Douglas-fir and Ponderosa Pine Growth and Biochemical Response to Various Multinutrient Fertilizer Treatments

Terry M. Shaw
Intermountain Forest Tree Nutrition Cooperative
Department of Forest Resources, University of Idaho, Moscow, ID

Abstract

Nearly all forest sites in the Inland Northwest are nutrient deficient, usually for nitrogen (N) but sometimes other nutrients as well. Furthermore, a single nutrient limitation cannot always be perceived and there is evidence that shows conifer growth and health may strongly depend on the interaction and availability of several mineral nutrients. In this paper, results are presented from two Intermountain Forest Tree Nutrition Cooperative (IFTNC) studies designed to investigate Inland Northwest Douglas-fir and ponderosa pine seedling nutrition as influenced by various nutrient treatments.

Results from IFTNC studies have shown that N alone or in conjunction with other mineral nutrient treatments significantly altered foliar nutrient levels, growth rates and carbon allocation patterns in Douglas-fir and ponderosa pine seedlings. As expected, growth was significantly higher for seedlings receiving N amendments than for those seedlings receiving low or no N in the treatment mix. Douglas-fir seedling allocation to needles was the same between the high and low N treatments, but allocation to roots increased while allocation to stem decreased under low N supply.

The effects of the N and potassium (K) treatments on Douglas-fir seedling root production of soluble sugar, starch, phenolic and protein-precipitable tannin were observed in this study. Root storage compounds such as starch were reduced in Douglas-fir seedlings receiving the high N treatments, whereas secondary defensive compounds like phenolics and tannins were reduced in plants receiving low K treatments.

Caliper growth in ponderosa pine seedlings grown under different multi-nutrient treatments showed significant differences between application rates, fertilizer release rates, and time of sampling. Seedlings receiving the 15 gram multi-nutrient treatment tended to show higher caliper growth response than seedlings receiving either the 5 or 30 gram treatments. Overall, caliper response after bud set in the fall tended to be higher for those seedlings receiving the medium release rate fertilizer treatment compared to those' receiving the slow or fast release rate fertilizers.

Introduction

Forest fertilization has long been used as a management tool to raise stand productivity (Anderson and Gessel 1966, van den Driessche 1988, Brix 1981, Margolis and Waring 1986). Availability of nutrients can dramatically change biomass and nutrient allocation within seedlings and in turn change the rate of leaf, root or stem production and tree survival (Ingestad and Lund 1979). Tree growth and nutrient uptake responses to fertilizers are complicated and vary constantly with many factors. Nutrients and their interactions are a major determinant of tree growth and survival, successful management of new plantations must consider the nutrient environment.

A number of studies have demonstrated that deficiencies in nutrients result in reduced tree vigor and increased susceptibility to disease (Stakman and Harrar 1957, Matson and Waring 1984, Entry et al. 1991a) as well as to some insects (Mattson 1980, Joseph et al. 1993, Mika and Moore 1994). Plants growing in suboptimal nutrient conditions become stressed and may alter the production of chemical defenses (White 1984, Waring and Pitman 1985, Bryant et al. 1987). Nitrogen nutrition has been a main focus in many nutrient stress/defense chemical studies (Larsson et al. 1986, Entry 1991b). However, few studies have been conducted that address seedling growth and defense chemical relationships to other mineral nutrients such as potassium.

IFTNC Background

In 1980, a group of forestry organizations formed the Intermountain Forest 'free Nutrition Cooperative (IFTNC) to study forest tree nutrition in the Inland Northwest region. Initial efforts were concentrated on studying the effects of N fertilization on growth and survival of Rocky Mountain Douglas-fir *(Pseudotsuga menziesii* var. *glauca* (Mirb.) Franco). Initial results showed that N fertilization increased tree growth (Moore et al. 1991). However, the initial results also indicated that mineral nutrient factors other than N might also limit tree response and survival. Upon investigation of all macro and micro foliar nutrient concentrations only K was present in levels thought to limit tree growth (Mika and Moore 1991b). Furthermore, evidence showed that low K levels, either naturally occurring or induced by additions of N, were related to poor N fertilizer response and high incidence of mortality (Mika and Moore 1991b).

Results from Entry et al. (1991b) may explain the physiological basis for the IFTNC results. Entry et al. (1991b) conducted a nutrition/root disease study in thinned and/or fertilized second-growth stands of Rocky Mountain Douglas-fir located in the Inland Northwest. Entry's investigation involved some of the same stands studied by the IFTNC cooperative. Results from Entry's study found significant changes in growth, root bark chemistry and incidence of infection of *Armillaria ostoyae* associated with N fertilizer amendment.

Results from further IFTNC investigations (Moore et al. 1994, IFTNC 1994, 1996) into N, K and other mineral nutrient treatments have consistently demonstrated that nutrient deficiencies result in reduced tree vigor and altered tree chemistry. Further investigations into the effects of mineral nutrition on tree growth and tree chemistry are now being undertaken.

Results from two IFTNC studies are presented in this paper. The first contains the final results from a three year nursery study on Douglas-fir seedlings under various N and K treatments, while the second includes first year growth effects from an ongoing ponderosa pine controlled-release fertilizer field study.

Douglas-fir Seedling Response Under Various N and K Treatments

In general, few studies, if any, have been conducted that have specifically addressed Douglas-fir seedling growth and development under high (luxury) and low (stressed) N and K treatments. However, evidence from several IFTNC Douglas-fir fertilization field studies (Mika and Moore 1991b, Moore et al. 1994) have shown evidence that low K levels, either naturally occurring or induced by additions of N, were related to growth response and the production of root defense chemistry. To further investigate the role of N and K nutrition, Douglas-fir seedlings were grown in a nursery shadehouse environment designed to meet two main objectives: 1) to determine the effects of N and K nutrition on Douglas-fir foliar nutrient concentrations, plant growth and carbon allocation patterns; and 2) to determine the effects of N and K nutrition on Douglas-fir root storage and chemical composition. Table 1 shows the nutrient treatments under which the Douglas-fir seedlings were grown.

Table 1. Nutrient treatments under which Douglas-fir seedlings were grown: low N low K (LNLK), low N and high K (LNHK), high N and low K (HNLK), high N and High K (HNHK). Numbers represent percentage of the solution optimal concentrations.

Year	Treatments*	N	K
1 and 3	LNLK	10	10
	LNHK	10	100
	HNLK	100	10
	HNHK	100	100
2	LNLK	25	10
	LNHK	25	100
	HNLK	100	10
	HNHK	100	100

*Nutrient solution used to supply nutrients to the Douglas-fir seedlings was adapted from Ingestad and Lund (1979) and was considered nutritionally adequate in every respect.

After three growing seasons in a shadehouse environment, the nutrient treatments significantly affected growth and dry matter allocation among the needles, stems and roots of Douglas-fir seedlings. Seedlings receiving either high N treatment had higher total growth and stem caliper (Table 2). Final measurements indicated that means of total dry weights and stem calipers of plants receiving the high N treatments were 216% and 84% higher than those plants receiving the low N treatments, respectively. Dry matter allocation to the roots, stems and needles was also significantly different by treatment, with seedlings receiving the low N treatments allocating significantly ($p < 0.05$) more carbon to root dry matter than those receiving the high N treatments, with 48% and 38% of total dry weight allocated to roots, respectively (Figure 1). The higher allocation of carbon to root dry matter for seedlings receiving the low N treatments was complemented by a significant ($p < 0.05$) increase in stem dry weight of seedlings receiving the high N treatments (Figure 1). To determine if the dry matter allocation patterns were due to the treatments or ontogenetic growth (Cannell 1976), a sub-sample of seedlings the same size was taken from each treatment. Results from this sub-sample showed that the dry matter stem, needle and root allocation patterns matched the allocation patterns from the entire population. Seedling growth and carbon allocation between the stems, roots and needles showed little effect from the K treatments.

Table 2. Mean total dry weights and stem calipers of Douglas-fir seedlings after three years of growth under different nutrient regimes. Treatments are the same as in Table 1.

Treatment	Total Dry Weight (g)	Stem Caliper (mm)
LNLK	19.30 a	7.39 a
LNHK	17.78 a	6.78 a
HNLK	62.22 b	13.16 b
HNHK	55.14 b	12.87 b

Note: Within each column, values followed by the same letter are similar at the $p < 0.05$ level.

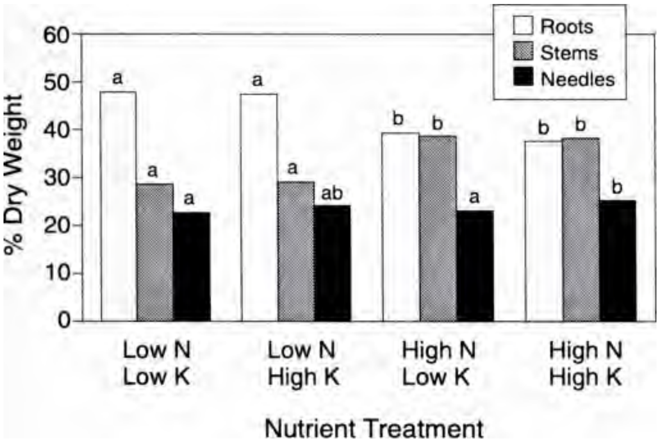

Figure 1. Dry matter allocation to the roots, stems and needles differed significantly by treatment.

A tree's ability to resist a particular kind of stress can be assessed by evaluating how easily it can mobilize carbohydrate reserves near the points of potential need (Waring and Schlesinger 1985). Also, competition for resources may affect the levels of storage carbohydrates in various tissues (Waring and Schlesinger 1985). Concentrations of root storage and defensive compounds such as sugar, starch, phenolics and protein-precipitable tannins in this study's Douglas-fir seedlings were significantly higher at the root collar sample than in the root tip area (Table 3). Furthermore, tree root storage and defensive compound ratios may influence a plant's ability to resist attack from disease and insects. For instance, Entry et al. (1991b) found a strong correlation of incidence of infection and phenolic to sugar ratios. Root collar phenolic to sugar ratios (P:S) in this study were higher than in the root tips, especially in the plants receiving the HNLK treatment, with the P:S ratio more than twofold lower in the root tips than the root collar (Table 3). Although sugar, starch, phenol and tannin concentrations were substantially higher in the root collar than in the root tip, the results show similar root chemistry trends by treatment. Observations from the two sampling locations were highly correlated with correlation coefficients for sugar of r = 0.8476, starch r = 0.7872, phenol r = 0.9296 and tannin r = 0.8936.

In this study, root tip starch concentrations were significantly higher (35%) under the low-N treatments, whereas sugar concentrations were lower for those plants receiving the same treatments. Seedlings receiving the high N-low K treatment had significantly lower concentrations of phenolics and protein precipitable tannins and lower ratios of defensive compounds to carbohydrates than seedlings receiving the high K treatments. This study shows that N and K imbalances led to secondary product imbalances, which may decrease resistance to disease.

Table 3. Root collar and root tip soluble sugar, starch, phenolics and protein precipitable tannin values collected from Douglas-fir seedlings. Treatments are the same as in Table 1.

Tissue/ Treatment	Sugar	Starch	Phenolics	Protein-precipitable tannins	Phenolic/ sugar ratio
	——% Dry Weight——				
Root Collar					
LNLK	9.45 a	17.81 a	10.99 c	5.94 c	1.19 b
LNHK	8.61 a	16.62 a	11.75 bc	6.33 c	1.39 ab
HNLK	10.39 a	14.28 b	14.28 ab	9.13 b	1.35 b
HNHK	10.11 a	13.28 b	15.48 a	11.22 a	1.56 a
Root Tip					
LNLK	4.04 a	12.12 a	2.44 bc	1.72 b	0.66 ab
LNHK	3.72 a	12.12 a	3.15 ab	2.08 ab	0.87 a
HNLK	4.26 a	8.59 b	2.34 c	1.20 c	0.57 b
HNHK	4.42 a	9.32 b	3.35 a	2.41 a	0.90 a

Note: Within each column, values followed by the same letter are not significantly different at $P \leq 0.10$.

Ponderosa Pine Under Various Controlled-Release Multinutrient Fertilizers

Choosing a fertilizer form to minimize fertilizer loss while maximizing tree uptake in proportions to the tree's requirements is complicated with varying site factors. Considering that most site factors contributing to loss of fertilizer in soils are directly related to rapid dissolution and hydrolysis. Decisions must be made regarding the source, the amount applied, and the application time. This study considered the impacts on tree growth from different fertilizer release rates and application rates of several kinds of fertilizers. The objectives of this study are: 1) to determine the optimal rate of a complete fertilizer for establishment and early growth; and 2) to evaluate the effects of different nutrient release characteristics. Table 4 lists treatment levels, release rates and application rates used for the multi-nutrient fertilizers.

At the end of the first growing season (after bud set) there were significant differences in caliper growth between the fertilizer treatments and the control. By late August, ponderosa pine seedlings receiving the 15-10-12 fast release treatment showed all three application rates (5, 15, and 30 g/seedling) having significantly higher caliper growth than the control. Significant August caliper response was also shown for seedlings receiving the 16-08-12 medium release treatment at the 5 and 15 g/seedling application rates and 15 and 30

Table 4. Treatment controlled-release and application rate categories under which ponderosa pine seedlings were grown in the field.

Treatment Levels	Release Rates	Application Rates g/seedling
15-10-12	Fast	5
16-08-12	Medium	5
15-08-11	Slow	5
14-07-10	Fast External	5
15-10-12	Fast	15
16-08-12	Medium	15
15-08-11	Slow	15
14-07-10	Fast External	15
15-10-12	Fast	30
16-08-12	Medium	30
15-08-11	Slow	30
14-07-10	Fast External	30

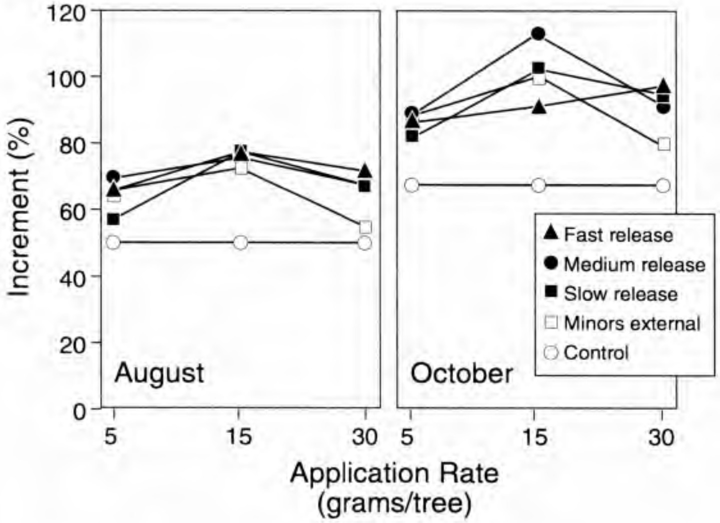

Figure 2. Caliper response to fertilizer type and release rate.

g/seedling application rates for the 15-08-11 slow release treatment, respectively. Only the 5 g/seedling rate of seedlings receiving the 14-07-10 fast external release treatment showed significant caliper response. Seedlings at the 15 g/seedling rate of the 15-10-11 fast release treatment showed the highest response for all treatments in August (Figure 2). Overall, results from this study have shown that differences in caliper growth were a function of release rates and application levels.

By late October, all fertilizer treatments were significantly higher than the controls. October caliper response tended to be highest at the 15 g/seedling application rate, except for those seedlings receiving the 15-10-12 fast release treatment where response tended to increase at a linear rate with application rate. The highest caliper growth in October was for those seedlings receiving the 16-08-12 medium release treatment at the 15 g/seedling application rate (Figure 2).

New IFTNC Seedling Research

In 1995, observations from IFTNC studies suggested a link between forest health and existing bed rock. Forest stand mortality tended to be higher on certain rock types with poor K status. In order to better understand and evaluate this phenomenon, and continue the ongoing evaluation of growth response to fertilization, a study focusing on rock types and forest health was developed. In 1996 cooperative members of the IFTNC steering committee directed IFTNC staff to establish 12 seedling research trials with the main objective to establish experimental areas which will study the effects of mineral nutrition on tree health and vigor within seedling establishment stands on different mineralogy ("good and bad") of underlying rock.

A randomized block design with two replicates of two species (Douglas-fir, ponderosa pine) and six slow release fertilizer treatment combinations was used. Table 5 shows the slow release fertilizer treatments. In addition, site selection consisted of paired geologic rock types that appear to have "good or bad" influences on tree growth and development. Table 6 shows the six paired geologic rock type sites selected.

Table 5. IFTNC Seedling Establishment / Rock Nutrition Study slow release fertilizer treatments.

Treatments	Product*	Analysis	Rate g / tree	Product g / tree
Control	n/a	n/a	n/a	n/a
N	Osmocote - Urea	39-0-0	16.0 N	41.0
N+K+S	Osmocote - Urea	39-0-0	16.0 N	41.0
	Osmocote - K_2SO_4	0-0-44-18	12.0 K	27.2
			4.8 S	
N+S	Osmocote - Urea	39-0-0	12.4 N	31.8
	Osmocote - $(NH_4)_2SO_4$	18-0-0-20	3.6 N	24.0
			4.8 S	
K+S	Osmocote - K_2SO_4	0-0-44-18	12.0 K	27.2
			4.8 S	
Balanced	Osmocote - Urea	39-0-0	6.7 N	17.1
	Osmocote - K_2SO_4	0-0-44-18	5.8 K	13.2
			2.37 S	
	Osmocote - $(NH_4)_2SO_4$	18-0-0-20	1.1 N	6.0
			1.2	
	Osmocote 160812	16-08-12	8.3 N	51.7
	+ minors		4.1 P	
			6.2 K	
		1.2	0.61 Mg	
		2.4	1.24 S	
		0.02	0.01 B	
		0.05	0.03 Cu	
		0.5	0.26 Fe	
		0.07	0.04 Mn	
		0.02	0.01 Mo	

*Slow release fertilizers (Osmocote®) with a 9 month release rate will be used as the fertilizer source and will be supplied by the Scotts Company.

Table 6. Selected rock types by region and ownership to be used for IFTNC Seedling Establishment / Rock Nutrition Study.

Region	Ownership	Rock Type # 1	Rock Type #2
N. Idaho	Potlatch	Metasedimentary	Basalt
C. Idaho	Boise Cascade	Granite	Basalt
N.E. Washington	Wash. DNR	Metasedimentary	Granite
C. Washington	Boise Cascade	Sandstone	Basalt
S.C. Washington	Champion	Basalt	Andesite
N.E. Oregon	Boise Cascade	Basalt	Andesite

Conclusions

Growth and development of plants obviously depends upon the environment. Nutrient deficiencies and imbalances result in reduced tree growth and differences in carbon allocation to storage and secondary compounds. IFTNC studies have shown that N and K imbalances resulted in decreased growth and changes in storage and secondary compounds. High and low N treatments caused clear growth and carbon allocation differences. In addition, N nutrition influenced levels of root storage compounds. K supply had little if any effect on growth rates or carbon allocation to stems, roots or needles. K shortages, however, reduced production of plant defensive compounds. These preliminary results indicate that it may be possible to grow plants with optimal growth and allocation patterns while controlling different root chemical properties.

Deficient and imbalanced nutrition are natural and common in forest stands. However, forest practices may augment nutrient imbalances and deficiencies in forest stands by removal or redistribution of substantial amounts of biomass. Forest managers should consider the nutritional potential of a site as a significant factor in making silvicultural decisions. Studies have shown that forest sites lack sufficient mineral nutrients to express maximum tree growth and suvival. Higher seedling productivity and survival may be achieved if improved and balanced mineral nutrition can be used to regulate growth and allocation of resources to storage and secondary compounds.

Literature Cited

Anderson, H.W. and S.P. Gessel. 1966. Effects of nursery fertilization on outplanted Douglas-fir. J. For., 64:109-112.

Brix, H., 1981. Effects of nitrogen fertilizer source and application rates on foliar nitrogen concentration, photosynthesis, and growth of Douglas-fir. Can. J. For. Res., 11:775-780.

Bryant, J. R, E.S. Chapin, P.B. Reichardt, and J.P. Clausen. 1987. Response of winter chemical defense in Alaska paper birch and green alder to manipulation of plant carbon/nutrient balance. Oecologia, 72:510-514.

Cannel, G.R. and S.C. Wilett. 1976. Shoot growth phenology, dry matter distribution and root:shoot ratios of provenances of *Populus trichocarpa, Picea sitchensis* and *Pinus contorta* growing in Scotland. Silvae Genet., 25:49-59.

Entry, J.A., K. Cromack Jr., E. Hansen, and R.H. Waring. 1991a. Response of western coniferous seedlings to infection by *Armillaria ostoyae* under limited light and nitrogen. Phyto., 81:89-94.

Entry, J.A., K. Cromack Jr., R.G. Kelsey, and N.E. Martin. 1991b. Response of Douglas-fir to infection by *Armillaria ostoyae* after thinning or thinning plus fertilization. Phyto., 81:682-689.

IFTNC. 1994. Two-year basal area response to nitrogen, sulfur and potassium fertilization on mixed conifer stands in northeast Oregon and southeast

Washington. IFTNC internal document. 14 p.

IFTNC. 1996. Two-year growth response to multi-nutrient fertilizer application on Boise Cascade Lands in northeast Oregon. IFTNC internal document.15 p.

Ingestad, T. and A.-B. Lund. 1979. Nitrogen stress in birch seedlings. 1. Growth technique and growth. Physiol. Plant., 45:137-148.

Joseph G., R.G. Kelsey, A.F. Moldeke, J.C. Miller, R.E. Berry, and J.G. Wernz. 1993. Effects of nitrogen and Douglas-fir allelochemicals on development of the gypsy moth, *Lymantria dispar.* J. of Chem. Ecol., 19:1245-1263.

Larsson, S., A. Wiren, L. Lundgren, and T. Ericson. 1986. Effects of light and nutrients stress on leaf phenolic chemistry in *Salix dasyclados* and susceptibility to *Galerucella lineola (Coleoptera).* Oikos, 47:205-210.

Margolis, H.A. and Waring, R.H. 1986. Carbon and nitrogen allocation patterns of Douglas-fir seedlings fertilized with nitrogen in autumn. Can. J. For. Res., 16:903-909.

Mattson, W.J., Jr. 1980. Herbivory in relation to plant nitrogen content. Annual Review of Ecology and Systematics, 11:119-161.

Matson, P, and R. H. Waring. 1984. Effects of nutrients and light limitations on mountain hemlock: susceptibility to laminated root rot. Ecology, 65:1517-1524.

Mika PG., and J.A. Moore. 1991a. Intermountain Forest Tree Nutrition Cooperative. Supplemental Report No. 1, 218 p.

Mika, PG., and J.A. Moore. 1991b. Foliar potassium status explains Douglas-fir response to nitrogen fertilization in the inland northwest, USA. Water, Air, and Soil Pollution, 54:477-491.

Moore, J.A., PG. Mika, and J.L. VanderPloeg. 1991. Nitrogen fertilizer response of Rocky Mountain Douglas-fir by geographic area across the inland northwest. West. J. Appl. For. 6(4):94-98.

Moore, J.A., PG. Mika, J.W. Schwandt, and T.M. Shaw. 1994. Nutrition and Forest Health. In: Symposium proceedings: Interior cedar-hemlock-white pine forests: ecology and management. Spokane, WA. Washington State University Coop. Ext., Pullman. eds. D.A. Baumgartner, J.E. Lotan, J.R. Tonn, pp. 173-176.

Stakman, E.C. and J.G. Harrar. 1957. Principles of plant pathology. Ronald, New York, NewYork, USA.

van den Driessche, R. 1988. Nursery growth of conifer seedlings using fertilizers of different solubilities and application time, and their forest growth. Can. J. For. Res., 18:172-180.

Waring, R.H. and G.B. Pitman. 1985. Modifying lodgepole pine stands to change susceptibility to mountain pine beetle. Ecology, 66:889-897.

Waring, R.H., and W.H. Schlesinger. 1985. Forest Ecosystems. Academic Press, Harcourt Brace, Jovanovich, 340 p.

White, T.C.R. 1984. The abundance of invertebrate herbivores in relation to the availability of nitrogen in stressed food plants, Oecologia, 63:90-105.