United States
Department of
Agriculture

Forest Service

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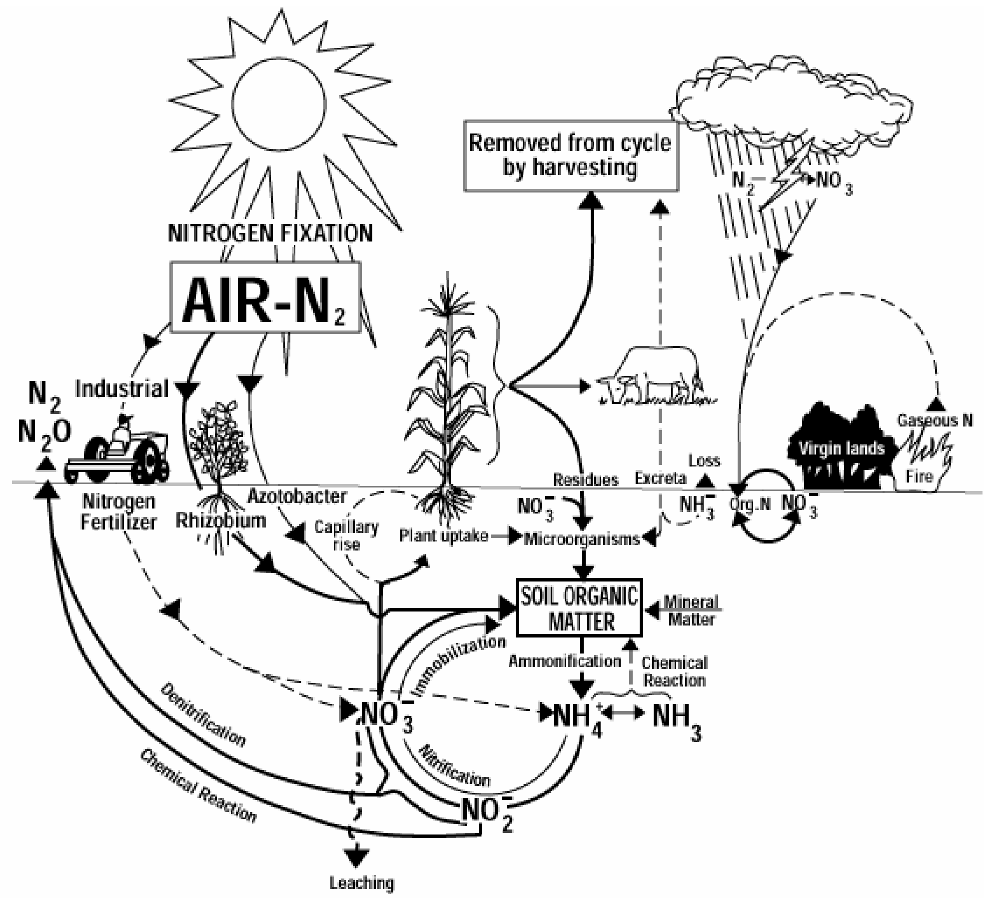
State and Private
Forestry

Cooperative
Programs

R6-CP-TP-04-03

Forest Nursery Notes

Summer 2003



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This technology transfer service is funded by:
USDA Forest Service, State and Private Forestry

Thoughts on Retirement. *You might have heard by now that I'm going to retire from the Forest Service this coming December. At that time, I will have accumulated 30 years of government service which makes me eligible for an annuity. However, since that will only cover about 50% of my current salary, I'm going to have to do some part-time work such as contracting to write FNN and finish Volume Seven of the Container Tree Nursery Manual.*

Retirement is one of those watershed times in your life when you should stop and take stock. I'm one of those lucky people who loves what they do. All of us in the nursery trade are not doing it for the money so it must be something else. What is it about nursery work? Well, reflecting back on the past decades, I've compiled the following thoughts. As you read through them, I think that you'll recognize some of the reasons why you are in the nursery game:

1. Doing something good for the world - Reforestation and restoration are "white hat" activities that we can all be proud of. When someone asks me what I do, I always take a little guilty pleasure in telling them that I help people grow "baby trees".

2. You never stop learning - I never intended to be here at the end of my career. I was going to work in the nursery for a few years until I learned all there was to know and then move on to reforestation - I never made it! I continue to be challenged by all aspects of nursery work, and catching the occasional glimpse of how nature works is rewarding indeed.

3. The Devil is in the Details - In this age of instant gratification, everybody wants quick answers but nursery work requires patient attention to specifics. Because we are working with native plants, we have to modify existing horticultural techniques or make-up some of our own.

4. Murphy's Law in Spades - I don't know what it is, but it seems like nursery problems always occur in the middle of the night or during a long holiday weekend. To be successful in nursery work, you have to try to anticipate problems. Of course, there's no substitute for experience and we are always learning from our mistakes and those of others. In addition, unpredictable and changing weather conditions always keep us on our toes.

5. An Art As Well as a Science - As you know, it takes more than book learning to grow quality nursery stock. A good background of botany and horticulture will give you the basic information, but plant propagation also requires a significant amount of art. People talk about good growers as having a "green thumb" and this is certainly evident in nursery work. You can teach the basic concepts but it's impossible to show someone how to grow a crop - either they have it, or they don't.

6. It's the People - It's been a real pleasure to work with all of you, and I've met a lot of nice folks in all my travels. Maybe it's because nursery work keeps you humble. I don't know anyone in the nursery business that has a big ego. Or, if you started out with one, you soon got cured.

Lastly, I'd like to thank all of you who wrote letters in support of my nomination for the Society of American Foresters' Technology Transfer Award and especially to Kas Dumroese for initiating this effort. He gave the responses to my boss, Charlie Krebs, who submitted them for the Chief's Award for Excellence in Technology Transfer (External) within the USDA Forest Service. To my surprise, I was recently notified that I won both awards! It's particularly gratifying to be recognized by your peers for work that I enjoy doing, so thanks again.

I ♥ Baby Trees

Forest Nursery Notes
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Please Update Your Address: The FNN mailing list is always out-of-date so we would like to make sure that we have your latest address. Please take the time to check the mailing label and write any additions or corrections on the Literature Order Form at the back of this issue. In particular, check your telephone and FAX numbers because area codes keep changing. Supply the country code if you are a foreign subscriber. Also list your E-mail and website addresses if you have them.

Technical Requests. Every day we receive letters, telephone calls, Faxes, and E-mail messages from around the world requesting publications or asking for technical assistance. Our technology transfer team prides itself on responding to all inquiries as soon as possible but we do have to set some priorities. Forest and conservation nurseries in the United States receive first priority and then we handle requests from foreign countries. Our contact information is listed on the inside cover of this issue. If Tom is not around, then contact David or Rae and we'll get back to you as soon as possible. You can make things easier if you will remember a few things when contacting us:

? Telephone calls are hard to understand sometimes, especially when the caller has an accent. If you leave a voice mail message, please speak slowly and give your full mailing address, phone, FAX, and E-mail numbers.

? FAX messages are easy to process but be sure to give your complete name, address, and return FAX number *including country code.*

? E-mail is the best option because it is non-invasive and accessible around the clock. If you are requesting publications, be sure and give us your full mailing address.

The Reforestation, Nurseries and Genetics Resources (RNGR) team has finished improvements on their website. In addition to new features and resources, the site has a new address. Be sure to update any bookmarks you have to reflect our new URL:

http://www.rngr.net

The new site now uses a content management system that will allow registered users of the site to actively interact with the site. Registration is fast and easy and requires only an email address. Registered users can post comments throughout the site, add events, documents, and images.

Additionally, registered users can manage their listings in the new "National Directory of Plant Material Providers". This new directory will combine the National Nursery Directory, the Commercial Seed Dealers Directory, and the new Native Plants Materials Directory into one easy to use online system. To find out more about the new directory and how you can participate, email Bryan at: bjordin@rngr.net.

New features of the RNGR website include the addition of a National Nursery Proceedings search engine, and an archive of Tree Planters Notes that is continually growing.

In the coming months, an image collection and an online simulator are planned to be released. If you have any suggestions or comments regarding the site, please contact :

Bryan Jordin
RNGR Webmaster
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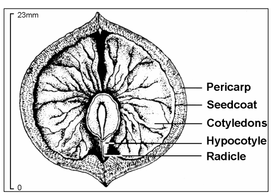
New Woody Plant Seed Manual

The new version of the Woody Seed Plant Manual (WPSM) has been in the works for over a decade but we are



pleased to announce that the manuscript has just been submitted to the Washington Office of the Forest Service. The WPSM contains seven introductory chapters and chapters on 237 genera of trees and shrubs, many of which are new including many tropical trees and shrubs and subshrubs from western US. The book will be handsomely illustrated with 520 photos, 430 line drawings and charts, and 494 tables.

The WPSM will be sold through the US Government Printing Office and, unlike in the past, no free copies will be available. We will also offer a CD-ROM version of the WPSM. The draft document is already on the following website and updates on the printing progress will also be posted there: <**www.ntsl.fs.fed.us/wpsm >**.

Spanish versions of the Container Tree Nursery Manual on WWW

Due to the efforts of Ricardo Sanchez, Dante Rodriguez, and Rebeca Aldana, two Spanish translations of the Container Tree Nursery Manual are now available on the SIRE-PRONARE section of the CONAFOR website:

Volumen Dos - Contenedores y Medios de Crecimiento (Volume Two - Containers and Growing Media)

Volumen Cuatro - Fertilizacion y Riego (Volume Four - Fertilization and Irrigation)

You can download files in PDF format from the following URL:
<http://www.conafor.gob.mx/programas_nacionales_forestales/pronare/sire/publicaciones.htm>

Hard copies of these softbound books are also for sale by contacting:

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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.

LUSTR Forest Renewal Co-op Inc**.** presents: **Tree Seedling Nutrition and Fertilization Workshop.** This workshop will be held **August 6, 2003** in **Dryden, Ontario, Canada.** Some topics included in the tentative agenda are Nutrition in the Nursery, Exponential Nutrient Loading and Safe handling of Fertilizer Products in the Nursery and in the Field. For registration information, please contact:

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The **International Union of Forestry Research Organizations [IUFRO], Seed Physiology and Technology Research Group [RG 2.09.00]** will hold their annual symposium **August 10 through 14, 2003**, at the University of Georgia, **Athens, Georgia, USA**. All interested people are requested to contact Gary Johnson. Pre-registration forms and information about the symposium are posted on the web page: <www.ntsl.fs.fed.us>, or contact:

Gary Johnson
National Tree Seed Laboratory
5675 Riggins Mill Road
Dry Branch, GA 31020
TEL: 478.751.3555
FAX: 478.751.4135
E-MAIL: wjohnson03@fs.fed.us

The Biocontrol Network**,** a research network on biological control of insect pests and diseases of greenhouses and tree nurseries will hold the **1st Regional Biocontrol Network** meeting in **Vancouver, British Columbia, Canada** on **September 18, 2003**. For registration and agenda information, please contact:

Stephane Dupont
Network Manager
TEL: 514.343.7950
FAX: 514.343.6631
E-MAIL: biocontrol-network@umontreal.ca

The theme for the **23rd Annual Meeting** of the **Forest Nursery Association of British Columbia** will be S.O.S.: Seedlings/Objectives/Service. This meeting takes place **September 22 through September 25,** in Courtenay, British Columbia. For more information please contact:

Dave Trotter
TEL: 604.930.3302
E-MAIL: dave.trotter@gemx4.gov.bc.ca

The **ISTA Forest Tree Seed and Shrub Seed Committee and the Forestry and Game Management Research Institute** of the Czech Republic will host this workshop from **October 20-25, 2003**, in **Prague, Czech Republic**. The workshop will deal with practical problems related to tree seed testing of both broadleaf and conifer species. Based on input from the preliminary registration the workshop will cover all fields of seed testing such as purity, germination, tetrazolium, health, excised embryo moisture content and x-ray. There will be two alternative post-meeting trips (from October 23-25): 1. Visit to the State Tree Seed Centre in Tyniste nad Orlici. 2. Visit to the seed Testing Laboratory for Forest Tree Seeds in Uherske Hradiste, SE Czech Republic and then continue on to visit the Forest Seed Testing Laboratory in Liptovsky Hradok, Republic of Slovakia. Workshop and registration information is available on the web, <http//www.seedtest.org> or contact:

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The Nursery Technology Cooperative at Oregon State University will be hosting two conferences in 2004 in **Eugene, Oregon**.

May 12-13, 2004: Forest Seedling Root Development from the Nursery to the Field

December 15-16, 2004: Native Plant Propagation and Restoration

If you would like to be a speaker at either of these conferences, or would like registration information, contact:

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Nursery Technology Cooperative
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Integrated Pest Management

Methyl Bromide Critical Use Exemption – Worthwhile Process or Exercise in Futility?

Opinions on the continued production and use of methyl bromide (MeBr) fumigants in the US agricultural industry are as far ranging as the types of crops for which it is used – whether regarded as an extreme environmental hazard requiring a global ban or as an on-going necessity for agricultural production. Although the forest nursery industry universally acknowledges the effectiveness of MeBr, opinions are divided on whether bareroot crop production can continue at its current levels without this fumigant.

Research on alternatives to MeBr has been conducted over the past 15 years, partly in response to the ratification by 183 countries of the Montreal Protocol in 1988 on Substances that Deplete the Ozone Layer. This 1988 report identified MeBr as an ozone-depleting substance and scheduled its complete phaseout by January 2005 in these countries. This research has yielded viable options. The effectiveness of the options, however, is highly dependent on the target pest, the crop type, and, in particular, the regional location of the nursery. In the US, southern forest nurseries find themselves far more dependent on MeBr than either eastern or western nurseries due to growing conditions and the wider variety of pests.

In 2002, the US Environmental Protection Agency solicited applications for a Critical Use Exemption from the phaseout of MeBr, providing users of the fumigant with the opportunity to submit technical and economic information to support this exemption (EPA 2002). In response, 9 applications for the use of MeBr for forest seedling nurseries were submitted to the EPA by 9 different consortia (Finman 2003). These consortia were comprised of Federal, State, and private nurseries and spanned the production of a variety of crop types and forest species. In February 2003, following an extensive review process by the EPA and the US Department of Agriculture, the US submitted a two-year exemption request to the International Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol. The proposed exemption would begin in 2005, with MeBr use at 39% of current baseline consumption and declining to 37% in 2006.

In May 2003, the TEAP recommended that the Parties to the Protocol approve less than 10% of the amount of MeBr requested by the United States, determining that the US government had not submitted sufficient information to substantiate their request (Riggs 2003). Although the information submitted by several of the forest nursery consortia was extremely detailed, the jury is still out on the reasons behind the determination.

The EPA is currently formulating responses to the Methyl Bromide Technical Option Committee and the TEAP. In addition, they are once again soliciting applications for a further Critical Use Exemption (EPA 2003). So in other words, it's not over yet folks. Stay tuned.

Information on EPA's Critical Use Exemption for methyl bromide is available at: http://www.epa.gov/ozone/mbr/

Sources

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Finman H. 2003. Personal communication. Washington (DC): US Environmental Protection Agency.

Riggs D. 2003. TEAP rejects EPA's application – the CUE process run amuck. The Crop Protection Coalition Memorandum 5/25/03. 3pp.

Cultural Perspectives

Managing Soil Tilth With Organic Matter
by Thomas D. Landis

Soils can be managed by their physical, chemical and biological properties. Nursery managers do a good job of managing the chemical characteristics of their soils by testing for pH and mineral nutrients and correcting with lime, sulfur, and fertilizers. However, the physical properties of nursery soils are managed less effectively. Many nursery managers only think about physical soil properties when a problem develops, such as when ripping must be used to break-up a plow pan.

The third and least appreciated aspect of nursery soils is biological - the microscopic animals and plants that live there. The biological properties of a good nursery soil are managed little or not at all. Like most things, there are good soil microorganisms and bad ones. Unfortunately, modern nursery management is geared almost exclusively to managing the bad ones - damping-off and root rot fungi. The fumigants and fungicides used to control soil pathogens also eliminate or reduce the beneficial critters. Beneficial microbes exist exclusively on the organic matter in the soil, which they use as a food source. Hold that thought until we have a brief discussion about the differences between soil texture and structure.

Texture vs. Structure. The physical characteristics of a soil can discussed in terms of texture and structure. Soil texture involves the basic size class of soil particles and their relative proportions, whereas structure is concerned with the arrangement of these particles into larger aggregates. Some types of soil structures such as crumbs are good for seedbeds, whereas others such as clods (blocky) and hardpans (massive) make farming difficult (Figure 1). It is instructive to compare the relative sizes of the textural and structural classes (Table 1). Traditionally, the ideal soil texture for a forest or conservation nursery is considered to be a sandy loam with "single-grain" structure. Realistically, however, many nursery managers have to deal with medium-textured silt soils and even some areas with a high percentage of clays.

While the ideal nursery soil has a sandy loam texture, what is the ideal structure for a forest and conservation nursery soil? The ideal seedbed should consist of firmly packed soil "crumbs" (Figure 1), ranging in size from 0.5 to 1.0 mm with few larger "clods" (Table 1). This compressed crumb structure provides moisture to the germinating seed while allowing good root penetration and drainage of excess water. Several forces act to break-down the crumb structure including the physical impact of rain or irrigation drops and the erosive effects of water.

Figure 1 - Various types of soil structure; in nurseries, a crumb structure is ideal but blocky (clods) and massive (hardpans) cause problems.

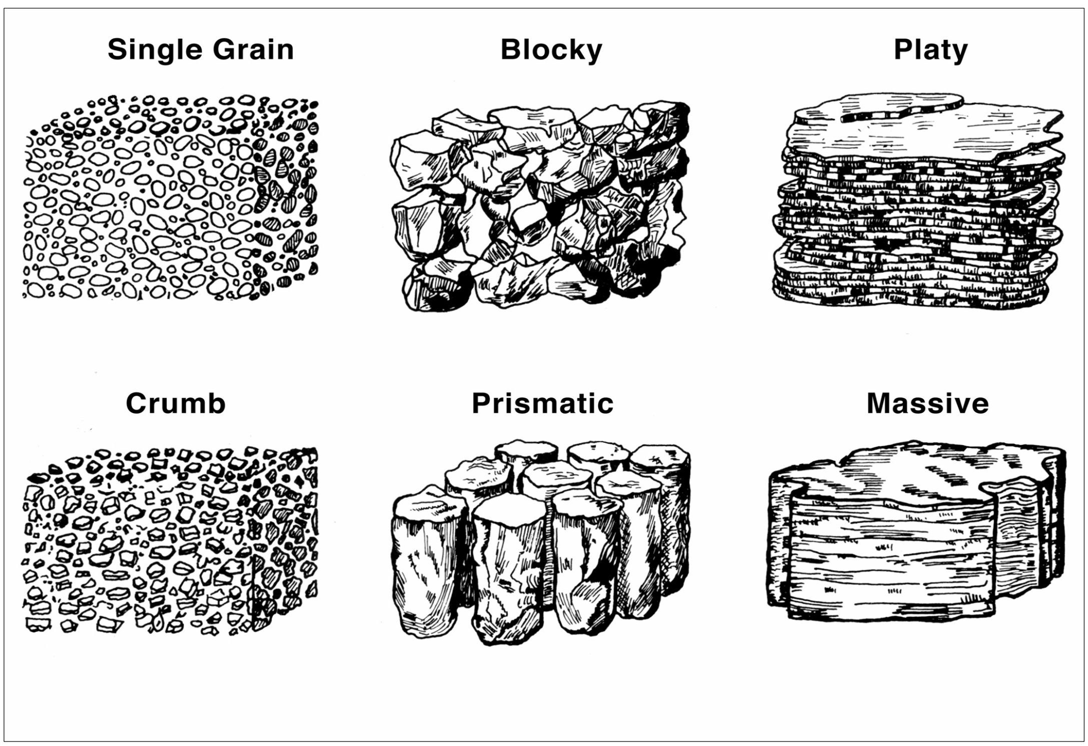


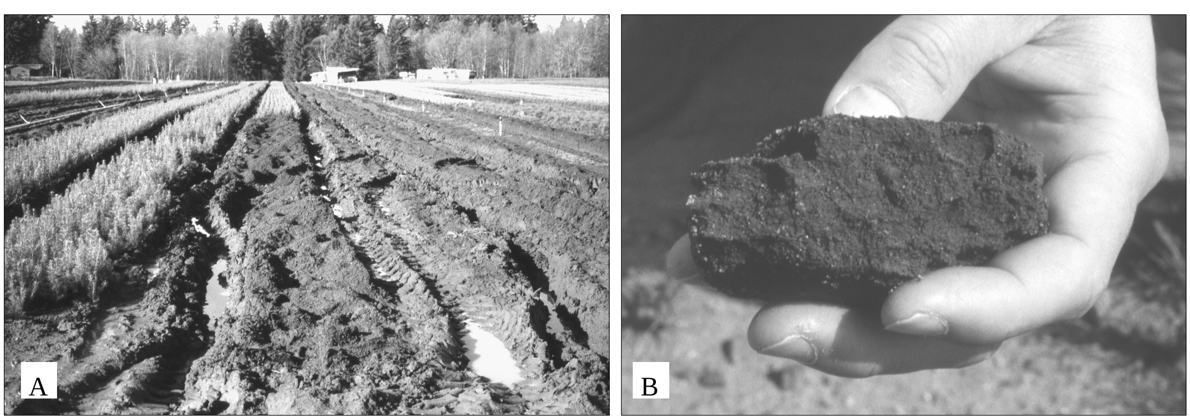
Table 1 - Size Comparison of Soil Texture and Structure Classes

Texture Class	**Size Range Diameter (mm)**	**Structure Class**	**Size Range Diameter (mm)**
Clay	Less than 0.002		
Silt	0.05 to 0.002		
Very fine sand	0.10 to 0.05		
Fine Sand	0.25 to .10		
Medium Sand	0.50 to 0.25	**Granules**	Less than 0.5
Coarse Sand	1.00 to 0.50		
Very Coarse Sand	2.00 to 1.00		
		Crumbs	2.00 to 10.00
		Clods	Larger than 10.00

The most damaging force to our ideal crumb structure, however, is the use of heavy equipment. Due to the necessity of harvesting during the wet winter dormant season, bareroot nurseries continually damage their soil structure (Figure 2A). Sandy soils drain faster and so suffer relatively less damage than finer-textures silt or clay soils. The small size and flat shape of silt and clay particles makes them much more prone to forming compacted soil layers called hardpans (Figure 2B). These pans restrict seedling root growth and inhibit good drainage and so nursery managers must continually rip their seedbeds to break-up them up. Unfortunately, they rather quickly reform unless your soil has good tilth.

A definition of tilth. When I think about the ideal properties of soils, one word comes to mind - tilth. My dictionary list several definitions mostly dealing with tillage, but the last one pertains to the current discussion: "the state of aggregation of a soil". Good nursery managers may not be able to define it but they can feel tilth when they pick-up a fistful of soil when their seedbeds are in the perfect condition for sowing. A soil with good tilth feels light and spongy in your hand because it is well drained, and the crumb structure resists compaction. Friable is another good description for a soil with good crumb structure. This subjective feel is humorously related in the "Boke of Husbandry" which was published in 1523. The grower was instructed to go out into the fields to determine whether the soil was ready for sowing: "If it synge or crye, or make any noise under thy fete, then it is to wete to sowe: and if it make no noyse, and wyll beare thy horses, thanne sow in the name of God".

Figure 2 - The use of heavy equipment, especially harvesters, during wet winter weather (A) shears and compacts the soil, destroying good crumb structure and creating hardpans (B).



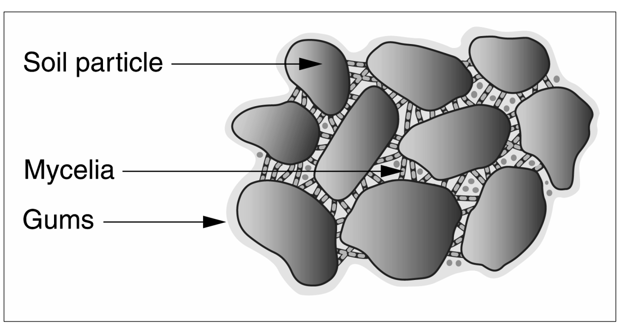
In 1937, a classic paper was published called "The significance of soil structure in relation to the tilth problem" and its author's observations still ring true today. This insightful article states that a soil with ideal tilth should:

1. Offer minimum resistance to root penetration
2. Permit free intake and moderate retention of water
3. Encourage an optimum soil air supply through gas exchange with the atmosphere
4. Achieve a balance of soil and water in soil pores
5. Provide maximum resistance to erosion
6. Promote microbiological activity
7. Provide stable traction for farm implements

The structure of a soil can be affected by physical, biological and especially cultural forces. Most forms of modern agriculture are geared towards mechanical tillage as the primary means to manage structure. Experienced nursery managers appreciate the importance of proper tillage. For instance, if a rototiller is used to form seedbeds, then the moisture content of the soil must be ideal and the RPMs must be kept low. While proper cultivation can help create good tilth, this condition is often transitory and does not last through the crop rotation.

Managing tilth with organic matter. Less appreciated is the role of soil organic matter in the formation and maintenance of the ideal crumb soil structure. While soil crumbs can be formed by proper cultivation at the right soil moisture content, these mechanically-formed crumbs are not stable. The actinomycetes and bacteria that live on soil organic matter leave polysaccharide gums on the surrounding sand, silt, and clay particles which glue them together. In addition, the mycelial strands of soil fungi grow between particles and bind them together (Figure 3). So, organic matter will not only help create good soil structure, it will provide a measure of resilience to resist breakdown.

Figure 3 - The decomposition of organic matter by soil microorganisms leaves polysaccharide gums and fungal mycelia which bind soil particles into "crumbs".



These beneficial effects on soil structure normally occur when the organic matter level is around 2%. One problem with the ideal sandy nursery soil is that it is difficult, if not impossible to keep the soil organic matter above 1% for very long. In fact, the productivity of a sandy loam soil decreases progressively after initial cultivation because the organic matter contributed by the original plant cover is quickly depleted. This is a function of soil temperature and moisture and so organic matter maintenance is more of a problem in the South than in the North. It is important to remember that soil organic matter levels are never stable and so it is important to continue to add organics whenever possible.

1. Organic amendments - I consider all materials added to soil to increase the organic matter content to be amendments. Organic materials added as mulches to protect seed or seedlings or control weeds can also be consider amendments, but they will not affect soil structure until they are incorporated. Another difference is that these surface applications will not breakdown until they are incorporated into the soil and so do not require simultaneous applications of nitrogen fertilizer.

Composts are the best choice for an organic amendment but most commercial sources are still too expensive for bareroot nursery applications. Many nurseries make their own composts or buy uncomposed material like sawdust or bark and mix them with supplemental nitrogen into fallow fields. Other nurseries add organics before sowing a green manure or cover crop. This additional nitrogen fertilizer is needed to compensate for the initial microbial tie-up during the decomposition process. It is important to realize that this nitrogen is not lost, it is merely tied-up in the bodies of the soil microbes and will be gradually released back to the seedlings as the microbes die. You are actually converting inorganic nitrogen fertilizer into a more stable organic form.

Unfortunately, little formal research has been published on the affects of organic amendments to soil tilth,especially on forest and conservation crops. Rose and others (1995) present a very comprehensive discussion of organic amendments and cover crops along with anecdotal information from nurseries. Davey (1984) also does an excellent job of discussing organic matter management in forest nurseries. Both contain handy tables to help with calculations, especially how much nitrogen fertilizer to add for various materials.

2. Green manure crops - Some nurseries prefer to grow their own organic matter and this is an effective practice when the field can be taken out of tree production for

one or more years. While green manure crops are grown primarily for their organic matter, they can also serve as cover crops to protect against wind or water erosion, or as catch crops to fix mineral nutrients.   A wide variety of legumes, grasses, and other agricultural crops such as corn and Sudangrass grass have been used for green manure crops. Remember that the main objective is to grow as much organic matter in as little time as possible. Some nursery pathologists question the wisdom of green manure or cover crops, because some can cause an increase in soil pathogens. Organic growers would strongly disagree and point out that the well-chosen green manure crops encourage the populations of beneficial microbes.   Like all cultural practices, their use depends on the local conditions and tests should always be done before operational practice. McGuire and Hannaway (1984) discuss common cover and green manure crops for forest nurseries in the Pacific Northwest.

3. Organic Fertilizers. I may be going a little far afield here but it occurs to me that the change from organic fertilizers may be related to the loss of soil tilth in modern nurseries. Before the advent of modern chemical fertilizers in the 1950's, nurseries used various types of organic materials to provide mineral nutrients to their crops. These organics had a very low fertilizer analysis, compared to modern products. Milorganite, for example, contains only 7% N and P compared to urea which has 34% N. In the case of Milorganite, the other 93% of the weight was pure organic matter but with many inorganic fertilizers, the filler is clay. To get sufficient mineral nutrients, nursery managers had to add tons of organic fertilizers to their crops each year which resulted in a huge amount of organic amendments to the soil. Our modern fertilizers are efficient in supplying mineral nutrients to our crops but we have lost a tremendous source of organics which helped to maintain soil tilth.

Summary. Good soil tilth can be managed by careful cultivation and organic matter maintenance. While soil can be cultivated into the ideal crumb structure, it takes the products of organic matter decomposition to give them resiliency. Some nursery managers question the financial benefit of adding organic amendments and growing cover crops, especially in warm climates, because it is so hard to show a significant rise in soil organic matter. Remember that the beneficial effects of organic matter decomposition on soil tilth will not be reflected in standard soil tests that only measure % organic matter. The improvement of soil tilth is one of those things that is difficult, if not impossible, to measure but experienced nursery managers can "feel" the difference in their soils - even from the tractor seat. Organic matter is also a wonderful buffer and makes the soil much more resistant to a range of possible problems.

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Subsurface Banding at J. Herbert Stone Nursery - A New Method for Applying Fertilizers in Forest Nurseries

by David E. Steinfeld

Most bareroot nurseries apply fertilizers the way it's been done for decades – by broadcasting fertilizer directly to the surface of the seedbed and then incorporating it into the soil through tillage or irrigation. While this is a tried and true method and perhaps the only fertilizer method most of us have ever known, it might be time to step back and consider a totally different approach to fertilizing your crop – by placing *all* fertilizers in a concentrated band below the surface of the soil at the time of sowing. The method is called *subsurface banding.*

Wait! Before you say to yourself that a change of this sort would be too much of a hassle or too expensive, consider what the potential benefits to your nursery might be.

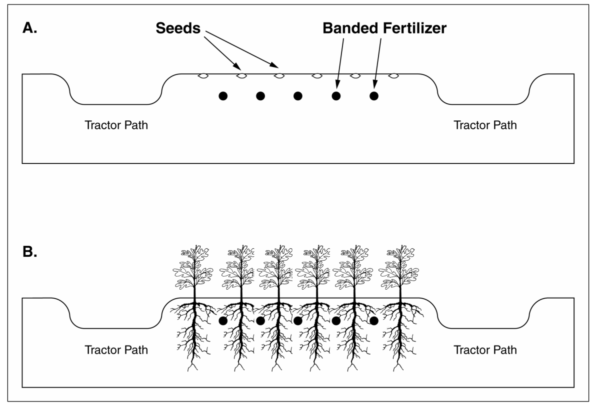
You could:

?? Eliminate all broadcast applications of fertilizer in the 1+0 year – which can be up to 9 times
?? Drastically reduce the amount of fertilizer applied
?? Free up tractors and people in late spring and early summer
?? Reduce the potential for nitrate leaching
?? Lower the risks for salt toxicity and seedling disease
?? Increase seedling quality
?? Lower costs

These are the benefits we are realizing at Stone Nursery. For over 15 years our nursery has banded phosphorus and potassium fertilizers with good results. We apply them at the same time we are sowing, whether the crop is being grown as a 1+0 or 2+0. Lately, we are working with control release nitrogen fertilizers as an alternative to broadcast applying ammonium nitrate and ammonium sulfate.

What is subsurface banding? Subsurface banding is the exact placement of fertilizers below and to the side of the seed at the time of sowing (Figure 1A). At Stone Nursery, the fertilizer bander is attached directly to the seed drill and fertilizer is delivered at the same time the seed is being sown. Having the bander attached to the drill assures that the placement of the fertilizer is always 3 inches (7.6cm) horizontally and 3 inches vertically away from the seed. This precise placement makes sure

Figure 1A and 1B: Fertilizer is banded precisely beneath the soil between seed rows.



that the fertilizer is available to the plants while eliminating the possibility of salt injury associated with the concentration of fertilizer near the roots of the developing seedling (Figure 1B).

The fertilizer bander is composed of a hopper that holds the fertilizer, a chain driven fertilizer distributor, coulters or knives that open the soil and drop tubes that deliver the fertilizer (Figure 2). In this way, any dry fertilizer or amendment that can flow through the drop tubes of the bander can be applied to the crop. This includes, but is not limited to, inorganic and organic granular fertilizers, control-release fertilizer, as well as non-fertilizer materials such as mycorrhyzae. In this article, two types of fertilizers will be discussed in respect to subsurface banding – phosphorus/potassium and control-release nitrogen fertilizers.

Figure 2: The fertilizer bander is attached directly to the seed drill but the application rate is controlled separately by hydraulics.

Banding phosphorus and potassium fertilizer. There were several very important reasons that Stone Nursery began to band P and K fertilizers. First, banding eliminated three tractor trips prior to sowing in the spring – two separate trips to apply each fertilizer and a pass to incorporate the fertilizers into the soil. Aside from saving employee salary and equipment costs, three trips over our soggy fields in the spring will definitely compact our soils and in the worst conditions, puddle them (another way of saying, sink a tractor!). If the spring is wet, like it was this year, our sowing window becomes so narrow that we can't afford to waste the few dry days applying fertilizers, when we could be sowing. Secondly, when P and K fertilizers are banded, they are readily and immediately accessible to the newly germinating seedlings. Thirdly, fertilizer rates can be reduced by a third to a half the broadcast incorporated rates. This is in part due to the fact that phosphorus does not move very far in the soil profile because it becomes chemically fixed on soil particles and unavailable to the seedling. The amount of fixation is directly related to the amount of fertilizer in contact with the soil. Since there is less soil contact with banded P and K, not only is less fertilizer needed but it is available for longer periods of time **-** up to two years.

Banding controlled release nitrogen fertilizer. Recently, we asked ourselves: if banding P and K fertilizers is this easy, why don't we band nitrogen fertilizers. If it worked, we might be able to eliminate some of the typical problems associated with broadcast N fertilization. Let's look at a typical broadcast nitrogen fertilizer program in a 1+0 year at Stone Nursery and see why an alternative might be beneficial.

When our seedlings begin to develop their first new leaves and the roots of the young seedlings are beginning to develop laterals, we hook up our three bed Barber spreader and apply ammonium nitrate over the seedbeds. This is usually done in late May and early June, generally 6 weeks to 2 months after we have sown the crop. Although we plug the fertilizer holes that drop fertilizer on the tractor paths, fertilizer prills end up in the paths anyway, becoming useless to the crop as well as potentially getting into the surface water with the first good rainstorm or irrigation. As the weather turns hot from late June on, our seedlings are at risk to the effects of high salts and diseases. Unfortunately, this is also the time we do most of our broadcast nitrogen fertilizer applications which can exacerbate these problems. Over the years, we have seen problems arise as a result of applying nitrogen fertilizers to our 1+0 crops when insufficient irrigation was applied to leach the fertilizer salts from the surface of the beds. As a result many seedlings either died or were severely stressed. Once, the tractor operator who applied the fertilizer forgot to inform the irrigator to water the fertilizer off the trees. The result the next day was a bright red field. Perhaps the risky aspect of broadcast fertilization in the late spring/early summer is the increased potential for damping-off or root rot diseases, resulting from the high concentration of nitrogen in the soil surface. After considering all these risks, we became interested in banding nitrogen fertilizers.

Since nitrogen is a very mobile ion in the soil, the benefits of subsurface banding ammonium nitrate and ammonium sulfate are different than for phosphorous or potassium fertilizers. This is where controlled release nitrogen fertilizers (CRNF) come in. By subsurface banding CFNF's at sowing, nitrogen slowly releases from the prills as the seedling develops. Since the release rates of most CRNF's increase with soil temperatures, more nitrogen is available during the optimum temperatures for seedling growth and less available during colder weather when the seedlings are not growing as much.

Several years ago, our nursery established two administration studies to evaluate the effectiveness and costs of banding subsurface CRNF's. The results of these studies demonstrated that seedlings grown with subsurface banded CRNF's equaled or exceeded the growth rates of seedlings grown under our standard broadcast fertilizer regimes even when the CRNF's were applied at a third of the standard rate. The evaluation of a 1+0 ponderosa pine crop, showed that after one growing season, seedlings were significantly taller on treatments using one third (50 pounds N/acre = 45 kg/ha) and two-thirds (100 pounds N/acre = 126 kg/ha compared to the standard broadcast rates (141 pounds N per acre = 116 kg/ha).

Is subsurface banding more expensive? For P and K fertilizers, reducing the number of tractor trips is a definite cost savings. Upon request, fertilizer distributors will mix P and K fertilizers at specified rates, eliminating the need to mix the fertilizers at the nursery. While the seed drill operator is transporting seed from the pickup to the seed drill, the tractor operator can take this time to fill the fertilizer bins, thereby minimizing the time handling fertilizers. Since the tractor operator controls the fertilizer application as the seed drill is being pulled, this saves labor and equipment costs.

At first glance, subsurface banding of CRNF may not appear to be cost effective because these fertilizers can be 3 to 5 times more expensive than ammonium nitrate and ammonium sulfate. Yet depending on the type of

CRNF being used, the total annual costs on a per acre basis are comparable. Consider a standard broadcast N fertilizer regime at Stone Nursery where 114 pounds of N/acre (102 kg/ha) is applied in four applications. Compared to a CRNF, such as polymer-coated urea, ammonium nitrate is a third the cost. However, since only half the rate of polymer-coated urea is applied to achieve the same result, the actual cost per acre of ammonium nitrate is just over half the cost of polymer-coated urea (Figure 3). Of course, the overall savings comes from eliminating four tractor applications of ammonium nitrate and ammonium sulfate. The cost for broadcast application of N fertilizers can actually be 25 percent more expensive than banding CRNF and almost 100 percent more expensive when P and K are banded at the same time.

Nitrate leaching. Cost comparisons aside, perhaps the best reason to consider banding control release N fertilizers is the effect this practice will have on ground water quality. If fertilizer use can be cut by a third to a half, leaching of nitrates into the ground water can be significantly reduced. This could be critical for your nursery as ground water issues take on greater importance.

Equipment availability. Fertilizer banders are readily available through your local agriculture equipment outlets. We purchased a bander through Gabilan Manufacturing, Inc (TEL: 800-538-5864), however there are several companies that manufacture this equipment. Any product you purchase will probably have to be adapted to your nursery equipment or needs. The J.E. Love Company is in the process of developing a fertilizer bander for bareroot nurseries that can be attached to the seed drill (see Figure 2). They can be reached at TEL: 509-635-1321 for further information.

Conclusions and recommendations. In summary, banding P, K and control release N fertilizers can reduce the amount of fertilizer used and substantially decrease the number of tractor trips. This will save money in the long run. Using a control release fertilizer can reduce nitrate leaching, reduce surface salt buildup and potentially reduce the incidence of early season diseases. Changing fertilization systems, as with any major change in nursery practices, should be accomplished first on small scale, to see what the effects will be at your nursery.

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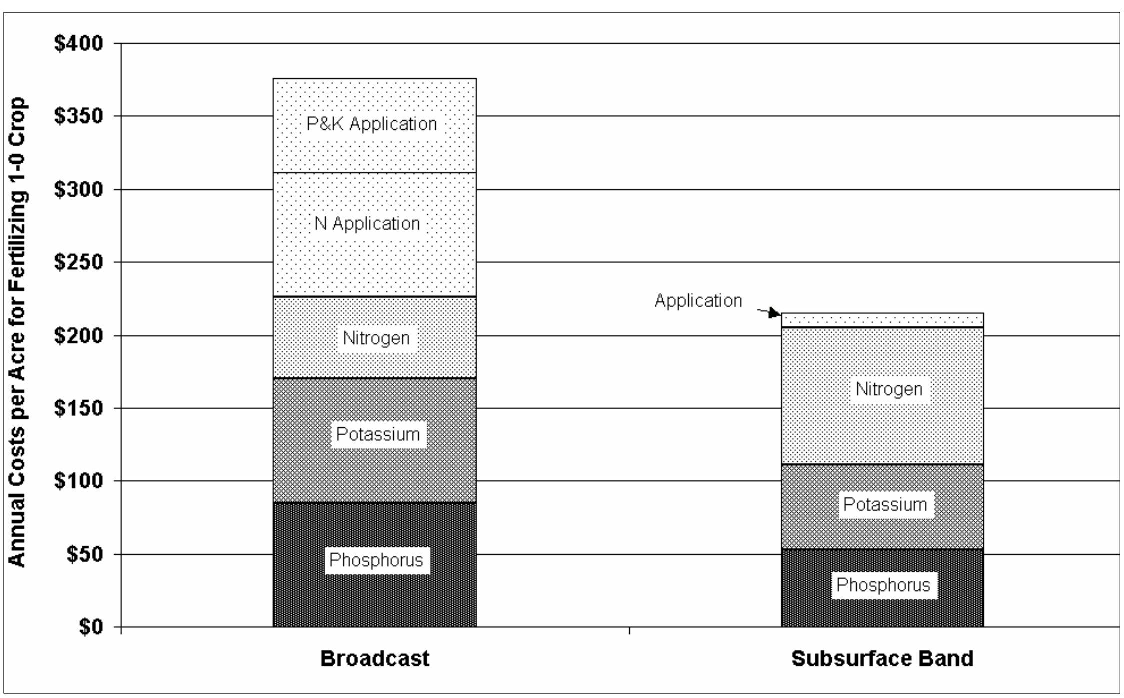
Figure 3: Even though fertilizer costs are higher, the real savings of subsurface banding comes from the single application cost.



Macronutrients - Nitrogen: Part 1

by Thomas D. Landis and Eric van Steenis

Starting back in 1996, we began writing articles on the 13 essential mineral nutrients that are needed for plant growth. To date, we have covered the 3 secondary macronutrients and 7 micronutrients and now we will finally get to the “Big Three”: nitrogen (N), phosphorus (P) and potassium (K). They are called macronutrients because they make-up such a high percentage of the total mineral nutrient content of plants. Together, nitrogen, phosphorus and potassium comprise almost two-thirds of the total mineral nutrients in a plant (Table 1). They also are called “fertilizer elements” because they are the principal mineral nutrients in major fertilizers. In fact, federal law requires that percentage of these elements must be clearly shown on fertilizer labels - nitrogen as % N, phosphorus as % P_2O_5, and potassium as % K_2O.

We will start discussing nitrogen in this issue but, because it is such a complex subject, we have had to divide it into two parts. This first part will discuss the ecological and physiological aspects of nitrogen including availability and how it is taken-up and assimilated by seedlings. The second part, which will be included in the next FNN issue, will look into all aspects of nitrogen management in nurseries including monitoring in soils and tissue, fertilizer types and application methods, and cultural and environmental effects of overfertilization.

Introduction

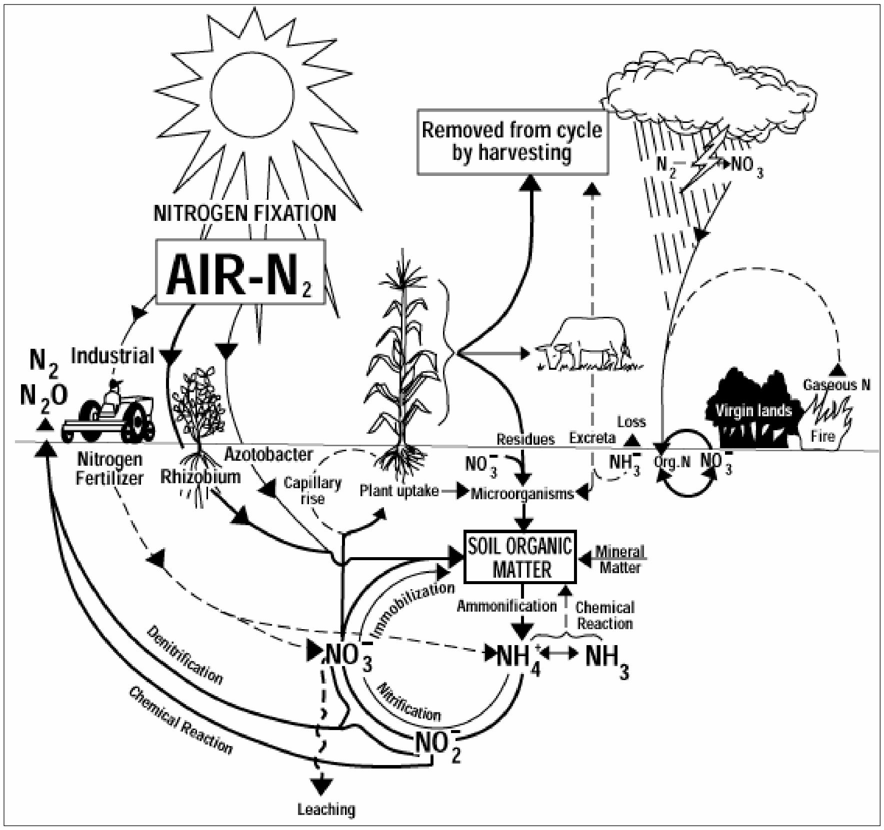
Nitrogen is the mineral nutrient found in the highest concentration in plant tissue, comprising over one-third of the total mineral nutrient content (Table 1). Nitrogen is almost always the most limiting mineral nutrient affecting crop growth and forest and conservation nursery seedlings are no exception. Nitrogen’s importance to nursery culture is confirmed by the fact that there are more articles dealing with nitrogen in the FNN database than any other nutrient: twice as many as P and 6 times as many as K.

Although nitrogen gas (N_2) makes up over three-quarters of the earth’s atmosphere, the majority of plants cannot access this nitrogen. One source estimated that 78,000 metric tons of nitrogen gas are in the air above each hectare of land. However, this vast supply of atmospheric nitrogen has to be converted to either ammonium (NH_4^+) or nitrate (NO_3^-) ions before most plants can use it. Some atmospheric nitrogen can be captured in precipitation and carried into the soil, but the majority is fixed by specialized soil bacteria. These microbes are either free-living or form nodules on the roots of legumes plants such as clover or on some non-leguminous plants such as red alder. Nitrogen-fixing bacteria form a symbiotic relationship with their hosts. The host plants benefit by having the atmospheric nitrogen fixed into a usable form, while the bacteria obtain energy from the chemical conversion and a place to live. Man has also learned to convert atmospheric

Table 1 - The three essential macronutrients and their typical concentration in seedling tissue

Element	Symbol	% of Total Mineral Nutrients in Plants	Adequate Range in Tree Seedling Tissue (%)		Where and When Published
			Bareroot	Container	
Nitrogen	N	37.5	1.2 to 2.0	1.3 to 3.5	Summer, 2003 & Winter, 2004
Phosphorus	P	5.0	0.1 to 0.2	0.2 to 0.6	To Do - Summer, 2004
Potassium	K	25.0	0.3 to 0.8	0.7 to 2.5	To Do - Winter, 2005

Figure 1 - All Nitrogen Originates as an Atmospheric Gas which is Fixed by Microorganisms or in Fertilizers, and Then Cycles Through Nature By Natural and Man-Made Processes (from Brown and Johnson)



nitrogen into fertilizers by the Haber process in which gaseous nitrogen and hydrogen is synthesized into ammonia at high pressure and temperature. Once fixed, nitrogen is cycled through the natural world by man-made and natural process (Figure 1).

Role in Plant Nutrition

Nitrogen is vital to every physiological process that takes place within living plants. It is a constituent of all 20 amino acids, which are the building blocks of proteins. Proteins have both structural and physiological functions in plants. Some proteins are part of the structure of cell walls and membranes while others are enzymes, which means that nitrogen is involved in virtually every biochemical and synthesis reaction that occurs in plants. Nitrogen is also part of the molecular structure of nucleic acids, the building blocks for DNA, which carries the genetic blueprint of every organism on earth. Then, if that's not enough, the molecular structure of chlorophyll contains 4 nitrogen atoms (Figure 2). An adequate supply of nitrogen promotes high photosynthetic activity, evidenced by the dark green color of well-fertilized plants. To sum it all up, nitrogen is an integral part of the physical structure of plants, all enzyme systems within plants, the genetic makeup of plants, and the process of photosynthesis. There is no structure or function within a green plant that can be completed in the absence of nitrogen. In order for a plant to be able to exist, support its own weight, grow, reproduce, defend itself and photosynthesize, it needs nitrogen. Without nitrogen, life as we know it could not exist.

Nitrogen is needed in highest concentrations in plant parts that are actively growing, namely young leaves, flowers, and root tips. When nitrogen is limiting, cell division and expansion slows and so it is no wonder nitrogen fertilization is used to control plant growth in nurseries. New cell construction requires duplication of genetic material, construction of cell walls and membranes, and activation of enzyme systems, all of which require nitrogen. When the nitrogen supply decreases, nitrogen is mobilized from mature foliage and translocated to areas of new growth. Because chlorophyll production also drops off when nitrogen is limiting, older leaves and needles turn yellow and, in severe cases, actually senesce. If the deficiency persists, chlorophyll production slows which decreases photosynthesis. At the same time, production of the many nitrogen-containing building blocks are reduced and the result is a smaller, slower growing plant.

Plants seem to have evolved so that accessing nitrogen is first priority among all physiological processes. In nature, this is a survival mechanism but, when excess nitrogen fertilizer is supplied in nurseries, plants continue to take it up with disastrous consequences. Overfertilized nursery plants divert energy, carbohydrates, water and other mineral nutrients to the assimilation of nitrogen, throwing all physiological systems out of balance. These and other adverse effects of excess nitrogen fertilization will be discussed in Part 2.

Availability in the soil and growing media. Nitrogen is available in soils from nitrogen fixation, the decomposition of organic matter or, from the addition of fertilizers (Figure 1). Although some nitrogen is made slowly available as plant residues and soil microorganisms decompose, the majority of nitrogen in nurseries is supplied by fertilizers in one of three forms: urea ($NH_{3)}$, ammonium (NH_4^+), and nitrate (NO_3^-) (Table 2).

Urea does not last long in the soil because it is water soluble and, if not lost to leaching, is quickly converted to ammonium by specialized soil bacteria (Table 2). Under warm and moist conditions, this conversion is very rapid. There are also many types of ammonium fertilizers and, since the ions are positively-charged, they are adsorbed on the cation exchange sites of clays and organic matter. However, ammonium ions not immediately used by plants are converted by another species of soil bacteria into nitrate ions.

Being negatively-charged, nitrate ions do not adsorb to the cation exchange sites and, if not taken-up by plants, will rapidly leach out of the soil profile (Table 2). Other soil microbes, given enough time and the right soil conditions, can covert nitrate back into organic forms or back into nitrogen gas (Figure 1). Excess nitrate is especially utilized by soil bacteria under conditions of low soil oxygen such as water logging. These bacteria use nitrate as a source of oxygen for respiration, thereby causing the production of nitrogenous gases, which are subsequently lost to the atmosphere (Figure 1).

It should be obvious by now that the nitrogen cycle in nurseries is a very "leaky" system. In fact, most applied nitrogen fertilizer is not absorbed by plants at all but lost to leaching or volatilization. Heavy fertilization only drives this process faster.

Uptake by plants. Roots of higher plants take up inorganic nitrogen as nitrate and ammonium ions which have different charges (Figure 3). Organic fertilizers must also be broken down into these ionic forms before uptake can occur. Because the mode of uptake differs for each ion, their effect on overall plant growth rate as well as the relative growth rate of roots vs. shoots is pronounced. As we have just discussed, reducing the amount of nitrogen fertilizer can be used to slow plant growth. However, cutting back on total nitrogen can lead to nutrient imbalances and impair important physiological and biochemical processes. A more sensible approach is to regulate seedling growth rates by applying fertilizers containing nitrate instead of ammonium-based fertilizers.

Ammonium, and especially its equilibrium partner ammonia, are toxic at quite low concentrations. When they are taken-up by roots, plants immediately detoxify them by forming amino acids, amides, and related compounds. This process requires stored energy and carbohydrates which supply the carbon skeletons. Once assimilated, these organic nitrogen compounds are translocated through the xylem to the shoots for further utilization.

Table 2—Characteristics of the different forms of nitrogen in nurseries

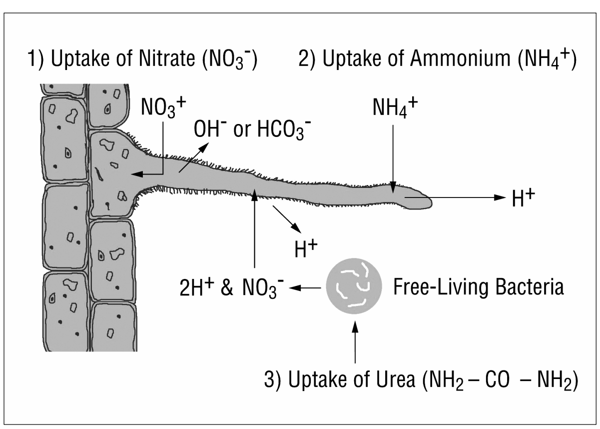
Name	Chemical Symbol & Ionic Charge	Leaching Potential	Remarks
Urea	**NH_3**	**High**	**Soil bacteria must convert urea to ammonium before uptake by plants**
Ammonium	**NH_4^+**	**Low**	**Held on cation exchange sites. Must be converted in roots after uptake**
Nitrate	**NO_3^-**	**High**	**Can be taken-up by plants and translocated without conversion**
Organic	**Several forms with no charge**	**Low**	**All organic fertilizers must be converted to ammonium ions before uptake**

Under high ammonium fertilization, the build-up of amino acids, amides, etc. essentially "drive" a plant to grow. Therefore, crops grown exclusively with ammonium fertilizers may deplete their carbohydrate resources to dangerously low levels, resulting in soft, succulent plant tissue. Roots may have their carbohydrate reserves depleted to the point where their growth and disease resistance is compromised. These conditions are most common during periods of low light and short days, when net carbohydrate synthesis rates are low. Warm conditions aggravate the situation further so greenhouse growers should be particularly careful using ammonium fertilizers for winter crops or during period of extended cloudy weather.

Nitrate, on the other hand, is not toxic and is mobile in the xylem on its own. This facilitates its transport to anywhere within the plant where nitrogen may be needed. Excess nitrate is stored in vacuoles in either root or shoot tissue. Nitrate cannot be used directly, however, but must be converted back to ammonia. This is a multi-step process requiring several enzymes, cofactors such as molybdenum, energy and time. Because nitrate does not have to be utilized immediately upon entry into the plant, it does not drive growth and carbohydrate depletion to the same degree as ammonium. And, because nitrate reduction takes place in growing plant tissue, carbohydrates in roots are not depleted.

Affects on pH. Plants grown on either ammonium or nitrate fertilizers change the pH of their soil or growing medium, specifically the zone immediately adjacent to the roots. Nitrate fertilizers cause soils and growing media to become more alkaline whereas organic nitrogen, urea or ammonium fertilizers make them more

Figure 3 - Although three forms of nitrogen are available to plant roots, only ammonium and nitrate ions are taken-up. Note that, because hydrogen and hydroxyl are released by this process, the pH of the soil will be affected.



acidic. These changes in pH are due to a couple of reasons. First, the nitrification of organic, urea, and ammonium fertilizers produces hydrogen ions (H^+). Secondly, hydrogen ions are excreted by the roots upon ammonium uptake, and hydroxyl ions (OH^-) upon nitrate uptake (Figure 3). Consequences of this can be positive or negative depending on the cultural context. Growers have used the acidifying effect of ammonium fertilization to reduce the upward pH drift associated with high alkalinity water sources.

Influences on Plant Growth and Development

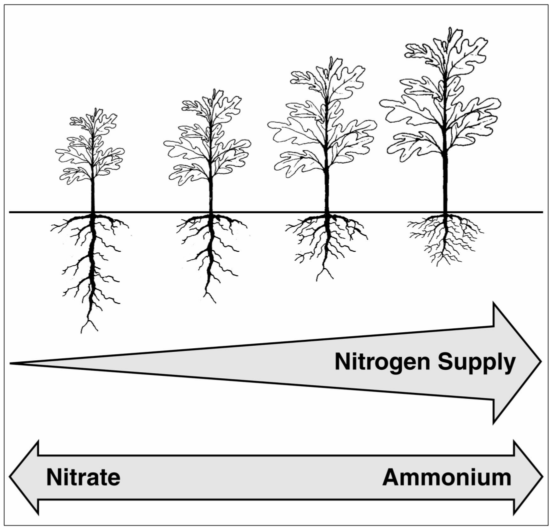
Growers use nitrogen fertilization to control the amount and type of tissue in their crops. When all other conditions are favorable, the amount and type of nitrogen fertilizer can be used to accelerate or slow down seedling growth. Not only the total growth rate, but the ratio of shoot growth to root growth can be affected by the type and amount of nitrogen fertilization (Figure 4).

Seedling Growth Phases. High nitrogen fertilization favors rapid shoot growth and produces leaves and needles which are larger and thinner. On the other hand, relatively low nitrogen levels lead to slower growth, smaller and thicker leaves, and a higher root:shoot ratio. The type of nitrogen fertilizer is also important. Ammonium-based fertilizers force more shoot expansion relative to root growth whereas nitrate fertilizers tend to favor stem and root growth (Figure 4).

Establishment Phase - Growers usually keep nitrogen levels low (for example, 50 ppm) when seedling are just getting established. This is because small plants cannot utilize high levels of nitrogen but also minimizes chances for damping-off because excess N stimulates fungal pathogens. Ammonium fertilizers are preferred because it takes young plants several weeks to develop the nitrate reductase enzyme.

Rapid Growth Phase - Once the crop is established, however, nitrogen levels are increased two to four times (typically to 100 to 200 ppm) and fertilizers with a higher proportion of ammonium are favored. The type of fertilizer and nitrogen rate must be adjusted for species differences, however. Naturally slower-growing species may need to be "pushed" with nitrogen levels up to 300 ppm whereas fast growers are kept at the 50 ppm rate. The cultural objective during this Phase is to maximize shoot growth, and seedling height increases rapidly during this period. However, this accelerated growth produces many cells with relatively weaker cell walls and this succulent growth is more subject to physical injury and other stresses. Even moderate

Figure 4 - Because nitrogen is so critical to seedling physiology, nitrogen fertilization can be use to speed-up or slow-down seedling growth as well as control their shoot-to-root ratio.



moisture stress or unusually high temperatures can physically damage ("burn") succulent foliage.

Hardening Phase - Growers typically lower nitrogen fertilization and change to nitrate fertilizers during the Hardening Phase as one of the cultural changes to induce dormancy and hardiness. Lower nitrogen rates are necessary as a first step in inducing dormancy and developing cold hardiness. Slower cell division produces thicker cell walls which are more resistant to physical stresses. Slowing the shoot growth rate is also the first step to inducing budset which is the start of the dormancy and hardening process. Calcium nitrate is a popular hardening fertilizer because the nitrate slows down cell division and the calcium helps build stronger cell walls.

Conclusions and Recommendations - Part 1

Well, that concludes the first part of our discussion of nitrogen as a essential plant nutrient and we think that you'll agree that it's a complicated and fascinating subject. Nitrogen is absolutely critical for controlling the amount and type of seedling growth in modern nurseries. Balanced against its cultural importance is the responsibility to minimize the environmental effects of overfertilization. We'll discuss nitrogen management in detail in the next issue of FNN.

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Seedling Quality Tests: Cold hardiness

by Gary Ritchie and Tom Landis

Introduction

In the Winter, 2003 issue of FNN, we initiated a series of articles on seeding quality tests with a discussion of the popular Root Growth Potential (RGP) test. In this issue we will consider a test that has been around much longer than RGP – the cold hardiness (CH) test.

Concepts Behind the Test

Cold injury to plants is one of the critical factors that determine where plants are able to survive in the Temperate Zone, and Hardiness Zones have been established based on tolerance to cold temperatures. Tree species exhibit a vast range of midwinter hardiness levels (Sakai and Weiser 1973), reflecting the climate of the regions in which the species occur. Boreal conifers, such as black and white spruce, jack pine and others attain hardiness levels below -112 ºF (-80ºC), while many Rocky Mountain conifers, such as lodgepole pine and Engelmann spruce, achieve this level or nearly this level. In contrast, Pacific coast conifers such as Douglas-fir, coast redwood and western redcedar, rarely harden to below -13ºF (-25ºC).

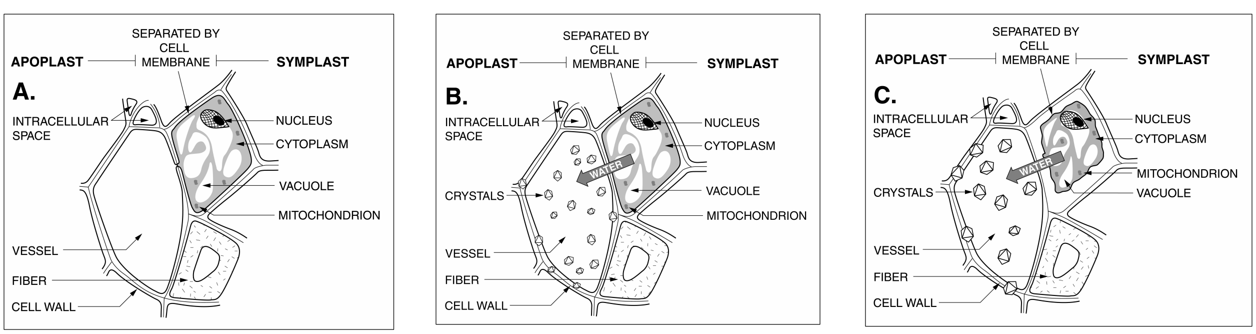
Although CH testing has been used since the early 1900's as a method of selecting cold hardy horticultural cultivars, its use as a seedling quality test has developed over only the past thirty or so years. As we will now discuss, CH tests have become of the most utilized tests of seedling quality with a variety of different applications in nursery management.

Annual Cold Hardiness Cycle. During the growing season, most temperate zone plants are killed when the air temperature drops to only few degrees below freezing. However, as winter approaches and growth slows, plants perceive the changing photoperiod (lengthening nights) and begin to develop tolerance to cold (Weiser 1970, Glerum 1976, 1985, Bigras and others 2001). When winter arrives, plants that would have been killed at slightly below freezing become conditioned to survive very cold temperatures. Then, as winter draws to a close and the growing season nears, this cold hardiness is rapidly lost and plants resume growth.

How Plant Cells Freeze. To understand how plants are able to progressively tolerate cold temperatures, it is necessary to discuss what happens inside plant tissue when it freezes. In a cross section of plant tissue (Figure 1A), there are various types of cells that have different functions. Some cells such as the fibers and vessels are empty while others are filled with living material called cytoplasm. The cells that contain cytoplasm are enclosed within a cell membrane made of a fatty material called lipid in which protein molecules are embedded. This membrane plays a key role in plant cold hardiness. All cells are surrounded by walls made primarily of cellulose, which is stiff and strong. The cell walls are packed tightly together, but occasionally spaces will occur between them – intracellular spaces that contain only air or water.

Everything within the plant that is enclosed by the membrane system is called, collectively, the symplast and is living tissue. Everything outside the membrane (cell walls, intercellular spaces, empty cells, etc.) is

Figure 1. Diagrammatic cross section through plant tissue illustrating the events that occur when tissue freezes: A - Living cell contents (symplast) are separated from non-living cell contents (apoplast) by the cell membrane. B - When temperatures fall below freezing, ice crystals begin to form in the apoplast. As these crystals grow, they draw water across the cell membrane causing dehydration of the cell contents. C - As temperature continues to fall, more water is drawn from the cells, the cytoplasm becomes severely dehydrated, and the membrane can rupture, and/or lose its semi-permeable properties. When this occurs, cell contents can leak into the apoplast resulting in severe injury or death.



referred to as the apoplast, and is non-living (Figure 1A). Both the symplast and apoplast are bathed in water. The apoplast water is nearly pure, so its freezing point is close to 32 ºF (0 ºC) . The water in the symplast, however, contains dissolved sugars and salts, suspended starch granules and protein molecules. These materials cause an osmotic effect and depress the freezing point of the water in the symplast to considerably below freezing. When this tissue is exposed to increasingly colder temperatures, the relatively pure apoplastic water begins to freeze and small ice crystals form within the cell walls, intracellular spaces and other voids within the apoplast (Figure 1B). The water in the symplast, with its lower freezing point, resists freezing. Thus, the ice that forms within the plant tissue is contained in the apoplast and does little or no damage to living plant tissue.

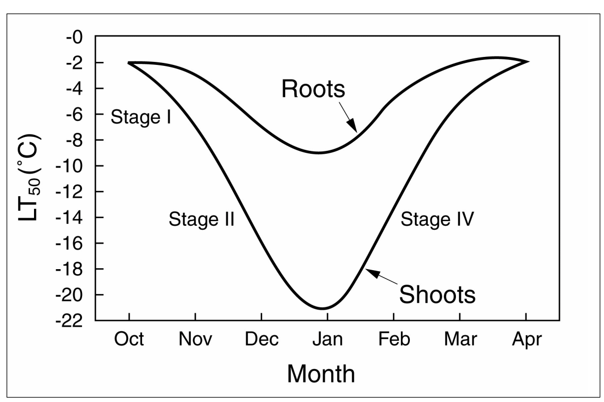
Ice has a very strong affinity for water – so strong that the ice crystals in the apoplast pull water tenaciously across the membrane and out of the symplast (Figure 1B). Since the membrane is permeable to water only, the dissolved sugars and other materials remain in the symplast even as water is being drawn out. This raises the concentration of the dissolved solutes, further lowering the freezing point of the symplast water. So, the more water that is pulled out of the symplast, the more stubbornly it resists freezing. When the temperature increases, the ice crystals gradually melt and the water trapped in the ice crystals is pulled back into the symplast by osmosis. The symplast regains its lost water, the living cells re-hydrate, and no tissue damage occurs.

Throughout winter, this process occurs over and over - even on a daily basis when nights are cold and days are warm. Ice routinely forms and melts in the apoplast, and water moves into and out of the symplast across the membrane. However, when plants are not cold hardy or when the temperature falls below their seasonal level of hardiness, the size of the ice crystals become larger causing severe dehydration of symplastic cells. When this happens, proteins denature and cell membranes are killed or damaged which allows cell contents to leak into the apoplast. Eventually, cells plasmolyze and their cytoplasmic volume decreases sharply, leading to cell death (Figure 1C). It is not clear whether low temperature itself, or desiccation, or both actually incite the damage (Adams and others 1991).

Mechanisms of cold hardiness. Cold hardy plants avoid cold injury by several mechanisms (Sutinen and others 2001, Öquist and others 2001). Solutes accumulate either actively or passively in the symplast lowering their freezing point. In addition, the properties of cell membranes change, making them physically more resistant to desiccation and rupture. Another important avoidance mechanism is deep supercooling of water (Quamme 1985). Pure water can cool to nearly -40 ºF (-40 ºC) without forming ice crystals if no ice nuclei are present. Some plants are able to exploit this property of water to prevent ice crystal formation down to nearly this temperature. However, when this "supercooled water" freezes it is nearly always lethal. The observation that many plant species do not occur north of the -40ºF mid-winter isotherm, suggests that they avoid cold damage by this mechanism (George and others 1974). Midwinter temperatures of about -40 °C also occur commonly at timberline, causing Becwar and others (1981) to speculate that supercooling may also limit survival of certain species to below timberline. Many conifers (pines excepted) employ supercooling as a method of avoiding cold damage. However, many tree species can survive temperature far below -40 °C, so they are able to resist cytoplasmic desiccation by other, less well understood, mechanisms.

Cold Hardiness Patterns and stages. Cold hardening and dehardening (also referred to as cold acclimation and deacclimation) occur in a series of two (Cannell and Sheppard 1982) or three (Timmis 1976, Timmis and Worrall 1975) stages depending on species. A typical cold hardiness pattern for coastal Douglas-fir shoots and roots for the Pacific Northwest is illustrated in Figure 2. The X-axis shows time from fall to spring and the Y-axis represents the LT_{50} value - the cold temperature that is lethal to 50% of a sample population. When discussing the relative cold hardiness of plants, the LT_{50} is traditionally used as a basis for comparison.

Figure 2. Temperate zone plants go through a seasonal cycle of hardening and dehardening. This generalized curve for coastal Douglas-fir seedlings shows that peak hardiness for both shoots and roots occurs in January. However, note that roots do not attain the same level of hardiness as shoots.



Stage 1 - By October, in response to shortening photoperiod and growth cessation, the LT_{50} begins to drop to around 28º to 23ºF (-2º to -5ºC).

Stage 2 - This stage begins in November and can take the plants down to -4°F (-20°C) or lower. This stage is apparently promoted by exposure to increasingly lower temperatures – normally at night. During this stage intercellular sugar concentration, soluble proteins, membrane permeability and cytoplasmic permeability increase.

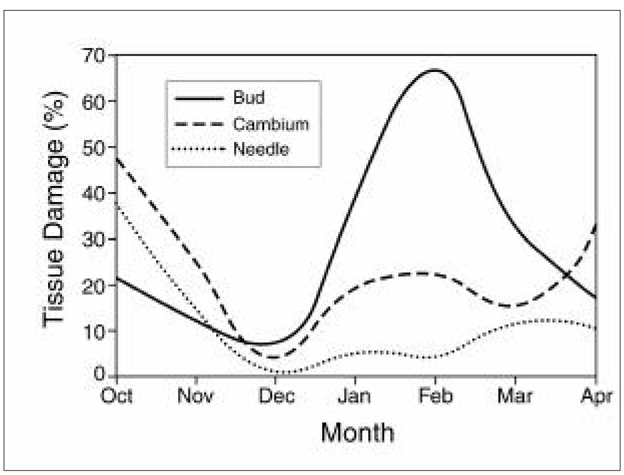
Stage 3 - Peak hardiness is normally achieved by mid-January. By then, hardening can take plants down to -148 ºF (-100ºC) or lower for very hardy species.

Stage 4 - By late winter and early spring, dehardening is triggered by longer days and especially warmer temperatures. This stage continues until active growth resumes in spring, at which time cold hardiness is completely lost.

The environmental cues that trigger and sustain the various stages of hardening and dehardening are discussed and evaluated in the interesting review of Greer and others (2001).

Differential tissue hardiness. Different plant tissues harden and deharden at different rates (Bigras and others 2001). For example, the roots of Douglas-fir seedlings do not harden nearly as much as the shoot although they exhibit the same seasonal hardiness pattern. This has important implications for outdoor container growers (Colombo and others 1995). The Oregon State University Nursery Technology Cooperative tested Douglas-fir seedlings through winter looking at hardiness of the buds, needles and cambium separately (Figure 3). In fall, buds were the most hardy tissues, with cambium the least hardy. By December, however, all tissues had similar hardiness. During late winter, buds dehardened most rapidly, followed by the cambium and finally needles, which retained hardiness into late winter. One would expect, then, to see more cambial damage resulting from fall frosts and more bud damage from spring frosts.

Figure 3. Douglas-fir seedling tissues exhibit differential sensitivity to cold during a winter season. In fall, buds show the greatest hardiness. In spring, this trend reverses, with foliage being hardiest and buds least hardy (used with permission: D. Haase and R. Rose, Oregon State University Nursery Technology Cooperative).



Cold Hardiness Testing

Practical Applications. Nurseries can use CH testing for a wide variety of purposes:

1. Monitoring Development of Hardiness - In fall, when the likelihood of cold fronts increases, it is useful to keep track of the hardiness level of outdoor nursery crops (Perry 1998). If a cold event is forecast to drop below the crop hardiness level, this signals the need for frost protection.

2. Lifting and Outplanting Windows - CH testing can be used as a quick and easy way to determine when bareroot and container stock is hardy enough for lifting, processing and storage. This test is being used operationally in British Columbia where conifer seedlings are considered ready to lift and cold store when they tolerate freezing to –18 °C (0 °F) with no more than 25% visible cold injury to the foliage (Burdett and Simpson 1984).

3. Overall Stress Resistance - Cold hardiness is a good surrogate measure for resistance to the many different stresses that occur during lifting, handling, storage, shipping, and outplanting. As such, CH tests have great value as a indication of overall stress resistance, which is otherwise difficult to measure (Ritchie 2000).

Cold Hardiness Testing methods

There are many ways to test seedlings for cold hardiness (Burr and others 2001), but only two types of tests are being widely used in forestry today: the whole plant freezing test (WPFT) (Tanaka and others 1997) and the freeze induced electrolyte leakage test (FIEL) (Dexter and others 1932, Burr and others 1990, McKay 1992). Both tests entail two steps (Ritchie 1991, Burr and others 2001). In the first step, plants or plant parts are exposed to a freezing stress. In the second step the stress damage sustained by the sample is evaluated.

Whole Plant Freezing Test. First, note that this is a "whole plant test" rather than a "tissue test". This means that the hardiness of several different tissues can be tested at once which will give a good indication of overall cold hardiness. WPFT is a bit of a misnomer, since root systems are normally protected during the low temperature exposure step. In the WPFT a representative sample of seedlings is subjected to a sub-freezing temperature, or a series of bracketing sub-freezing temperatures, for a pre-determined time period – often a few hours. This can be accomplished in a programmable chest freezer or a Thermotron. Next, the seedlings are incubated in a warm growth promoting environment such as a greenhouse for several days. Finally, the test plants are evaluated for cold injury. A wide range of techniques have been used for assessing damage to stem, buds and foliage including visible injury, freeze induced electrolyte leakage, pressure chamber analysis (Ritchie 1990), and chlorophyll fluorescence (Mohammed and others 1995). Each of these methods has its advantages and disadvantages but visible injury is the most widely-used because it is quick, easy and does not require any sophisticated equipment. When plant tissue is injured by cold temperature, the cell membranes begin to leak and the contents become oxidized. The injured tissue turns brown in a few days (Figure 4), and this can be used to rate cold hardiness (Tanaka and others 1997).

Freeze-Induced Electrolyte Leakage. The FIEL test is a tissue test that is based on the fact that freeze-damaged cell membranes tend to leak electrolytes into the apoplast. When freeze-damaged tissue samples are placed into de-ionized water, this leakage of electrolytes will increase the electrical conductivity of the water which can be measured with a conductivity meter. The technique can be used on foliage, stem segments or root sections.

Figure 4 . In the whole plant freezing test, seedling tissue turns brown (arrow) after being exposed to the test temperature. The degree and extent of the browning give a good indication of the total damage.

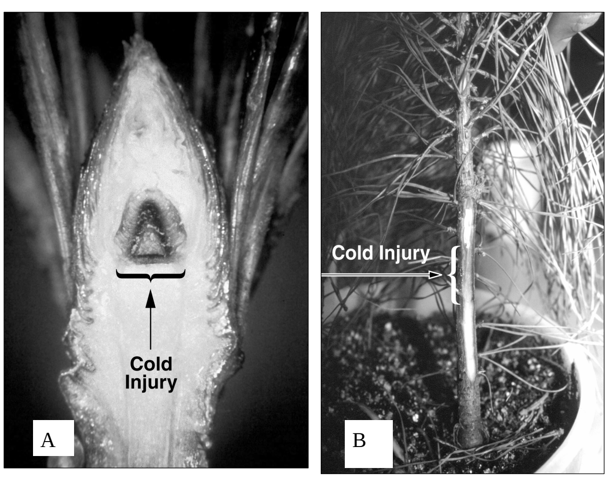


Figure 5. In the freeze induced electrolyte leakage test, samples of foliage, roots, or stem tissue are exposed to the test temperature and then the relative amount of cellular leakage is measured with an electrical conductivity meter.

The first step is to expose the tissue to sub-freezing temperatures in a programmable freezer or Thermotron. One advantage of the FIEL test is that the samples take much less space than the entire seedlings in the WPFT. After exposure to the desired temperature, the sample is sectioned and placed into vials containing deionized water where they are incubated until leakage stabilizes (Figure 5). Next, the initial conductivity of the solution (EC_1) is measured. The sample is then completely killed by heating or freezing and the final conductivity (EC_2) is measured. A relative conductivity index is calculated as:

$$RC\ (\%) = (EC_1 - B_1) \times 100 / (EC_2 - B_2) \quad [1]$$

Where B_1 and B_2 are optional blanks included to account for possible ion leakage from the vials. See Burr and others (2001) for a detailed discussion of this method.

The FIEL test has been widely used because it is relatively simple and produces a numerical result, compared to the subjective assessment in the WPFT. Some researchers prefer to test foliage whereas others use root tissue as the definitive indication of seedling cold hardiness.

Sources of Seedling Quality Testing

In the introductory article we presented a table listing all the seedling quality testing facilities in North America. However, several readers pointed out that we missed one - the Laboratory for Forest Soils and Environmental Quality in Eastern Canada. Hopefully, the following table is complete but, if not, let us know and we'll make any additions or corrections.

Conclusions and Recommendations

Seedlings that are easily killed by temperatures near freezing during the growing season can survive much lower temperatures in winter when they are cold hardy. Winter injury is generally caused by the loss of cell water as it is pulled across the cell membrane to feed ice crystals growing outside the cells. This can severely dehydrate cytoplasm and injure membranes callusing them to leak cell contents.

Hardiness develops in fall triggered by photoperiod, and increases during early winter as seedlings are exposed to increasingly low temperatures. Peak hardiness occurs in January in plants from the northern temperate zone. Following peak hardiness, as photoperiod begins to lengthen and temperatures begin to rise, hardiness is rapidly lost.

Cold hardiness testing is often used along with Root Growth Potential testing to provide quantitative information on the physiological status of forest planting stock. The most commonly used CH tests are the whole plant freezing test, in which entire seedlings are exposed to low temperature stress then evaluated for their response, and the freeze induced electrolyte leakage test, which can be applied to foliage, stems, or root segments.

Cold hardiness tests can be used to indicate when frost protection may be needed in the nursery, to determine lifting and outplanting windows for different species and stock types, and as a surrogate index for overall stress resistance.

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Table 1—Seedling Quality Testing Facilities and Their Procedures

Company	Address	Types of Tests Offered			
		Morphology	Root Growth Capacity	Cold Hardiness	Others
Roseburg Forest Products	34937 Tennessee Rd. Lebanon, OR 97355 TEL: 541.259.2651 FAX: 541.259.3661 E-mail: mjalbrecht@msn.com	X	X	X	X
Nursery Technol-ogy Cooperative	Seedling Quality Evaluation Ser-vices OSU Dept. of Forest Science 321 Richardson Hall 3015 SW Western Ave. Corvallis, OR 97331 TEL: 541.737.6576 FAX: 541.737.1393 E-mail:SQES@orst.edu	X		X	
KBM Forestry Consultants	SQA Coordinator 349 Mooney Avenue Thunder Bay, ON CANADA P7B 5L5 TEL: 807.345.5445 ex. 34 E-mail: sgelleert@kbm.on.ca	X	X	X	X
Laboratory for Forest Soils and Environmental Quality	Tweeddale Centre for Industrial Research 1350 Regent Street Fredericton, NB E3C 2G6 TEL: 506.453.4507 FAX: 506.453.3574 E-MAIL: lfsez@unb.ca		X	X	X

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Horticultural Humor

"What do you mean we don't communicate? I sent you e-mail on Monday."

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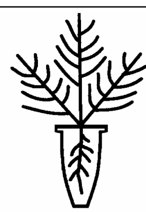

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Genome
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Bb
cc
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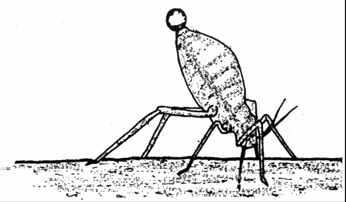

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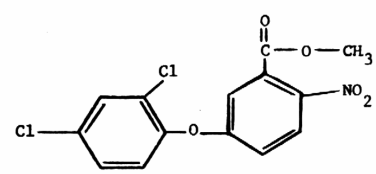

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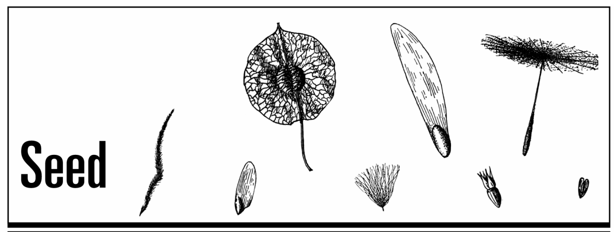

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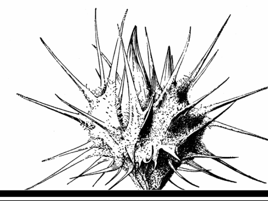

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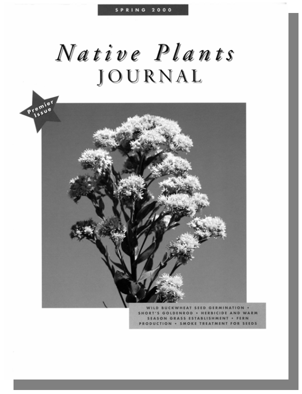

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