Macronutrients - Nitrogen: Part 2
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This article is the second part of a look at the importance of nitrogen in nursery management. Part One can be found in the Summer, 2003 issue of FNN and covered the role of nitrogen in plant nutrition and influences on seedling growth and development. Figure 2 was inadvertently omitted from that article and so we are including it here:

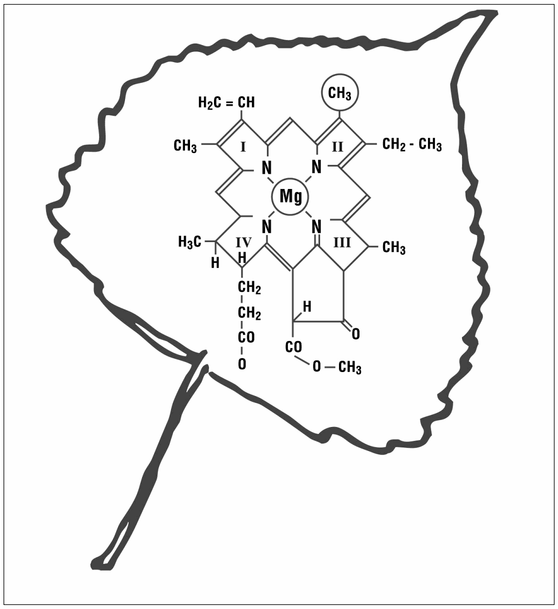

Figure 2 **-** *Nitrogen is critical to photosynthesis because each chlorophyll molecule contains four nitrogen atoms at its very heart.*

Influences on Plant Growth and Development

Because nitrogen is so critical to nursery production and has so many different affects on seedling physiology, you can occasionally see deficiency symptoms in forest and conservation nurseries.

Deficiency Symptoms.

The initial stages of nitrogen deficiency are difficult to diagnose because nitrogen is very mobile within the plant and minor deficiencies will first be expressed as slower growth rates ("hidden hunger"). In individual seedlings, nitrogen is translocated from older to younger tissues resulting in a color change in the older leaves or needles. First, they turn a light green, then yellow as the chlorophyll is broken down. Severely deficient foliage will appear scorched on the margins. In bareroot nursery seedbeds, competition for nitrogen can be severe between adjacent seedlings and results in a characteristic "scalloped" growth pattern (Figure 5). This symptom occurs because the larger green seedlings in the outside rows have access to fertilizer in the tractor paths while the stunted and chlorotic seedlings in the center rows must compete with each other.

Chlorosis is a poor diagnostic symptom for nitrogen deficiency, however, because yellowing can be caused by many other mineral nutrient deficiencies. Nevertheless, the symptom pattern of chlorosis beginning in the older (lower) foliage of seedlings can be diagnostic to distinguish nitrogen from magnesium, sulfur, or iron deficiencies.

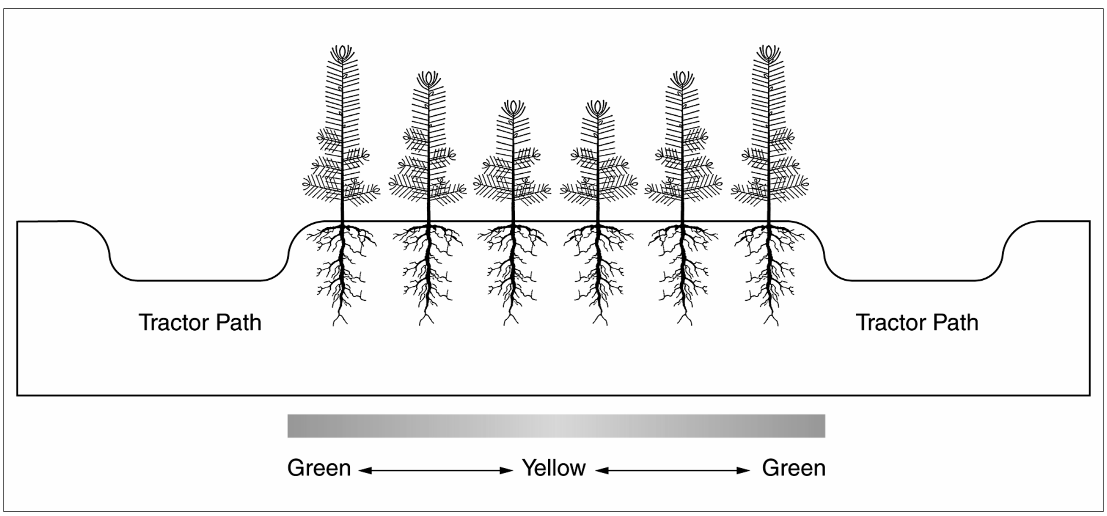

Figure 5. "Scalloped" nursery beds are a common nitrogen deficiency symptom in bareroot nurseries.

Toxicity Symptoms.

Because nursery plants can take-up so much nitrogen fertilizer as luxury consumption, there are no specific nitrogen toxicity symptoms. However, over application of nitrogen fertilizer can cause typical salt damage symptoms such as scorching and curling of needle tips or leaf margins. Toxicity can also be caused by high levels of ammonium-based nitrogen fertilizers, resulting in the death of root tips. These damaged root systems are expressed as drought stress and reduced nutrient uptake ability, and so wilting of succulent seedling tissue when water is not limiting and evapotranspiration is low should be investigated.

Oversupply of nitrogen fertilizers can also be expressed in deficiencies of other nutrient elements. These “induced deficiencies” may be due to ion competition in the root zone such as ammonium competing with calcium, or they may be the result of internal nutrient imbalances. Induced deficiencies result because mineral elements are utilized in varied proportions according to need. For example, sulphur atoms are needed for protein synthesis at approximately one-tenth the rate of nitrogen atoms. Oversupplying nitrogen causes a relative depletion of sulphur, resulting in a “nitrogen-induced sulphur deficiency”. The plant responds by preferentially constructing proteins that require less sulphur atoms, which sacrifices processes and structures that require high-S-proportion proteins.

Monitoring Nitrogen

Nitrogen can be monitored by chemical analysis of soils, growing media or plant tissue.

Soil Tests.

The many organic and inorganic forms of nitrogen in the soil make it extremely difficult to use soil tests as a diagnostic tool. Therefore, many nurseries apply nitrogen fertilizer based on crop response rather than soil test results. Some nurseries do monitor nitrate concentrations in soils as a rough indication of nitrogen availability or as an indication of the need to leach high nitrate levels from the root zone.

Artificial Growing Media Tests.

Chemical tests for nitrogen availability are not common in container nurseries either. Because of their high organic matter content, artificial growing media have large reserves of nitrogen in the peat moss, compost or other organic components. Therefore, most container growers have developed their fertilization regimes based on seedling growth response rather than media tests.

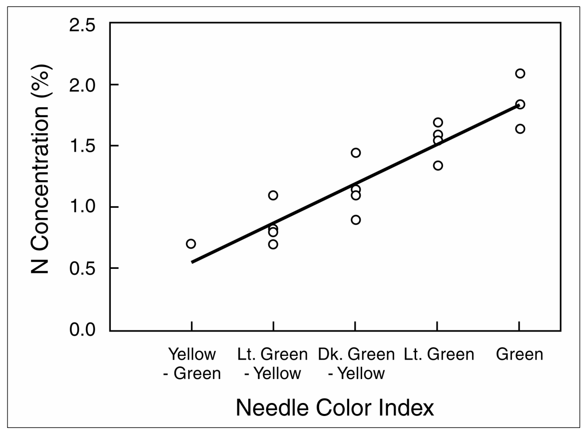

Figure 6. Nitrogen concentration in relation to color of Norway spruce needles (modified from 5).

Seedling Tissue Analysis.

Chemical analysis of plant tissue has been done more for nitrogen than for any other mineral nutrient. However, because of its high mobility in the plant and growth

Table 3 - Nitrogen Concentration (%) in Conifer Seedling Tissue During the Growing Season For Conifers in Eastern Canada

Species Group	Seedling Age of Production Stage			
	3 to 10 weeks	**10 to 16 weeks**	**Hardening**	**Storage**
Pine	2.8 to 3.0	2.5 to 2.8	2.2 to 2.5	1.9 to 2.2
Spruce	3.2 to 3.6	2.5 to 3.0	2.5 to 2.8	1.9 to 2.2
Modified from 4				

dilution effects during the season, good standards have been hard to develop for many forest and conservation crops. Nevertheless, experienced nursery managers frequently test foliage samples to fine-tune crop development or test the effectiveness of a particular fertilizer regime. Some growers do analyze foliar samples during the growing season to develop their own standards (Table 3). More commonly, foliar samples are collected from seedlings in the fall or during the hardening phase eliminate the growth dilution effect.

The nitrogen adequacy range for conifer foliage is generally considered to be between 1.5% and 3.5%. Below 1.5% seedling growth will be retarded - this is the "hidden hunger" symptom that is so difficult to diagnose. Towards the lower end of the adequate range (1.5 - 1.8% nitrogen) most species will grow slower and display lighter green foliage. Seedlings being grown at levels between 2.5 and 3.5% nitrogen generally display lush green color and can produce very soft, succulent tissue under optimum growing conditions (Figure 6). Under operational conditions, growers generally maintain seedling foliage nitrogen levels between 2 and 3% during active growth and allow it to ramp down to about 2% prior to lifting or winter storage (Table 3). When monitoring crops for nitrogen status, it is important to base decisions on solid data trends rather than "snapshots in time". Having a series of foliar nutrient analyses done over several seasons and graphing the results is easy with computer software. Tracking the status of several nutrients on the same graph can be valuable in exposing mineral nutrient interactions.

Nitrogen Management

Managing nitrogen in forest and conservation nurseries is critical, not only because large amounts of nitrogen fertilizers are used to force growth but because nitrogen pollution is an increasingly serious problem in all forms of agriculture.

Fertilizers, Application Methods and Rates in Bareroot Nurseries.

A wide variety of nitrogen fertilizers are being used in forest and conservation nurseries (Table 4). In bareroot nurseries, recommendations are often given as "actual nitrogen" instead of bulk fertilizer which allows growers to convert easily to whatever fertilizer they are using. For example, 40 lbs (18.1 kg) of actual nitrogen would convert to an application of 190 lbs (6.2 kg) of ammonium sulfate (21-0-0), or 121 lbs (54.9 kg) of ammonium nitrate (33-0-0).

Organic Nitrogen Fertilizers **-** In the early days, manure was the most common nitrogen fertilizer but it is not widely used today because of its volume and weight, variable quality, and contamination with weed seeds. All organic fertilizers are slow-release and contain a full complement of mineral nutrients compared with many synthetic brands. Today, only a few organic fertilizers such as Milorganite® have been used in bareroot nurseries because of their lower analysis and consequently higher application costs (Table 4). One of the underappreciated benefits of organic fertilizers is the large amount of organic matter that they add to the soil. For example, applying Milorganite® at an annual rate of 200 lbs of N/acre (224 kg/ha) will supply almost 2 tons (1.8 mt) of organic matter to the soil as a by-product of fertilization.

Synthetic Nitrogen Fertilizers **-** Most contemporary fertilizers used in forest and conservation nurseries are synthetically produced and are inorganic salts (Table 4). The choice of fertilizer is dependent on the application method. Applying granular fertilizer to the soil surface ("top dressing") is the most common application method for nitrogen fertilizers in bareroot nurseries although incorporation and banding are sometimes used. For example, monammonium or diammonium phosphate are banded at the time of sowing to ensure uniform placement in the root zone. After seedling emergence, ammonium sulfate and ammonium nitrate are commonly top-dressed and their choice depends on their effect on soil pH, the former lowering it and the latter raising it.

The newest option for applying nitrogen fertilizers is through sprayers. A stock solution of soluble fertilizer is diluted with water in a spray tank and then sprayed over the crop. An exciting feature is that new computer-controlled sprayers can change application rates for different crops or soil types without stopping. Spray application is also much more uniform than other fertilizer application equipment (15).

Application Rates and Timing **-** Nitrogen applications for bareroot nurseries are generally applied based on estimates of crop use because there is no acceptable soil test for determining total available nitrogen. The actual amount of nitrogen that a seedling crop requires is dependent on species, seedling density, climate, and soil type. Fertilizer nutrient recovery is also relatively low ranging from 13 to 16% nitrogen for a 1+0 crop to perhaps 50% during the 2+0 year. Therefore, most nursery managers apply from 50 to 250 (56 to 280 kg/ac) of nitrogen during a rotation (16).

One of the most scientific ways of determining the proper time for nitrogen applications is the degree day

Table 4 - Types of Fertilizers Commonly Used in Forest and Conservation Nurseries

Fertilizer	Nutrient Analysis			Nursery Type	Application Method	Remarks
	%N	$\%P_2O_5$	$\%K_2O$			
Milorganite®	6	2	0	BR	Top-Dressed or Incorporated	An organic fertilizer made from municipal sludge
Urea (NH_2-CO-NH_2)	46	0	0	BR	Top-Dressed or Incorporated	A dry material in dry or prilled form
Ammonium nitrate NH_4NO_3	33-34	0	0	BR & C	Top-Dressed or Fertigation	A dry material in dry or prilled form
Ammonium sulfate $(NH_4)_2SO_4$	21	0	0	BR	Top-Dressed	A dry crystalline material. Contains 24% sulfur.
Diammonium phosphate (DAP) $(NH_4)_2HPO_4$	18	46	0	BR	Incorporated or Banded	A dry granular or crystalline material
Monoammonium phosphate (MAP) $NH_4H_2PO_4$	11	52	0	BR	Incorporated or Banded	A dry granular material
Potassium nitrate KNO_3	13	0	45	C	Fertigation	Dry crystalline material.
Plant Products 20-20-20	20	20	20	C	Fertigation	Completely soluble with micronutrients
Scotts Excel Cal-Mag 15-5-15	15	5	15	C	Fertigation	Completely soluble, with calcium, magnesium, sulfur and micronutrients.
Scotts Peters Plant Starter 9-45-15	9	45	15	C	Fertigation	Completely soluble with high P for young plants.
Scotts Peters Foliar Feed 27-15-12	27	15	12	C	Fertigation	Completely soluble with high urea for quick "green-up."
Controlled-Release Formulations						
Osmocote Fast Start; 8 to 9 month release	18	6	12	C	Incorporation	Polymeric resin-coated prills; 10.4% Ammonium, 7.6% Nitrate
Osmocote High N; 8 to 9 month release	24	4	8	C	Incorporation	Polymeric resin-coated prills; 18.5% Urea/ Ammonium, 5.5% Nitrate
Polyon 25-4-12; 8 to 9 month release	25	4	12	C	Incorporation	Polyurethane-coated prills; 22.4% Urea/ Ammonium, 2.6% Nitrate
Nutricote 270; 8 to 9 month release	18	6	8	C	Incorporation	Thermoplastic resin-coated prills 8.6% Ammonium, 9.4% Nitrate

system which uses accumulated heat units. The degree day approach is attractive because the fertilizer applications are synchronized with seedling growth which, of course, is closely controlled by 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 the nutrient uptake is actually occurring. Because of climatic and edaphic variation, each nursery must develop its own degree day system.

Another effective procedure is to schedule nitrogen fertilizer applications in bareroot nurseries based on seedling growth curves. Plots of growth increments show the times when shoot growth generally occurs and so fertilizer applications can be scheduled at regular intervals during this period (Figure 7). This approach ensures that the fertilizer is available during the time of maximum seedling growth rather than later in the year when the fertilizer would he wasted or could adversely affect the onset of dormancy or frost hardiness.

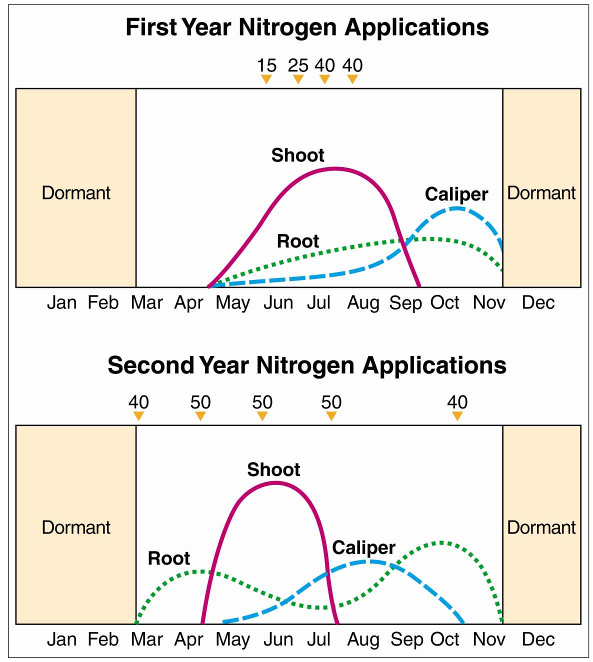

*Figure 7. Nitrogen fertilizer should be scheduled in 4 to 5 applications per season, the majority applied early in the growing season to promote shoot growth. In this example, the fertilizer applications are given as amount of actual nitrogen in pounds per acre (*1 lb/ac = 1.12 kg/ha).

Fertilizers, Application Methods and Rates in Container Nurseries.

With regards to nitrogen fertilizers, there are two options for container nursery managers: 1) incorporate controlled-release fertilizers (CRF) into the growing media prior to sowing, or 2) apply liquid fertilizer through the irrigation system ("fertigation"). With larger containers, it is possible to top-dress with soluble or CRF fertilizers but this is not common in forest and conservation nurseries.

Incorporation of Controlled Release Fertilizers - Some nurseries traditionally mixed a "starter dose" of soluble fertilizer in their growing media but the newest trend is to incorporate controlled release fertilizers. Although Osmocote® and some other products have been around for decades, the newest brands and formulations offer better nutrient release patterns lasting up to 12 to 14 months (Table 4). These longer release formulations are designed to promote some growth in the nursery but also give a boost to seedlings after outplanting. To supplement the incorporated CRF, growers add enough additional nitrogen through fertigation to achieve desired growth rates and seedling quality.

One thing to notice about CRF is that the ammonium to nitrate ratio is different from brand to brand and between formulations of the same brand. Polyon® 25-4-12 contains a much higher percentage of urea/ammonium than nitrate nitrogen compared to Nutricote® 18-6-8, which contains an almost even balance of the nitrogen ions. Likewise, Osmocote High N® contains much more urea/ammonium than nitrate compared to Osmocote Fast Start®, which is much closer to equal proportions (Table 4).

Fertigation with Soluble Fertilizers - Fertigation is a quick, easy, and cheap application method and so most nurseries inject soluble nitrogen fertilizer through the irrigation system. Of course, the rate and uniformity of nitrogen applied to each container is completely dependent on the efficiency of the irrigation system. Regulating the amount of nitrogen fertilizer is used to control seedling growth rate and plant succulence, and container growers typically apply from 50 to 250 ppm nitrogen, depending on species and growth stage. Formulations should generally contain a mixture of ammonium and nitrate, favoring more nitrate during low light conditions in the winter and early spring, and adding more ammonium as light increases. For examples of typical fertigation regimes, see Volume Four of the Container Tree Nursery Manual (9).

Exponential fertilization is a relatively new fertigation technique which applies nitrogen fertilizer at an increasing rate over the growing season. This corresponds more closely to the exponential growth rate of seedlings, providing more nutrient gradually as the crop increases in size. This technique has been advocated by Timmer (14) and is being done operationally in eastern Canada. Although the theory is attractive, exponential fertilization has yet to find widespread use in container nurseries in the rest of the country.

Nutrient Loading.

Some nurseries in Eastern Canada have used high nitrogen fertilizer rates (up to 6X normal rates) to buildup nutrient reserves prior to harvesting. This "nutrient loading" involves forcing foliar nitrogen levels into the luxury consumption range without causing bud break or other detrimental changes in morphology. When combined with exponential fertilization, these exponentially loaded seedlings have exhibited greater growth after outplanting compared to conventionally fertilized stock. This practice is particularly recommended for outplanting sites with severe vegetative competition where rapid height growth is advantageous (11). So far, nutrient loading has only been proven in specific situations and it remains to be seen whether it will achieve widespread use in other outplanting environments.

Effects of Overfertilization.

Over-application of nitrogen fertilizers can create several problems including:

1) Poor shoot-to-root balance **-** High nitrogen fertilization rates, especially with ammonium, can produce excess shoot growth at the expense of root growth (Figure 8A**)**. This can cause problems both in the nursery and after outplanting. Top-heavy seedlings are often culled because customers know that they will be at a disadvantage on the outplanting site.

2) Delayed dormancy or hardiness **-** High levels of nitrogen fertilizer have been shown to prolong tissue succulence, stimulate growth of lammas shoots, and increase the possibility of cold injury in the Fall (Figure 9). Because nitrogen fertilization has such an overriding control on both the seedling growth rate and hardening, it is intuitive to make this association. Several specific research studies are documented in Volumes Four and Six of the Container Tree Nursery Manual (8 & 9).

3) Water pollution **-** It is hard for nursery managers not to be tempted to overfertilize with nitrogen fertilizer, considering the tremendous growth boost that it provides (Figure 8A). After all, fertilizer is still relatively cheap. However, a combination of a rising environmental consciousness and fear of restrictive legislation has made nurseries take another look at their fertilization practices. Plants are only able to uptake and utilize a given amount of nitrogen at a time which is known at their "nitrogen use efficiency". This efficiency has been shown to decrease with increasing fertilization rates (Figure 8B), increasing the pollution potential. For example a study at the Forest Research Greenhouse at

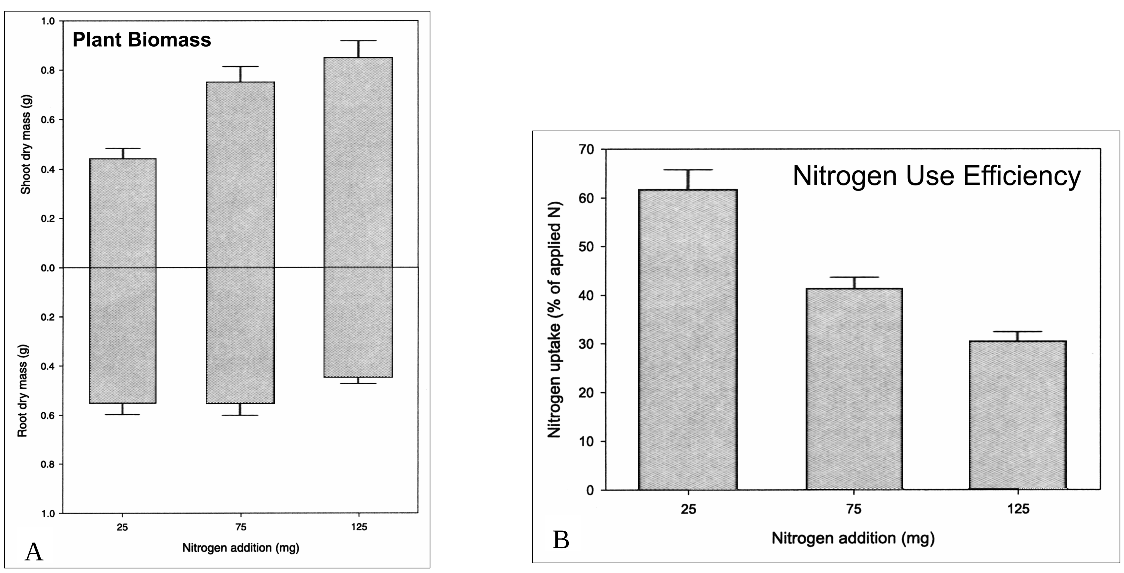

*Figure 8. Increasing nitrogen fertilization stimulated both shoot and root growth of container seedlings of interior spruce (*Picea glauca x engelmannii*) but, at the highest level, root growth was depressed (A). As the nitrogen fertilizer rate increased, the ability of the seedlings to utilize the fertilizer decreased (B) and the potential for nitrogen runoff increased (modified from 13).*

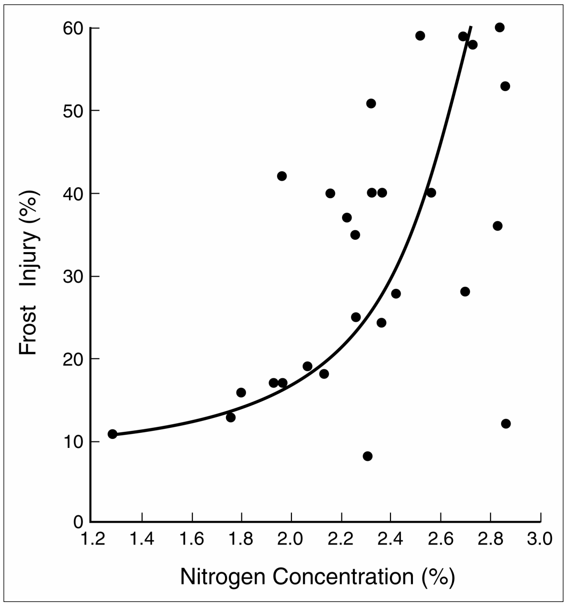

Figure 9. Cold injury was found to increase with foliar nitrogen concentration in these balsam fir transplants (modified from 4).

the University of Idaho showed between 32 and 60% of all nitrogen applied in fertigation was discharged in the wastewater (2).

Nitrates are very mobile in water and can easily escape from nurseries in surface runoff or leach to groundwater. This nitrate pollution can adversely affect human health, especially in babies, and nitrates also pose a significant threat to water quality through eutrophication. Eutrophication refers to the excessive nutrient enrichment of water, which results in nuisance production of algae and other water plants (12).

4) Reduced Outplanting Performance - High nitrogen fertilization has been shown to adversely affect seedling survival and growth after outplanting. The exact reason for this varies but has been attributed to non-hardy stock, seedlings with disproportionately small root systems, and an increased amount of animal damage. Although many of these reports are anecdotal, several research studies have linked high foliar nitrogen levels and poor outplanting performance.

Note that this is apparently in direct conflict with the practice of exponential nutrient loading as discussed earlier. The reasons for this apparent contradiction are unclear but can most likely be related to conditions on the outplanting site. As has been found to be true for fertilization at time of outplanting, nutrient-loaded seedlings have performed best on mesic sites with high levels of vegetative competition (14). The added nutrient boost apparently helps seedlings outgrow the surrounding vegetation and the presence of other vegetation reduces the animal damage. On drier outplanting sites, however, the nutrient-loaded seedlings are more exposed to animals and the higher salts levels in the foliage is thought to actually attract herbivores.

Conclusions and Recommendations - Part 2

Nitrogen is by far the most important mineral nutrient in forest and conservation nurseries but managing nitrogen fertilization has environmental as well as economic effects. Nitrogen deficiency rarely occurs in nurseries due to the high levels of fertilization, and toxicity is not seen because plants can uptake large amounts of nitrogen as luxury consumption. Monitoring nitrogen is primarily done by observing seedling growth rates and through chemical analysis of foliage. In bareroot nurseries, synthetic nitrogen fertilizers are sometimes applied by incorporation or banding but top-dressing is still most common. Injecting soluble fertilizers through the irrigation system is the most widespread technique for applying nitrogen in container nurseries. Some container growers incorporate controlled-release fertilizers into their growing media and supplement it with soluble fertilizers. Because of growing concern about the serious consequences of overfertilization with nitrogen, both bareroot and container growers are monitoring fertilization more closely. The benefits of nutrient loading seedlings on outplanting performance is currently being tested on outplanting sites across the country.

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