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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.

The **Forest Nursery Association of British Columbia (FNABC)** and the Northern Silviculture Committee Summer Field Tour is scheduled for **28 to 30 September 2009** in Prince George, BC at the Prince George Civic Centre. For more information visit the website: http://www.unbc.ca/continuingstudies/events/nscsummer.html
or contact:

Workshop Information
Steve Kiislika
TEL: 250-565-4344
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Registration & Exhibitor Information
UNBC Continuing Studies
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SERNW Regional Conference — New Date and Location:
16 to 18 February 2010
Shoreline Conference Center, Shoreline WA
(formerly 19 to 22 May 2009 at the Lynnwood Convention Center)

We must regretfully announce that the SERNW Regional Conference will be postponed until February 16 -19, 2010 and moved to the Shoreline Conference Center (just a few miles from the Lynnwood location). Despite an excellent array of speakers, workshops, fieldtrips, and sponsors; economic uncertainty has caused insufficient registration. We are committed to providing an enriching conference experience for restoration practitioners in the Pacific Northwest and will formally announce our 2010 conference by the end of May. Scheduled speakers, sponsors, and registrants will be notified by e-mail and are encouraged to participate in the 2010 conference. Registration fees may be credited toward the 2010 conference or reimbursed in full. Please accept our deepest apologies for this turn of events and we encourage you to join us next year.

The **16th Wildland Shrub Symposium** will be held **26 to 27 May 2010** at Utah State University in Logan, Utah. Papers on Climate Change, Wildlife, Energy Extraction, Invasive Species, Restoration, Wildfire, Recreation, Livestock Grazing. Social and Economic Aspects, and Shrub Biology are encouraged.

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The **Southern Forest Nursery Association (SFNA)** meeting will be in Little Rock, Arkansas, **26 to 29 July 2010**. For more information please contact:

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Fertigation - Injecting Soluble Fertilizers into the Irrigation System

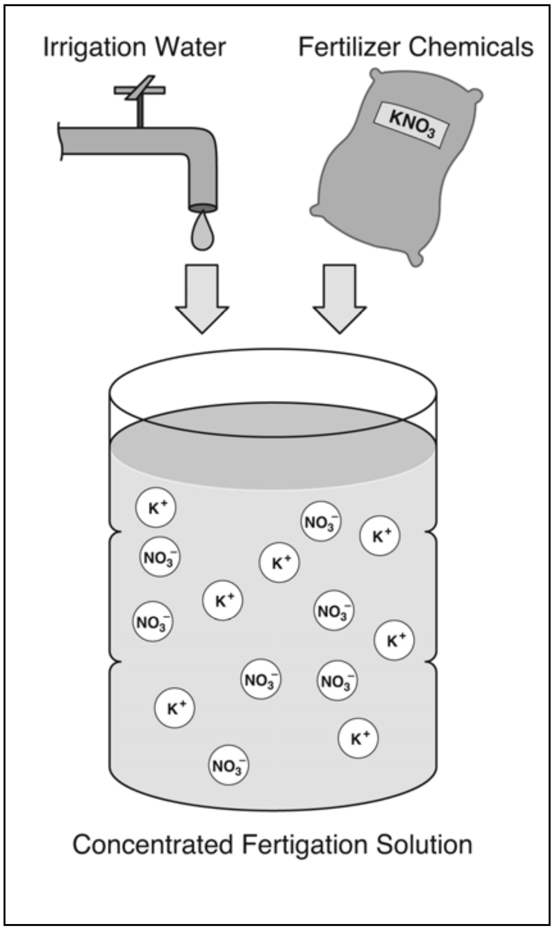
by Thomas D. Landis, Jeremy R. Pinto, and
Anthony S. Davis

Introduction

Fertigation (fertilization + irrigation) is the newest way for nursery managers to apply fertilizer, and has become a standard practice in container nurseries. Because of the inherent inefficient water distribution patterns in field irrigation systems, fertigation has not been widely used in bareroot nurseries. However, a bareroot nursery with a center-pivot irrigation system has successfully used fertigation (Triebwasser and Altsuler 1995), and other nurseries have applied soluble fertilizer through a tractor-drawn sprayer. Compared to traditional fertilization with dry, granular fertilizers, spray application of soluble fertilizer solutions was faster, more uniform and accurate, and easier to calibrate (Triebwasser 2004).

A Brief History

Fertigation can be traced back to the mid-1800s when plants were grown in water or sand cultures as part of basic plant nutrition research. A variety of soluble fertilizer solutions were used in these experiments but the first commonly-used recipe was known as Hoagland's solution, and was developed by plant scientists at the University of California at Berkeley back in the 1930s as part of nutriculture experiments. The composition of this solution was originally patterned after the solution extracted from soils of high productivity (Hoagland and Arnon 1950). Subsequent research has shown that plants are not very selective in their nutrient uptake so a modified Hoagland solution can be used to produce a wide variety of container crops (Jones 1983). When the first container tree nurseries were started back in the early 1970's, a modified Hoagland's solution was used to grow a wide variety of western conifers and some broadleaved woody plants (Tinus and McDonald 1979). A further modification was used for target nutrient levels in Volume Four of the Container Tree Nursery Manual (Landis and others 1989) and the Target Nutrient Levels in Table 1.



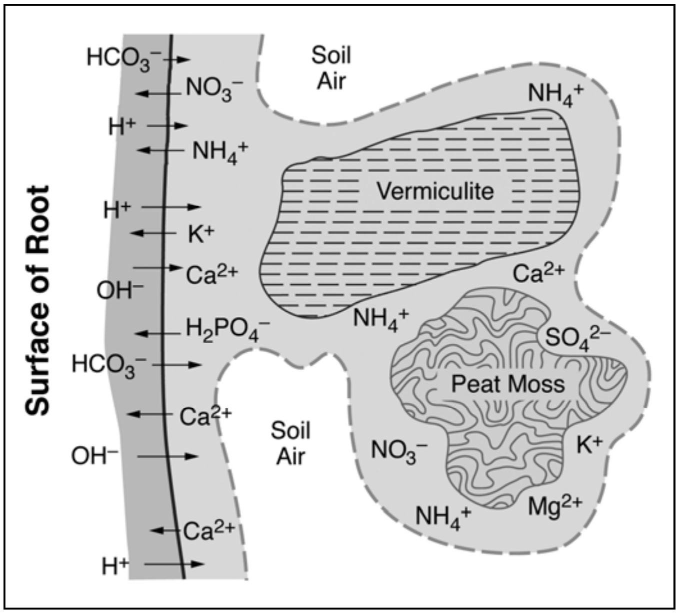


Figure 1 — The chemicals used to formulate fertigation solutions are technically salts; for example, potassium nitrate (KNO_3) dissolves into charged nutrient ions (K^+ and NO_3^-) (A). Because the nutrient ions supplied through fertigation have already dissolved into charged ions, they are easily taken-up by plant roots in exchange for an ion of the opposite charge (B).

Table 1 — Nutrient analysis of irrigation water from diverse forest and conservation nurseries compared to recommended mineral nutrient target concentrations (modifed from Landis 1997)

Essential Mineral Nutrients	**Target * Nutrient Levels**	**Irrigation Water Analysis**			
		Hawaii Nursery	**Colorado Nursery**	**California Nursery**	**Idaho Nursery**
Macronutrients in parts per million					
Total Nitrogen (N)	200	Not Tested	3	7	2
Nitrate-nitrogen (NO_3)	150	Not Tested	3	5	2
Ammonium-nitrogen (NH_4)	50	Not Tested	0	0	0
Phosphorus (P)	60	0	0	0	0
Potassium (K)	160	0	2	2	4
Calcium (Ca)	60	1	82	66	26
Magnesium (Mg)	40	1	14	113	9
Sulfate-sulfur (SO_4)	60	Not Tested	43	315	13
Micronutrients in parts per million					
Iron (Fe)	4.00	0.20	0.00	0.00	0.09
Manganese (Mn)	0.50	0.00	0.00	0.01	0.03
Zinc (Zn)	0.05	0.00	0.00	0.05	0.34
Copper (Cu)	0.02	0.00	0.00	0.00	0.00
Chloride (Cl)	4.00	Not Tested	3.00	132.00	2.52
Molybdenum (Mo)	0.01	Not Tested	0.00	0.00	0.00
Boron (B)	0.50	0.00	0.06	1.00	0.00
Total Dissolved Salts in mS/cm					
Electrical Conductivity	1200 to 1800	30	470	1610	186

*** = Target N levels will vary with plant species and nursery growth phase**

Mineral Nutrient Uptake

The chemicals used to make soluble fertilizers for fertigation are technically salts, which means that they readily dissolve in water into charged ions. For example, potassium nitrate (KNO_3) dissolves into two nutrient ions: the cation potassium (K^+) and the anion nitrate-nitrogen (NO_3^-) (Figure 1A). One of the benefits of fertigation is that all the mineral nutrients are already in an ionic form when they are applied to the crop. With other granular or controlled release fertilizers, the nutrients must first dissolve in the ground water before they become available for plant uptake **(**Figure 1B).

Like most cultural practices, fertigation has both advantages and disadvantages (Landis and others 1989):

Advantages:

1. Fertigation allows precise control of both the concentration and balance of all 13 mineral nutrients.

2. Nutrient solutions can easily be customized or modified for any plant growth stage or species.

3. When properly formulated and applied, the chance of excessive fertilization and resultant salt injury is low.

4. Fertigation solutions are easily to monitor.

Disadvantages:

1. Nutrient injectors must be used for maximum effectiveness.

2. Frequent mixing and applying of liquid fertilizers increases labor costs.

3. A well-designed, automated irrigation system is essential to ensure even fertilizer application.

4. Excessive fertigation can damage nursery crops and pollute the environment.

Three Components of a Fertigation System

Fertigation should be thought of as a system with 3 major components (Figure 2), which should be considered in reverse order of how they actually occur:

1. Applied fertigation solution

This is the most important component because it is what actually reaches the plants. Checking the pH and EC of the applied fertigation solution shows how well the entire system is working, and should be done at least weekly. The concentration of the 13 mineral nutrients in the applied solution should be close to the target nutrient levels that you've selected for your crop. The ideal nutrient concentration will vary with the plant species that you are growing, and also with the phase of crop development. Have the applied fertigation solution tested by a laboratory at least once a season, and compare to the target nutrient levels.

Nitrogen (N) is one of the most important nutrients affecting plant growth and is the most frequently applied fertilizer element. Therefore, all fertigation programs are based around the N concentration, and the levels of all the other nutrients are established relative to N.

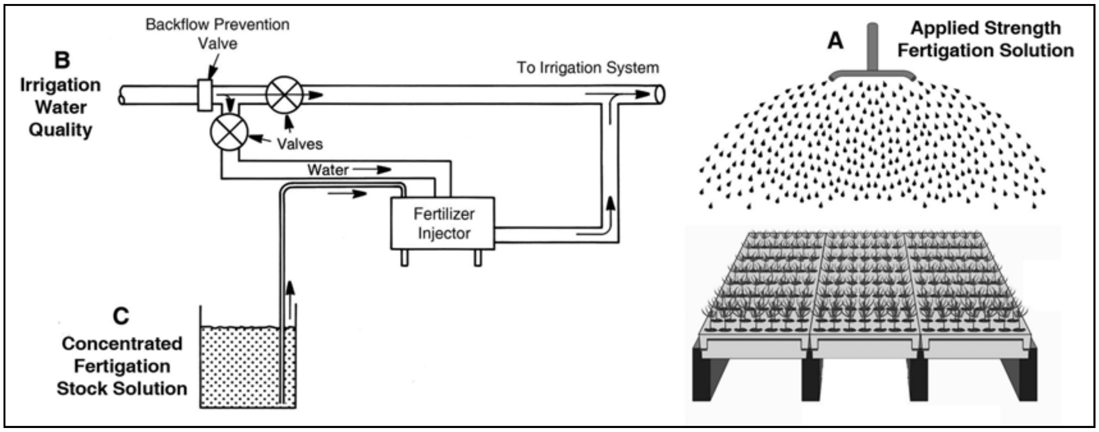


Figure 2 — The three major components of any fertigation system are: A) nutrient concentrations in the applied fertigation solution , B) base level of nutrients in the irrigation water, and C) composition of the concentrated fertigation stock solution (modified from Nelson 1978).

Each of the 3 growth phases for container nursery crops has its own N target concentration (Landis and others 1999):

Establishment phase: 25 to 50 ppm N — All nutrient levels are kept low to allow the young seedlings to become established in the container without risk of salt injury. Phosphorus (P) is important because very little of this nutrient is stored in the seed and the new roots have limited absorption ability. Calcium (Ca) is also important for new root growth.

Rapid growth phase: 75 to 200 ppm N — This is the period of rapid shoot growth and the target N concentration will vary with crop characteristics, and how well shoot growth is occurring relative to the desired growth curves. Fast growing species, such as quaking aspen or sagebrush, are given 50 ppm N to prevent excessive height growth. N levels of 75 to 150 ppm will be sufficient for most native plant species. Some very slow growing plants, such as whitebark pine (*Pinus albicaulus*), may require 200 ppm N or more to force growth.

Hardening phase: 50 to 75 ppm N — High N levels, and ammonium-N in particular, stimulate shoot growth at the expense of stem or root growth, can be detrimental to cold hardiness development. Therefore, target N levels are kept at low concentrations during the hardening phase. The purported benefit of high potassium (K) during hardening has never been proven but higher Ca levels aid in the hardening process.

2. Irrigation water quality

Water quality has a major influence on any fertigation program. The most important considerations are the total salt level, as measured by electrical conductivity (EC), and the mineral nutrient concentrations in the water that will be applied to your crop (Table 1).

Nutrients in the irrigation water — Most people don't consider water a source of nutrients and, if they are talking about animal nutrition, then that's correct. For plants, however, irrigation water can be a valuable source of secondary mineral nutrients. In fact, some irrigation waters can contain all or a substantial portion of the (Ca), magnesium (Mg), and sulfur (S) needed for normal growth. The concentrations of soluble mineral nutrients in irrigation water vary considerably from nursery to nursery depending on the water source and the local geology. Because it has had less time to dissolve soluble minerals in the soil, irrigation water from surface sources such as streams and ponds will usually have lower soluble salt levels than well water. Water quality can also vary seasonally, especially if different wells are used.

The mineral nutrient content of three very different water sources is presented in Table 1. In Hawaii, rain filters through young, pumice soils that do not contain many soluble minerals and so the irrigation water is very pure. Actually, such irrigation water can be too pure for good plant growth because it quickly leaches out the soluble nutrients from the soil or growing medium — this same thing happens in open growing compounds during periods of heavy rainfall. The water at many places in the semi-arid Western US, such as Colorado, is called "hard" because it contains high levels of Ca and Mg that cause scale deposits on pipes and other surfaces. Nurseries with moderately hard water are fortunate because it often supplies all or most of the plant's Ca and Mg requirement. Water from some irrigation wells can be too high in soluble salts, as the analysis from the Sacramento Valley of California illustrates. Although their Ca, Mg, and S levels are above the recommended levels, the most serious factor is direct toxicity from high chloride levels (Table 1).

Mineral nutrient analyses of irrigation water can be performed by most analytical testing laboratories, but growers should be sure to specify that they want a nutrient analysis, instead of a standard water quality test. It's a good idea to supply a list of the nutrients from Table 1 that you want tested**.** A complete water analysis for both nutrients and quality should cost around USD $50 to $100, and many labs will E-mail results in around a week. The pH and electrical conductivity (EC) of the water should also be measured. The pH gives an indication of how much acid will be required to reach the desired 5.5 level, and the EC reflects the total dissolved salts.

Acidify irrigation water pH to target level — Once the base nutrient level of the water is known, its buffering capacity should be determined by acid titration. Titration is a process in which small increments of an acid are added to a known quantity of irrigation water (1 liter) to determine the amount of acid that will be required to lower the pH to the desired level (pH 5.5). Titrations can be done by any water testing lab or by nursery personnel using a pH meter and a burette or pipette. Any acid can be used for titrating as long as its normality is known so that conversions between different acids can be made. The floriculture department at North Carolina State University has posted a spreadsheet on their website that allows growers to calculate the amount of acid to inject to neutralize alkalinty in their irrigation water. Users can specify their choice of sulfuric, nitric, and phosphoric acid as well as their target pH at the following website: http://www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html

Several acids have been used for acid injection in container tree nurseries including nitric, sulfuric, and phosphoric but we prefer phosphoric acid (H_3PO_4) because it is relatively safe to handle. An added benefit is that the acidified water produces a constant source of soluble phosphorus, which is particularly valuable during germination and early growth. Sometimes, when irrigation water is very alkaline (high pH), so much phosphoric acid is required that the P level would exceed the target level of 60 ppm (Table 1). In this situation, a stronger acid such as nitric acid can be used ,or even acetic acid, which is safe and contributes no nutrient ions. Another consideration is to be sure that your fertilizer injector is equipped to tolerate acids.

To keep calculations simple and safe, we use a 1% phosphoric acid solution for our titrations. Both 75 or 85% phosphoric acid are commercially available, and the calculations to make the 1% solution are proportional (Table 2**.** Once the amount of 1% H_3PO_4 needed to lower the pH of the water sample is known, the conversion to back to the 75 or 85% stock acid solution is made by dividing by either 75 or 85.

Titration curves for the irrigation water at two forest nurseries in Colorado are given in Figure 3**.** Note the difference between the two curves: the steeper the slope of the line, the lower the buffering capacity of the water. The water at the Colorado State Nursery has a very low buffering capacity and requires only 3 ml of H_3PO_4 to lower the pH of 1 liter of irrigation water to the desired level, whereas the Mt. Sopris Nursery water requires almost 16 ml of 1 % H_3PO_4 to reach the target pH.

Because the amount of acid may need to be adjusted for seasonal changes in water quality, regular pH monitoring is necessary. The pH will also change after the fertilizer chemicals have been added to the fertilizer solution, so other minor adjustments may be required.

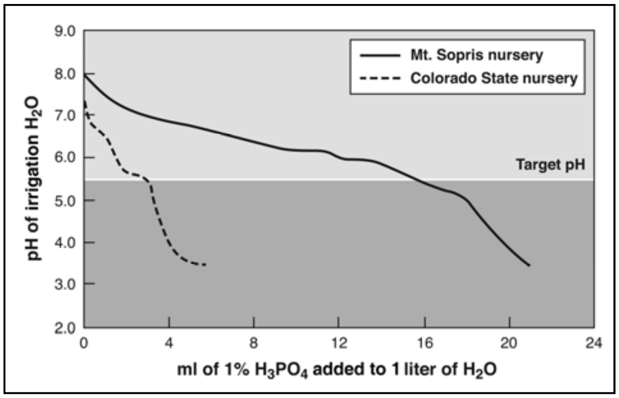


Figure 3 — Acid titration curves for two different nurseries in Colorado which were developed by adding successive 1 ml increments of 1 % phosphoric acid H_3PO_4 to 1 liter of irrigation water (Landis and others 1989).

3. Formulating fertilizer stock solutions

At this step, you have 2 options. The first is to use a commercial soluble fertilizer, and the second is to create a custom fertilizer from stock chemicals. We recommend using plastic containers for the concentrated fertilizer solutions to avoid corrosion, and most nurseries use 50 gallon (200 liter) tanks.

One inherent problem with formulating concentrated stock solutions is solubility — the more concentrated the solution, the greater the risk of precipitation. Calcium in particular causes problems because it forms precipitates when it is combined with high concentrations of phosphorus and sulfur. The best practice is to use two separate tanks and a nutrient injector with 2 heads: the commercial fertilizer in the first, and the acid and any calcium and sulfate fertilizers in the second. Once the 2 solutions are mixed in the applied fertigation stream they have been diluted enough to prevent precipitation problems. For more information on fertilizer compati-

Table 2 — Calculations for making 1 liter of 1% phosphoric acid titrating solution from a 75% stock acid and distilled water

$$\text{Concentration x Volume} = \text{Concentration x Volume}$$
$$(0.01)(1{,}000\text{ ml}) = (0.75)(X)$$
$$10 = 0.75X$$
$$X = 13.3\text{ ml}$$

For safety reasons, always add acid to water: partially fill the flask with distilled water, slowly add the acid to it, and then add enough water to make 1 liter.

Table 3 — Elemental mineral nutrient concentration in an applied 100 ppm nitrogen solution of Peters Professional® Conifer Grower (modified from Scotts Company 2004)

Mineral Nutrient (Symbol)	ppm
Macronutrients	
Total Nitrogen (N)	100
Ammoniacal-N (NH_4 & NH_3)	(58)
Nitrate-N (NO_3)	(42)
Phosphorus (P)	15
Potassium (K)	79
Calcium (Ca)	0
Magnesium (Mg)	4
Sulfur (S)	0
Micronutrients	
Iron (Fe)	2.00
Manganese (Mn)	0.30
Zinc (Zn)	0.30
Copper (Cu)	0.30
Molybdenum (Mo)	0.02
Boron (B)	0.12

bility, see Figure 4.1.22 in Volume Four of the Container Tree Nursery Manual (Landis and others 1989).

Using commercial soluble fertilizers. When we wrote Volume Four: Seedling Nutrition and Irrigation of the Container Tree Nursery Manual, 88% of the container nurseries in North America used commercial brand fertilizers, either alone or in combination with custom mixes. Some fertilizer brands contain both macronutrients and micronutrients whereas others contain only the major fertilizer elements, so be sure and check the label. Nutrients supplied by a typical fertilizer (Peters Professional® Conifer Grower) at a 100 ppm N rate are listed in Table 3**.** Note that neither Ca nor S is supplied by the fertilizer due to solubility problems. If these nutrients are not sufficient in the irrigation water, then a second stock tank with calcium chloride and magnesium sulfate should be used.

Most commercial brands of soluble fertilizer will provide mixing instructions; the weight of Peters Professional® Conifer Grower (20-7-19) to add to 1 gallon of water is shown in Table 4. Note that all fertigation solutions are based on the parts per million of nitrogen. To calculate the concentrations of all the nutrients, use the following procedure, which is based on the fact that parts per million (ppm) is the same as milligrams per liter (mg/l):

1. Set the target N level for the applied fertilizer solution (100 ppm, for example).

2. Determine how much bulk fertilizer must be used to produce the target concentration (100 ppm). The fertilizer in our example is 20-7-19, or 20% N. 100 ppm = 100 mg/l, but remember that this fertilizer is only 20% N. So, 100 mg of bulk fertilizer contains only 20 mg N:

    100 mg/l divided by 0.20 = 500 mg/l bulk fertilizer

3. Adjust for the nutrient injection ratio (1:200, for example):

    500 mg/l bulk fertilizer x 200 = 100,000 mg/l bulk fertilizer

4. Convert from milligrams per liter to grams per liter:

    100,000 mg/l = 1,000 mg/g = 100 g/l bulk fertilizer

If using English units, convert grams per liter to ounces per gallon:

    100 g/l x 0.1334 = 13.34 ounces of bulk fertilizer per gallon of water (Note that this value agrees with the value in the mixing instructions in Table 4 for 100 ppm N and a 1:200 injector).

5. Now that we have established the amount of 20-7-19 bulk fertilizer (step #2) needed to supply our N target (step #1), we need to calculate how much P will be contained in the applied fertilizer solution (note that the fertilizer contains 7% P_2O_5, NOT 7% P):

    500 mg/l x 0.07 = 35 ppm

6. Now, we need to convert from the oxide form (P_2O_5) to the elemental form:

    35 ppm P_2O_5 x 0.4364 = 15 ppm P

Again, note that this agrees with the value in Table 4. Just to confirm, you can do similar calculations to compute the ppm of each of the mineral nutrients.

Table 4 — Ounces of Peters Professional® Conifer Grower (20-7-19) to add to 1 gallon of water to produce stock solutions with the following nitrogen concentrations (modified from Scotts Company 2004)

Nitrogen (ppm)	Nutrient Injector Ratios			EC (mS/cm)
	1:15	1:100	1:200	
25	0.30	1.69	3.38	0.15
50	0.50	3.38	6.75	0.30
75	0.80	5.06	10.13	0.45
100	1.00	6.75	13.50	0.60
150	1.50	10.13	20.25	0.90
200	2.00	13.50	27.00	1.20
300	3.00	20.25	40.50	1.80

If this is all a bit intimidating, horticulture suppliers like Scotts® employ technical specialists who can help with the calculations, and have valuable information on their websites, for example*:* http://www.petersabc.com/.

Developing a custom fertigation program — Custom fertilizer mixes utilize bulk chemicals to supply all the mineral nutrients necessary for plant growth. Several grades of commercial chemicals are classified according to use, but technical or purified grades are best for custom fertilizer mixes in terms of purity and cost. Fertilizer grade chemicals are formulated for bareroot applications and are not recommended for soluble fertilizer mixes because they contain high percentages of impurities. A list of commonly-used chemicals can be found in Table 4.1.9 of Volume Four of the Container Tree Nursery Manual (Landis and others 1989). As mentioned in the first section, 2 stock solutions are typically used to prevent formation of insoluble precipitates.

Stock solution 1 (SS#1) contains the acid to lower the water pH and Ca and S if they are needed. The calculations for how much acid to add consist of expanding the ml per liter of water obtained in the titration (Figure 2) to the quantity of water in the stock tank. The accuracy of these computations should be checked by collecting some of the applied irrigation water and testing its pH. Due to changes in irrigation water quality over the season and the effect of other chemicals in the applied fertigation solution, the amount of acid added to the stock solution may have to be adjusted occasionally. See Volume Four of the Container Tree Nursery Manual (Landis and others 1989) for more details.

Stock solution 2 (SS#2) contains all mineral nutrients except Ca and S. An example of the computations for this stock solution is provided in Table 5**.** The upper portion shows the target nutrient concentrations in parts per million, the amount of each nutrient in the irrigation water, and the amount needed to be added as fertilizer. The chemicals used to supply nutrients and their contribution in parts per million are shown in the left column. The final column on the right shows the total amount of the chemical that would be present in the applied fertilizer solution.

The total parts per million of each nutrient must be converted to the weight of the chemical that needs to be added to each liter of water. This conversion is simple because 1 liter of water weighs 1 kg by definition. Therefore, on a weight per volume basis, 1 mg/l = 1 ppm. A list of mineral nutrients are supplied by each compound is given in Table 4.1.23 of Volume Four of the Container Tree Nursery Manual (Landis and others 1989). Using magnesium sulfate ($MgSO_4$) as an example, this chemical contains 10% Mg and 13% S and the calculation in Table 5 shows that we need 38 ppm of Mg. So, how much $MgSO_4$ do we need?

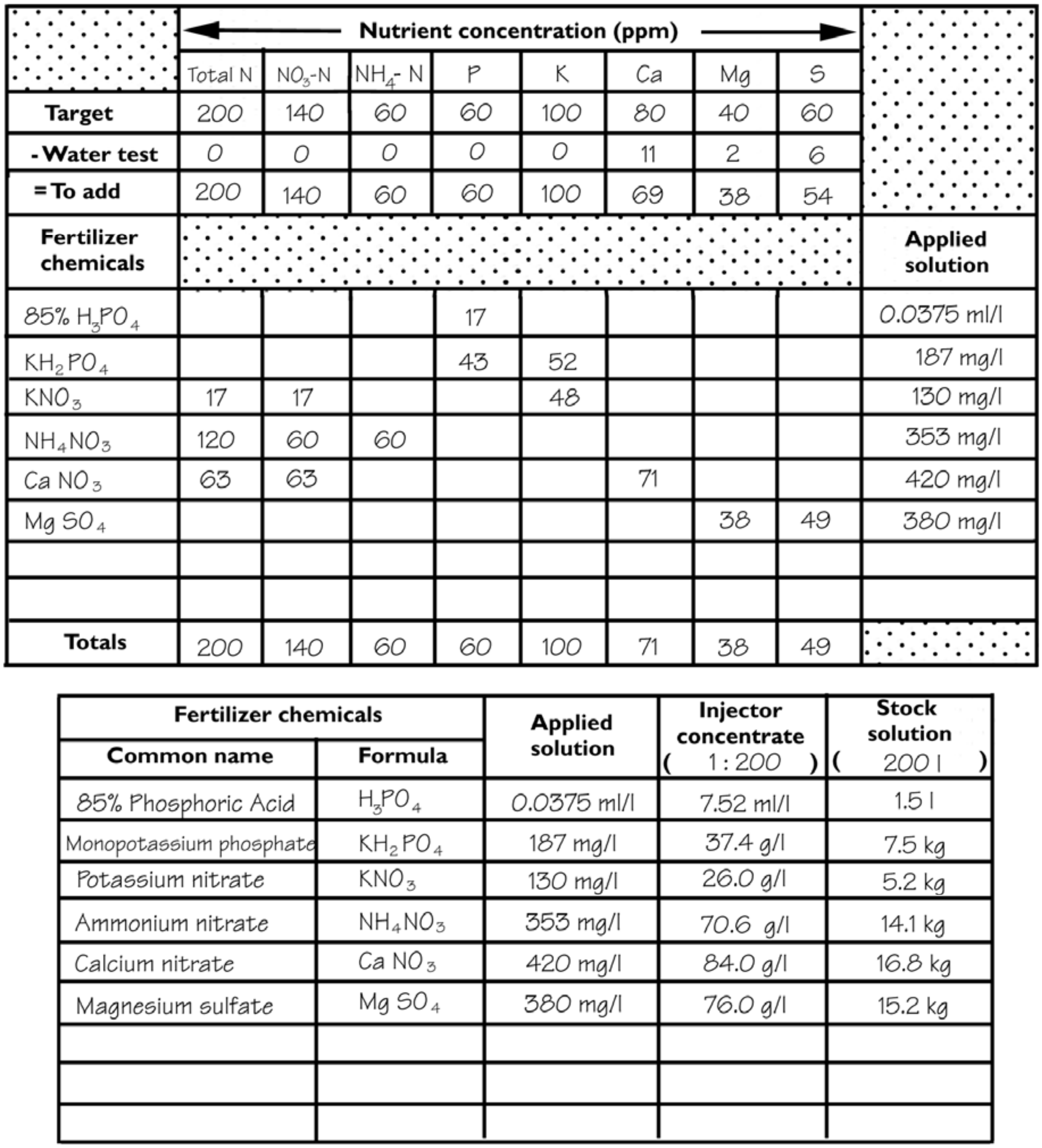
$$\frac{38\text{ mg/l Mg}}{0.10} = 380\text{ mg/l}$$

To compute how much sulfur this would contribute:

$$380\text{ mg/l} \times 0.13 = 49\text{ ppm S}$$

The recipe for all the ingredients is given in the "applied solution" column in Table 5 — this is the actual concentration of fertilizer that is applied to the seedlings. These values are carried down to the "applied solution" column

Table 5 - Sample calculations for a custom fertigation stock solution



	Nutrient concentration (ppm)								
	Total N	NO_3-N	NH_4- N	P	K	Ca	Mg	S	
Target	200	140	60	60	100	80	40	60	
- Water test	0	0	0	0	0	11	2	6	
= To add	200	140	60	60	100	69	38	54	
Fertilizer chemicals									**Applied solution**
85% H_3PO_4				17					0.0375 ml/l
KH_2PO_4				43	52				187 mg/l
KNO_3	17	17			48				130 mg/l
NH_4NO_3	120	60	60						353 mg/l
Ca NO_3	63	63				71			420 mg/l
Mg SO_4							38	49	380 mg/l
Totals	200	140	60	60	100	71	38	49	

Fertilizer chemicals		**Applied solution**	**Injector concentrate** (1 : 200)	**Stock solution** (200 l)
Common name	**Formula**			
85% Phosphoric Acid	H_3PO_4	0.0375 ml/l	7.52 ml/l	1.5 l
Monopotassium phosphate	KH_2PO_4	187 mg/l	37.4 g/l	7.5 kg
Potassium nitrate	KNO_3	130 mg/l	26.0 g/l	5.2 kg
Ammonium nitrate	NH_4NO_3	353 mg/l	70.6 g/l	14.1 kg
Calcium nitrate	Ca NO_3	420 mg/l	84.0 g/l	16.8 kg
Magnesium sulfate	Mg SO_4	380 mg/l	76.0 g/l	15.2 kg

at the bottom of the table, where the conversions are made for the nutrient injector and the volume of concentrated stock solution. The adjustment for the nutrient injector (1:200) consists of multiplying the applied solution values by 200 and then converting milligrams to grams. Continuing with our example for $MgSO_4$:

380 mg/l x 200 = 76,000 mg/l = 76 g/l

To compute how much bulk chemical is needed for the 200-liter concentrated stock solution tank, multiply by 200 and convert to kilograms:

76 g/l x 200 = 15,200 g = 15.2 kg

While custom fertilizer calculations may seem complicated at first, using a computer spreadsheet program can make calculations quicker, easier, and changeable over time (for example, changes in growth phases or additions of new fertilizers). A well-built spreadsheet can calculate target applied solutions with adjustments for water tests, injector ratios, stock solution volumes, and use of multiple fertilizer types — all you have to do is select your target nutrient concentrations! Start simple by using spreadsheet calculation functions to determine nutrient concentrations for the chemical fertilizers you use. To do this, select a primary nutrient for each of your fertilizer chemicals (for example, ammonium-N in Peters Professional Conifer Grower 20-7-19). The primary nutrient will be a changeable reference cell containing the target concentration of your choice. For each of the other nutrients in the fertilizer (for example, nitrate-N, Urea, P, K, Mg, Fe, Mn, Mo, Zn, Cu, and B in Peters Professional Conifer Grower), write formulas that calculate concentrations using the primary nutrient reference cell. So, for any selected change in ammonium-N concentration, the applied solution amount and all other nutrient concentrations would be automatically calculated for you. Set up the spreadsheet to sum nutrient concentrations for all fertilizer types used so you can compare them to target levels. Make concentration adjustments to your primary nutrient cells to closely balance and match your target levels. The resultant applied solution calculations can be multiplied by injector ratios and stock solution volumes for your final recipe; don't forget to separate incompatible fertilizers into their own stock solutions.

Remember, the true test of the fertigation calculations is to collect a sample of the applied fertigation solution and have it chemically analyzed. Table 6 shows the total fertigation program for the Mt. Sopris Nursery for pH, EC, and all the mineral nutrients. The values in the applied solution reflect the base levels in the irrigation water plus what was added in the fertigation stock solutions. Comparing these values with the targets shows that our calculations were reasonably close. The applied values are the final check on the fertigation programs and should be retested each season to make certain that everything is working properly.

Part 2 of this article will be in the Winter 2010 issue and will cover *Types of Injectors, When to Fertigate,* and *How to Monitor Fertigation.*

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Table 6 — Custom fertigation program used at Mt. Sopris Nursery, Carbondale, CO

	Units	Irrigation Water	Applied Fertigation Solution	Target
Water Quality Indices				
pH	**log units**	6.9	6.0	5.5
Electrical conductivity	**mcS/cm**	470	1,680	1,200 to 1,800
Macronutrients				
Nitrate Nitrogen	ppm	3	170	156
Ammonium Nitrogen	ppm	0	11	66
Total Nitrogen	ppm	3	181	222
Phosphorus	ppm	0	54	60
Potassium	ppm	2	140	155
Calcium	ppm	82	80	60
Magnesium	ppm	14	48	40
Sulfate Sulfur	ppm	43	135	63
Micronutrients				
Iron	ppm	0.02	2.60	4.00
Manganese	ppm	0.01	1.1	0.50
Copper	ppm	0.01	0.07	0.02
Zinc	ppm	0.01	0.07	0.05
Molybdenum	ppm	0.10	0.10	0.01
Boron	ppm	0.06	0.14	0.50
Chlorine	ppm	3.00	4.00	4.00

Determining Fertilizer Rates and Scheduling Applications in Bareroot Nurseries

by Thomas D. Landis and Charles B. Davey

Going through past issues of FNN revealed that it has been quite a while since we talked about fertilization in bareroot nurseries. Sure, there have been the occasional research or proceedings papers (for example, Landis and Fischer 1985), but the last comprehensive discussions of fertilization were in the nursery manuals that are becoming a little dated (for example, Duryea and Landis 1984; Aldhous and Mason 1994). Bareroot nursery production still accounts for the majority of forest nursery production, especially loblolly pine (*Pinus taeda*) —so, it's time to take another look.

Fertilization has been shown to effect both the quantity and quality of seedling growth and, therefore, application of the correct amount of fertilizer at the proper time is critically important to the production of high-quality seedlings. One of the most erroneous maxims of early nursery management was that, because they often grew on sites with low fertility, forest tree seedlings did not require fertilization. On the contrary, one of the primary benefits of growing plants in nurseries is that, with proper fertilization, plantable-sized stock can be obtained many times faster than would occur naturally (Figure 1A). This fact was realized in the earliest forest nurseries where water slurries of animal waste were the first fertilizers (Figure 1B). Early experiments at the Savenac Nursery showed that the "naturally slow growth" of Engelmann spruce (*Picea engelmannii*) could be accelerated through fertilization in the nursery, and also resulted in better outplanting survival (Wahlenberg 1930).

The best nursery soils are selected for their physical properties rather than their inherent fertility, but all nursery soils contain a least small amounts of all the essential mineral nutrients. However, because the entire plants are removed during harvesting, nursery crops can quickly deplete soil fertility. When a crop of 2+0 conifer seedlings was analyzed, they had removed 110 to 440 lbs (50 to 200 kg) nitrogen (N), 9 to 77 lbs (4 to 35 kg) phosphorus (P), and 55 to 231 lbs (25 to 105 kg) of potassium (K) from the soil in each rotation (van den Driessche 1980). This large nutrient requirement is compounded by the fact that only a relatively small percentage of the mineral nutrients in applied fertilizers are actually taken-up by plants. For example, a 1+0 Sitka spruce (*Picea sitchensis*) crop utilized only 13 to16% of the N, 2 to 4% of the P, and 10 to 22% of the K in applied fertilizers (Benzian 1965).

Characteristics of Mineral Nutrient Ions

The 13 essential mineral nutrients can be divided into groups based on relative plant demand. We are mainly concerned with the 3 "fertilizer elements" because they are taken-up by plants in such large amounts (Table 1):

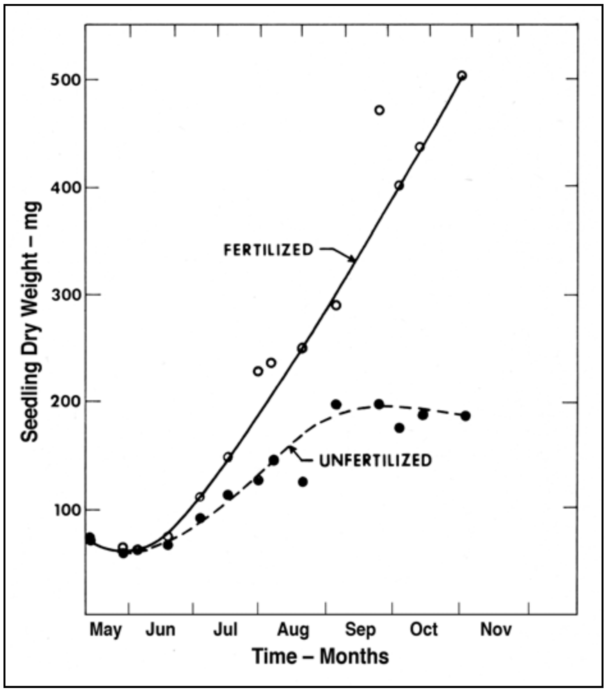

Figure 1 — The tremendous improvement in growth due to fertilization can be seen by this growth comparison for bareroot white spruce seedlings (A). The benefits of fertilization were recognized early where the first fertilizers were water slurries of animal manure (B) (A - modified from Armson and Sadreika 1979).

Table 1 — Characteristics of the three "fertilizer nutrients" (nitrogen, phosphorus, and potassium) that affect fertilizer application and timing

Mineral Nutrient	Ionic Symbol & Charge	Mobility & Leaching Potential	Time of Peak Demand	Fertilizer Application Method and Timing	
				Method	**Timing**
Nitrate-Nitrogen	NO_3^-	High	During rapid growth	Top dressing	4 to 5 times per season
Ammonium-Nitrogen	NH_4^+	Low	During rapid growth	Top dressing	4 to 5 times per season
Phosphorus	$H_2PO_4^-$	Low in soil; high from fertilizers	Early & late in growing season	Incorporation or banding	Pre-sowing
Potassium	K^+	Moderate	All season	Incorporation	Half pre-sowing
				Top dressing	Half mid-season

Nitrogen

Nitrogen (N) is the most important fertilizer nutrient because it fuels plant growth and development, and is taken-up by plants in two different forms. Nitrate (NO_3^-) is a negatively-charged anion and is very mobile in the soil and subject to leaching because anions are not held on the negatively-charged cation exchange (CEC) sites. Ammonium (NH_4^+) ions are positively-charged and so can be bound on the CEC complex that makes them less subject to leaching.

Phosphorus

Plants take-up phosphorus (P) as phosphate ions ($H_2PO_4^-$), but only about 1% of the total P in the soil is in this available form. Most of the soil P is unavailable because it is usually chemically bound in the soil, and so its mobility and leaching potential are low.

Potassium

Potassium (K) occurs in the soil solution as positively-charged cations (K^+) that can be bound on the CEC complex, which makes it moderately susceptible to leaching.

These chemical characteristics, in combination with the time of peak nutrient demand, should be considered for both fertilizer application method and timing (Table 1). N fertilizers should be applied as topdressings at regular intervals throughout the season so that a constant supply of nutrient is available. P is normally applied as a pre-sowing incorporation or banded during sowing to ensure that the immobile P ions are available to the young seedlings. K fertilizers are often applied both as an incorporation at the beginning of the season and again as a top dressing about midseason.

Factors Affecting Fertilizer Nutrient Utilization

The uptake and utilization of mineral nutrients is affected by a variety of factors related to nursery crop characteristics, to the nursery environment, and specific to the individual fertilizer ions.

Moisture

Soil moisture levels can affect mineral nutrient uptake in several different ways. Nutrient uptake due to mass flow occurs when ions dissolved in the soil solution move with the soil water towards the roots during transpirational uptake. Nutrient absorption is greatest when soil moisture is at field capacity which gives the ideal balance of both water and air. Low soil water content reduces nutrient uptake directly because the resultant low hydraulic conductivity restricts water movement whereas saturated soils reduce nutrient uptake indirectly because the anaerobic conditions adversely affect root and microbial activity.

Plant species and source

Different crops have different growth characteristics and therefore different fertilizer requirements. Rapidly-growing pioneer species, such as jack pine (*Pinus banksiana*) and quaking aspen (*Populus tremuloides*), require lower amounts of fertility (particularly N) than slower-growing spruces (*Picea*) or ash (*Fraxinus*) (Stoeckeler and Arneman 1960). Davey (1994) concluded that broadleaved species require significantly more fertilization than conifers, especially N and calcium (Ca). Some nursery managers do not add any supplemental fertilizer to the seedbeds of aspen or western larch (*Larix occidentalis*) in an effort to control height growth whereas spruces or true firs (*Abies*) are heavily fertilized to force height growth. High elevation and interior sources of wide-ranging species such as ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) must be given higher fertilizer levels than low elevation and coastal sources.

Crop age

All 3 fertilizer nutrients are required in relatively large amounts by young plants but actual uptake patterns vary. The amount of P stored in the seed is quite limited and therefore supplies of this nutrient are required almost immediately after germination. Armson (1960) studied the uptake patterns of N, P, and K and found that P was rapidly taken up early in the 1+0 growing season and again later in the year (Figure 2). N and K, on the other hand, have high early uptake rates which gradually drop off during the growing season. These data suggest that P should be made available to the plant early and late in the growing season whereas N and K should be supplied during periods of rapid seedling growth.

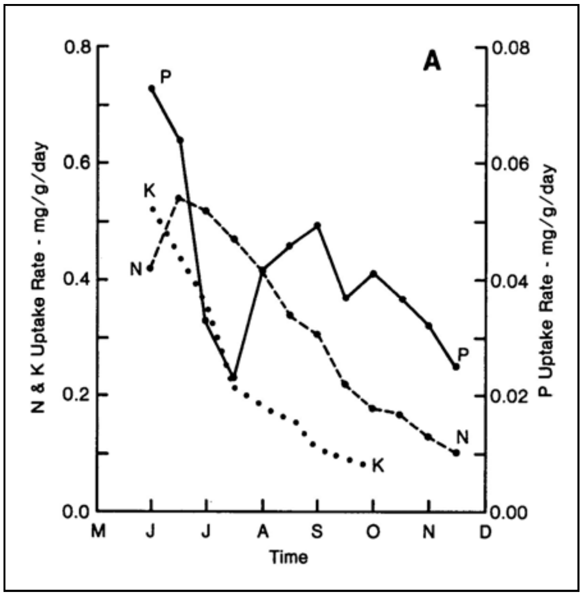

Figure 2 — Nutrient uptake rates of nitrogen (N) and potassium (K) are high relative to seedling size and peak early and then decrease through the growing season, whereas the relative uptake of phosphorus (P) has peaks both early and late in the season (modified from Armson, 1960).

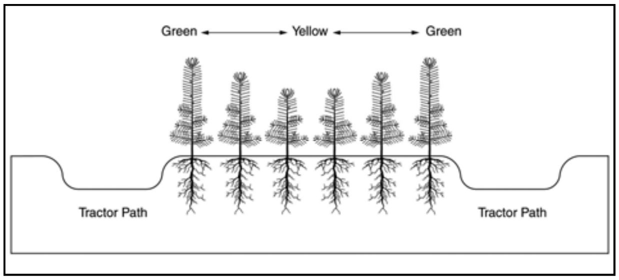

Figure 3 — Plants utilize more nitrogen than any other mineral nutrient which results a characteristic deficiency symptom where plants on the interior are more stunted and chlorotic than those on the outside.

Seedbed density

The number of plants growing per unit area of seedbed has a significant effect on their nutrient uptake. Experienced nursery workers are familiar with the "dished", chlorotic pattern in seedbeds suffering from N deficiency (Figure 3); this condition occurs because plants in the interior of the seedbed are under more competition and receive relatively less N than those in the outside rows (Armson and Sadreika 1979). This effect of seedbed density varies between species, however, as van den Driessche (1984a) found that Douglas-fir and Sitka spruce (*Picea sitchensis*) were more sensitive than lodgepole pine (*Pinus contorta*). Many nursery managers do not appreciate the very high growing density of tree seedlings compared to agricultural crops. If we assume a seedbed density of 25 plants per square .foot and a field efficiency of 60%, the resultant growing density of 650,000 plants per acre would be extremely high, compared to a typical density of 20,000 plants per acre for corn.

Temperature

The effect of temperature on nutrient uptake is not surprising but few people realize how significant it can be. van den Driessche (1984b) found that seedling growth is severely restricted below 50 ^{o}F (10 ^{o}C), regardless of the level of P fertilization; this growth reduction is very abrupt, which suggests that root function is impaired at low temperatures (Figure 4). Because this is a general

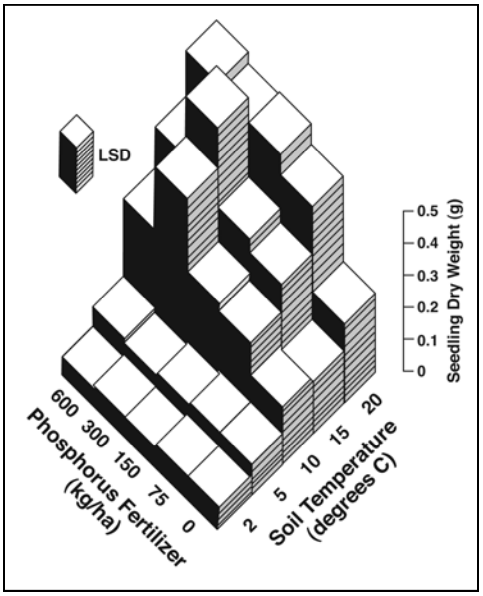

Figure 4 — Soil temperatures below 50 ^{o}F (10 ^{o}C) have a significant effect on phosphorus upake and resultant growth of Douglas-fir seedlings (van den Driessche 1984).

physiological effect rather than a specific ion effect, this temperature restriction probably occurs for all mineral nutrients.

Ways to Establish a Fertilization Plan

Every bareroot nursery needs a fertilization plan — a systematic, documented approach describing fertilizer application practices. Each plan will be different and will reflect the characteristics of the individual nursery and their specific crops. Most fertilization plans are established using one or more of the following approaches:

1. Personal experience
This is probably the most common and certainly the most traditional way to set up a fertilization program. As in any farming operation, nursery managers can build up real expertise based on their experiences over the years. In addition to keen powers of observation, nursery workers should have a basic understanding of fertilizer action and soil science in order to learn what works best at their own nursery. The real limitation to this method, however, is the time required to accumulate this experience. Because of the multi-year rotations inherent in tree production, a person must remain at the nursery long enough to witness several different rotations and experience a range of weather and crop variation over a period of many years.

2. Recommendations
This category includes both advice from consultants and recommendations from technical articles and nursery manuals. Nursery consultants are able to visit a variety of different nurseries and learn specifics about soil factors, crop characteristics, and climatic conditions, which helps them to develop customized fertilizer programs. On the other hand, consultants are expensive and nursery managers could become overly dependent on outside assistance. Nursery manuals and technical articles usually give "generic" fertilizer recommendations and the nursery managers must be able to modify these recommendations to fit their own soil and weather conditions and plant species requirements.

3. Nursery fertilizer trials
Undoubtedly, the best way to develop a fertilization program is to conduct a series of fertilizer trials right in the nursery so that specific crop responses can be measured. Ideally, trials should be performed on each major soil type and plant species, and also should be conducted over several rotations so that all sources of variation can be sampled. That's "ideally", which doesn't usually apply because most nurseries are just too busy with day-to-day operations. Still, fertilizer trials can lead to valuable insights into how the fertilizer-soil-water-plant complex really works under specific nursery conditions.
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4. Soil testing
Most tree nurseries have had soil tests performed at one time or another but many managers are not comfortable with their own interpretation of the test values. Soil tests are a good way to monitor soil fertility and fertilizer response but they have certain limitations. Most tests report in terms of "available" nutrients but these values vary with the extracting solution used by the lab. These extracting solutions supposedly remove the same amount of nutrient that would be available to the tree seedling during one growing season. P availability is particularly hard to measure and testing labs across the country use a variety of different extracting solutions which give different values on P "availability". Although any agricultural soil testing lab can perform soil tests, most are not familiar enough with tree seedlings to provide relevant interpretation of the results. Most published soil fertility standards for tree seedlings have usually developed from fertility trials with one of the major commercial species such as Douglas-fir or loblolly pine and may not be applicable to other species of seedlings.

5. Seedling nutrient analysis (SNA)
As with soil tests, SNA is expensive but can be invaluable because it is the only real way to determine if the nutrients applied as a fertilizer are ever taken up by the

seedling. Interpretation of the test results can be difficult and many of the published standards are ranges of values that may not be sensitive enough to detect a problem with one particular species. Assistance with interpretation is often required and again consultants can be helpful (Landis and others 2005).

Calculation of Fertilizer Application Rates

The amount of fertilizer that should be applied to a nursery seedbed can be determined by soil test results or crop use. "Maintenance" fertilizer applications maintain soil fertility at some target level and are based on soil tests and/or SNA. "Replacement" applications replace the nutrients used by the seedling crop during the year. P and K are usually applied as maintenance applications using target values for the nutrients. Soil N exists in many organic and inorganic forms in nursery soils and there is no widely-accepted test for available N; therefore, N fertilizers are normally applied as replacement applications.

The type of fertilizer to apply is very important and single element fertilizers (for example, ammonium sulfate [21-0-0]) are generally recommended so that fertilizer amendments can be directed at a specific nutrient element. Complete fertilizers (for example, 15-15-15) should not normally be used because there is usually no need to supply N-P-K at the same time (Table 1). Complete fertilizers are also more expensive than most single element fertilizers. Ammonium phosphates (for example, 18-46-0) are exceptions because these multi-nutrient fertilizers are sometimes applied as pre-sowing incorporations or in bands during sowing. As we mentioned, diammonium phosphate can also be applied as a mid-season topdressing.

Replacement applications of N

Nitrogen applications are generally applied based on estimates of crop use because there is no acceptable soil test for available N. van den Driessche (1980) reported that 2+0 conifer crops use from 45 to 178 lbs/ac (50 to 200 kg/ac) of N during a rotation, so these values can be used as replacement application rates. The actual

Table 2 — An example of how to convert parts per million (ppm) from soil test results to application rates in pounds per acre (lbs/ac)

1. Determine amount of nutrient needed

Target phosphorus (P) level: 35 ppm
Subtract soil test P level: -18 ppm
Need to add as fertilizer: 17 ppm

2. Convert from ppm to lbs/ac

$$17\text{ ppm} = \frac{17\text{ parts}}{1{,}000{,}000\text{ parts}} = \frac{17\text{ parts}}{1{,}000{,}000\text{ lbs}}$$

Given: One acre-foot of loam soil weighs 4,000,000 lbs, therefore a 9-inch rooting depth weighs 3,000,000 lbs:

$$\frac{17\text{ lbs}}{1{,}000{,}000\text{ lbs}} = \frac{X}{3{,}000{,}000\text{ lbs}}$$

X = 51 lbs/ac of P

3. Convert from the elemental to the oxide form (P to P_2O_5 or K to K_2O)

51 lbs/ac x 2.3 = 117.3 lbs of P_2O_5

4. Convert to weight of bulk fertilizer

Concentrated superphosphate (0-46-0) contains 46% P_2O_5

$$\frac{117.3\text{ lbs/ac } P_2O_5}{0.46} = 255\text{ lbs of 0-46-0 per acre}$$

amount of N that a tree seedling crop requires is dependent on species, seedbed density, climate, and soil type. As a general rule, the N demands of broadleaved species can be about 50% greater than conifers (Davey 1994). N-fixing species often require only a starter dose of N to establish the plants but crop growth rates and SNA are the best guides (Davey 2002). Tissue tests at the end of the growing season should be used to fine-tune fertilizer applications during the following season. Late summer foliar tests allow time to apply additional nitrogen to bring levels to ideal levels before lifting.

SNA can also be used for trouble shooting during the season if nutrient deficiency symptoms such as chlorosis or dished beds (Figure 3) become evident. When collecting samples be sure to collect both symptomatic and normal seedlings so that comparisons can be made. Target values for N in conifer needle tissue range from 1.20 to 2.00%, so each nursery should strive to accumulate enough data to develop standards for their own situation (Landis and others 2005).

Maintenance applications of P and K

Soil test targets for P and K are usually given in parts per million (ppm) or pounds per acre (lbs/ac). The ppm units can be converted to amount of fertilizer per acre using the process provided in Table 2. Note that these calculations only supply the bare minimum amount of fertilizer and actual availability is dependent on soil texture. Sandy soils may require 10% more, loams 20% more, and some clays up to 40% more fertilizer. Again, use foliar tests for confirmation.

Many fertilizer specialists recommend that P be incorporated into the seedbed or banded at the time of sowing regardless of the soil test level. Root systems of newly germinated seedlings are very restricted whereas demand for P is high during germination and early seedling growth; these “starter” applications help ensure that a supply of P is readily accessible. For example, van den Driessche (1984a) recommends applying ammonium phosphate (11-55-0) at a rate of 27 lbs/ac (30 kg/ha) in a band 3 to 5 inches below the drill row and reports a substantial increase in growth for spruce seedlings. If top dressing is required during the season, use diammonium phosphate which is more soluble than other fertilizers.

Potassium fertilization is not normally required in western nurseries because most western soils contain an abundance of K-bearing minerals, particularly in the Great Plains and Intermountain areas. On sandy soils, particularly in the southeastern states, a late-season top-dressing of potassium is frequently needed. Nursery managers should utilize soil tests, to determine the K availability at their own specific nurseries and convert ppm recommendations to application rates (Table 2). SNA should also be used to monitor P and K fertilizer uptake at the end of each growing season or for trouble shooting during the season.

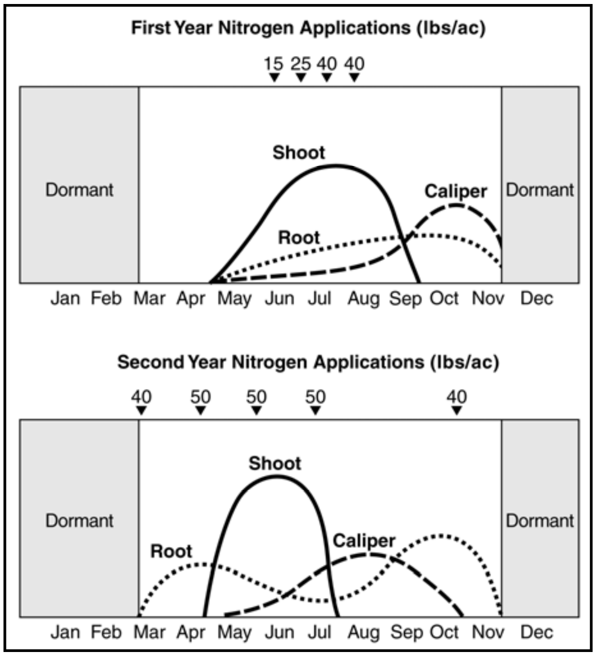

Figure 5 — Nitrogen fertilizer applications should be scheduled around plant growth cycles. In the first year, the first applications are delayed to prevent damping-off disease, but applications should precede bud break for established crops to allow time for the fertilizer to dissolve and move into the root zone.

Fertilizer Application Timing

Once the total annual fertilizer application rate has been calculated, the problem of when to apply the fertilizer and the rate per application must be decided. Because of the different characteristics of these three fertilizer nutrients (Table 1), they will be discussed separately.

Nitrogen

N is normally applied in a series of 4 to 6 applications over the growing season (Figure 5). Because many commonly-used N fertilizers (for example: urea, ammonium sulfate) are water soluble, they are applied as top dressings with standard fertilizer spreaders. N fertilizers can burn succulent seedling foliage and so the fertilizer should be brushed from the foliage or be watered-in immediately. The first application of N is usually delayed until after seedlings have become established because of concerns about stimulating damping-off fungi and fertilizer burn. During the 2+0 year, however, N fertilizers should be applied as early as possible so that the nutrients are available prior to the first flush of spring growth. Because N is so soluble in the soil, repeat applications may be necessary after heavy spring rains particularly in coarse-textured soils. Some progressive nurseries are applying all their N as a liquid top-dressing which ensures quick uptake and reduces chances for foliar burning (see Fertigation section).

One of the most scientific ways of determining the proper time for N applications is the degree day system which uses accumulated heat units. The degree day approach is attractive because the fertilizer applications are synchronized with seedling growth, which is also tightly linked to temperature. Either ambient or soil temperature can be used as a degree-day basis although soil temperatures are more stable and more accurately reflect the environment where nutrient uptake is actually occurring. Because of climatic and edaphic variation, each nursery must develop its own degree day system; one used by Ontario nurseries can be found in Armson and Sadreika (1979).

Phosphorus

P can be applied during the fallow year or prior to sowing so that the nutrient is available early in the growing season (Table 1); these pre-sowing applications are effective because P is immobile in soil. Fallow year applications applied to cover or green manure crops ensure that P will be fixed into the organic matter and slowly released in subsequent growing seasons. Many soil scientists feel that P is best applied immediately before or during sowing to minimize the potential for chemical immobilization. Again, P uptake is temperature dependent (Figure 4) and so it is important that adequate supplies are available during the early spring. Mycorrhizal fungi are very important in the P nutrition of tree seedlings but many young seedlings do not become mycorrhizal until late in the 1+0 season, especially in fumigated seedbeds. This early mycorrhizal deficiency is further justification for pre-sowing P applications. Banding P fertilizers below the seed is especially effective and is discussed in the section on P application rates.

Potassium

K is moderately mobile in the soil and is required during periods of active growth and can therefore be applied as either a top dressing or incorporated (Table 1). Leaching losses are more serious in sandy soils with a low CEC so frequent top dressings would be more appropriate under these conditions. Probably the most practical procedure would be to apply half the annual amount as a presowing incorporation and the other half as a midseason top dressing. The need for late season K applications can be determined through tissue testing.

Conclusions and Recommendations

The utilization of fertilizer nutrients by tree seedlings is affected by many factors including seedling development, species of seedling, seedbed density, soil temperature, and soil moisture. The characteristics of the individual fertilizer elements (N, P, and K) also affects their availability and utilization in nursery soils.

All bareroot nurseries could benefit from a fertilization plan — a systematic, documented approach to fertilizer use. Fertilization plans must be developed specifically for individual nurseries to reflect unique climatic and edaphic characteristics and the response of individual seedling species. These plans can be developed using several different procedures: personal experience, recommendations, nursery fertilizer trials, soil testing and seedling nutrient analysis. Ideally, nursery managers will use a combination of all five of these procedures to produce a balanced fertilization plan, and accommodate new information as it becomes available.

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New Western Nursery Specialist

Diane Haase (pronounced “Haa – zee”) is the new Western Nursery Specialist with the USDA Forest Service. She is stationed in Portland, OR and is available to provide technological assistance to nurseries in the western states as a member of the national Reforestation, Nurseries, and Genetics Resources team. Prior to joining the Forest Service, Diane was the associate director for the Nursery Technology Cooperative at Oregon State University for nearly 20 years. Diane has conducted dozens of research projects designed to develop nursery practices, increase seedling quality, and maximize growth and survival after outplanting. She has also provided technology transfer to the nursery, conservation, and reforestation communities through meetings, publications, presentations, workshops, and conferences covering a wide variety of topics. She has a BS degree from Humboldt State University and an MS degree from Oregon State University.

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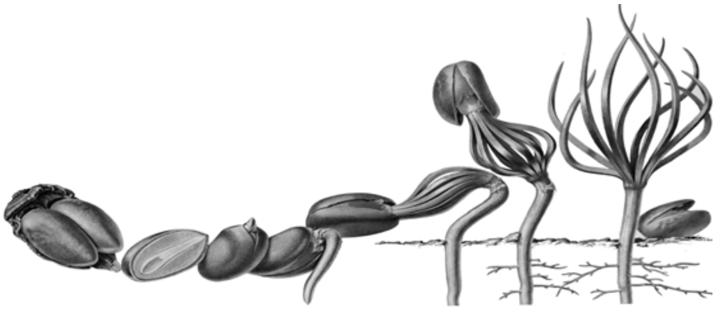

The Latest on Soil Fumigation in Bareroot Forest Nurseries

by Diane L. Haase

Background

Soil fumigation has been used in bareroot forest nurseries to control pathogens, nematodes, insects, and weed seed for many decades (Cordell 1989; Landis and Campbell 1996). Many fungal pathogens are difficult or impossible to control with post-emergent pesticide applications so a majority of nurseries rely on fumigation to keep disease incidence at a minimum. Depending on the fumigant used, some of the target pests include soil fungi (*Fusarium, Pythium, Cylindrocarpon*, charcoal root rot, *Cylindrocladium, Phytophthora)*, parasitic nematodes, and most weed seeds. At a cost of more than $1000 per acre, soil fumigation can be the most costly cultural practice in a bareroot nursery. This cost is usually justified by the healthy, uniform seedling crop that results from a relatively pest-free field.

Fumigation materials and application procedures

The primary chemicals currently used for fumigation in bareroot forest nurseries are methyl bromide (in combination with chloropicrin), chloropicrin, Basamid (Dazomet), Telone, metam-sodium, and methyl iodide (listed in order of overall usage preference and frequency among forest nurseries). Each of these are either injected or incorporated into the soil and covered with a tarp to seal the surface for a period of time following application (2 to 40 days depending on the fumigant). After application, a toxic gas develops and penetrates the soil profile by moving through the soil pores and coming into contact with the target pest. Fumigant type, application rate, soil characteristics (temperature, moisture, texture, bulk density, and organic matter content), tarp material, duration of tarping, and target organisms all influence the degree of pest control (Cordell 1989; Landis and Campbell 1996; Wang and others 2006). Some nurseries used to do their own fumigant applications, but most bareroot forest nurseries in the US are currently using professional applicators to fumigate their soil. This is to ensure maximum safety, efficiency, and effectiveness.

Methyl bromide phase out

In 1991, methyl bromide was detected in significant concentrations within the earth's stratosphere. Subsequent testing determined it to be a contributor to ozone depletion. As a result, methyl bromide was categorized as a Class 1 ozone depleting substance and was put under a phase out schedule pursuant to the Montreal Protocol and the Clean Air Act (Table 1). Since that time, many trials have been conducted to examine alternatives to methyl bromide. Chemical, biological, and cultural treatments have been examined to evaluate their efficacy for pest control as well as their effect on seedling growth, yield, and quality. Specific treatments have included cover crops, compost, solarization, steam, fungicides, and others (Cooley 1985; Stevens 1996; Hildebrand and others 2004). The forest nursery industry is only one small sector that is

Table 1 — Production and import phase-out schedule followed for Methyl Bromide (Source: US EPA, The Phaseout of Methyl Bromide, http://www.epa.gov/Ozone/mbr [accessed 8 Sep 2009])

1993 to 1998	Freeze at 1991 baseline levels (US Consumption ~25,500 metric tons) (consumption = production + imports - export)
1999 to 2000	25% reduction from baseline levels
2001 to 2002	50% reduction from baseline levels
2003 to 2004	70% reduction from baseline levels
2005	100% phase out - except for allowable exemptions[1]

[1] Allowable exemptions to the phaseout (agreed to by the Montreal Protocol Parties) include 1) the Quarantine and Preshipment (QPS) exemption, to eliminate quarantine pests, and 2) the Critical Use Exemption (CUE), designed for agricultural users with no technically or economically feasible alternatives.

significantly impacted by the loss of methyl bromide; many agricultural crops such as strawberries, melons, tomatoes, and peppers also rely on this fumigant for optimum production. As a result, the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions has been held since 1994 with the goal to develop and implement economically viable and environmentally sound alternatives (http://mbao.org).

Soil Fumigants and the EPA Re-registration Eligibility Decisions

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA reviewed several soil fumigants over the past few years to ensure that they meet current scientific and regulatory standards. In 2008, the EPA announced new rules for soil fumigants as a result of their Re-registration Eligibility Decisions (REDs). Prior to announcing those rules, there was a great deal of input from the forest nursery industry and other agricultural entities regarding the importance of soil fumigation, the safe practices already in place, the long-standing safety record, and the economic impact of reduction or elimination of soil fumigant use. Nevertheless, the rules (as published in 2008) were expected to have severe impacts on bareroot forest nurseries and other agricultural crops. The rules for chloropicrin were especially worrisome given the fact that many years of research identified it as the most promising alternative to methyl bromide (Carey 2000; South 2007).

There was widespread outcry and numerous submissions to the public docket in opposition to the REDs published in 2008. Many were asking how this could come about when there had had not been any noteworthy instances of injury. It was noted that a person has a higher probability of dying from a fall in this country than of experiencing eye irritation from soil fumigation. Some of the new requirements were expected to result in nursery closures, doubled or tripled bareroot seedling prices, and reduced seedling quality and uniformity. Depending on the product and application rate, required buffer zones around fumigated beds and nearby buildings would effectively take many acres out of production and necessitate multiple entries for fumigation thereby increasing costs and raising safety concerns. Intensive monitoring for emissions was also expected to be very costly. Additionally, there was concern that the mandated community outreach would unnecessarily frighten neighbors who had lived in harmony with nearby nurseries for decades without incident. From a scientific standpoint, the statistical validity of the data used to generate the risk models and develop the REDs was in question since it was based on data collected from arid sites in Arizona and did not

As methyl bromide is injected into the soil, it is immediately covered with a plastic tarp

Table 2 — Modifications from 2008 to 2009 Amended Soil Fumigant REDs (Source: US EPA, Implementation of risk mitigation measures for soil fumigant pesticides, http://www.epa.gov/oppsrrd1/reregistration/soil_fumigants/#soilreds [accessed 8 Sep 2009])

Mitigation	2008 REDs	2009 Amended REDs
Buffers	Buffer zones based on available data	● New chloropicrin data support smaller buffers and increased confidence in safety ● New dazomet data support larger buffers
Buffer Credits	Credits allowed based on available data	● New data support more credits
Rights-of-Way	Permission from local authorities must be granted if buffers extend onto rights of way	● Permission from local authorities is only required when sidewalk is present
Buffer Overlap	Buffers may not overlap	● Buffers may overlap; separate applications by 12 hours
Restrictions for Difficult-to-Evacuate Sites	¼ mile restriction around hard-to-evacuate areas including day care centers, nursing homes, schools	● Maintain 1/4 mile restriction but allow a reduced restricted area of 1/8 mile for applications with smaller buffers (less than 300 feet)
Respiratory Protection	Required monitoring devices to trigger additional measures	● Allow sensory irritation properties to trigger additional measures for MITC and chloropicrin ● Device required for methyl bromide formulations with <20% chloropicrin
Emergency Response and Preparedness	If neighbors are near buffers, they must be provided with information or buffer zones must be monitored every 1 to 2 hours over 48 hours with monitoring devices	● Same basic measures ● Monitoring is required only during peak emission times of the day; irritation acceptable trigger for MITC and chloropicrin in lieu of devices; methyl bromide requires devices

account for critical soil characteristics (for example, moisture), which have a profound influence on fumigant behavior following application. The EPA staff acknowledged several "gaps" and "uncertainties" in their risk models but were hampered by a limited amount of available data. Another concern was that decreased production of forest seedlings and other agricultural commodities in the United States would result in more importing of these goods, possibly from sources without adequate safety and quality standards.

Although the 2008 REDs were labeled "final", the considerable objection and the availability of new emissions data for development of more accurate risk models led to revision of the REDs (Table 2). While these new rules will not be nearly as devastating to forest nurseries, they will still have a significant impact on bareroot seedling production.

Clearly, no one in the nursery industry wants to compromise safety for their employees, their surrounding community, and the environment. That is evidenced by the excellent chemical safety record among nurseries. All operations should routinely take protective and preventative measures as dictated by all applicable laws and regulations for their pest management activities. Nonetheless, as the EPA and the general public focus more and more on being "green", there is likely to be continued scrutiny for chemical usage in plant production. Therefore, it is critical for the industry to be proactive by continuing to explore alternative treatments as well as to collect rigorous scientific data on current treatments should it be needed during future reviews.

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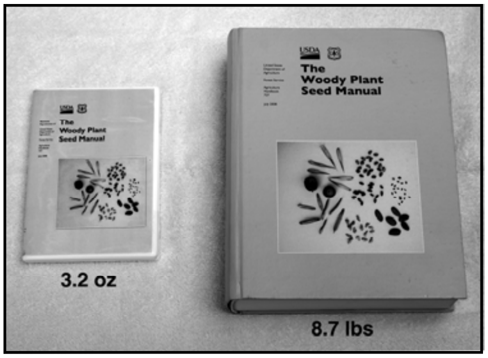
New Nursery Publications

The Woody Plant Seed Manual
Edited by Bonner FT and Karrfalt RP
Publication Date: 2008

We announced the publication of the hard copy of this nursery classic in the Summer 2008 issue, but now the E-book version is available. Besides being much lighter and easier to ship and handle, the E-book contains Adobe PDF files of the entire volume and also each chapter.



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National Nursery Proceedings, 2007 & 2008

Dumroese RK, Riley LE, technical coordinators. 2008. National Proceedings: Forest and Conservation Nursery Associations—2007. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-57. 174 p

Dumroese RK, Riley LE, technical coordinators. 2009. National Proceedings: Forest and Conservation Nursery Associations—2008. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-58. 124 p.

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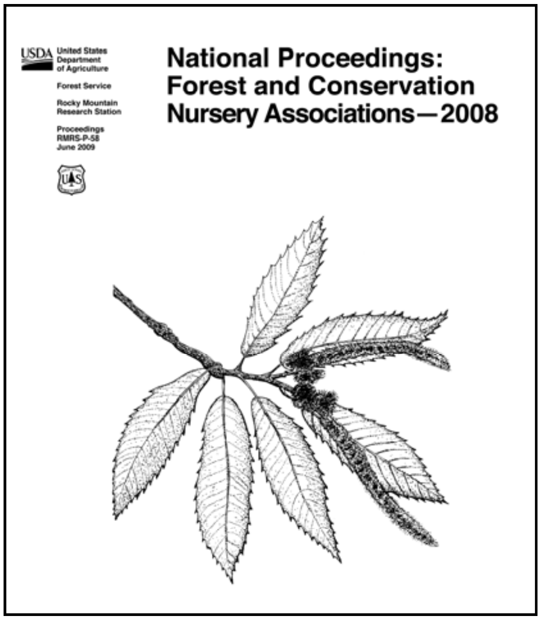
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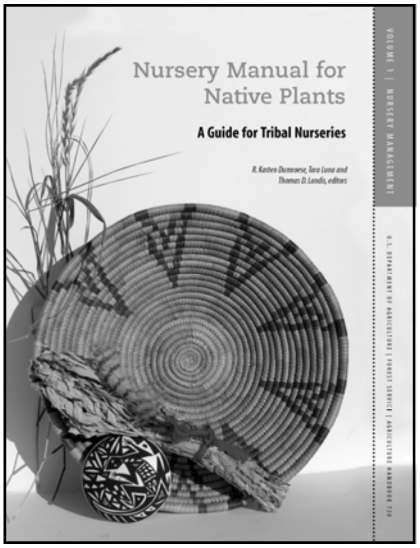
National Proceedings: Forest and Conservation Nursery Associations—2008

Nursery Manual for Native Plants: A guide for Tribal Nurseries — Volume 1: Nursery Management

Dumroese RK, Luna T, Landis TD, editors. 2008. Nursery management, vol 1. Nursery Manual for Native Plants: A Guide for Tribal Nurseries. Washington (DC): USDA Forest Service, Agriculture Handbook 730. 302 p.



This comprehensive book is a look at how to grow native plants in container nurseries. It was written specifically for American Indian nurseries, but will be a useful reference for other growers as well. The book is organized into 4 sections containing 17 chapters. The *Getting Started* section consists of chapters on Planning a Native Plant Nursery, Target Plant Concept, and Planning Crops and Developing Propagation Protocols. In the *Developing Your Own Nursery* section are chapters on Propagation Environments, Growing Media, and Containers. The *Growing Plants* section contains Collecting, Processing and Storing Seeds; Seed Germination and Sowing Options; Vegetative Propagation; Water Quality and Irrigation; Fertilization; Hardening; Harvesting, Storing, and Shipping; and Beneficial Organisms. The final section, *Problem Solving,* consists of Holistic Pest Management, Nursery Management, and Discovering Ways to Improve Crop Production and Plant Quality.

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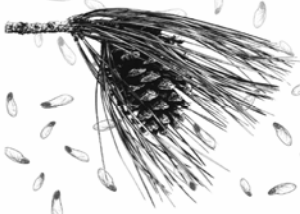

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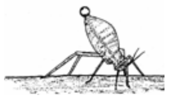

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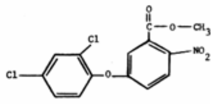

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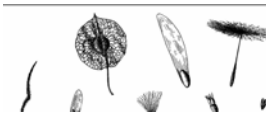

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