Two-Year Growth Response of Douglas-fir and Ponderosa Pine Seedlings to Boron and Multi-Nutrient Fertilization in Northeast Oregon

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SUMMARY

The two-year growth effects for Douglas-fir and ponderosa pine seedlings receiving boron and/or multi-nutrient fertilizer treatments were evaluated on sites with two contrasting parent materials, basalt and andesite, in northeast Oregon. In general, the overall growth effect of fertilization was low and varied by treatment, species and site. In most cases, when boron was applied alone, response was low or antagonistic for both species. Boron in combination with other nutrients did not consistently show higher responses over treatments without B in the mix. However, ponderosa pine at the Noregaard site did show higher response when B was in the fertilizer treatment. Significant ($p \leq 0.10$) two-year response was shown for ponderosa pine at Noregaard with 22% and 36% increase in volume growth for the N+B and multi-nutrient with B treatments, respectively. Overall, trees did have better growth response to fertilization at the Noregaard (good rock) basalt site than at the Glass Hill (bad rock) andesite site. The varied and unusually low growth response may be attributed to confounding effects caused by repeated fertilization treatments over the duration of this study.

INTRODUCTION

A continuous supply of boron is important for plant growth. Boron deficiencies result in reduced height growth, top die back and trees with a "brush-like" appearance. Low to marginal foliar and soil boron deficiencies have been well documented throughout the Inland Northwest and British Columbia (Mahler and McDole 1981, Wikner 1983, Stone 1990, Brockley 1996, Shaw et al. 2001, Xiao et al. 2003, Blevins et al. 2005). Boron deficiencies seem to relate to soil organic matter content and conditions and to the rock type underlying the soils of the forest stands.

The original objective of the seedling establishment study was to determine the effects of mineral nutrition on tree health and vigor within seedling establishment plantations that had different mineralogy, namely "good and bad" underlying rocks. The study sites received two fertilizer applications, one in 1998 (sub-surface slow release fertilizer) and one in 1999 (surface spot broadcast commercial fertilizer). Foliar nutrient results suggested that boron, among other micronutrients, might have been limiting even after micronutrient fertilization. To analyze and isolate the effect of higher boron as well as other micronutrient rates on tree growth response of Douglas-fir and ponderosa pine seedlings, a third experiment was superimposed over two of the original seedling establishment sites located in northeast Oregon. The third seedling establishment experiment involves two different rock types with several treatments that involve various combinations of boron with nitrogen and other micronutrient fertilizer blends.

One-year stem growth (Xiao et al. 2004) and foliar nutrient (Xiao et al. 2005) response of Douglas-fir and ponderosa pine seedlings to the different fertilization treatments was reported. This report will provide an evaluation of 2-year growth response as influenced by the fertilizer treatments, sites and rock types.

METHODS

Site Characteristics

The two sites are located north of the town of Wallowa, (Noregaard -TWN 3N, RGN 41E, SEC 8) and southwest of the city of La Grande, (Glass Hill - TWN 4N, RGN 38E, SEC 28) in northeast Oregon. The stands were initially established and fertilized in 1998 and were then re-fertilized in 1999 and 2003. The underlying parent materials are basalt ("good rock") at Noregaard and andesite ("bad rock") at Glass Hill. Soils are characterized by deep ash/loess at Noregaard and by shallow loess/ash at Glass Hill. The vegetation series for both sites is grand fir.

Plot Establishment

The two sites were established on paired lithology types in northeast Oregon in the spring of 1998. The original experiment consisted of a randomized block design with two replicates of each species and each treatment combination, requiring a total of 24 plots (2 reps x 2 species x 6 treatments). In addition, the original plot design was made of a central block (7 x 7) of 49 trees surrounded by two rows of buffer seedlings, all of which received a treatment.

The 2003 boron experimental design split each of the 24 plots into four equal subplots for a total of 96 subplots. A buffer row of trees was used to bisect each of the plots and to serve as a buffer between subplots. Under the new design, the original central block of 49 trees per plot was split into four subplots with 9 trees each. Figure 1 shows the installation design.

Treatments

Each of the subplots received one of the six treatments listed in Table 1. A total of four treatments per plot were randomly assigned in the field. Treatments 1, 2 and 4 are common in all plots while treatments 3, 5 and 6 alternate in the treatment design. Some plots were dropped from the study due to an insufficient tree numbers and the residual effects of previous treatments. A treatment matrix design by block and plot is presented in Table 2.

Table 1. Treatments for the 2003 boron re-treatment study in northeast Oregon.

TREATMENT		NUTRIENT	PRODUCT	COMMERCIAL 2003 RATE LBS/ACRE
1	**Control**	-	-	-
2	**Boron Only**	B	Boron FG	3
3	**Nitrogen Only**	N	Urea	50
4	**Nitrogen + Boron**	N B	Urea Boron FG	50 3
5	**Multi-nutrient with Boron**	N K S B Cu Zn Fe	Ammonium Sulfate Potassium Chloride Ammonium Sulfate Boron FG Copper Sulfate Zn Sulfate Fe Chelate	50 200 50 3 10 10 10
6	**Multi-nutrient without Boron**	N K S Cu Zn Fe	Ammonium Sulfate Potassium Chloride Ammonium Sulfate Copper Sulfate Zn Sulfate Fe Chelate	50 200 50 10 10 10

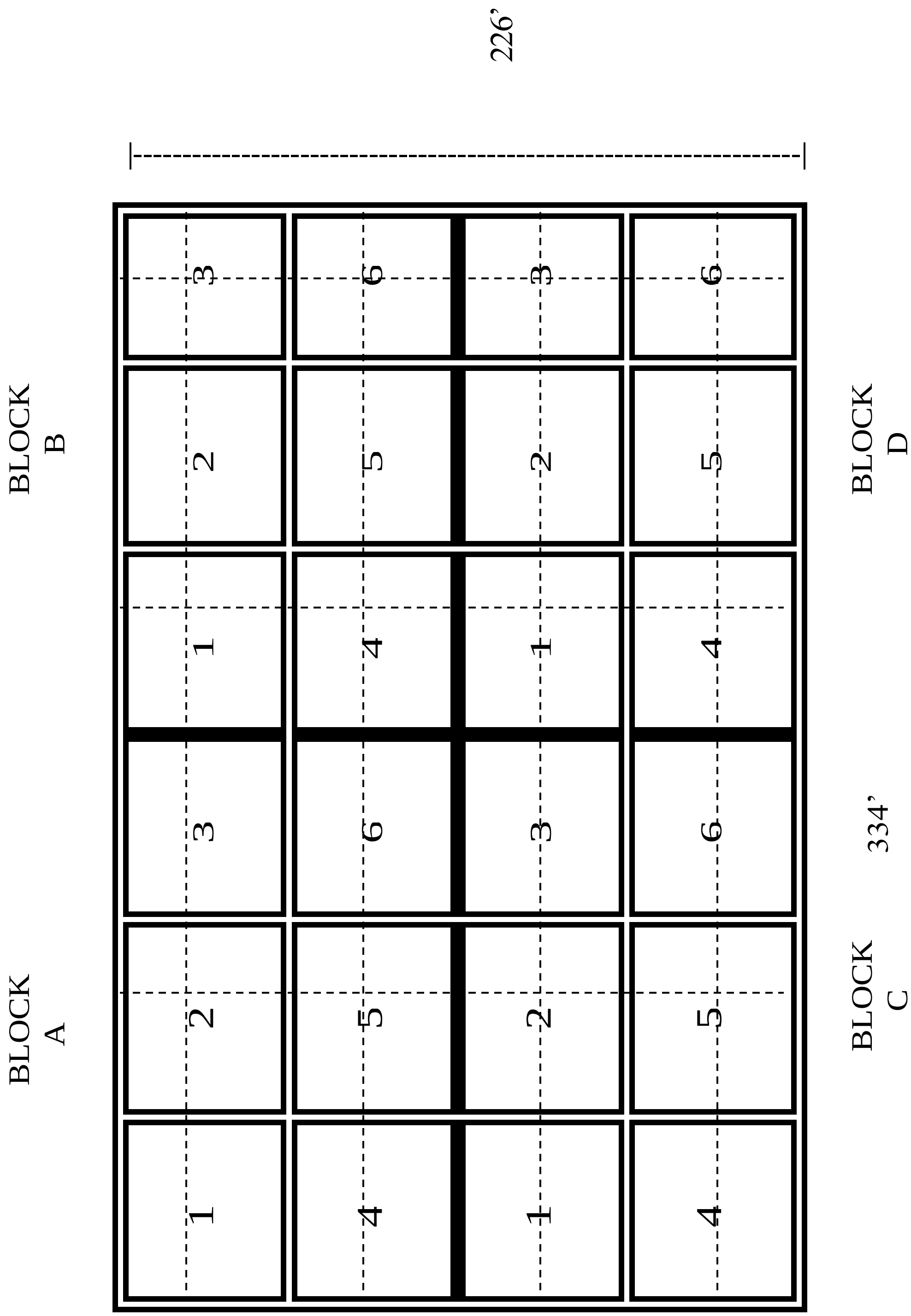

Figure 1. Schematic of installation design with 4 blocks, 24 plots and 96 subplots surrounded by 10’ unplanted and untreated buffer strip.

Table 2: Subplot treatment design matrix by installation, block and plot for boron retreatment study in northeast Oregon.

INSTALLATION 411 (Glass Hill)								
			Subplot Treatment					
Species	**Block**	**Plot**	**1**	**2**	**3**	**4**	**5**	**6**
DF	1	2	X	X	X			X
DF	1	3		X	X	X	X	
DF	1	4	X		X	X	X	
DF	1	5	X	X			X	X
PP	2	2		X	X	X	X	
PP	2	3	X	X	X		X	
PP	2	4	X		X	X	X	
PP	2	5	X	X		X		X
DF	3	1	X		X	X	X	
DF	3	2	X	X			X	X
DF	3	4	X	X		X		X
DF	3	5		X	X	X		X
PP	4	1	X		X		X	X
PP	4	2	X	X			X	X
PP	4	3		X		X	X	X
PP	4	4	X		X	X		X
PP	4	6		X	X	X		X
TOTAL SUBPLOTS			**12**	**12**	**11**	**11**	**11**	**11**

INSTALLATION 412 (Noregaard)								
			Subplot Treatment					
Species	**Block**	**Plot**	**1**	**2**	**3**	**4**	**5**	**6**
DF	1	2	X		X	X	X	
DF	1	3		X	X		X	X
DF	1	4	X	X			X	X
DF	1	5		X	X	X		X
DF	1	6	X			X	X	X
PP	2	1	X		X	X	X	
PP	2	2		X	X		X	X
PP	2	3	X		X	X	X	
PP	2	4	X	X			X	X
PP	2	5		X	X	X		X
PP	3	1	X			X	X	X
PP	3	2		X	X	X	X	
PP	3	3		X	X	X		X
PP	3	4	X	X			X	X
PP	3	5	X	X	X			X
DF	4	1		X		X	X	X
DF	4	2	X	X	X	X		
TOTAL SUBPLOTS			**10**	**12**	**11**	**11**	**12**	**12**

Field Measurements

Initial tree measurements were taken at the time of re-fertilization in the fall of 2003. Caliper measurements were taken at ground level for each seedling, and total heights were also recorded. Trees were re-measured in the fall 2004 and 2005 to obtain the one and two-year caliper and height growth response to the different treatments. Volume growth was calculated as the net change in total stem volume ($(\text{Caliper})^2$ x height) between the two annual measurements.

Statistical Analyses

Analysis of variance (ANOVA) was used as the primary method for analyzing the variation of nutrient data. A full model with site, treatment and species as the main effects was used to test growth response.

$$Y_{ijkl} = \mu + s_i + t_j + a_k + (st)_{ij} + (sa)_{ik} + (ta)_{jk} + (sta)_{ijk} + e_{ijkl}$$

where: Y_{ijkl} is observation on sample tree l under treatment j at site i for species k,
μ is the overall mean of the experiment,
s_i is the fixed effect of site locations (Glass Hill, Noregaard),
t_j is the fixed effect of treatment (control, B only, N only, N+B, N+K+S+B+Cu+Zn+Fe, and N+K+S+Cu+Zn+Fe),
a_k is the fixed effect of species (Douglas-fir, ponderosa pine)
$(st)_{ij}$ is the fixed effect of site*treatment interaction,
$(sa)_{ik}$ is the fixed effect of site*species interaction,
$(ta)_{jk}$ is the fixed effect of species*treatment interaction,
$(sta)_{ijk}$ is the fixed effect of site*treatment*species interaction,
e_{ijkl} is the error term ~ NID $(0, \sigma^2_e)$.

where i = 2 for sites, j = 6 for treatments, k = 2 for species; l = 10 – 12 for sample trees per treatment per site.

The SAS procedure PROC GLM was used to test all fixed effects and to perform linear single-degree-of freedom contrasts among fertilizer treatments (SAS Institute

1996). A default level of $\alpha = 0.10$ was used to declare significance unless otherwise specified.

RESULTS

Site and Treatment Effects

Site influences on caliper, height and volume growth were less pronounced for Douglas-fir than for ponderosa pine (Table 3). Both species showed a statistically significant ($\alpha = 0.10$) block affect for caliper growth, while only Douglas-fir showed a significant block affect for height and ponderosa pine for volume. Treatment effect was highly insignificant for all three Douglas-fir growth attributes, however, ponderosa pine showed significant treatment effect for both height ($p = 0.0595$) and volume ($p = 0.529$). Douglas-fir treatment*height interaction was the only significant interaction term for both species, indicating significant Douglas-fir height response differences between sites.

Table 3 – Summary of statistical tests (p > F) for caliper, height and volume growth of Douglas-fir and ponderosa pine two years after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon. Significant effects at $\alpha = 0.10$ are in bold.

Source of variation	Caliper growth	Height growth	Volume growth
------------------------------ Douglas-fir ------------------------------			
Site	**0.0021**	**0.0195**	**0.0033**
Block	**0.0179**	**0.0323**	0.1995
Treatment	0.9509	0.9713	0.8124
Site*Treatment	0.7753	**0.0294**	0.4072
Block*Treatment	0.8784	0.9986	0.6654
-----------------------------Ponderosa Pine ----------------------------			
Site	**0.0004**	**0.0098**	**0.0015**
Block	**<0.0001**	0.1767	**<0.0001**
Treatment	0.3970	**0.0595**	**0.0529**
Site*Treatment	0.7759	0.2150	0.5945
Block*Treatment	0.3822	0.6451	0.9024

Caliper Growth

One year after treatment, Douglas-fir at the Noregaard site receiving the N Only and mulitnutrient without B treatments showed a significant ($p \leq 0.10$) 40% and 36% increase in caliper growth over trees receiving no fertilizer treatment, respectively (Table 4). In addition, caliper growth was significant for ponderosa pine at both Noregaard and Glass Hill sites when receiving the multi-nutrient treatment including B. Significant caliper growth over the control was also shown two years after treatment, but only for Glass Hill Douglas-fir receiving the multi-nutrient treatment without B (Table 5). Neither species showed a significant caliper growth difference when comparing the N only to the N+B treatments (Tables 4 and 5). However, when B was present in the multi-nutrient treatment, ponderosa pine at Noregaard showed a significant 20% increase in caliper growth over the multi-nutrient treatment without B. Overall, only Douglas-fir at Noregaard showed a positive (non-significant) one-year annual response to the B only treatment. Both species at both sites showed insignificant annual caliper response to the B only treatment two years after application.

Table 4 – Douglas-fir and ponderosa pine caliper growth (mm tree^{-1} yr^{-1}) one year after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Fertilizer Treatment	**--------- Douglas-fir ----------**		**------- Ponderosa Pine -------**	
	Glass Hill	**Noregaard**	**Glass Hill**	**Noregaard**
Control	10.6a	9.0a	11.1cd	11.9ab
B Only	9.6a	11.8ab	10.3c	11.5ab
N Only	9.7a	12.6b	12.5abc	13.6a
N+B	10.6a	11.6ab	10.2c	13.5abc
Multi-nutrient with B	10.0a	12.1ab	13.9ab	14.8c
Multi-nutrient w/o B	10.8a	12.2b	12.9abd	12.3a

Note: Means followed by the same letters were not statistically different at the 90% confidence level.

Table 5 – Douglas-fir and ponderosa pine annual caliper growth (mm tree^{-1} yr^{-1}) two years after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Fertilizer Treatment	**--------- Douglas-fir ----------**		**------- Ponderosa Pine -------**	
	Glass Hill	**Noregaard**	**Glass Hill**	**Noregaard**
Control	13.7b	13.8a	13.5ab	11.3a
B Only	15.3ab	12.5a	13.8ab	12.3a
N Only	15.5ab	13.8a	16.5b	10.7a
N+B	15.0ab	12.6a	14.8ab	11.4a
Multi-nutrient with B	14.7ab	12.3a	12.5a	11.0a
Multi-nutrient w/o B	15.8a	12.6a	13.4ab	11.2a

Note: Means followed by the same letters were not statistically different at the 90% confidence level.

Two-year average caliper response over the control showed generally higher rates of response at the Noregaard "good rock" site than at the Glass Hill "bad rock" site for both species (Figure 2), indicating better fertilizer response on the good rock type. For example, Douglas-fir percent response over the control was almost always twice that at Noregaard than at Glass Hill, except the multi-nutrient without B treatment. The N only treatment showed the highest Douglas-fir response at Noregaard with a 16% ($p \leq 0.10$) increase over the control, followed by the multi-nutrient without B at 9%. Ponderosa pine response over the control was highest when receiving the N+B treatment at 8% and the multi-nutrient with B at 12%. Notably, ponderosa pine response was generally higher with B in the fertilizer mix while Douglas-fir response was lower.

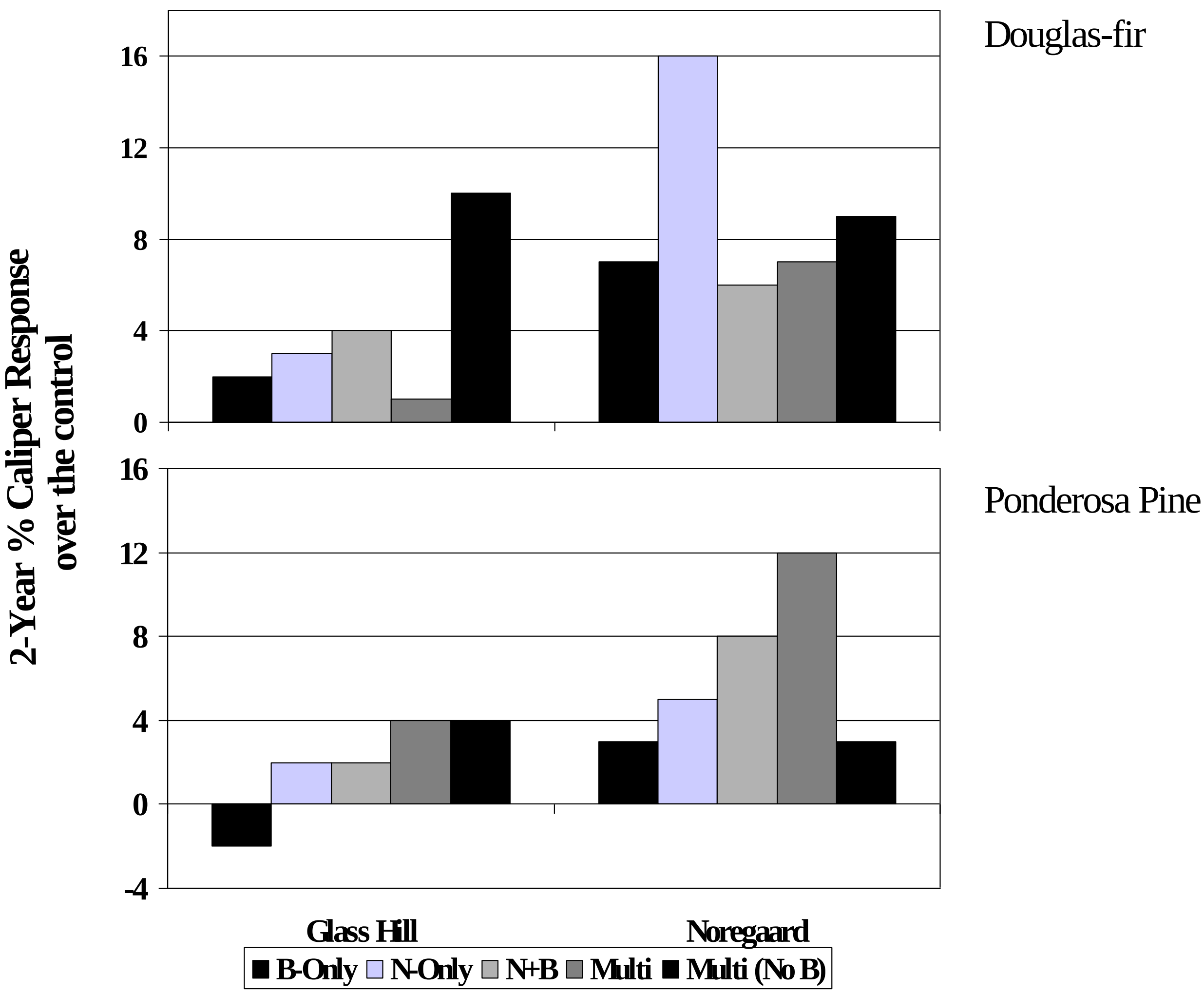

Figure 2 – Douglas-fir and ponderosa pine two-year % caliper response over the control at Glass Hill and Nregaard boron / multi-nutrient seedling trials in northeast Oregon.

Height Growth

Height growth each growing season is determined by the number of nodes and elongation patterns set the previous growing season. As a result, height growth fertilizer response after one growing season is unlikely to show an effect. Therefore, only height response two years after treatment is presented in this report.

Two-years after treatment, no significant ($p \leq 0.10$) increase in height growth was shown over the control for any of the treatments. However, a significant decrease in growth was shown for Douglas-fir receiving the multi-nutrient treatment and for ponderosa pine receiving the B only and N+B treatments at Glass Hill (Table 6). Notably, low or negative height growth response was common when B was included in the fertilizer mix.

Table 6 – Douglas-fir and ponderosa pine annual height growth (cm $tree^{-1}$ yr^{-1}) two years after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Fertilizer Treatment	**---------- Douglas-fir ---------**		**-------- Ponderosa Pine ------**	
	Glass Hill	**Noregaard**	**Glass Hill**	**Noregaard**
Control	57a	60ab	54b	55a
B Only	58a	56a	47a	56a
N Only	57a	62ab	57b	58a
N+B	56a	61ab	49a	59a
Multi-nutrient with B	52b	66b	56b	56a
Multi-nutrient w/o B	60a	59ab	52ab	57a

Note: Means followed by the same letters were not statistically different at the 90% confidence level.

Seven years after initial establishment in 1998, average total tree heights for both species and across all treatments combined were significantly ($p \leq 0.10$) taller for trees growing at the Noregaard "good rock" site over trees growing at the Glass Hill "bad rock" site (Figure 3). Additionally, total tree heights were taller for ponderosa pine than for Douglas-fir.

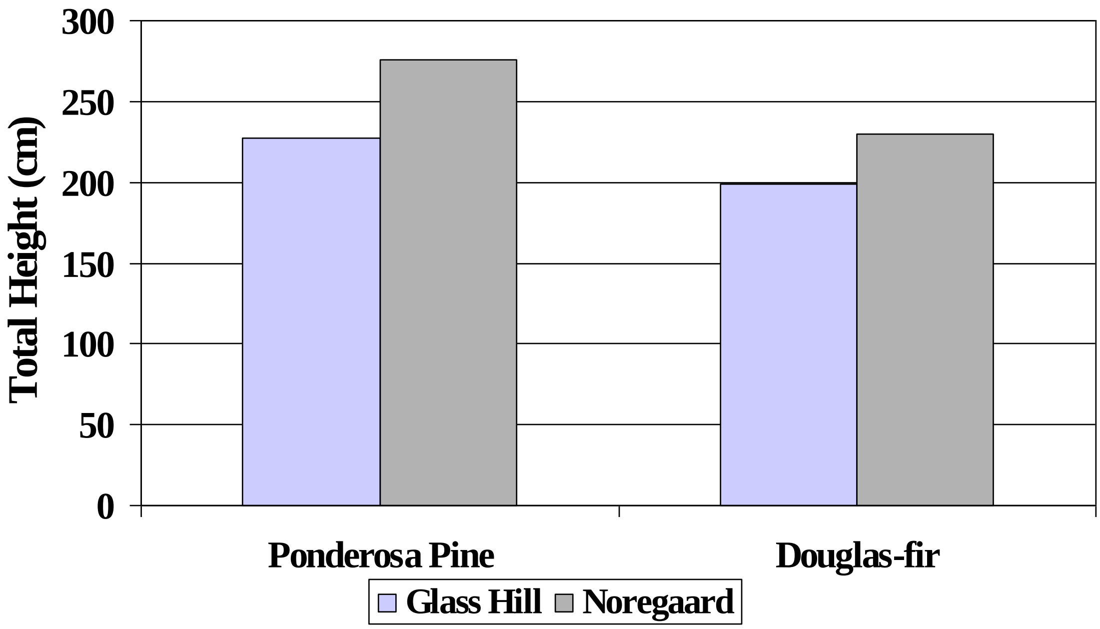

Figure 3. Average total tree height by species and site at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Volume Growth

Average annual volume growth increase over the control one and two years after fertilization was insignificant across all treatments for Douglas-fir at both Glasshill and Noregaard and for ponderosa pine at Glass Hill (Tables 7 and 8). Only ponderosa pine at Noregaard showed a significant first year volume growth response over the control, with the N only treatment showing a 1170 cu. cm/yr (25%) response and the N+B treatment a 1607 cu. cm/yr (35%) response. The N+B treatment was the only treatment to show a significant response the second year, with a 2633 cu. cm/yr (36%) increase over the control.

Table 7 – Douglas-fir and ponderosa pine annual volume growth (cm^3 $tree^{-1}$ yr^{-1}) one year after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Fertilizer Treatment	**--------- Douglas-fir ----------**		**------- Ponderosa Pine -------**	
	Glass Hill	**Noregaard**	**Glass Hill**	**Noregaard**
Control	2322a	2926ab	3612a	4600a
B Only	2424a	2525a	2809a	4664a
N Only	1844a	3085ab	3757a	5770b
N+B	1923a	3676ab	2831a	6207b
Multi-nutrient with B	1742a	3876b	3672a	5579ab
Multi-nutrient w/o B	2376a	3957b	3390a	4684a

Note: Means followed by the same letters were not statistically different at the 90% confidence level.

Table 8 – Douglas-fir and ponderosa pine annual volume growth (cm^3 $tree^{-1}$ yr^{-1}) two years after treatment at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Fertilizer Treatment	**---------- Douglas-fir ---------**		**-------- Ponderosa Pine ------**	
	Glass Hill	**Noregaard**	**Glass Hill**	**Noregaard**
Control	4812ab	6915a	6916a	7218a
B Only	5919ab	5187a	6003a	8220ab
N Only	4815ab	6057a	8076a	8693ab
N+B	4688ab	6662a	6558a	9851b
Multi-nutrient with B	4042a	6526a	6121a	8183ab
Multi-nutrient w/o B	5699b	6934a	5882a	7764a

Note: Means followed by the same letters were not statistically different at the 90% confidence level.

Average two-year volume response for Douglas-fir receiving the N+B and the multi-nutrient with B treatments was higher at Noregaard than at Glass Hill (Figure 4). However, Douglas-fir response to the B only treatment was a positive 17% at Glass Hill but a negative 22% at Noregaard. Ponderosa pine two-year volume response was similar to two-year caliper responses with all treatments showing higher response at Noregaard than at Glass Hill. The highest two-year ponderosa pine response over the control was shown for the N only at 22% and for the N+B at 36% (Figure 4). Ponderosa pine response did tend to be higher if the treatment had B in the fertilizer treatment, when comparing the N only to the N+B or the multi-nutrient with B to the multi-nutrient without B treatments.

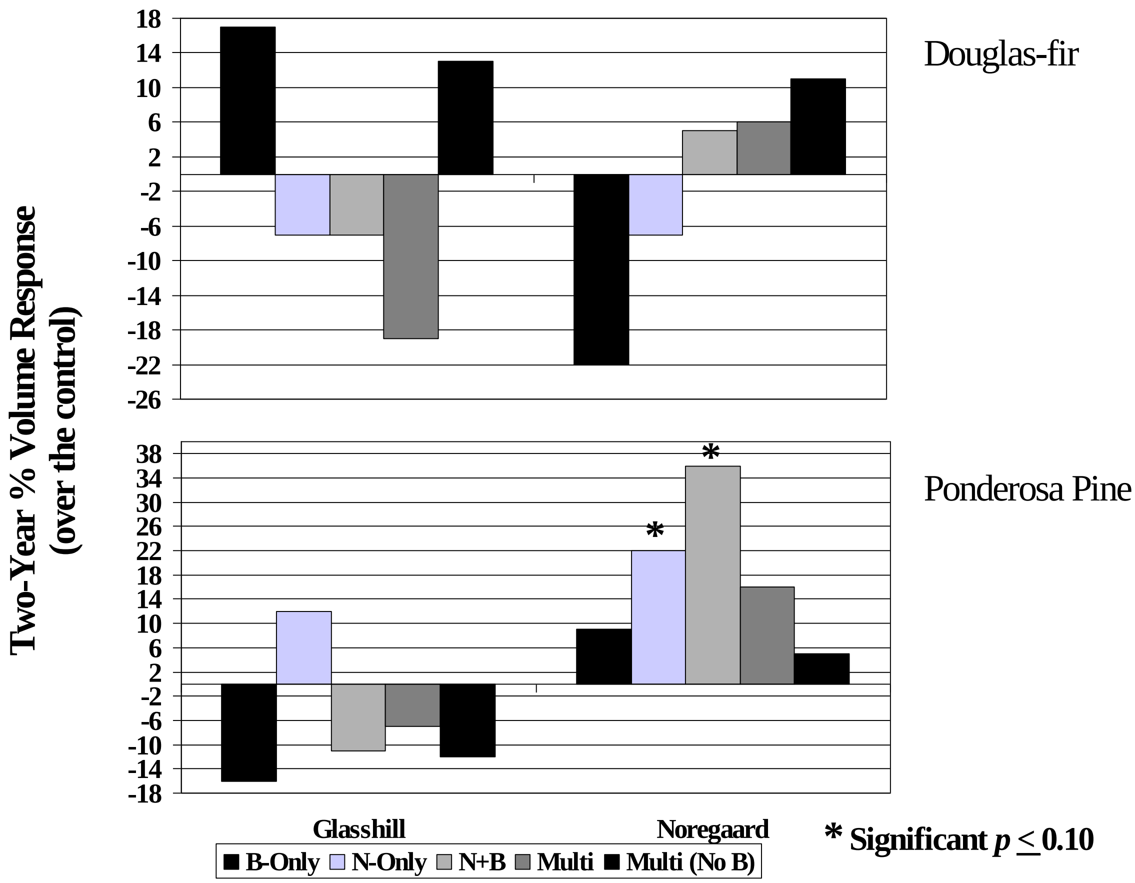

Figure 4. Two-year volume response for Douglas-fir and ponderosa pine at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

DISCUSSION

Growth Response to Fertilizer Treatments

Examination of two-year caliper growth did not reveal strong or consistent treatment response over the control for either species at either the Glass Hill or Noregaard sites. For example, two-year caliper response over the control at the Glass Hill site was below 4% for both species on all treatments except for an insignificant 10% Douglas-fir response on the treatment of the multi-nutrient without B. Overall treatment response for both species was generally higher at Noregaard than at Glass Hill, but treatment responses differed by species. For example, Douglas-fir receiving the N only treatment at Noregaard showed a significant 16% response while ponderosa pine receiving this same treatment failed to show a response. Additionally, Douglas-fir receiving the B only or multi-nutrient without B treatments showed more than twice the response as ponderosa pine receiving these same treatments. Comparisons between treatments were also inconsistent and did not show a strong B affect for treatments with B over those without B in the fertilizer mix. The B only treatment, however, was generally the lowest responding treatment for Douglas-fir and ponderosa pine caliper growth at both sites, indicating that other nutrients were needed to show a fertilizer response.

Overall height growth response two-years after fertilization was generally low or was significantly negative. For example, height growth response over the control did not exceed 5% for ponderosa pine and the highest response across all treatments was only 13% for Douglas-fir at Noregaard when receiving the multi-nutrient treatment with B. Significant responses were always negative and only when B was present in the fertilizer mix, suggesting that in some cases boron may have had an antagonistic effect on height growth, particularly when B was applied alone.

Volume growth represents caliper plus tree height growth and therefore will reflect the combination response of the two growth variables. Two-year volume growth at Glass Hill was similar to the height growth response with both Douglas-fir and ponderosa pine showing low or negative response to the fertilizer treatments. Only the

Douglas-fir receiving the B only or multi-nutrient without B treatments and ponderosa pine receiving the N only treatment showed a positive response at Glass Hill. All other treatments showed a negative response. Douglas-fir volume growth response at Noregaard was generally low or negative, while ponderosa pine volume response was positive for all treatments and significantly so for the N only at 22% and the N+B treatment at 36% response over the control.

One of the primary objectives of this study was to determine the effects of B fertilization alone and in combination with other nutrients. In general, the B alone treatment did not show a response across growth attributes for either species at either site. Adding boron to the fertilizer mix did not appear to consistently increase growth response when comparing the multi-nutrient with B to the multi-nutrient treatment without B. However, the combined application of N and B was generally higher than the B alone or the N alone treatments for both species at both sites. These results were similar to results shown for lodgepole pine in interior British Columbia where the N+B treatment was superior to N alone in stimulating height development (Brockley 2003). Notable, however, were the significant negative responses shown for Douglas-fir at Noregaard and ponderosa pine at Glass Hill when receiving the B only treatment. These results may either suggest that other nutrients were deficient and limited growth or that a possible antagonistic B effect occurred.

Foliar Response to Fertilizer Treatments

Foliar nutrient response can provide an indication of potential stem growth response (Xiao et al. 2005). Douglas-fir at Noregaard and ponderosa pine at Glass Hill receiving the B only treatment showed significant negative growth response and the highest foliar B concentrations of all treatments, an increase of 76% and 59% foliar B response over the control (Figure 5). These results suggest B toxicity or antagonistic effects. In addition, graphical vector analysis reported by Xiao et al (2005) diagnosed B antagonistic effects for ponderosa pine at Glass Hill. In contrast, foliar N concentrations did not respond significantly to the fertilizer treatments for either species at either site (Figure 6). These are unusual results for N foliar concentrations because other IFTNC studies almost always show foliar N response. In addition, N concentrations for Douglas-fir and ponderosa pine were above recommended critical levels (Moore et al. 2004) for all treatments, including the control (Figure 6). These results indicate that foliar N levels for the Douglas-fir and ponderosa pine in this study are generally not N deficient. Sufficient supplies of N across treatments could lead to low overall growth response over the controls in this study.

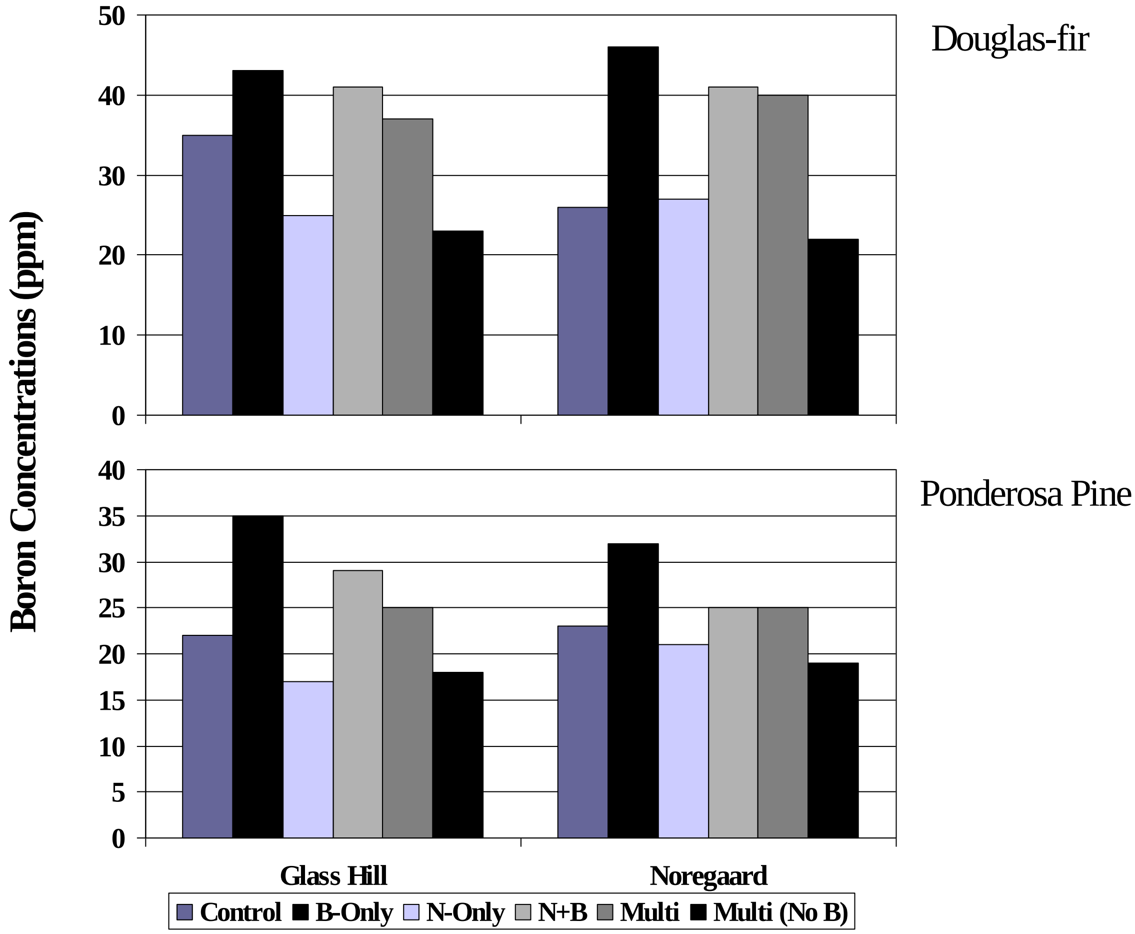

Figure 5. Foliar boron concentrations one-year after fertilization for Douglas-fir and ponderosa pine at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

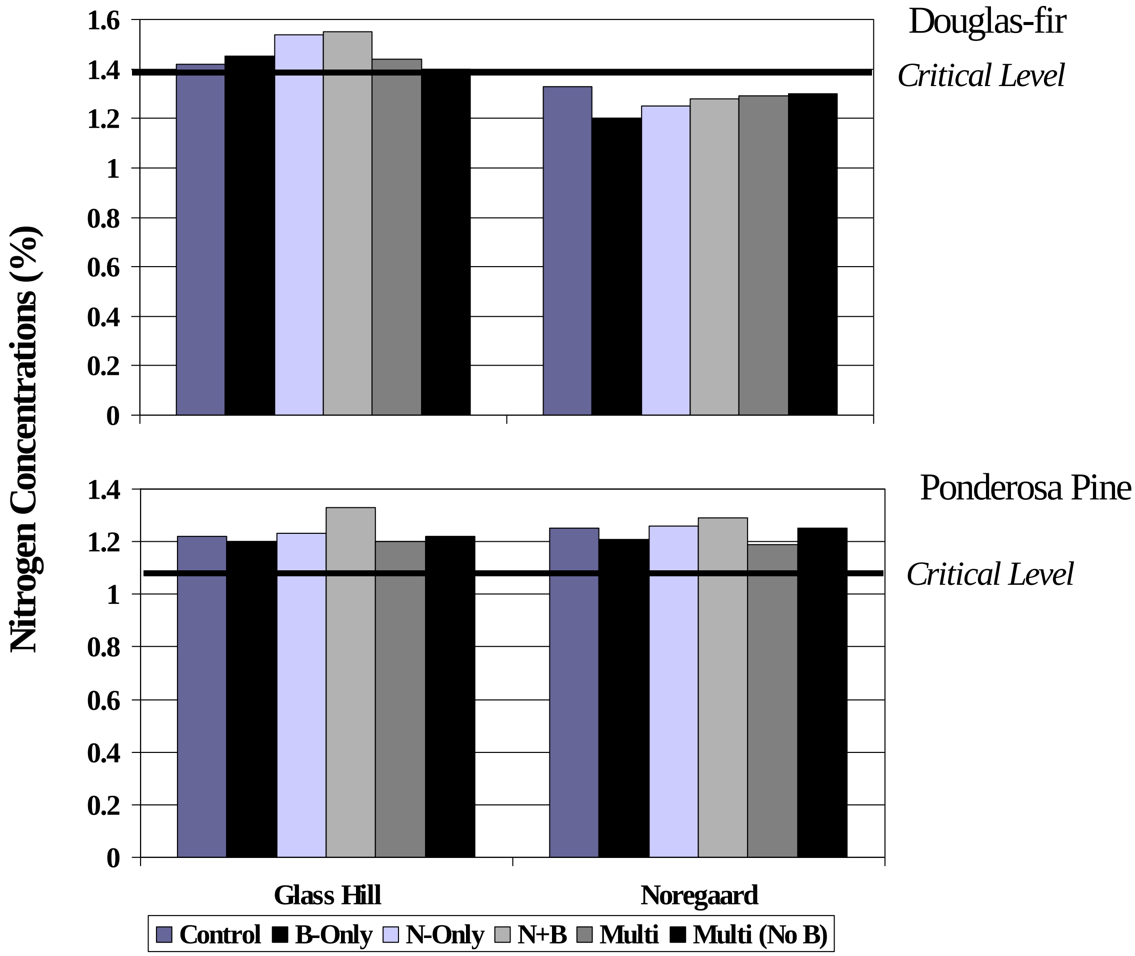

Figure 6. Foliar nitrogen concentrations one-year after fertilization for Douglas-fir and ponderosa pine at Glass Hill and Noregaard boron / multi-nutrient seedling trials in northeast Oregon.

Noticeable size and growth response differences were shown for both species between the Glass Hill "bad rock" site and Noregaard "good rock" site. Eight-years after establishment, average Douglas-fir caliper across all treatments combined were 10% smaller at Glass Hill than at Noregaard, while ponderosa pine were 14% smaller. Furthermore, average two-year caliper growth response for trees receiving N in the treatment mix were 5% less for both species at Glass Hill than Noregaard. Even though site factors such as slope, aspect, elevation, vegetation series (moisture regimes) and soil characteristics were similar between sites, the rock type difference did appear to contribute to marked caliper size differences. These results indicate that fertilization treatments for both species on the “bad rock” were less effective than those on the “good rock”.

CONCLUSIONS

Fertilization resulted in increased Douglas-fir and ponderosa pine caliper, height, and volume growth on some treatments. However, response was generally low and was variable by treatment, species and site. The boron only treatment tended to have antagonistic growth effects and B in combination with other nutrients in the fertilizer mix did not always show significant response over treatments without B in the mix. Low foliar N response was indicative of low tree growth response, even though foliar nutrient levels for all treatments, including the control, were well above recommended critical levels for optimal growth. Perhaps nutrient and growth response were confounded by repeated fertilization in this study.

Stem growth for Douglas-fir and ponderosa pine on the “bad rock” was generally less than on the “good rock”. Growth response for treatments with B in the mix were not always higher than treatments without B in the mix, however, ponderosa pine at the Noregaard “good rock” site receiving the multi-nutrient treatment with B showed a 9% increase in caliper over the multi-nutrient treatment without B. In addition, volume response improved by 18% for ponderosa pine receiving the N+B treatment over the N only treatment at Noregaard. These results indicate that B is a needed nutrient for ponderosa pine on these study site types.

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