, www.sungro.com, www.diffusionfertilizer.com

Because CRF technology is continually evolving and fertilizer manufacturers are constantly improving the nutrient content and release characteristics of their products, we stress that growers should consult company internet sites for the latest information.

Advantages of Using Polymer-Coated Controlled-Release Fertilizers

Polymer-coated controlled release fertilizers offer several advantages to nurseries, especially those that grow small lots of many species or ecotypes:

Easy to adjust fertilization type and rate for different crops - With the wide variety of N-P-K formulations and nutrient release timings, growers can easily customize their fertilization programs. By incorporating different PCRF into the soil or batches of growing media, different species or ecotypes can receive the proper amount of fertilizer at the proper time.

Better fertilizer use efficiency - Placing the fertilizer directly in the root zone is much more efficient than liquid fertilization that is lost when sprayed on benches or walkways, runs off the foliage, or drips through openings in containers. This is particularly true with broadleaved species that shed a high percentage of applied fertigation. PCRF are ideal for open compounds in rainy climates where applying liquid fertilization to already wet plugs is very inefficient.

Less fertilizer pollution in wastewater - Fertilizers in nursery runoff, especially N and P, lead to eutrophication in ditches and ponds. These excess nutrients promote the growth of moss and algae on the surface of soils, growing medium, and floors. Weeds are stimulated by non-target nutrients, and moist, nutrient rich environments are ideal for nursery pests such as fungus gnats.

No rinsing required after fertilization - After fertigation, the concentrated fertilizer solutions need to be rinsed off plant foliage to prevent burning (Drahn 2007). This extra irrigation can cause more nutrients to leach from the medium and keeps humidity high in the growing area, which can create disease problems during cloudy, cool weather.

Nutrients present at root initiation - When rooting cuttings, incorporating PCRF into the rooting medium ensures that nutrients will be available as soon as roots form. This is preferable to fertigation that can keep the medium too damp and discourage root formation (Drahn 2007).

Fertilizer reserves for after sale or outplanting - Using long-term PCRF in growing media ensures that plugs will be delivered to the customer with a nutrient reserve (Drahn 2007). For forestry applications, the benefit of this reserve depends on moisture condition on the outplanting site. For example, incorporation of Apex 14 to16 month PCRF in the plugs of Douglas-fir (*Pseudotsuga menziesii*) seedlings produced significant growth benefits for 2 to 3 years after outplanting on wet sites. However, on a drier site, initial survival of fertilized Douglas-fir and ponderosa pine (*Pinus ponderosa*) seedlings was significantly less than nonfertilized controls and growth after 2 years was the same with or without PCRF (Jacobs and others 2003b).

Cultural Advantages when Using Polymer-Coated Controlled-Release Fertilizers

Application method - For the larger volume containers used in ornamental nurseries, PCRF are applied in 2 ways: incorporation into the growing medium at the time of sowing, and top-dressings during the growing season. Incorporation into growing media is by far the most common way of using PCRF in the smaller containers used in forest, conservation, and native plant nurseries. Growers should be mindful of 2 concerns when incorporating PCRF into growing media. The first concern is to ensure that the small prills are even distributed so that each container has the same number. This becomes very problematic with small volume miniplugs, which is why Scotts developed Osmocote® Miniprill formulations (Figure 1B). Counting the number of prills per container or volume of growing media is extremely tedious, but some soil and plant testing laboratories (www.mmilabs.com or www.qal.us) will perform this service on a fee basis (Pilon and Passchier 2007). The second concern is mechanical damage to the prills that can occur when they are mixed with the growing medium. Overmixing in cement mixers or other mechanical mixers may rupture the polymer-coating and cause an immediate release of fertilizer salts that will not only damage the mixer but, more importantly, may kill young germinating seedlings or newly-struck cuttings. Having PCRF incorporated with a ribbon-type mixer is the best way to make sure that the prills are evenly distributed and not damaged during the process. Prill damage can be monitored by taking electrical conductivity measurements of a sample of the growing medium before sowing. This type of testing is discussed in detail in a subsequent section.

During outplanting, PCRF may be placed under or near plants (Jacobs and others 2003b). Some researchers recommend placing PCRF in the bottom of the planting hole, which ensures that released nutrients will be easily accessible to the plant (Gleason and others 1990). Other applications include applying the PCRF in a dibbled hole alongside the plant or broadcasting it around its base. To minimize the possibility of fertilizer burn to roots and prevent the nutrients from being "stolen" by competing vegetation, the side application makes the most sense.

Variable nutrient release - Laboratory testing in sand columns has shown that the major environmental factor controlling the pattern and longevity of nutrient release from PCRF is the temperature of the soil or growing medium. Most PCRF are based on a standard 70 ºF (21 ºC) benchmark and nutrient release increases or decreases as soil or growing medium temperatures change. Laboratory tests also show that soil moisture has a relatively minor influence on nutrient release within the range typically maintained in container seedling production (Kochba and others 1990). In actual practice, however, nutrients will continue to move outward from the prill as long as an osmotic gradient exists. As the nutrient ions are taken-up by plant roots or leach downward with irrigation, the osmotic gradient becomes higher and more nutrient ions are released (Huett and Gogel 2000). Leaching tests have shown that a certain proportion of total nutrients (10 to 20%) may never release from the PCRF prills because the internal osmotic pressure within the prill decreases as most nutrients are released (Jacobs 2005).

When the leaching patterns of 3 brands of PCRF were tested in sand columns (Huett and Gogel 2000), the time to 90% nutrient release varied among products (Figure 3A). The nutrient release rate was also different for N, P, and K, which can affect crop development. The slower release of P could be problematic because young plants have a high requirement for P early in the growing season. This was confirmed in another leaching trial which concluded that, when PCRF are used, another supplemental source of fertilizer P may be required for early in the growing season (Handreck 1997)

Sand column research is one thing, but nutrient release patterns in soil or growing media could be radically different because of differential adsorption of mineral nutrients on cation exchange sites. The Nursery Technology Cooperative at Oregon State University buried plastic mesh bags containing PCRF in forest soil and monitored the release of mineral nutrients for more than a year (Haase and others 2007). Like the sand column studies, they found that the different macronutrients had different release rates with N being released the fastest and P the slowest (Figure 3B). The release rate of micronutrients was almost nil and the prill content of iron, manganese, zinc, and molybdenum had decreased very

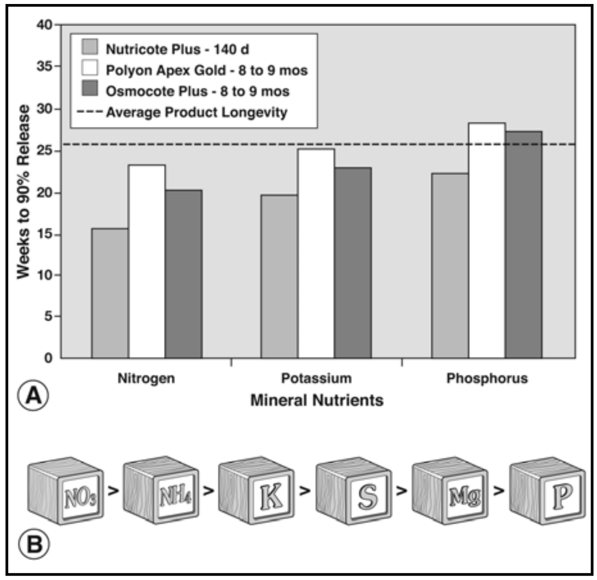

Figure 3 - The nutrient release rates were different for 3 brands of polymer-coated controlled- release fertilizers but, in each, phosphorus was released much slower than nitrogen or potassium (A). When the fertilizers were buried in soil, nitrogen ions were released fastest and phosphorus was again the slowest (B). (A - modified from Huett and Gogel 2000, and B - modified from Haase and others 2007).

little from their initial levels. They hypothesized that P was inactivated by forming insoluble compounds with the metal micronutrients which remained in the prill membrane.

The possibility of the slow release of P affecting plant uptake was confirmed when Douglas-fir seedlings were fertilized with 3 rates of Osmocote; the foliar N concentration increased with fertilization but foliar P decreased (Jacobs and others 2003a). As mentioned earlier, this can be compensated for by incorporating another source of P fertilizer such as concentrated superphoshate (Handreck 1997) or, for container stock, injecting phosphoric acid into the irrigation system. Of course, the ultimate way to determine if mineral nutrients are being used by plants is to have foliar samples analyzed throughout the growing season (Landis and others 2005).

Premature nutrient release causes fertilizer "burn" - Research has shown that when PCRF prills are surrounded by a slightly moist medium they begin nutrient release, which accelerates under warm conditions. Therefore, PCRF should not be incorporated into growing media more than about 2 weeks before it is used. Otherwise, salts can build-up and cause fertilizer burn when seeds begin to germinate or cuttings begin to root

Table 2 - Comparison of various techniques of measuring electrical conductivity *

EC Technique	EC Readings (µS/cm)				Containers	Soil	PCRF
Saturated Media Extract	1,000	2,000	3,000	4,000	All but Miniplugs	Yes	Yes **
1:2 Dilution	300	700	1,200	1,600	All but Miniplugs	Yes	No
Pour-Through	1,500	2,800	4,200	5,500	All but Miniplugs & Very Large Sizes	No	Yes
Plug Squeeze	1,300	2,700	4,100	5,600	Jiffy, Cone-tainers, Rootrain-ers, Miniplugs	No	No
Direct Sensor	700	1,300	1,800	2,400	All but Miniplugs	Yes	Yes

* modified from Fisher and others 2006 ** = vacuum extraction, not squeezing

(Huett and Gogel 2000). Another potential problem is release of salts when container plants with incorporated PCRF are kept under long-term refrigerated storage. Even though the temperatures are very low, the root plugs are moist and fertilizer salt levels can reach damaging levels, which has been observed during operational cold storage and during a research trial. Ponderosa pine container seedlings were grown with moderate release (12 to 14 mo) or slow release (16 to 20 mo) PCRF and then harvested and stored under refrigeration at 33 °F (0.5 °C) for about 4 months. When a sample of the stored seedlings were subjected to a root growth capacity test, the roots in many of the plugs were completely killed (Fan and others 2004). This type of damage would be hard to detect without the root tests, and affected seedlings could be transplanted or outplanted without any awareness of the problem. Obviously, more research into this potential problem is needed.

Monitoring nutrient levels with PCRF - The best way to avoid problems with PCRF or any fertilizer is through regular monitoring. All mineral nutrients are taken-up from the solution in the soil or growing medium as fertilizer salts. Therefore, the relative concentration of fertilizer salts can be measured with an electrical conductivity (EC) meter. For PCRF, this allows the grower to monitor precisely when fertilizer is being released from the prills, and Bilderback (2008) recommends that the EC should remain in the range of 200 to 500 µS/cm. It's a good idea to measure EC at least once a month, especially with small containers, and more often during hot and dry periods. The ideal situation is to plot EC readings over the course of the growing season to keep track of trends, especially of any accumulation of salts due to insufficient leaching (Figure 4A).

EC can be measured by several different techniques, but the saturated media extract remains the standard (Landis and Dumroese 2006). Note this restriction on monitoring EC in growing media with incorporated PCRF: any compression or squeezing of the amended medium will force extra nutrients out of the prills and provide erroneous results (Table 2). Catching leachate under the container or using the pour-through technique are good ways to keep track of EC trends for an entire block (Figure 4B**)** but the readings are just an average of conditions in the various cells. Using a direct sensor is quick and effective in larger containers (Figure 4C) but the probes are too large for use in miniplugs. With sensors, it's critical to always measure EC at the same moisture content, such as an hour after irrigation (Scoggins and van Iersel 2006).

Using Polymer-Coated Controlled-Release Fertilizers in Bareroot Nurseries

By far, the most work has been done with PCRF in container plants but this type of fertilization also has application in field soils. In a Wisconsin bareroot nursery, crops of red pine (*Pinus resinosa*), jack pine (*Pinus*

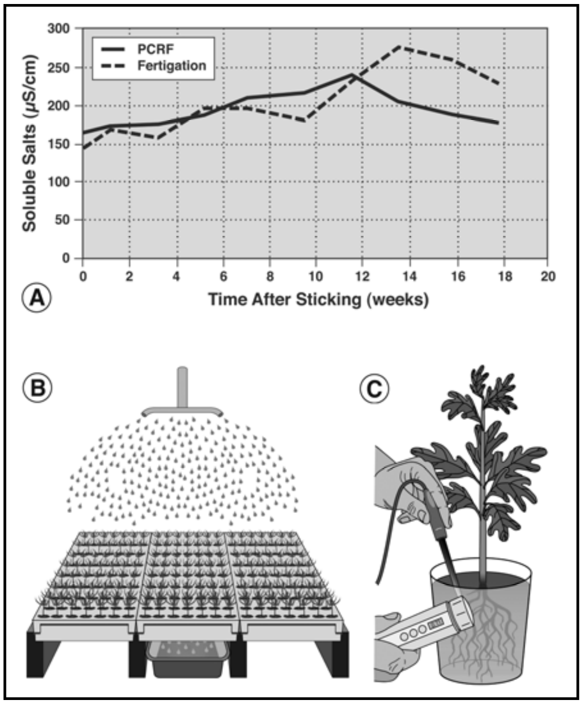

Figure 4 - Measuring the electrical conductivity of the soil or growing medium is the best way to monitor the effectiveness of polymer-coated controlled-release fertilizers (A). Because extra fertilizer can be squeezed out of the prills, catching leachate (B) or using the pour-through technique is best for smaller-volume containers. In larger containers and soil, EC can be measured directly with new sensors as long as the measurements are always taken at the same moisture content (C).

banksiana), white spruce (*Picea glauca*), and other conifers are grown on a 2-year schedule. Initial trials with top-dressing Polyon® PCRF had 2 main drawbacks: 1) prills became sticky and didn't flow well through a typical drop-type fertilizer spreader; and 2) heavy rains washed the prills from the raised seedbeds into the tractor paths. Switching fertilizer brands to Diffusion® (Wilbur-Ellis Company, San Francisco, CA) solved the first problem because the coating did not gum up the fertilizer spreader. A shallow incorporation of the fertilizer into the seedbeds just before sowing and covering the seedbeds with hydromulch solved the problem of the prills washing away. PCRF applications later in the first year and during the second growing season did not wash or blow away because they were held in place by the rows of plants. In a comparison with standard fertilization, PCRF produced satisfactory plants, reduced nitrate leaching, and was more cost effective. Even though PCRF was triple the cost of conventional fertilizer, less frequent applications saved appreciable labor and equipment expenses (Vande Hey 2007).

When porous cup lysimeters were installed in pine seedbeds at 3.3 ft (1 m) spacing below the soil surface, nitrate-nitrogen leaching was significantly less with PCRF in the first and second growing seasons compared to standard fertilization (Dobrahner and others 2007).

In an Oregon bareroot nursery, nitrate leaching and soil compaction were serious concerns so subsurface banding of polymer-encapsulated sulfur-coated urea was compared to the standard fertilizer top-dressing. The CRF was banded below the soil surface and between the seed rows with a specially-modified seeder (Figure 5A). This allowed roots of seedlings to grow toward the N source and uptake the nutrient without burning (Figure 5B). Subsurface banding eliminated 3 tractor trips per season, which reduced soil compaction in the seedbeds. Because the N was gradually released during the growing season, concerns about nitrate leaching were reduced. As with the Wisconsin nursery, a cost comparison showed that the CRF was less expensive to use because of reductions in application costs, yet seedlings were larger with fewer culls (Steinfeld and Feigner 2004).

Summary

Of the 3 types of controlled-release fertilizers, polymer-coated products are most commonly used in forest, conservation, and native plant nurseries. Depending on the type of coating and temperature of the medium, these fertilizers release their nutrients over periods from 3 to 18 months. For growers, PCRF afford many advantages, including ease of adjusting fertilizer rate for many crops,

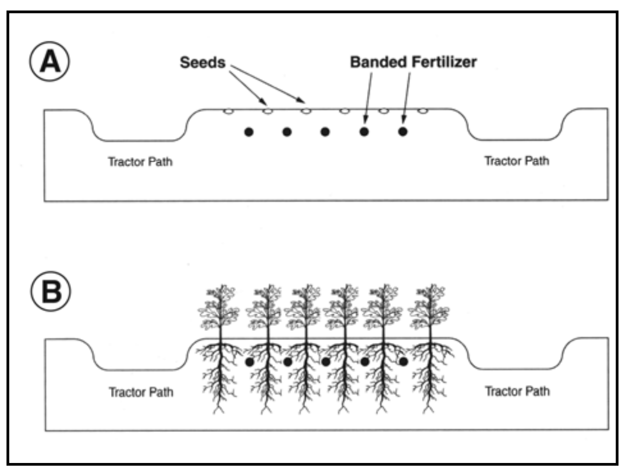

Figure 5 - Polymer-encapsulated urea fertilizer was banded at the time of sowing 3 to 4 inches (7.5 to 10 cm) below the soil and between the seed rows (A). This allowed the seedling roots to access the released nutrients during the growing season without concern about fertilizer burn (B). (From Steinfeld and Feigner 2004).

better fertilizer use efficiency, and less concern about potential groundwater pollution. In addition, nutrients are more available for germinating seeds or new roots forming on cuttings, and PCRF create fertilizer reserves to be used by the plants after outplanting. In order to achieve uniform and healthy plant growth, it is important to mix PCRF uniformly and without damaging their coatings. The various PCRF products release nutrients differently, but diligent monitoring of electrical conductivity can be used to avoid problems with salt accumulation, or to indicate when supplemental fertigation may be required. Although mainly used in container nurseries, PCRF has been used in bareroot nurseries to produce quality seedlings with less expense.

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Inoculate with Mycorrhizae, Rebuild Your Soil, and Help Stop Global Warming
by Thomas D. Landis and Michael A. Amaranthus

Mycorrhizal fungi form symbiotic partnerships with most plant families and all forest trees. Just to review, "myco" means "fungus" and "rhizae" means "root", and so the word "mycorrhizae" means "fungus-roots." In these mutually beneficial partnerships, root of the host plant provide a convenient substrate for the fungus, and also supply food in the form of simple carbohydrates. In exchange for this free room-and-board, the mycorrhizal fungus provides several benefits to the host plant.

Three types of mycorrhizal fungi are important to forest, conservation and native plants. (Wilkinson 2008):

Ectomycorrhizae - These fungi form partnerships with many temperate forest plants, especially pines, oaks, beeches, spruces, alder, hemlocks and firs.

Arbuscular Mycorrhizae (aka endomycorrhizae) - These fungi are found on a wide variety of wild and cultivated plants: most grasses, tropical plants, and understory species; some temperate tree species, including maples, dogwoods, redwoods, junipers and cedars.

Ericoid Mycorrhizae. These fungi form partnerships with plants in the families of heath (Epacridaceae); crowberry (Empetraceae); sedge Cyperaceae); and most of the rhododendrons (Ericaceae).

In this article, we're concerned with arbuscular mycorrhizae which we'll abbreviate as AM.

We've discussed the many benefits of inoculating your nursery stock with mycorrhizae several times in past FNN issues but we've just become aware of a new reason why you should. First, however, let's review the other reasons:

Potential Benefits of Inoculating Plants with Mycorrhizae

1. Increased water and nutrient uptake - Mycorrhizal fungi help plants absorb mineral nutrients, especially phosphorus and several micronutrients such as zinc and copper. Mycorrhizae increase the root surface area, and the fungal hyphae access water and nutrients beyond the normal root zone (Figure 1A).

2. Stress and disease protection - Mycorrhizal fungi protect the plant host in several ways. With some fungi, the mantle completely covers fragile root tips and acts as a physical barrier from dryness, pests, and toxic soil contaminants. Some fungal partners produce antibiotics that provide chemical protection against root pathogens.

3. Increased nursery vigor and growth - Plants that require AM associations perform better if they are inoculated in the nursery. This effect is often difficult to demonstrate under ideal nursery conditions but becomes obvious where soil fumigation has eliminated mycorrhizal fungi from the seedbed. If they are not purposefully inoculated with AM, nursery plants will eventually become naturally inoculated but growth will vary considerably from plant to plant creating a "mosaic" pattern in the seedbeds or nursery containers.

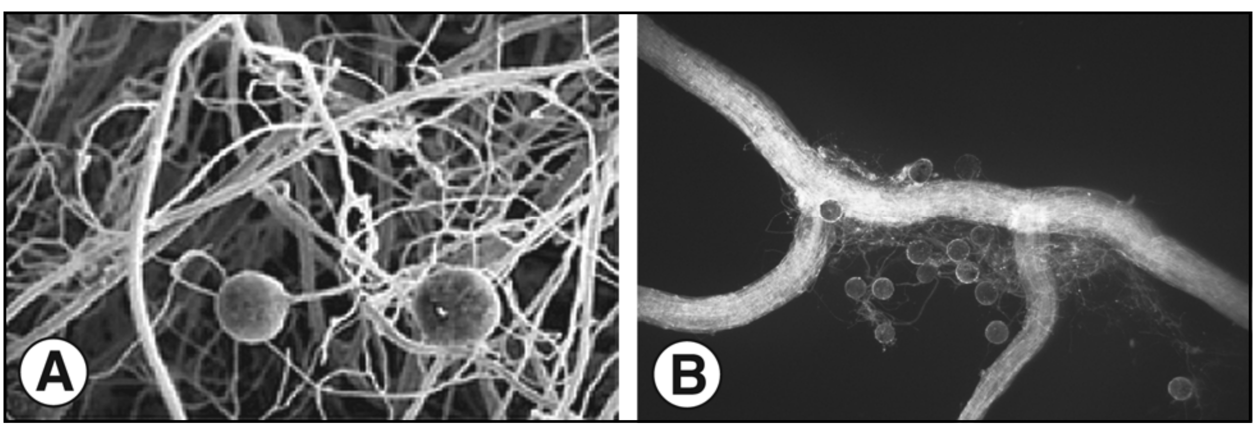

Figure 1 - The fungal partner of arbuscular mycorrhizae on grass roots sends out hyphae into the soil, greatly increasing access to water and nutrients. The round structures are spores (A). A microscopic view shows an arbuscular mycorrhizal fungus growing on a corn root (B). The shiny coating is glomalin, a glue-like substance which gives soils their structure (B- Photo k9968-1 courtesy of ARS)

4. Reduced transplant shock - Since we are able to supply all plants needs in the nursery, many of the above benefits are not readily obvious. The real payoff for having inoculated your nursery stock will often show up after outplanting. Non-mycorrhizal plants often become stunted and chlorotic ("yellow") after they are out-planted, especially on restoration sites where soil conditions are less than optimal.

5. Glomalin: the newest mycorrhizal benefit - In 1996, pioneering research by Sara Wright of the USDA-Agricultural Research Service showed AM produce a sticky glycoprotein called glomalin (Comis 2002). Wright named glomalin after Glomales, the taxonomic order to which AM belong (Amaranthus and others 2009).

From a soil management standpoint, the most important property of glomalin is this stickiness " (Figure 1B) which gives soils their "tilth. Tilth is one of those terms that's hard to describe on paper but you can feel it from the seat of your tractor. The best definition that we could find for tilth is "a sensory measure of the soil's ability to be worked easily, to hold water, to smell sweet, to crumble easily into large aggregates, and to resist wind and water erosion" (Podoll 2009). You probably remember from college that some of the best soils in the world developed under grasslands (Grieve 1980), and now you know why. Soils formed under grasses are very high in organic matter due to their massive fibrous roots and annual senescence and decomposition of their shoots. Grassland soils are also known for their excellent structure and, since all grasses have AM, we now know that structure can be attributed to glomalin.

From an ecological standpoint, one of the fascinating properties of glomalin is that it contains 30 to 40% carbon; in fact, glomalin can comprise one-third of all carbon in the soil and can persist for 40 years. We are all familiar of the deleterious connection between greenhouse gases and global warming. It has been estimated that up to a third of all of the increase in global CO_2 that has been generated since the industrial revolution can be attributed to carbon losses through poor agricultural practices. Because of glomalin's high carbon content, grass crops and natural grasslands are now being recognized as potentially valuable for offsetting carbon dioxide emissions from industry and vehicles. In fact, some private markets have already started offering carbon credits for grassland owners (Amaranthus and others 2009).

Rebuild Your Soil with Cover Crops and Green Manure crops

So, what does all this have to do with you? All bareroot nurseries are only as good as their soil, and harvesting during the winter is one of the most destructive things that you could do to a soil. Growing cover crops and green manure crops are the best ways to rebuild it. Just to review, cover crops are primarily used to prevent wind and water erosion whenever the land is fallow, whereas green manure crops are grown specifically to add organic matter to the soil (Rose and others 1995). Bareroot managers typically choose cover or green manure crops for their organic matter additions or resistance to root pathogens but now there's another consideration - glomalin. By inoculating the seeds of your cover crop with the spores of AM fungi, you could increase tilth in your nursery soil.

Choose grasses - The species that you use for a green manure and cover crop is critical. Perennial grasses and deep-rooted legumes are the best for soil building. Shallow rooted legumes and annual grasses are next in line, and grain legumes like soybeans are the most destructive of soil tilth. Lush green crops decay quickly after incorporation and much of the biomass is lost to the atmosphere as CO_2 (Podoll 2009). Perennial grass crops are most effective in soil building because they grow more root mass and the AM have more opportunity to form glomalin.

Inoculate with arbuscular mycorrhizae - So, it makes sense to inoculate your cover crops and green manure crops with AM. In a recent study, tall fescue grass plants (*Schedonorus phoenix*) were grown in pots with and without mycorrhizal inoculation and carbon and glomalin levels were monitored (Amaranthus and others 2009). At the end of one year, the inoculated grasses had significantly higher carbon and glomalin levels than the controls. The curvilinear relationship between mycorrhizal colonization and glomalin levels is intriguing - if you can achieve greater than around 30% AM colonization, then the amount of glomalin produced increases exponentially (Figure 2).

Sources of Arbuscular Mycorrhizal Inoculum

1. MycoApply® is a mixture of the active spores of several species of AM fungi: *Glomus intraradices, Glomus aggregatum, Glomus mosseae and Glomus etunicatum*. For more information, contact:

Mycorrhizal Applications, Inc.
TEL: 866.476.7800
FAX: 541.476.1581
E-mail: info@mycorrhizae.com
Website: www.mycorrhizae.com

2. BioVam is a mycorrhizal soil biotic that contains a mixture of ectomycorrhiza, endomycorrhiza, several species of bacteria, and 2 species of *Trichoderma* fungi. For more information, contact:

T&J Enterprises
TEL: 800-998-8692
E-mail: thomas@tandjenterprises.com
Website: www.tandjenterprises.com

3. Plant Revolution Inc. has several forms of mycorrhizal inoculum in their Plant Success product line. For more information, contact:

Josh Eagan
TEL: 714.545.5335
FAX: 714.545.5345
Email: info@plantrevolution.com
Website: www.plantrevolution.com

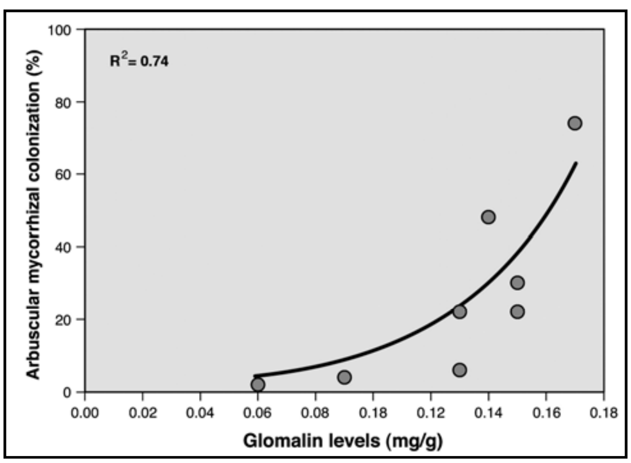

Figure 2 - When tall fescue plants were inoculated with arbuscular mycorrhizae, the more effective the colonization, the more glomalin was produced (modified from Amaranthus and others 2009).

4. Bio-organics™ offers an inoculum blend with 8 AM species: *Glomus aggregatum, G. clarum, G. deserticola, G. intraradices, G. monosporus, G. mosseae, Gigaspora margarita, and Paraglomus brasilianum*. For more information, contact:

Don Chapman
TEL: 1.888.332.7676
E-mail: moreinfo@bio-organics.com
Website: www.bio-organics.com

Inoculating Grass Seed - Grass seed can be inoculated with AM in several different ways. Powder, granular or liquid formulations can be applied directly into the planting furrow during sowing. One especially effective application technique is to coat seeds with AM powders or liquids which ensures that inoculum is in close proximity to the germinating seeds. Exudates produced by the young roots stimulate the mycorrhizal spores to germinate and colonize nearby roots. Smart Seed™ with MYCO Advantage™ from Pennington Seed features improved selections of turfgrass inoculated with a mixture of AM spores from MycoApply. They offer a specialized grass mixture for the erosion market called Slopemaster™ which contains MYCO Advantage™, and also looking into inoculating their forage and annual grass seed products (Pennington 2009).

Summary

The benefits of inoculating nursery stock with mycorrhizal fungi are well documented, but the newly discovered relationship between arbuscular mycorrhizae and glomalin is particularly interesting. Arbuscular mycorrhizae are found on a wide variety of plants from around the world, and produce glomalin on their roots. This sticky protein is responsible for giving soils their tilth, which is critical to nursery soil management and reforestation, conservation, and restoration planting projects. Perennial grasses are most effective in soil building because they grow more root mass and the AM have more opportunity to form glomalin. Because it contains 30 to 40% carbon and ties it up for decades, glomalin can help counteract the buildup of greenhouse gases and lessen the effects of global warming. We're sure that we'll be hearing more about the glomalin connection in coming years but it makes sense to start inoculating cover and green manure crops as well as nursery stock.

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Thawing, Handling, and Outplanting Frozen Stock
by Thomas D. Landis

The 2 different types of refrigerated storage used in forest, conservation, and native plant nurseries are cooler storage and freezer storage, and they are differentiated by the ambient temperatures (Figure 1) and the recommended duration of storage. Cooler storage is best for storage periods of 2 months or less whereas, freezer storage is recommended if plants must be held longer. In particular, freezer storage has proven ideal for plants that are harvested in early winter but can't be outplanted until later in the spring. While frozen storage has real advantages, many customers have had questions about what happens when the stock is ready to be shippped:

1) Can frozen stock be shipped without damage?
2) What is the best way to thaw the stock?
3) Is it possible to outplant frozen stock?

Handling and shipping frozen nursery stock - Although this question has not been addressed in any formal research, operational experience has shown that nursery plants can be handled and shipped while frozen without any significant injury. Frozen stock is still alive, however, and so storage containers should not be handled roughly or tossed around like packages of frozen food.

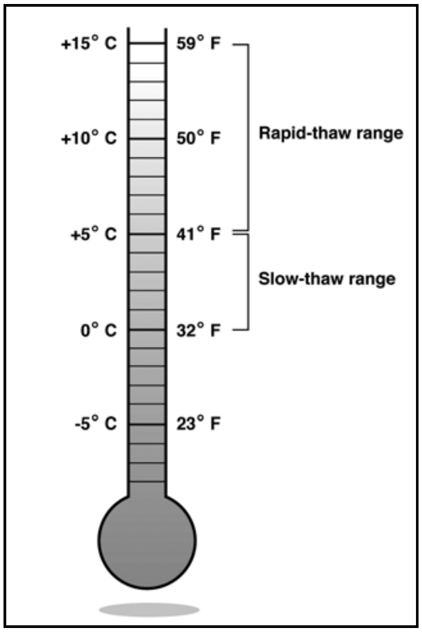

Figure 1 - Frozen nursery stock has traditionally been thawed by a "slow" regimen of cooler temperature for a longer time, or a "rapid" regimen of warmer temperatures for a shorter time (modified from Paterson and others 2001).

Table 1 - Common thawing regimes for frozen container nursery stock

Speed of Thawing	Temperatures	Duration	Reference
"Slow" Thaw	5 °C (41 °F)	7 days	Camm and others (1995)
	0 to 3 °C * (32 to 37 °F)	42 days	Rose and Haase (1997)
	0 to 3 °C * (32 to 37 °F)	21 to 35 days	Kooistra and Bakker (2002)
"Rapid" Thaw	5 to 15 °C (41 to 59 °F)	9 days	Camm and others (1995)
	7 °C (45 °F)	5 days	Rose and Haase (1997)
	5 to 10 °C (41 to 50 °F)	5 to 10 days	Kooistra and Bakker (2002)
	12 °C (54 °F)	4 to 8 days	Helenius and others (2004)

* Operational cooler storage conditions

Thawing frozen plants - The root plugs of container stock freeze together and so must be thawed before they can be separated and outplanted. Some customers want their stock thawed before shipping by either "rapid" or "slow" thawing **(**Figure 1). However, the thawing temperatures and time intervals recommended in the literature vary considerably (Table 1). Originally, slow thawing was considered best (for example, Mitchell and others 1990) and was typically done at the nursery. Research trials found no differences, however, between rapid or slow thawing after two growing seasons (Rose and Haase 1997). When the quality of seedlings thawed with both techniques was tested**,** rapidly thawed stock was more cold hardy and also resumed shoot growth earlier than slowly thawed seedlings (Camm and others 1995). Three months after outplanting, shoot and root growth were similar for plants from both thawing regimens. In one of the most well-designed and long-term studies (Helenius and others 2004), freezer-stored Norway spruce *(Picea abies*) container stock was thawed in cardboard boxes at 39 or 54 ^{o}F (4 or 12 ^{o}C) for up to 16 days before outplanting. When checked 3 years later, the best thawing temperature was 12 ^{o}C (54 ^{o}F) for about a week.

These results suggest that a good operational procedure would be to remove bundles of frozen stock from shipping containers and lay them on the ground overnight, or open shipping boxes or bags in a well-ventilated shady location. Never attempt to thaw frozen nursery plants by placing them in direct sunlight (Figure 2A) as this can cause serious moisture and temperature stress. Do not physically pry frozen root plugs apart because this can cause serious damage (Mitchell and others 1990). Defrost only enough stock that can be planted in a couple of days. The ideal situation is to set-up a thawing operation where frozen stock is removed from refrigerated storage and then thawed in a shade structure (Figure 2B).

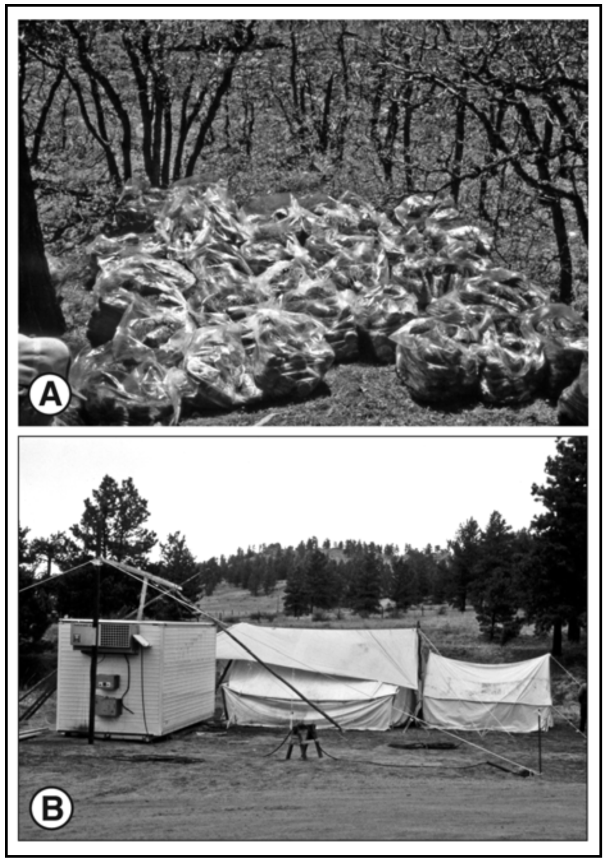

Figure 2 - Never expose frozen plants to direct sunlight (B), but open boxes or bags and leave them in a protected, shady location (B)

Outplanting frozen stock - Outplanting nursery stock with frozen root plugs would save the time and effort needed to thaw plants. The initial obstacle was that root plugs were frozen together, but technology for packing singulated plants is now available. However, field trials of outplanting frozen stock have had mixed results. In British Columbia, the performance of western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), and interior spruce (*Picea glauca* x *Picea engelmannii)* planted while frozen was not significantly different from thawed plants 2 years after outplanting (Kooistra and Bakker 2005). This was on a cool, cloudy site, however, and subsequent studies found that site conditions have an overriding effect. In an outplanting study of Norway spruce seedlings in Finland, thawed seedlings outperformed frozen stock in survival and shoot and root growth in both warm and cold soils (Helenius 2005). In a more recent trial, the physiological processes of thawed and frozen Douglas-fir container seedlings that were exposed to either "cool and moist" or "warm and dry" conditions were monitored. Thawed plants had higher photosynthesis rates and more active buds and roots than plants that were planted frozen, which could affect subsequent outplanting performance (Islam and others 2008). Obviously, more research trials under a wide variety of outplanting site conditions are needed before outplanting frozen stock can be recommended.

Summary

Freezer storage has become an accepted practice in forest, conservation and native plant nurseries, but concerns have been raised about how best to thaw and handle frozen nursery stock. Boxes or bags of frozen seedlings should be handled with care but can be shipped to the outplanting site without special consideration. While both slow and rapid thawing regimens have been used, research and operational experience has found that opening the boxes or bags in a sheltered and shady location will be effective in a few days to a week. Seedling can be outplanted while still frozen on low moisture stress sites but it's probably best to thaw all stock first.

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A Visit to Finland - An Opportunity to See with "New Eyes"
by Thomas D. Landis and R. Kasten Dumroese

Last August, we were invited to Finland to attend the 40th anniversary of the Suonenjoki Research Station. The small town of Suonenjoki, located in the Lake District of south-central Finland (Figure 1A**)**, is home to one of 8 research stations of the Finnish Forest Research Institute. Dr. Marja Poteri helped us get through the governmental paperwork, made local arrangements, and was the consummate host and local guide. The trip would not have been possible without the financial support of Dr. Heikki Smolander who, in addition to being the station director, takes an active role in research projects.

Figure 1 - The Suonenjoki Research Station is located in southcentral Finland (A), and is their center for nursery and reforestation research. Our interview in the national forestry magazine (B) shows the importance of nurseries and reforestation in Finnish life.

Our visit began with a reception and tour of the research station that, in addition to state-of-the-art laboratories and research equipment, also has large production greenhouses. These facilities allow researchers at Suonenjoki to "ramp-up" research done in small growth chambers to the operational level. These exceptional facilities and caliber of the scientists make Suonenjoki a world-class research institute.

We've both traveled extensively but it was nice to visit a country like Finland where forestry is a major industry, and nursery and reforestation research are so well-supported. This was evidenced by an interview with the national forestry magazine where they were interested in our impressions of Finland's nursery and reforestation program (Figure 1B).

After giving presentations at a research symposium, we were escorted on a field trip of forest nurseries and outplanting sites. We would also like to express our gratitude to all the nursery managers: Anne Immonen and Riitta Väisäinen at the UPM nursery in Joroinen, Jari Peteri of the Fin Forelia Saarijärvi nursery, and Markku Räsänen of the Tuomiahon Tamaisto nursery. It was a great learning experience for us to observe nursery practices with "new eyes". Each of these nurseries was very well run, and the color and quality of seedlings appeared to be very good. We were impressed by the coordination between the operational nurseries and Suonenjoki Research Station, which is an excellent example of how technology transfer should work.

Of all that we saw and experienced in our short visit, we were particularly impressed by the following 3 nursery cultural practices which we thought were worth sharing:

1. Problems with "holdover" nursery stock - We've preached for years about the dangers of holding plants over from one season to the next in the same containers. These holdover plants have shoots too large for their root systems, which become woody and "rootbound". One concept that we stress during training sessions with novice growers is that nursery plants, like all perishable products, have a "shelf-life" and should be shipped and outplanted by their "expiration date". If that's not possible, plants should be transplanted to larger volume containers or to bareroot beds where they can be grown as plug transplants.

Very little research has been done showing the hazards of outplanting holdover stock. Therefore, we were excited when Dr. Risto Rikala presented data from Sweden at the research symposium which demonstrated that outplanting performance suffers when nursery stock has been held too long in the container (Figure 2).

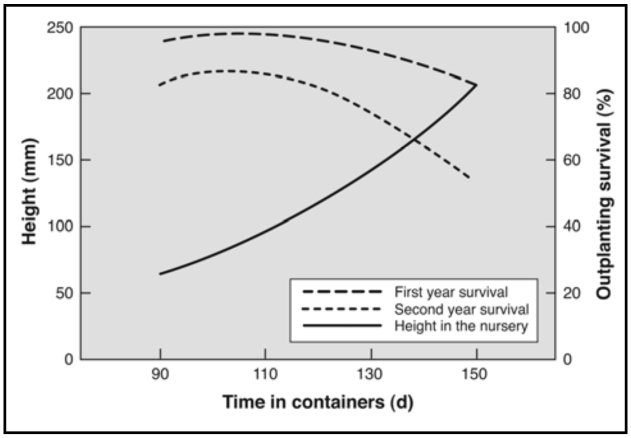

Figure 2 - Because it becomes "rootbound", the quality of "holdover" nursery stock is severely reduced. Work done in Sweden shows that survival is significantly reduced for several years after outplanting (courtesy of R. Rikala).

2. Rehydrating nursery stock before outplanting - It only makes sense to send nursery stock to the field fully-hydrated to minimize moisture stress after outplanting. However, after harvesting, nursery storage, shipping, and on-site storage, plants undoubtedly suffer some amount of desiccation. We discussed the benefits of root dipping bareroot stock in the Winter 2006 issue of FNN, but we have wondered why no research had been done with container plants.

To test the benefits of watering plants before outplanting, Jaana Louranen and her colleagues at Suonenjoki set-up a research trial with silver birch (*Betula pendula*) container stock that was hot-lifted and outplanting during summer (Luoranen and others 2004). You would think that this would increase post-planting moisture stress because the birch seedlings would be in full leaf. However, they found that survival and growth was significantly improved when the moisture content of the root plugs was greater than 30 to 40% (Figure 3). A companion study with Norway spruce (*Picea abies*) showed that it is possible to plant spruce container seedlings in summer as long as they are well watered before planting (Luoranen and others 2006). Dr. Juha Heiskanen and Risto Rikala investigated the water relations of irrigating plugs before outplanting and found that dry container plugs actually absorbed water from the surrounding soil, whereas wet plugs had significantly better root egress (Heiskanen and Rikala 2000).

3. Widening outplanting windows with container stock - An outplanting window is defined as the period of time during which environmental conditions on the project site favor survival and growth of nursery stock. The start and end dates are constrained by limiting factors of the environment on the planting site. Soil moisture and temperature are the usual constraints on most sites and therefore, in most of the continental US and Canada, nursery stock has traditionally been outplanted during late winter or early spring when soil moisture is high and evapotranspirational losses are low.

In Finland, seedlings have traditionally been stored under refrigeration or outdoors under snow and then outplanted while still dormant during May and early June. With such a short outplanting window, it is often difficult to get all the seedlings in the ground. In addition, more and more nursery stock is being planted mechanically due to the high labor costs and a wider outplanting window would make mechanical planting more economical. So, Finnish researchers have been conducting outplanting research on hot-lifted Norway spruce and silver birch for several years (Louranen and others 2006).

To investigate the effect of drought on outplanting performance, hot-lifted Norway spruce seedlings were subjected to up to 6 weeks of water stress in a research plot (Helenius and others 2002). They found that hot-lifted stock with wet plugs that were outplanted in July had better root egress than those planted later that year or stored and outplanted the following spring (Figure 4).

Amazingly enough, summer outplanting has even been successful with silver birch plants that were leafed-out and actively growing. When container birch seedlings were outplanted in mid-summer, they survived and grew

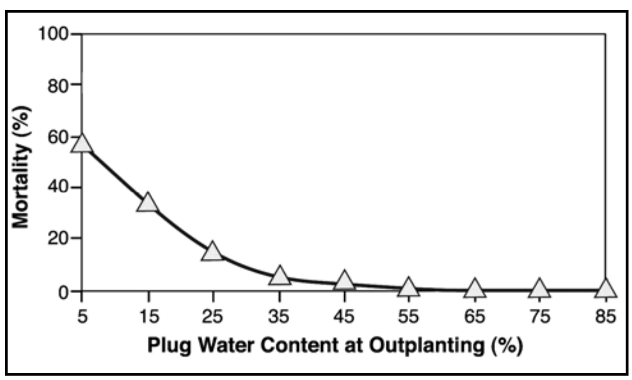

Figure 3 - The relatively simple procedure of fully-hydrating root plugs immediately before outplanting has proven beneficial for hot-planted silver birch (modified from Luoranen and others 2004)

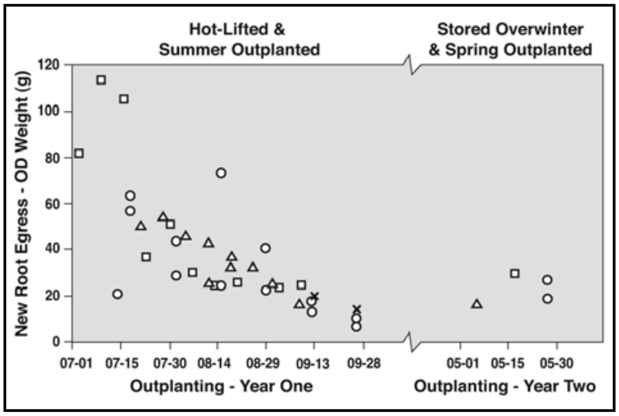

Figure 4 - The rapid outgrowth of new roots ("root egress") is critical for survival and growth after outplanting. Hot-lifted Norway spruce outplanted in early summer had more root egress than those planted later that year, or even overwintered stock planted during the traditional spring outplanting window (modified from Louranen and others 2006).

as well as those planted during the traditional outplanting windows. This was attributed to warmer soil temperatures that stimulated high root egress and rapid establishment (Luoranen and others 2004).

Of course, summer outplanting should only be attempted on appropriate sites without extended drought conditions but these experiences support the notion that well-conditioned container stock with fully hydrated root plugs may have a wider outplanting window than originally thought.

Summary and Recommendations

We feel that growers and seedling users in North America could learn some things from our Finnish friends:

1) Avoid holding-over container stock. Either plant it at the proper time, or transplant it into larger containers or bareroot beds.

2) Make sure that root plugs of stock shipped to the field are at field capacity. Nursery managers should ensure that their stock is fully hydrated before processing and that roots do not become desiccated during storage or shipping. Nursery customers should consider watering their plants during "on-site" storage, and encourage planters to minimize root exposure during outplanting.

3) Consider broader outplanting windows with container stock. Summer planting on sites with adequate soil moisture and low evaporative demand or those that receive summer precipitation has several advantages, including improved seedling survival growth and serving to "even out" nursery and outplanting scheduling demands.

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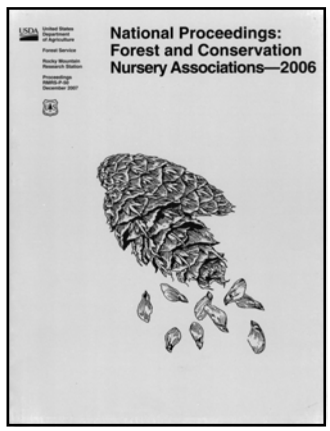
National Nursery Proceedings - 2007

Dumroese RK, Riley LE, technical coordinators. 2008. National Proceedings: Forest and Conservation Nursery Associations-2007. Proceedings RMRS-P-57. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.174 p.

These proceedings are a compilation of the papers that were presented at the regional meetings of the forest and conservation nursery associations in the United States and Canada in 2007. The Northeastern Forest and Conservation Nursery Association meeting was held July 16 to 19 in Concord, NH. Subject matter for the technical sessions included seed collection, handling, and storage, soil management, seedling nutrition, disease management, and fumigation alternatives. The combined meeting of the Forest Nursery Association of British Columbia and the Western Forest and conservation Nursery Association was held in Sidney, BC, on September 17 to 19. The meeting was hosted by the Forest Nursery Association of British Columbia. Subject matter for the technical sessions included global climate change, business practices and marketing, forest nursery practices, nursery technology, disease management, and labor management.

National Nursery Proceedings - 2006



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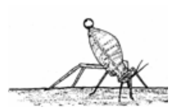

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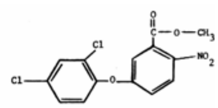

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