# Fall Fertilization Effects on Douglas-fir Seedling Nutrition in the Nursery

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## Introduction

The objective of forest tree nurseries is to produce seedlings that meet specified targets, i.e. those morphological and physiological characteristics that can be quantitatively linked with reforestation success (Rose et al. 1990). With limitations on vegetative control techniques, it is increasingly important to reforest with quality seedlings capable of rapid establishment in the midst of competing vegetation to provide rapid return on investment. Standard grading practices, which measure height and diameter to ensure the seedlings meet specified criteria, are easy to do, but these measurements alone do not fully describe the physiological condition of seedlings and as such are not very useful for predicting outplanting performance in terms of survival and subsequent growth. Physiological characteristics such as seedling water status, mineral nutrition, carbohydrate content, and cold hardiness are more difficult and time consuming to measure, but provide more pertinent physiological information for predicting outplanting performance (Ritchie 1984, Rose et al. 1990).

Seedling mineral nutrition is an important consideration in producing quality seedlings and is commonly addressed through nursery fertilization programs. A survey of 19 Pacific Northwest nurseries reported the average amount of fertilizers applied per hectare each rotation included 224 kg nitrogen, 126 kg phosphorus, 103 kg potassium, 9 kg magnesium, 136 kg sulfur, and 557 kg ground limestone (OSU Nursery Survey in Duryea and Landis 1984). These are typically applied as numerous top dressings during the growing season (van den Driessche 1984) with the objective of enabling the seedlings to attain desired morphological and physiological characteristics while maintaining nutrient levels within specific ranges. In a summary of foliar samples collected in October from 2+0 Douglas-fir *(Psuedotsuga menziesii* Mirb. Franco) grown in PNW nurseries, analyses revealed adequate nutrient levels of 1.8% nitrogen, 0.18% phosphorus, 0.8% potassium, 0.2 % calcium, 0.12% magnesium, 0.18% sulfur, 80 ppm sulfate, 390-1294 ppm manganese, 5.1-7.7 ppm copper, 9-39 ppm boron, and 17-63 ppm zinc (van den Driessche 1984). This conventional regime of repeated and constant nutrient additions applied during the growing season is typical in bareroot nurseries.

Increased seedling nutrient levels may improve seedling cold hardiness (Thompson 1983, Gleason et al. 1990), increase root growth potential

(Simpson 1985, van den Driessche 1988), hasten bud break (Benzian et al. 1974, Thompson 1983, Simpson 1985, van den Driessche 1985, Margolis and Waring 1986), and ultimately affect outplanting performance. Nonconventional nutrient regimes, such as exponential fertilization and fall fertilization, have the objective of producing seedlings with target morphology but with above normal levels of nutrition. Exponential fertilization provides the same quantity of nutrients as conventional regimes but the fertilizer is applied in levels that reflect the growing rate of the seedling. Smaller, more frequent doses gradually increase with the exponential growth of the seedling with the idea of constantly providing sufficient nutrients. The resulting seedling size is similar to conventionally fertilized seedlings, but the nutrient levels are higher (Timmer and Armstrong 1987, Timmer et al. 1991, Miller and Timmer 1994, Timmer and Aidelbaum 1996). This practice, depending on the species and amounts applied, may significantly alter seedling morphology (Miller et al. 1994) which may not be desirable. In contrast, fall fertilization provides additional nutrients late in the season after seedling growth has ceased, buds have set, and dormancy has been induced. As long as environmental conditions permit (i.e. adequate soil moisture and temperature), roots are still growing, and nutrients are available in the rhizosphere, uptake should continue thereby addressing any nutrient deficiencies incurred during the growing season and allowing for luxury uptake (nutrient loading).

Foliar nitrogen concentrations in fall-fertilized Douglas-fir increased 15 to 70% (Simpson 1985, van den Driessche 1985, Margolis and Waring 1986, Brown 1988, van den Driessche 1988) and foliar phosphorus levels increased 11 to 55% (Simpson 1985, van den Driessche 1985, van den Driessche 1988). Changes in potassium concentrations were infrequent, ranging from a 16% increase (Simpson 1985) to a 27% decline (van den Driessche 1988). Increases in seedling nitrogen levels were also reported for Sitka spruce *(Picea sitchensis* (Bong.) Carr.), Norway spruce *(Picea abies* (L.) Karsten), lodgepole pine *(Pines contorta* Dougl.), western hemlock *(Tsuga heterophylla* (Rafn.) Sarg.), grand fir *(Abies grandis* (Dougl.) Lindl.) and longleaf pine *(Pines palustris* Mill.), but potassium levels were largely unaffected (Benzian et al. 1974, Hinesley and Maki 1980). Although micronutrients are as important to seedling physiology and subsequent outplanting performance as the macronutrients, no mention is made in the literature regarding the effects of fall fertilization on micronutrient levels.

The objective of this study is to examine the effect of fall-fertilizer applications on Douglas-fir seedling nutrient dynamics and its relationship to cold hardiness, root growth potential, needle dry weights, bud break timing, and outplanting performance. This report presents the effects of fall fertilization on nutrient uptake and dynamics in the nursery. Future reports will present the effects of fall fertilization on cold hardiness, variable chlorophyll fluorescence, root growth potential, bud break timing, and outplanting performance.

Null hypotheses:

Fall fertilization with nitrogen and potassium does not affect:

1. concentrations and contents of TKN, $NO_3$, P, K, Ca, Mg, Cl or micronutrients
2. nutrient ratios
3. needle dry weights

# Materials and Methods

## Nursery Stock

Two year old (1+1) bareroot Douglas-fir seedlings from a coastal Oregon seed source (M417295 071C12, elev. 1500 ft) were grown under standard nursery cultural practices at the D.L. Phipps State Forestry Nursery located 5 km south of Elkton, OR. Seedlings were sown in March, 1995, lifted, pruned, and transplanted in October, 1995 at a density of approximately 74 seedlings per square meter. After transplanting, but before the initiation of this study, approximately 126 kg N/ha, 8 kg P/ha, 15 kg K/ha, and 27 kg S/ha along with micronutrients were applied over four applications between late March and early June. Seedlings were topmown in July, wrenched in early September, and drought stressed for 2 weeks prior to the initiation of this study to induce bud set and the onset of dormancy. Treatments for this study began on September 19, 1996.

## Fertilizer Applications

The treatments consisted of two types of fertilizers ($NH_4NO_3$+$K_2SO_4$ and $(NH_4)_2SO_4$+KCl ) at four rates (0, 80, 160, 320 kg/ha) of total nitrogen and potassium divided over three application dates (i.e. the first application for the 80 kg/ha rate would be 80/3 or 26.7 kg/ha). Three equal applications were implemented to maximize the duration of the nutrients in the rooting zone since all of the included cations and anions can be readily leached from the soil as a result of the typically high fall and winter precipitation in the Pacific Northwest. Fertilizers were applied on September 19, October 11, and November 1 using a $CO_2$ powered applicator constructed of 1/2 inch PVC tubing. The applicator had six nozzles designed to apply fertilizer between the seedling rows of seedlings as close to the ground as possible. The fertilizers were added to water in a three gallon tank to allow for good dissolution and sufficient quantity for multiple passes by the applicators to ensure uniform application.

## Seedling Sampling

Seedlings were sampled from each treatment plot for nutrient analyses on September 16, October 8, November 1, November 22, 1996 and January 10, 1997. Six to ten seedlings were carefully lifted by shovel from each treatment plot on each date. The seedlings were washed free of soil, placed in coolers, and transported to Oregon State University.

Seedlings were separated into roots and shoots and dried for 72 hours at 70°C. Foliar samples were submitted for total Kjeldahl nitrogen analysis (TKN) and inductively coupled argon plasma analysis (ICP) for the determination of P K, Ca, Mg, Mn, Fe, Cu, B, and Zn; and ion chromatography for the determination of nitrate, phosphate, sulfate, and chloride. A portion of the roots were also submitted for TKN analysis and the remainder placed into a freezer at -20°C to await possible starch analysis. A sample of 100 needles from each treatment replicate were weighed to obtain a unit dry weight for determination of nutrient contents and the construction of vector diagrams (Haase and Rose 1995). Foliar TKN levels were set to 100 and nutrient ratios were determined as a proportion of the TKN level times 100.

## Nursery Soil Analysis

Prior to the first fertilizer application (September 19, 1996) two soil samples were taken from each treatment plot in one of the replications. Using a spade, soil was sampled to a depth of approximately six inches and mixed in a bucket. A composite sample was submitted for analysis at the Central Analytical Laboratory at Oregon State University. Initial ranges were: pH 5.0-5.2, 0.12-0.13% N, 42-66 ppm P 222-293 ppm K, 7.7-9.5 meq Ca, 2.3-2.6 meq Mg, 0.2-0.3 ppm B, 102-120 ppm Fe, 8.8-12.8 ppm Mn, 1.2-1.4 ppm Cu, and 0.74-1.0 ppm Zn.

## Experimental Design and Statistical Analysis

The experimental design was a randomized complete block design with four blocks and a 2x4 factorial (two fertilizer types and four rates). The eight treatments were randomly assigned to a 6 m length of nursery bed on each of four nursery beds (blocks or replications).

Nutrient and dry weight data were analyzed on each harvest date using analysis of variance (ANOVA)to examine the effects of the fertilizer types and rates on needle weights, and nutrient concentrations, contents, and ratios. At each harvest date, Fisher's Protected Least Significant Difference procedure at a 0.05 level of significance was utilized to isolate treatment differences among means.

Needle dry weights, and nutrient concentration and content trends over time were examined using multivariate analysis of variance (MANOVA). Significant multivariate tests based on Wilks' criteria were followed by Fisher's Protected Least Significant Difference at a 0.05 level of significance.

**ANOVA Table:**

| Source | SS | df |
|---|---|---|
| Treatment (A) | SSA | 7 |
| Type | | (1) |
| Rate | | (3) |
| Type x Rate | | (3) |
| Block (B) | SSB | 3 |
| Error | SSE | 21 |
| Total | SST | 31 |

162.03.8366..

The assumptions of normality, linearity, and constant variance were verified by examination of the residuals but no transformations were necessary. Statistical Analysis Software (SAS Institute 1989) was used for all data analysis.

# Results

Fall fertilization with nitrogen and potassium led to significant increases in foliar TKN concentrations and contents and root TKN concentrations. Nitrogen levels changed from September to January and increased with the rate of nitrogen applied. Potassium levels changed slightly over time, but were unaffected by the treatments. The levels of P Ca, Mg, Mn, Fe, Cu, B, and Zn were not affected by fertilization. January nutrient ratios for most of the elements were not drastically changed even though TKN levels increased nearly 30%.

## Foliar Total Kjeldahl Nitrogen

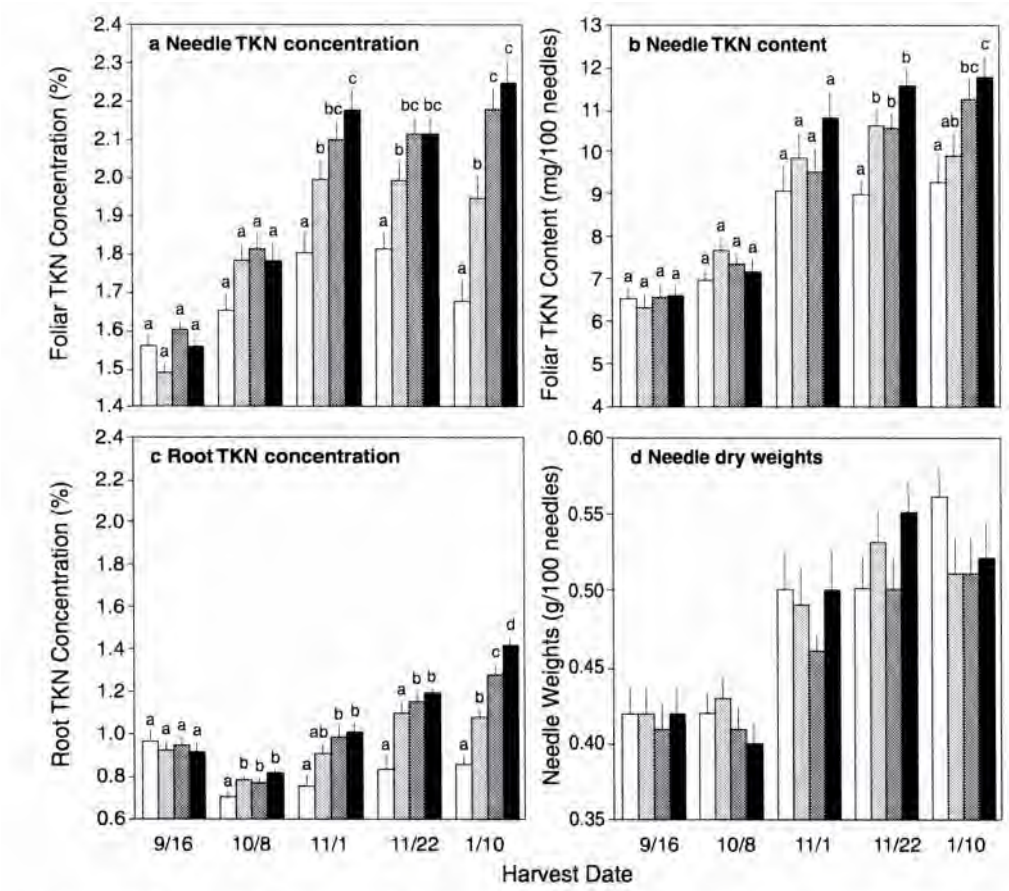


*Figure 1. Foligar TKN concentration and content, root TKN concentration, and needle weight changed over time by fertilizer rate. For TKN concentrations, means followed by different letters within a date are significant at P=0.05.*

Mean foliar TKN concentrations did not differ by fertilizer type. Significant differences as a result of fertilizer rate occurred on November 1 and 22, and January 10 (P=0.0006, 0.0003, 0.0001). Seedlings fertilized with 320 kg N/ha had significantly more foliar TKN (2.17%) than seedlings fertilized with 80 kg N/ha (1.99%) which was significantly greater than the unfertilized seedlings (1.80%, Figure la). These levels remained constant through November 22. On January 10, differences in TKN due to fertilizer rate were even greater (1.67, 1.94, 2.17, 2.24%, respectively). The vector diagram (Figure 2) graphically illustrates the relative differences among the rates on each harvest date. Foliar

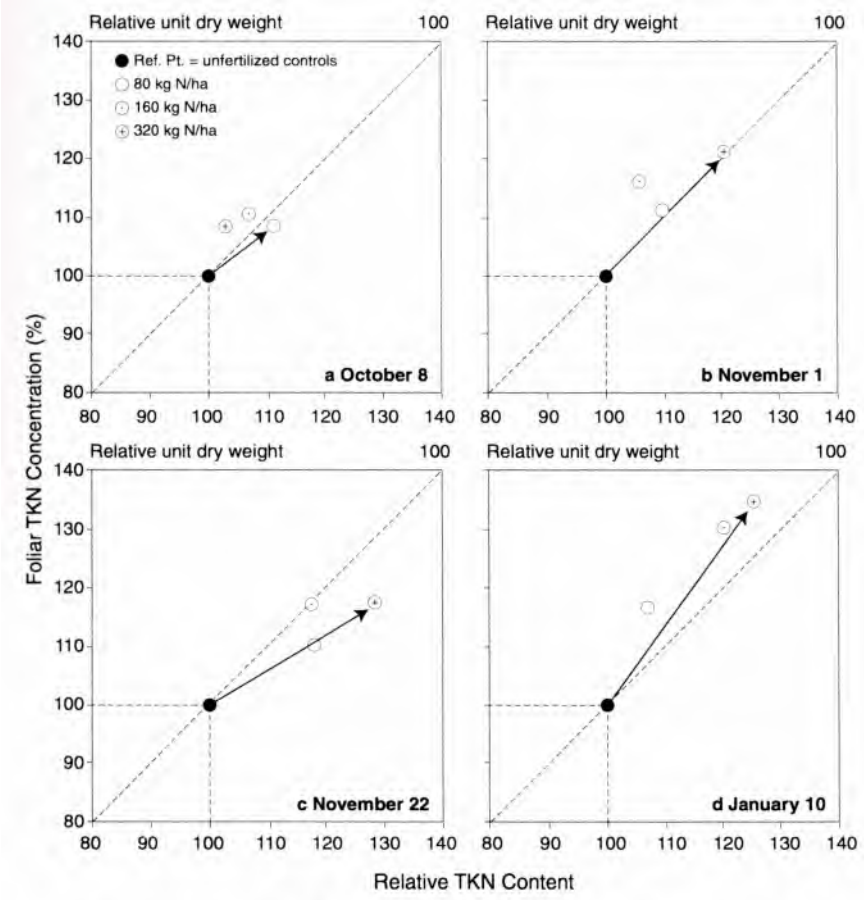


*Figure 2. Shifts in relative TKN levels over time by fertilizer rate. The reference point is the TKN level of the unfertilized control at each respective date set to 100.*

TKN of unfertilized seedlings increased from 1.56 to 1.67% between September and January.

Mean foliar TKN contents significantly differed on November 22 and January 10 (P=0.0009, 0.0224). Fertilized seedlings had significantly more nitrogen (10.6, 10.5, 11.5 mg/100 needles) than unfertilized seedlings (8.9 mg/100 needles) on November 22 (Figure lb). By January 10, the foliar TKN contents of the 160 and 320 kg N/ha treatments were higher (11.2, 11.7 mg/100 needles) than of the unfertilized seedlings (9.3 mg/100 needles). Foliar TKN contents of unfertilized seedlings increased from 6.5 to 9.3 mg/100 needles.

There was a significant rate by time interaction effect on foliar TKN concentrations and contents (P=0.0016, 0.0039). The greatest increases between September and January in foliar TKN concentrations and contents occurred for the 160 and 320 kg N/ha treatment (from approximately 1.60 to 2.20%, and 6.6 to 11.4 mg/100 needles, respectively).

TABLE 1. January 10 harvest date nutrient ratios by fertilizer rate. Results are compared with data from Krueger (1967) and van den Driessche (1984). Means followed by a different letter within a column are significant at P=0.05.

| Rate | | N | P | K | **Ca** | **Mg** | Mn | Fe | **Cu** | B | **Zn*** | **SO4** | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 kg N/ha | | 100 | 10.8b | 51.4b | 23.6c | 7.6c | 1.2b | 1.68b | 0.03b | 0.13 | 0.20b | 11.24 | |
| 80 kg N/ha | | 100 | 9.8b | 47.5b | 20.8b | 6.8b | 1.Oab | 1.67b | 0.03b | 0.13 | 0.20b | 10.84 | |
| 160 kg N/ha | | 100 | 8.1a | 40.7a | 19.Oab | 6.1a | 0.9a | 1.35a | 0.02a | 0.11 | 0.14a | 10.00 | |
| 320 kg N/ha | | 100 | 8.3a | 39.0a | 17.9a | 5.8a | 0.8a | 1.30a | 0.02a | 0.10 | 0.14a | 10.11 | |
| Krueger (low) | a | 100 | 8.2 | 34.2 | 16.8 | 5.5 | 1.28 | 0.59 | 0.03 | 0.01 | 0.18 | | |
| Krueger (high) | b | 100 | 19.0 | 70.4 | 27.4 | 7.1 | 4.30 | 1.12 | 0.07 | 0.04 | 0.26 | | |
| Krueger | c | 100 | 15.7 | 46.1 | 17.3 | 6.6 | 2.24 | 0.43 | 0.03 | 0.04 | 0.18 | | 9.9 |
| van den Driessche | d | 100 | 10.0 | 44.4 | 11.1 | 6.6 | 2.2-7.2 | | .03-.04 | .05-.22 | .09-.63 | 0.44 | 10.0 |

* there was a fertilizer type by fertilizer rate interaction on this date for Zn
a lower range of ratios for fall harvested 2+0 nursery grown Douglas-fir seedlings (Krueger 1967)
b upper range of ratios for fall harvested 2+0 nursery grown Douglas-fir seedlings (Krueger 1967)
c values for 3 to 5 year old forest grown Douglas-fir seedlings (Krueger 1967)
d summary of extrapolated values for October harvested 2+0 Douglas-fir (van den Driessche 1984)

Unfertilized seedlings increased least, from 1.56 to 1.67% and 6.5 to 9.3 mg/100 needles, respectively.

January nutrient ratios were significantly affected by the rate of nitrogen applied. The ratios in Table 1 show that as the rate of nitrogen increased, the ratio decreased in almost all cases. In all instances the unfertilized treatment was significantly different from the 320 kg N/ha rate.

### Root Total Kjeldahl Nitrogen

Mean root TKN levels differed significantly by fertilizer rate on October 8, November 1 and 22, and January 10 (P=0.0065, 0.0081, 0.0016, 0.0001). On October 8, the unfertilized seedlings had less TKN (0.71%) than the fertilized seedlings (0.79, 0.78, 0.82%) (Figure 1c). This difference continued through November 1 and 22. On January 10, differences in TKN due to fertilizer rate were even greater (0.86, 1.08, 1.28, 1.41%, respectively). Root TKN concentrations of unfertilized seedlings declined from 0.97 to 0.86% from September to January.

There was a significant rate by time interaction effect on root TKN concentrations (P=0.0003). Between September and October, root TKN concentrations of seedlings fertilized with 320 kg N/ha decreased the least (from 0.92 to 0.82%) while unfertilized seedlings decreased the most (0.97 to 0.71%). Similarly, between November 22 to January 10 root TKN concentrations of seedlings fertilized with 320 kg N/ha increased the most (from 1.19 to 1.41%) whereas unfertilized seedlings increased least (0.84 to 0.86%).

### Seedling Needle Weights

There were no treatment effects on mean weight per 100 oven dried needles on each harvest date (Figure 1d). Dried needle weights varied considerably which made detecting treatment differences difficult. Mean levels by harvest date significantly increased over time from a mean of 0.42 g/100 needles in September to 0.53 g/100 needles in January (P=0.0001). Interestingly in January, the unfertilized seedlings had the largest needle weights!

## Discussion

These data suggest that Douglas-fir seedlings continued to take up and translocate nitrogen over the course of the fall and winter and that luxury uptake of nitrogen occurred.

September foliar TKN concentrations were slightly lower than those reported by van den Driessche (1984) for 2+0 Douglas-fir in October. By January 10, the 80, 160, and 320 kg N/ha rates led to a 16, 30, and 34% increase in foliar TKN concentrations over the unfertilized seedlings. These increases in foliar TKN concentrations are similar to the approximate 37%

increase reported by Margolis and Waring (1986) after a February harvest and the approximate 40% increase reported by van den Driessche (1985) after a January harvest of fall fertilized seedlings. The slightly lower response observed here may be due to the higher initial TKN levels. The increases in foliar TKN obtained after fall fertilization are on the low end of the increases reported (23 to 78%) after exponential fertilization or nutrient loading containerized white and black spruce seedlings during the growing season (Timmer and Munson 1991, Miller et al. 1994, Malik and Timmer 1995).

By January 10 root TKN concentrations in seedlings fertilized with nitrogen had increased 26, 49, and 64% above levels in unfertilized seedlings. This suggests that luxury uptake was stimulated by the late season fertilizer applications. Although root nitrogen levels are not typically analyzed, these results are similar to those reported for the increase in fine root nitrogen in November (64%) and February (50%) (Margolis and Waring 1986) although the actual values in this study were higher. This study analyzed the total root up to the root collar which suggests a higher concentration of nitrogen may have resulted if less of the stem had been included in the analysis. Nonetheless it appears substantial nitrogen is stored in the roots up to the root collar. It is interesting to note that the largest differences in root TKN levels between rates occurred over two months (and 1000 mm of precipitation) after the final application of fertilizer. This suggests a relatively long nitrogen residual duration in the rhizosphere. This may be due to low nitrification because of lower soil temperatures. Examinations of root concentrations are not often conducted and should be investigated more in the future.

January nutrient ratios in this study were generally within the ranges extrapolated from Krueger (1967). At the high rates of fertilizer application, the ratios of P, K, Ca, and Mg to TKN were at the low end, and Fe at the high end. Cu, Mn, and B were outside of these ranges (Table 1). Thus, even though TKN levels increased from 1.67% to 2.24% by January 10 for the 320 kg N/ha treatment, nutrient ratios were not drastically altered. This suggests that the other nutrients were readily available over time and were taken up nearly proportionately to nitrogen.

Although shoot growth had ceased and there were no treatment effects on mean seedling needle weights over the course of the fall, the fact that needle weights increased with time is evidence of continued biomass accumulation. The largest increase occurred between October 8 and November 1 (Figure 1d) which suggests that needle dry weight accumulation continues late into the fall, after the cessation of active shoot growth, as does caliper and root growth. This increase occurred at the same time foliar TKN levels dropped sharply. The needle weights observed in this study are comparable to those reported by Krueger (1967) for October analyzed 2+0 Douglas-fir seedlings from the same nursery (0.414 g/100 needles).

## Conclusion

This study was successful in stimulating luxury uptake of nitrogen without disturbing the balance of the other nutrients. Fall fertilization with nitrogen is a viable alternative for improving seedling nutrition if applied after growth has ceased and buds have set. However, the benefits of this practice cannot be completely described until the link between fall fertilization with nitrogen and outplanting performance is established.

These results suggest the soil fertility and nutrient availability were adequate at this nursery as evidenced by the increases in foliar nitrogen and other nutrient levels of the unfertilized seedlings over time. Increased uptake of nitrogen without disruption of the nutrient balance is possible through the implementation of a fall fertilization program.

## Literature Cited

Benzian, B., R. M. Brown and S. C. R. Freeman. 1974. Effect of late-season top-dressings of N (and K) applied to conifer transplants in the nursery on their survival and growth on British forest sites. Forestry 47:153-184.

Brown, H. 1988. D.L. Phipps State Forestry Nursery. Unpublished data.

Duryea, M. L. and T. D. Landis. 1984. Development of the *Forest Nursery Manual:* a synthesis of current practices and research. *In* Forest Nursery Manual: Production of Bareroot Seedlings. Duryea, M. L. and T. D. Landis, Eds. The Hague, Martinus Nijhoff/ Dr. W. Junk. pp 3-5.

Gleason, J. F., M. L. Duryea, R. Rose and M. Atkinson. 1990. Nursery and field fertilization of 2+0 ponderosa pine seedlings: the effect on morphology, physiology, and field performance. Canadian Journal of Forest Research 20:1766-1772.

Haase, D. L. and R. Rose. 1995. Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science 41:54-66.

Hinesley, L. and T. E. Maki. 1980. Fall fertilization helps longleaf pine nursery stock. Southern Journal of Applied Forestry 4:132-135.

Malik, V and V R. Timmer. 1995. Interaction of nutrient-loaded black spruce seedlings with neighboring vegetation in greenhouse environments. Canadian Journal of Forest Research 25:1017-1023.

Margolis, H. A. and R. H. Waring. 1986. Carbon and nitrogen allocation pat terns of Douglas-fir seedlings fertilized with nitrogen in autumn. I. Overwinter metabolism. Canadian Journal of Forest Research 16:897-902.

Margolis, H. A. and R. H. Waring. 1986. Carbon and nitrogen allocation pat-terns of Douglas-fir seedlings fertilized with nitrogen in autumn. II. Field performance. Canadian Journal of Forest Research 16:903-909.

Miller, B., V. Timmer, C. Staples and L. Farintosh. 1994. Exponential fertiliza-

tion of white spruce greenhouse transplants at Orono nursery. Nursery Notes. 130. pp.

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

Ritchie, G. A. 1984. Assessing seedling quality. *In* Forest Nursery Manual: Production of Bareroot Seedlings. Duryea, M. L. and T. D. Landis, Eds. The Hague, Marinus Nijhoff/Dr.W. Junk. pp 243-259.

Rose, R., W. C. Carlson and P. Morgan. 1990. The target seedling concept. *In* Proc. Combined Meeting Western Forest Nursery Associations. Rose, R., S. J. Campbell and T. D. Landis, Eds. U.S.D.A. Forest Service, General Technical Report RM-200. pp 1-8.

Simpson, D. G. 1985. Late season fertilizer effects on 2+0 bareroot seedlings. B.C. Ministry of Forests. Unpublished data.

Thompson, B. 1983. Why fall fertilize? *In* Proc. Western Nurseryman's Conference and Western Forestry Nursery Council. U.S.D.A Forest Service.

Timmer, V R. and A. S. Aidelbaum. 1996. Manual for exponential nutrient loading of seedlings to improve outplanting performance on competitive forest sites. Canadian Forest Service. Sault Ste. Marie, Ontario. NODA/ NFP Tech. Rep. TR-25. pp.

Timmer, V. R. and G. Armstrong. 1987. Growth and nutrition of containerized *Pin us resinosa* at exponentially increasing nutrient additions. Canadian Journal of Forest Research 17:644-647.

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

Timmer, V R. and A. D. Munson. 1991. Site-specific growth and nutrition of planted *Picea mariana* in the Ontario Clay Belt. IV Nitrogen loading response. Canadian Journal of Forest Research 21:1058-1065.

Timmer, V R. and E. L. Stone. 1978. Comparative foliar analysis of young balsam fir fertilized with nitrogen, phosphorus, and potassium, and lime. Soil Science Society of America Journal 42:125-130.

van den Driessche, R. 1984. Soil fertility in forest nurseries. *In* Forest Nursery Manual: Production of Bareroot Seedlings. Duryea, M. L. and T. D. Landis, Eds. The Hague, Marinus Nijhoff/ Dr.W. Junk. pp 63-74.

van den Driessche, R. 1985. Late-season fertilization, mineral nutrient reserves, and retranslocation in planted Douglas-fir *(Psuedotsuga menziesii* (Mirb.) Franco) seedlings. Forest Science 31:485-496.

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.