Hardening Fertilization and Nutrient Loading of Conifer Seedlings

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Abstract

Continuing to fertilize bareroot and container seedlings during the hardening process (from cessation of height growth until lifting) can improve seedling viability. The process of fertilizing during hardening has many names, but in the last decade a new term, nutrient loading, has come into use. The process of nutrient loading seedlings leads to luxury consumption indicated by foliar nitrogen (N) concentrations > 2.5%. Increasing foliar nutrient concentrations during hardening can result in increased cold hardiness, seedlings with thicker stems, heavier root systems, better root-to-shoot ratios, higher foliar N concentrations and contents, and the potential for better survival and growth on the outplanting site.

Key Words:

Loblolly pine, *Pinus taeda*, slash pine, *Pinus elliottii*, longleaf pine, *Pinus palustris*, irrigation, crop scheduling, bareroot, container seedlings, water management, hardening

Introduction

Nursery managers are most concerned with levels of nitrogen (N) in seedlings because this nutrient fuels seedling growth rate. Traditionally, in bareroot and container nurseries a standard operating procedure is to reduce N applications once target height is achieved (Tinus and McDonald 1979; Duryea 1984; Landis and others 1989). The idea behind this is that seedlings need to be hardened for outplanting, and cessation of shoot growth is necessary for the hardening process to begin. However, reducing N applications while the seedling is still growing results in a "dilution" of N within the plant—the N *concentration* will decline because the N *content* is spread throughout more tissue (see sidebar).

> Seedling N content is usually expressed as a weight, often in milligrams—it is the physical amount of N within the seedling. The N concentration, however, is N content divided by biomass and expressed as a percentage. Both N content and concentration can be determined for particular seedling parts such as needles, buds, stems, or combined together as shoots or roots or even whole seedlings. For nursery stock, foliar N concentration is the most commonly used value.

Realizing that seedling nutrient reserves are important for survival and growth after outplanting, nursery managers can begin to increase seedling nutrient concentrations prior to harvesting. The rationale is that these nutrients can be translocated during the establishment phase until seedling root systems can again provide the necessary nutrient uptake. Such fertilization applications have often been referred to as late-season, post budset, late summer, early fall, or fall fertilization. In the past decade, a new term has come into use: nutrient loading.

Nutrient loading is the practice of applying large doses of fertilizers to seedlings in order to allow luxury consumption of those nutrients (fig. 1). Luxury consumption is, simply, an increase in nutrient concentration above what the seedling can use for growth under optimum conditions. In conifer seedlings, foliar N concentration ranges from about 0.8% to 3.5%, with the optimum range considered to be from 1.5% to 2.5% (Landis and others 1989). Therefore, using my definition, foliar N concentrations > 2.5% are the result of nutrient loading and indicate luxury consumption. Although nutrient loading is usually done just prior to harvesting, Dr VR Timmer advocates using this technique throughout the growing season (see

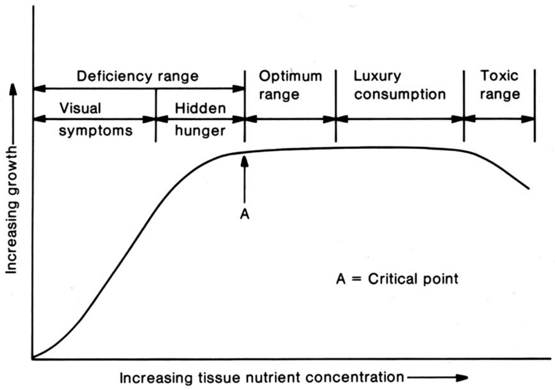

Figure 1. Growth increases with increasing nutrient levels up to a critical point (A), after which, increasing nutrient levels do not result in more growth, but lead to luxury consumption. Nutrient loading is a new term for luxury consumption. Source: Landis and others (1989).

Timmer and Aidelbaum 1996). His trials have been mainly done with Canadian conifer seedlings with determinant growth patterns (Timmer and Munson 1991; Miller and Timmer 1994).

Because of Dr Timmer's prolific publishing on nutrient loading, this phrase is being more commonly used in bareroot and container nurseries. My objective for the remainder of this paper is to review a little of what we know about the interactions of seedling growth, cold hardiness development, and hardening and nutrient loading fertilization of conifers in general, and southern pines in particular.

Nitrogen and Conifer Seedling Cold Hardiness

One justification for reducing N late in the growing season is to stimulate cold hardiness development. Unfortunately, reducing N too much may actually suppress development of cold hardiness (fig. 2). Timmis (1974) found that Douglas-fir (*Pseudotsuga menziesii*) seedlings with low N concentration (0.8%) had a LT_{50} (the temperature at which 50% of the population died) of 9 °F (–13 °C) but those with a higher concentration (1.6%) were much more cold hardy (–22 °F [–30 °C]). Similarly, red spruce (*Picea rubens*) with 2.3% foliar N concentration were as cold hardy as those with only 0.6% N (Klein and others 1989) and in a study with many types of plants, Pellet and others (1981) found that plants with luxury amounts of N hardened as well as those with optimum N and better than those with N deficiency.

Well-fertilized Scots pine (*Pinus sylvestris*) suffered less frost damage than nutrient-deficient seedlings (Rikala and Repo 1997), and Norway spruce (*Picea abies*) seedlings showed similar frost damage despite a range of foliar N concentrations between 2.2% and 3.3% (Floistad 2002). Sugar metabolism, and therefore presumably other seedling physiological processes, were not affected by late season N applications to loblolly pine (*Pinus taeda*) in Georgia (Sung and others 1997). Hansen (1992) found that prolonged fertilization of Japanese larch (*Larix leptolepis*) did not translate into low cold hardiness development. Coastal Douglas-fir seedlings, given an additional 285 lb N/ac (320 kg N/ha) over a 10-week period from mid-September to early November, had the same cold hardiness as nonfertilized seedlings (Birchler and others 2001).

It is important to realize that these fertilization practices were not designed to "push" seedlings to continue height growth late into the season, but rather to maintain or enhance foliar N concentrations. Naturally, we are all aware that conifer seedlings with active height growth are very susceptible to frost injury. Therefore, the difficulty in nutrient loading is balancing N inputs while avoiding bud break or shoot extension.

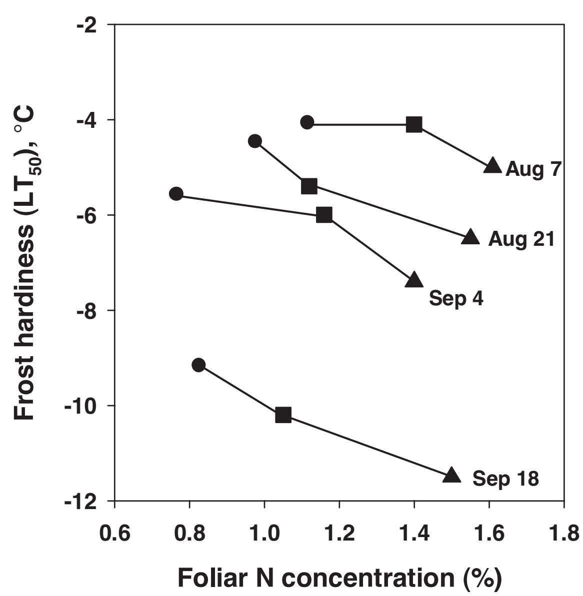

Figure 2. At each sampling date, seedlings receiving the highest rate of fertilizer (triangles) had the highest foliar N concentration and were more cold hardy than seedlings receiving the least amount of fertilizer (circles). Source: Rikala and Repo (1997).

Does Nutrient Loading Apply to Southern Pines?

In reading through the following studies on fall fertilization of southern pine species, note that none of them truly addresses foliar concentrations > 2.5% N. In other words, no nutrient loading occurred. Despite this lack of nutrient loading, benefits to fertilizing in fall were still realized.

Bareroot Slash Pine

Slash pine (*Pinus elliottii*) seedlings grown in Florida with 2 applications of 150 lb/ac (168 kg/ha) ammonium nitrate (51 lb N/ac [57 kg N/ha]) and receiving an additional 150 lb/ac ammonium nitrate in late August were taller and had larger root collar diameter (RCD), root dry weight, and foliar N concentration at lifting in January than seedlings that did not receive supplemental fertilization (Duryea 1990). Seedlings fertilized much later in the season (early November) with 75 lb/ac (84 kg/ha) ammonium nitrate had similar morphology but foliar N concentration and content were higher. After the first year in the field, August-fertilized seedlings were taller than the controls, but this characteristic failed to persist after 3 growing seasons (Duryea 1990).

Subsequently in Florida, Irwin and others (1998) grew seedlings in beds incorporated with 300 lb/ac $10N:10P_2O_5:10K_2O$ (30 lb N/ac [34 kg N/ha)]) and later topdressed with 5 ammonium sulfate applications at various rates during the growing season (mid June to mid August; 143 lb N/ha [160 kg N/ha] total applied). Seedlings were fertilized 1 or 3 times between mid November and mid December with 51 lb N/ac (57 kg N/ha) ammonium nitrate. A month later (mid January) seedlings were lifted. The 1 to 3 additional fertilizations had no effect on RCD, height, bud length, dry weight, root:shoot, premature bud break, days to budbreak, or the number of lateral roots. Foliar N concentration was higher, however, in all fertilizer treatments and N content was higher in the roots, stems, and needles of seedlings given 3 late season fertilizer applications (fig. 3). Foliar N concentration ranged from 1.8% in the 3X fertilizer treatment to 1.4% in the 1X treatment and 1.1% in the control. Not only are none of these treatments nutrient loading, the 1X fertilization and the control are below optimum levels. Seedlings with the higher N concentrations, however, had higher survival, more height growth, and thicker stems after the first field season than control seedlings.

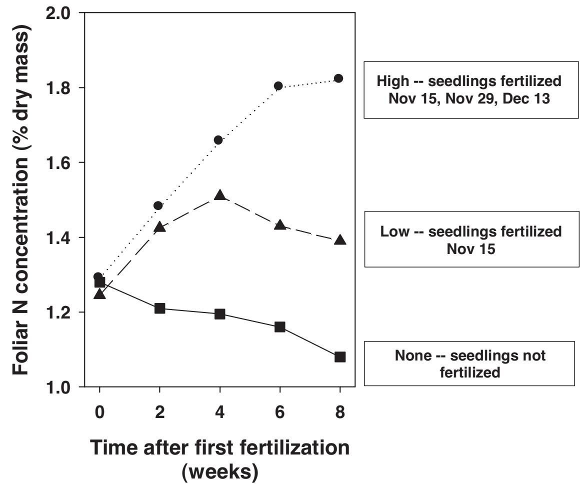

Figure 3. Slash pine seedlings without fertilization (None) continued to grow, but nitrogen (N) content remained the same resulting in the dilution of foliar N from 1.3% to 1.1% over a 2-month interval. Although seedlings in the Low treatment showed an initial increase in foliar N concentration after being fertilized, after 1 month seedling growth again outpaced N uptake and dilution occurred, with concentration dropping from 1.6% to 1.4%. None of these seedlings were nutrient-loaded. Source: Irwin and others (1998).

Bareroot Longleaf Pine

During spring and early summer, longleaf pine (*Pinus palustris*) seedlings were given small periodic applications of ammonium nitrate totaling about 100 lb N/ac (112 kg N/ha). In late October, seedlings were fertilized once with a variety of fertilizers, but always with 150 lb N/ac (168 kg N/ha). Fertilized seedlings had 20% more dry weight with roots and buds accounting for three-fourths of that increase. RCD was 11% greater and subsequently root:shoot was increased. Foliar N content averaged 60% more than nonfertilized controls. The average foliar N concentration of fertilized seedlings was 1.4% versus 1.1% in the control. Again, neither of these treatments were nutrient loading and both resulted in less than optimal foliar N concentration. The result, however, was a trend toward fall fertilization decreasing the time the seedlings spent in the grass stage and better survival after 8 years in the field (Hinesley and Maki 1980).

Bareroot Loblolly Pine

One study with loblolly looked at the effects of foliar N concentration on subsequent seedling performance in the field (Larsen and others 1988). Data from 20 nurseries indicated the average foliar N concentration was only 1.7%, a value at the low end of the optimum range (1.7% to 2.3%) suggested by Fowells and Krauss (1959). This low average value was unfortunate because Larsen and others (1988) found that foliar N content was positively correlated with initial and subsequent field growth, and in fact, was the only variable after 3 years in the field that was significantly correlated with both diameter and volume growth—seedlings with higher N content performed better than those with low content. A modest application of 41 lb N/ac (46 kg N/ha) in mid September in a southern Georgia nursery raised foliar N concentration from 1.2% to 1.6% (Sung and others 1997). The fertilized crop had fewer culls and more first-order lateral roots, thicker stems, and higher dry weights of roots and shoots. Further, fertilization had no effect on sugar metabolism or the pattern of dry matter allocation. Recently, South and Donald (2002) report that applications of N and phosphorus one month before lifting increased foliar N concentrations up from 2.0% to 2.4% which translated into taller seedlings, higher volume production, and better survival 5 years after outplanting. Again, none of these studies involved nutrient-loaded seedlings but show that fall fertilization can increase seedling viability.

Container Seedlings

Although the container industry is relatively young in the South and mostly restricted to longleaf pine (although interest is mounting in growing loblolly and slash in containers too), it is important to recognize that fertilization during hardening can greatly improve seedling viability.

For container nursery managers, more methods are available for applying nutrients: conventional, foliar, and steady-state. Conventional fertilization, applying soluble fertilizers through the irrigation system, is the most straight-forward way of applying nutrients. In Scots pine, late-season fertilization increased RCD and resulted in more cold-hardiness development (Rikala and Repo 1997).

In addition, foliar fertilizers, specially formulated for application onto needles at high rates, can be used to quickly recharge nutrient-depleted seedlings or to add high doses of nutrients for luxury consumption. An advantage of foliar fertilization is that nutrients can be applied to the crop without adding water to the medium, allowing the grower to keep seedling growth under control through water management while still adding nutrients directly to the crop. This has been demonstrated in a crop of ponderosa pine (*Pinus ponderosa*), where Montville and others (1996) used foliar fertilizer during the bud initiation phase to concurrently cease height growth, grow buds, and avoid foliar N concentration dilution—the benefit was a 45% increase in RCD (fig. 4).

The theory of steady-state nutrition is that during production, seedling foliar N concentration is maintained at the same level. Much of the literature on this deals with red pine (*Pinus resinosa*), black

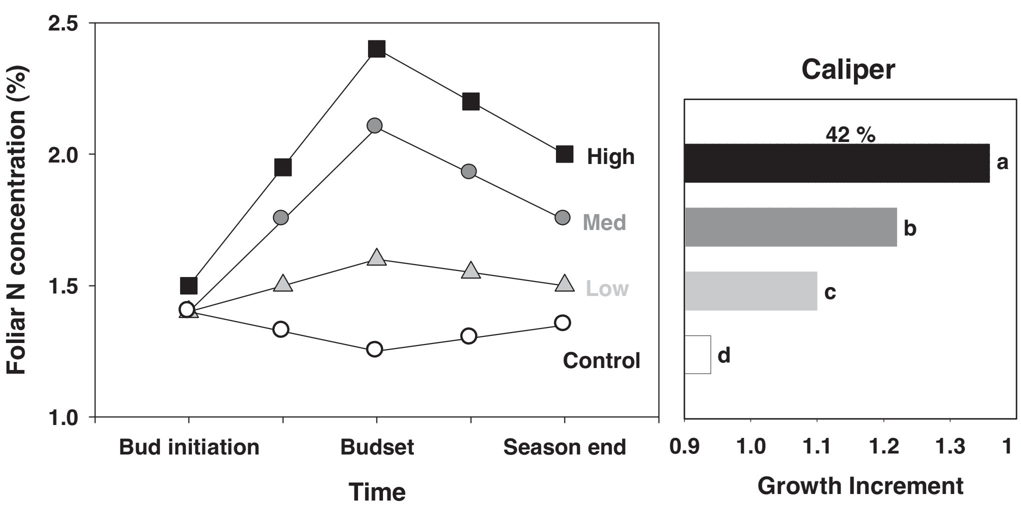

Figure 4. At bud initiation, seedlings received 3 rates of foliar fertilizer with a nonfertilized control. Note the dilution of N in the control seedlings during the bud initiation treatment. Avoiding N dilution increased RCD (caliper) growth—higher rates of fertilizer resulted in higher RCD increments (cm) compared to the control. Source: Montville and others (1996).

spruce (*Picea mariana*), and white spruce (*Picea glauca*) in Canada. The benefits of maintaining optimum or luxury foliar N concentrations (3.0%+), particularly late in the growing season, include increased root:shoot, N accumulation in roots, and height and biomass growth on the outplanting site (Timmer and Miller 1991; Timmer and others 1991; Miller and Timmer 1994; Malik and Timmer 1995; McAlister and Timmer 1998).

Caution—Animal Damage

Animal damage is a problem on many plantations—the literature is full of "animals ate our seedlings" stories. Further, plenty of anecdotal information exists from plantations that animals prefer "normal" nursery seedlings over naturals, presumably because of their higher nutritional value. Unfortunately, I could not find any published information on the correlation between foliar N concentration and herbivory in seedlings. In young plantations, however, fertilization resulted in increased animal damage (Sullivan and Sullivan 1982) and in a plantation where fertilization raised foliar N concentrations 20%, damage increased 6X (Gessel and Orians 1967). I think we should be concerned about nutrient loading because it may exacerbate this problem on some sites.

Summary and Recommendations

The only way to know seedling nutrient concentrations is to measure them—sending in a few foliar samples during the hardening process will enable you to know if your crop has optimum nutrition. As seen from the above discussion, seedling viability can be enhanced by maintaining optimum nutrient concentrations during the hardening process. For southern pines, that probably does not involve true nutrient loading, but adherence to a hardening fertilization program that keeps foliar N concentrations in the optimum zone (1.5% to 2.5%) and regulates height growth through water management. At these optimum nutrient levels, growers may expect normal development of cold hardiness; improved RCD, bud size, and root biomass (and therefore improved root-to-shoot ratio); and enhanced survival and growth after outplanting.

It is important to remember that each nursery has its own idiosyncrasies, and fertilizer regimes develop in response to many variables, including species, seed sources, irrigation system, water quality, nursery elevation and subsequent microclimate, annual days of sunshine, age of greenhouse roofs and subsequent light quality, feedback from customers, anticipated conditions on the planting site, and the experience and philosophy of the nursery manager. Elucidating "the" fertilizer regime that will work universally well in all nurseries is impossible (Dumroese and Wenny 1987). With that in mind, however, I hope you are encouraged to reexamine the use of hardening fertilization toward the goal of improving seedling viability.

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References

Birchler TM, Rose R, Haase DL. 2001. Fall fertilization with nitrogen and potassium: effects on Douglas-fir seedling quality and performance. Western Journal of Applied Forestry 16:71–79.

Dumroese RK, Wenny DL. 1997. Fertilizer regimes for container-grown conifers of the Intermountain West. In: Haase DL, Rose R, coordinators and editors. Symposium proceedings, forest seedling nutrition from the nursery to the field; 1997 Oct 28–29; Corvallis, OR. Corvallis (OR): Oregon State University Nursery Technology Cooperative. p 17–26.

Duryea ML. 1984. Nursery cultural practices: impacts on seedling quality. In: Duryea ML, Landis TD, editors. Forest nursery manual: production of bareroot seedlings. The Hague, Netherlands: Martinus Nijoff/Dr W Junk Publishers. 386 p.

Duryea ML. 1990. Nursery fertilization and top pruning of slash pine seedlings. Southern Journal of Applied Forestry 14:73–76.

Floistad IS. 2002. Effects of excessive nutrient supply and short day treatment on autumn frost hardiness and time of bud break in *Picea abies* seedlings. Scandinavian Journal of Forest Research 17:295–303.

Fowells HA, Krauss RW. 1959. The inorganic nutrition of loblolly pine and Virginia pine with special reference to nitrogen and phosphorus. Forest Science 5:95–112.

Gessel SP, Orians GH. 1967. Rodent damage to fertilized Pacific silver fir in western Washington. Ecology 48:694–697.

Hinesley LE, Maki TE. 1980. Fall fertilization helps longleaf pine nursery stock. Southern Journal of Applied Forestry 4:132–135.

Irwin KM, Duryea ML, Stone EL. 1998. Fall-applied nitrogen improves performance of 1-0 slash pine nursery seedlings after outplanting. Southern Journal of Applied Forestry 22:111–116.

Kormanik PP, Kormanik TL, Sung SS, Zarnoch SJ. 1999. Nitrogen levels, top pruning, and lifting date affect nursery development and early field performance of loblolly pine seedlings. In: Landis TD, Barnett JP, technical coordinators. National proceedings: forest and conservation nursery associations—1998. Asheville (NC): USDA Forest Service Southern Research Station. General Technical Report SRS-25. p 57–62.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. Seedling nutrition and irrigation, Volume 4, The Container Tree Nursery Manual. Washington (DC): USDA Forest Service. Agriculture Handbook 674. 119 p.

Larsen HS, South DB, Boyer JM. 1988. Foliar nitrogen content at lifting correlates with early growth of loblolly pine seedlings from 20 nurseries. Southern Journal of Applied Forestry 12:181–185.

Malik V, Timmer VR. 1995. Interaction of nutrient-loaded black spruce seedlings with neighbouring vegetation in greenhouse environments. Canadian Journal of Forest Research 25:1017–1030.

McAlister JA, Timmer VR. 1998. Nutrient enrichment of white spruce seedlings during nursery culture and initial plantation establishment. Tree Physiology 18:195–202.

Miller BD, Timmer VR. 1994. Steady-state nutrition of *Pinus resinosa* seedlings: response to nutrient loading, irrigation and hardening regimes. Tree Physiology 14:1327–1338.

Montville ME, Wenny DL, Dumroese RK. 1996. Foliar fertilization during bud initiation improves container-grown ponderosa pine seedling viability. Western Journal of Applied Forestry 11:114–119.

Rikala R, Repo T. 1997. The effect of late summer fertilization on the frost hardening of second-year Scots pine seedlings. New Forests 14:33–44.

South DB, Donald DGM. 2002. Effect of nursery conditioning treatments and fall fertilization on survival and early growth of *Pinus taeda* seedlings in Alabama, U.S.A. Canadian Journal of Forest Research 32:1171–1179.

Sullivan TP, Sullivan DS. 1982. Influence of fertilization on feeding attacks to lodgepole pine by snowshoe hares and red squirrels. Forestry Chronicle 58:263–266.

Sung SS, Black CC, Kormanik TL, Zarnoch SJ, Kormanik PP, Counce PA. 1997. Fall nitrogen fertilization and the biology of *Pinus taeda* seedling development. Canadian Journal of Forestry Research 27:1406–1412.

Timmer VR, Miller BD. 1991. Effects of contrasting fertilization and moisture regimes on biomass, nutrients, and water relations of container grown red pine seedlings New Forests 5:335–348.

Timmer VR, Munson AD. 1991. Site-specific growth and nutrient uptake of planted *Picea mariana* in the Ontario Clay Belt. IV. Nitrogen loading response. Canadian Journal of Forest Research 21:1058–1065.

Timmer VR, Armstrong G, Miller BD. 1991. Steady-state nutrient preconditioning and early outplanting performance of containerized black spruce seedlings. Canadian Journal of Forest Research 21:585–594.

Tinus RW, McDonald SE. 1979. How to grow tree seedlings in containers in greenhouses. Fort Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-60. 256 p.

van den Driessche R. 1988. Nursery growth of conifer seedlings using fertilizers of different solubilities, and application time, and their forest growth. Canadian Journal of Forest Research 18:172–180.