Growth, Mortality and Soil Characteristics at Vanstone Western Larch Fertilization Trial in Northeast Washington

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SUMMARY

This report evaluates western larch stand growth and mortality under different multi-nutrient treatments four growing seasons after initial establishment. The report also examines the nutritional aspects of the soil and tree foliage observed at the time of collection in summer and fall 2004, four years after treatment.

The four-year effects of fertilization on western larch basal area stand growth were examined for three different treatments (N-Only, N+K and N+K+S+B). Western larch receiving the N-Only and N+K+S+B treatments showed a relative net four-year basal area response over the control of only 6.6% and 2.2%, while relative net response of trees receiving the N+K treatment was much higher at 24%. Relative gross basal area response for the N-Only and N+K+S+B was rated fair at 11% and 18% respectively and rated good for the N+K treatment at 26%. The reason for different results between gross and net response on the N-Only and N+K+S+B treatments and not on the N+K treatment was mortality. Mortality rates for western larch receiving the N-Only and N+K+S+B treatments were 6.4% and 18.2% while mortality for the N+K treatment was only 1.5%. Notably, most (94%) of the mortality occurred the second two-year period (years 3 and 4) after treatment. Periodic annual increment (PAI) showed a significant growth response decline between the years 1-2 and years 3-4. Gross basal area PAI response (ft^2/ac) for the N-Only, N+K and N+K+S+B treatments during the first-two years was 0.83, 1.33 and 1.57 while response the second two-years was 0.20, 0.77 and -0.20, respectively. Clearly, the effects of fertilization on stand growth declined in the third and fourth years following treatment.

Several research techniques were used to determine western larch foliar nutrient characteristics and nutrient status of the soils at Vanstone. Results derived from standard surface (0-12") soil chemistry and upper surface soil ion exchange capsules were similar with N, K and B showing higher soil nutrient concentrations on those plots receiving a treatment than soils receiving no fertilizer amendment. However, neither soil nutrient analysis technique showed increased S concentrations due to fertilization. Ion exchange capsules buried at several depths along the soil profile generally showed decreased soil nutrition with depth. General comparison ranking of soil nutrient concentrations at Vanstone and other IFTNC Inland Northwest glacial soils showed N, K and S nutrition ranking low while soil B concentrations ranked high. Similar to the soil results, foliar nutrient concentrations also showed significant N and B response to fertilization, even four-years after treatment. However, even though K was abundant in the soils at Vanstone, foliar nutrient concentrations suggest K was lacking. Notably, K/N ratios were far below control ratios or ratios considered balanced for optimal nutrition.

Results from this study indicate that the fertilizer treatments applied at Vanstone had a significant impact on the growth, mortality and overall nutrient capital of the site. Initial growth responses to fertilization during the first two years after establishment were promising for all treatments. However, subsequent response declined sharply and mortality increased on the N-Only and multi-nutrient fertilizer plots well beyond that of the control or N+K treatment. Potassium may have played an important role in maintaining and enhancing growth and health on the N+K plots. Evidence shows that other factors such as drought conditions and soil disturbance caused by management activity also played a role. Further investigations will need to be conducted to fully determine western larch fertilization response on these site types and conditions.

INTRODUCTION

In the fall of 1999, Boise Corporation established a growth and yield multi-nutrient fertilization test site in the Northeast Washington Region of Boise lands. The test site is located in a managed, young and predominately pure stand of western larch. Site characteristics include undifferentiated glacial till lithology and western hemlock vegetation series. The four treatments randomly applied in five repetitions over 20 plots were a control, N-Only, N+K and N+K+S+B.

Boise Corporation contracted the IFTNC to perform one and two-year growth measurements plus evaluate the effects of the treatments on stand basal area and volume growth response. In 2001, two years after treatment establishment, the western larch at Vanstone were subjected to a long summer drought, which resulted in early needle abscission that occurred more frequently to trees receiving fertilizer treatments. Even though the drought may have prompted early needle abscission, there was no observable growth reduction at that time. Growth response results taken in the fall of 2001 indicated that all three fertilizer treatments, N-Only, N+K, and the N+K+S+B, responded well with 22.4%, 32.9% and 41.1% higher stand basal area increments over that of the control, respectively. In the fall of 2003, Boise foresters noted high occurrence of top dieback and mortality in the western larch stand. This prompted a subsequent investigative study in spring and summer 2004.

The objectives of the 2004 study were to (1) evaluate the health effects of past management practices and fertilization treatments on western larch in the stand; (2) diagnose and interpret responses of needle growth and nutrient status to fertilization treatments; (3) estimate four-year growth responses of the stand to the different fertilizer treatments; and (4) evaluate and interpret chemical and physical soil characteristics of the site.

MATERIALS AND METHODS

Experimental Design and Treatments

A randomized complete block design was used for this study. Five blocks were established with each randomly assigned four levels of fertilizer treatments: control (no fertilizer), N only (200 N lbs/ac), N+K (200 N and 170 K lbs/ac), and N+K+S+B (300 N + 170 K + 80 S + 3 B lbs/ac). Each block and treatment plot was chosen as uniformly as possible with regards to stand density, species composition, and site characteristics. Each treatment plot was circular and was 0.1 acre in size. The experiment was established in the fall of 1998 and fertilization treatments were applied in the spring of 1999, before the onset of the growing season.

Western larch is the dominate species on the site, accounting for 80 – 100% by plot of the total trees and ranging in age from 15-20 years old at establishment. A small amount of Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), and lodgepole pine *(Pinus contorta* var. *latifolia* Engelm.) also occurred within the stand. Mensurational characteristics at establishment and four and a half growing seasons after establishment are given in Appendix A.

Tree Measurements

Stand Growth

Diameter at breast height and total tree heights were remeasured by plot for all the tagged trees in the experiment in July 2004, about 4.5 growing seasons after establishment. Basal area estimates during this period were calculated and growth response was evaluated for each treatment. Basal area growth was computed as the net change in total basal area ($1/4 * \pi * (DBH)^2$) between the two measurements.

Foliar Chemistry

Foliage from ten western larch trees were sampled for chemical analysis in July 2004. Current-year foliage samples were selected from five trees on the control and six trees on the N+K+S+B treatments. Samples were placed on ice and brought to the laboratory for processing. All tissue samples were oven-dried at 70^{o} C for 48 hours. Dried needles were then ground in a coffee grinder, placed in sealed plastic bags and sent to Harris Analytical Laboratory in Lincoln, Nebraska for nutrient analyses. Samples were analyzed for N, P, K, Mg, Ca, S, Zn, Cu, B, Mn and Fe concentrations. Foliar N concentrations were analyzed using a standard micro-Kjeldahl procedure. Other elements were determined by inductively-coupled plasma emission photospectrometry (ICP) following wet digestion in acid.

Vector Analysis

Vector analysis was used to compare plant growth, nutrient concentrations and nutrient content. Current year foliar nutrient concentrations, nutrient content, and dry weights were used in a graphical vector analysis approach (Timmer and Stone 1978;

Weetman and Fournier 1982). Each point on the vector analysis represents the magnitude and directional shift of each nutrient from the control. Distance from the control represents the responsiveness of the treatment for the nutrient being analyzed. Appendix B shows a schematic of the approach for added nutrients and vector results for this study. A detailed description of vector analysis can be found in Weetman and Fournier (1986) and Hasse and Rose (1995).

Soil Measurements

Standard Surface Soil Chemistry

Surface soil samples were collected for chemical analysis on the control, N only and multi-nutrient (N+K+S+B) treated plots. Surface soils were analyzed for N0-3 N, NH-4 N, mineralizable N, P, K sulfate sulfur, boron, extractable cations, Zn, Mn, Cu, Fe, pH and organic matter at the Holmes Research Lab, University of Idaho, Moscow, Idaho.

Ion Resin Exchange Capsules

Ion-exchange resin capsules measure *in situ* plant-available nutrients in the soil. Two sets of four ion resin exchange capsules were buried for five months at five plot locations. One capsule was placed at each of four levels along a soil profile: within the organic matter (duff)/surface mineral soil interface; the upper mineral soil horizon (~ 6 inches depth); the interface between upper and lower mineral soil horizon (~18 inches depth); and the lower mineral soil horizon (~24 inches depth). Ion exchange capsules were analyzed for N0-3 N, NH-4 N, Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S and Zn at the Unibest Laboratory, Pasco, WA.

Soil Strength

Surface soil strength was measured by cone penetrometer (Rimiks CP-40) on one N-Only and three N+K+S+B treatment plots, the two treatments with highest western larch mortality rates. Soil strength can be used to provide an indication of soil density. Higher resistance to penetration (higher soil strength) usually indicates higher soil density. Two live and two dead trees were randomly selected within each plot to compare potential soil strength effects on tree mortality. Soil strength was measured in eight directions around each sample tree (N, NW, W, SW, S, SE, E, and NE) at 10cm, 20cm and 30cm belowground, respectively. Five replications per direction were applied.

Statistical Analyses

A statistic model with main effects (treatment, block) and their interactions (treatment*block) in the following form was used to test basal area growth:

$$Y_{ijk} = \mu + t_i + b_j + (tb)_{ij} + e_{ijk}$$

where: Y_{ijk} is height, or diameter observed on sample tree k under treatment i at block j,

μ is the overall mean of the experiment,

t_i is fixed effect of fertilization treatments (control, N, N + K, and N + K + S + B),

b_j is the random variable for block ~ NID (0, σ^2_b),

$(tb)_{ij}$ is the random variable for treatment*block interaction ~ NID (0, σ^2_{tb}),

e_{ijk} is the error term ~ NID (0, σ^2_e).

where i = 4 for treatment, j = 5 for block, k = 10 – 20 for sample trees per treatment per block.

For all analyses PROC GLM in the SAS® System was utilized to test for significance of random effects, while PROC MIXED was used to test the fixed effects and to perform linear single-degree-of freedom contrasts among treatments (Littell et al. 1996; SAS Institute 1996). A default level of ∀ = 0.10 was used to declare significance unless otherwise specified. Analyses included estimation of response on the fertilized plots relative to control plots. Average basal area increment to the fertilizer treatments was adjusted to a common initial basal area of 10.4 ft^2/ac. Fertilization response was calculated by subtracting the model estimates of growth on the control plots from the estimates on the fertilized plots. Soil strength data were only analyzed to test differences around live and unhealthy and/or dead trees.

RESULTS AND DISCUSSION

<u>Stand Growth Response</u>

Net four-year basal area growth for Vanstone western larch on the N-Only and multi-nutrient treatments was not statistically significant with only 6.6% and 2.2% relative response over the control (Table 1). However, western larch receiving the N+K treatment showed a statistically significant 24% response over the four-year period. Four-year relative gross response was also insignificant for the N-Only treatment, but both the N+K and multi-nutrient treatments showed significant gross growth with 26.4% and 17.6% response over the control, respectively. The reason for different response rates between the net and gross basal area is mortality. High western larch mortality was observed in fertilized plots. This was particularly true on plots receiving the multi-nutrient treatment where there was a 15.4% difference in mortality between net and gross response. Of the 17 dead trees recorded on all plots, only one was found dead before 2002. The remaining 16 trees were died over the past two years. All dead trees occurred on the fertilized plots with 6.4% on the N only, 1.5% on the N+K and 18.2% on the N+K+S+B treatments (Figure 1).

Table 1. Average four-year net and gross basal area growth response to fertilization treatments by treatment for western larch at Vanstone in northeast Washington

	Net Basal Area			Gross Basal Area		
	Increment	Response		Increment	Response	
Treatment	ft^2/acre	ft^2/acre	Percent	ft^2/acre	ft^2/acre	Percent
Control	9.1			9.1		
N-Only	9.7	0.6 NS	6.6	10.1	1.0 NS	11.0
N+K	11.3	2.2	24	11.5	2.4	26.4
Multi-Nutrient	9.3	0.2 NS	2.2	10.7	1.6	17.6

Averages are adjusted to a common initial basal area of 10.4 ft^2/acre. NS = Not significant at $p \leq 0.10$.

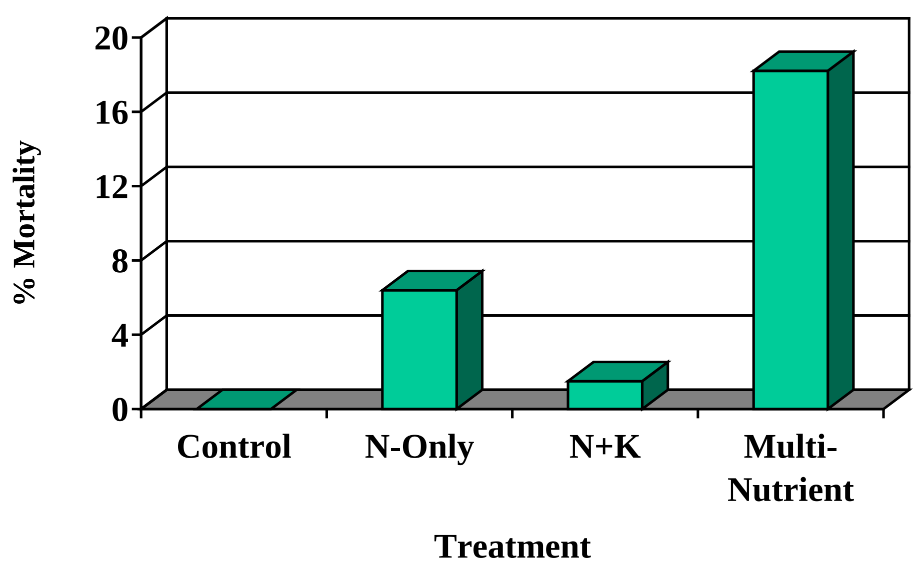

Figure 1. Percent mortality of western larch to different fertilizer treatments at Vanstone northeast Washington.

Growth response over the four-year period may better be explained by looking at the average periodic basal area response shown in Table 2. Periodic annual increment (PAI) growth response to the fertilizer treatments was significant on all three-fertilizer treatments for the first two-year growth period but declined significantly the second two-year period. In fact, the N-Only and multi-nutrient treatments both showed negative PAI response (Figure 2) with growth response declining 150% and 220% in the second period compared to first period, respectively. PAI response on the N+K treatment also declined by 48% from period one to period two, although response was not negative when compared to the control. Notably, gross PAI was negative for the multi-nutrient treatment during the second period. Not only do the results show that treatment response declined during the second period, but comparisons between net and gross response suggest that the fertilizer treatments may have accelerated mortality on the N-Only and multi-nutrient treatment plots.

Table 2. Periodic basal area increment response to multi-nutrient fertilization for years 1-2 and 3-4 for Vanstone western larch in northeast Washington

Treatment	**Net Response ft^2/acre**	**Gross Response ft^2/acre**
Period 1 (Years 1-2)		
N Only	0.72	0.83
N+K	1.31	1.33
Multi-Nutrient	1.42	1.57
Period 2 (Years 3-4)		
N Only	-0.36 NS	0.20 NS
N+K	0.64 NS	0.77
Multi-Nutrient	-1.70	-0.20

Averages are adjusted to a common initial basal area of 10.4 ft^2/acre. NS = Not significant at $p \leq 0.10$.

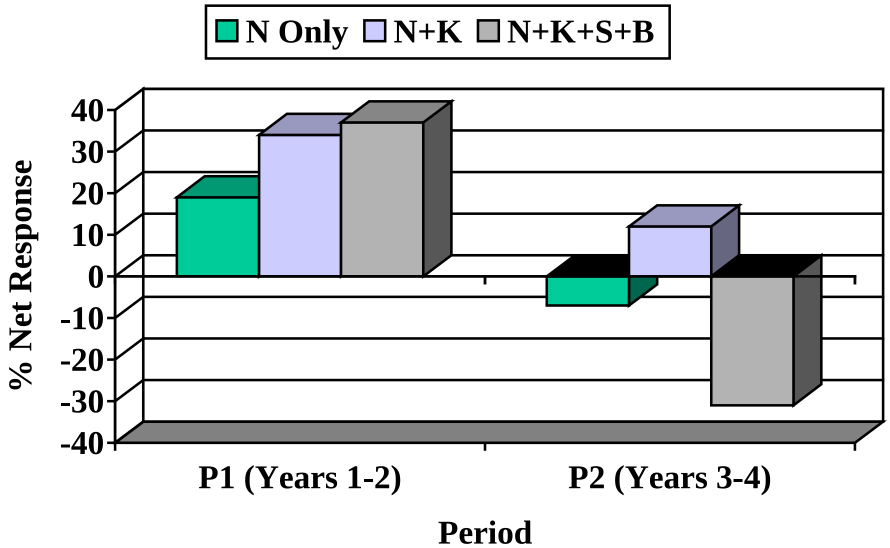

Figure 2. Relative PAI net response during years 1-2 and 3-4 of western larch to different fertilizer treatments relative to the control at Vanstone, northeast Washington.

Upon examination of stand growth and mortality comparisons under different treatments, it is clear that western larch mortality played a significant role in reducing stand productivity in fertilized plots, especially under the N only and N+K+S+B treatments. The improved effects of fertilization shown in the first two-year response period stand in contrast to the diminished response observed during the second two-years. Undoubtedly, the early needle abscission and color loss expressed during the drought period in the 2001growing season had a strong impact on growth performance and mortality of fertilized stands relative to controls in subsequent growing seasons. IFTNC studies have shown the negative impacts of fertilization on water or K limited sites (Moore et al. 1993, Shaw et al. 1998). Perhaps the western larch trees at Vanstone were stressed because the fertilizer-induced accelerated growth was not being supported by sufficient water during the extended drought in 2001. Field observations also noted significant disturbance to the site from past management activities that may also have contributed to negative impacts on growth and mortality at Vanstone. Interestingly, the N+K treatment showed beneficial effects in reducing western larch mortality while improving stand growth relative to control. IFTNC studies and others have shown that K generally has no significant growth effect, but it can have an effect on tree mortality. In addition, K has a strong effect on stomatal control and thus the water relations within plants. Potassium in the fertilizer mix may have played an important role in reducing mortality and improving water conservation in Vanstone western larch.

Foliar Chemistry

Conventional foliar nutrient analysis was performed on western larch trees within the control and the multi-nutrient treatments. Because western larch nutrition has not been well studied in the Inland Northwest, critical levels have not been developed. Therefore, this report will evaluate foliar response by treatment using only vector analysis and nutrient ratios.

More than four years after initial fertilization, Vanstone western larch receiving the multi-treatment showed significantly higher N (33%), S (31%) and B (61%) foliar nutrient concentrations than the control trees (Table 3). Potassium was the only nutrient used in the fertilizer mix that did not show a higher concentration than the control. These results are similar to those of other regional IFTNC western larch fertilization study sites located on glacial till parent materials in northeast Washington (Xiao et al. 2002). For example, one year after fertilization average multi-nutrient treatment foliar N concentrations improved by 31%, S by 44%, B by 119%, while foliar K concentrations decreased by 11%, relative to the control. Foliar content (nutrient concentration x needle weight) in this study showed similar trends as concentrations with significantly higher levels of N, S, and B on the multi-nutrient treatment over that of the control. These results demonstrate a strong fertilizer response more than four years after treatment (Table 3).

Optimal nutrient ratios relative to N were examined for nutrients applied in the fertilizer mix. Nutrient ratios for K/N and B/N were developed by Ingestad (1979) and are considered imbalanced if the ratio is below the recommended level of 0.65 and 20, respectively. The optimal nutrient ratio for S was reported by Blake et al. (1990) and is considered imbalanced if is above the N/S ratio of 14.7. K/N ratios for control western larch at Vanstone were at the 0.65 level and were considered balanced (Table 3). However, with the application of the N+K+S+B multi-nutrient treatment the K/N ratio shifted significantly below the control K/N ratio and well below the recommended 0.65 K to N balanced level, suggesting imbalanced K to N nutrition. IFTNC ponderosa pine trials showed large negative responders (mortality) when K/N ratios were below the recommended 0.65 K to N balance (Shaw et al 1998). Perhaps high mortality rates observed on the multi-nutrient treatment are associated with imbalanced K to N. Control B/N ratios were also at the recommended balanced ratio, but instead of decreasing with fertilization, as with the K/N ratios, B/N ratios improved after fertilization to a ratio above the 20 recommended balanced ratio (Table 3). N/S ratios for both the control and the multi-nutrient treatments were slightly below the recommended 14.7 ratio, suggesting balanced N to S.

Needle weight differences between the control and the multi-nutrient treatment were slight and were not significantly different (Table 4). Apparently, even though the treatments were successful in improving nutrient status in the foliage, the effects of fertilization on needle growth diminished four years after fertilization. Notably, diminished four-year needle weight results parallel the diminished stem growth response in this study.

Vector analysis is a useful graphics tool for predicting tree growth by comparing needle growth, nutrient concentrations and nutrient content changes in foliage following a particular treatment. Vector analyses were performed for those nutrients in the fertilizer mix and are shown in graphical form in Appendix B. Similar to nutrient concentration and content foliar results, vector analysis showed strong magnitude foliar deficiency response for N, S and B nutrients. Vector analysis did not show a K deficiency response to fertilization. Instead, a weak K dilution response was diagnosed for those trees receiving the multi-nutrient treatment.

Table 3 – Western larch foliar nutrient concentrations and ratios in summer 2004 (4.5 years after fertilization) for the control and multi-nutrient fertilization treatments at Vanstone

Nutrient	N	P	K	Mg	Ca	S	Zn	Mn	Cu	Fe	B	Ratios		
Treatment	(%)						ppm					N/S	K/N	B/N
Control	1.10	0.16	0.58	0.11	0.15	0.09	15	148	5	50	23	12.8	0.50	20
Multi-nutrient	1.46*	0.20	0.56	0.16*	0.30*	0.13*	20	198	6*	28	37*	11.8	0.40*	25

*Significantly different than the control at $p \leq 0.10$.

Table 4 – Western larch foliar fascicle nutrient contents and needle dry weight (g/30 needles) in summer 2004 (4.5 years after fertilization) for the control and multi-nutrient fertilization treatments at Vanstone

Nutrient	N	P	K	Mg	Ca	S	Zn	Mn	Cu	Fe	B	Needle dry weight
Treatment	(mg / 30 needles)						(µg / 30 needles)					
Control	0.067	0.010	0.036	0.007	0.009	0.005	0.90	8.89	0.30	3.01	1.41	0.0601
Multi-nutrient	0.095*	0.013	0.037	0.011	0.020	0.008*	1.32	13.09	0.40	1.85	2.36*	0.0661

Standard Surface Soil Chemistry

Surface soil samples were collected from the control, N Only and multi-nutrient treatment plots for chemical analyses. Soil chemistry showed that nutrient concentrations were higher on treated plots than on the control for all applied nutrients except SO_4-S (Table 5). NH_4-N and mineralizable NH_4-N on the N-Only treatment were 279% and 96% higher than control concentrations, respectively. Notably, soil pH on the N-Only treatment was 5.5, much lower than either the control (6.3) or multi-nutrient (6.4) treatments. These results suggest oxidation of ammonia to nitrate, which releases hydrogen ions and results in acidification of the soil. Low soil pH can affect the relative availability of nutrients to plants. Loss of availability of N, P, K, S, Ca, Mg and Mo may occur at pH levels less than 6.0. The multi-nutrient treatment increased soil K and B concentrations by nearly two and three fold above control concentrations. However, results from foliar K tissue analysis on the multi-nutrient treatment did not indicate a K response in the foliage. The reason for low foliar K response with high concentration of K in the soil is unclear, but may be related to antagonistic relationships of K to Ca and Mg. A low ratio of K to Ca and Mg can result in a mineral antagonism and the reduction in plant uptake of plant available K.

Glacial till nutrient concentrations at Vanstone were compared to surface soil nutrient values measured at other IFTNC sites located throughout the Inland Northwest (Table 5). Control plot chemistry showed mineralizable NH_4-N, K and SO_4-S soil concentrations ranking lower than 80% of the compared glacial till soils in the Inland Northwest. Boron soil concentrations, in contrast, were higher than 80% of compared Inland Northwest sites. Notably, the N Only treatment raised soil mineralizable N

Table 5 – Standard surface (0-10") soil nutrient characteristics (ppm) with percentile ranking in parentheses at Vanstone, northeast Washington.

Treatment	**pH**	**%OM**	**NO_3-N**	**NH_4-N**	**Min. NH_4-N**	**K**	**SO_4-S**	**B**
Control	6.3(90)	3.3	BDL	2.4	26(5)	170(5)	3.4(18)	0.17(80)
N Only	5.5(8)	8.5	3.2	9.1	51(48)	145(3)	2.6(8)	0.31(93)
N+K+S+B	6.4(95)	3.5	2.3	3.6	29(8)	313(55)	1.7(2)	0.50(98)

Note: Percentile ranking for NO_3-N and NH_4-N was not available. BDL – Below detection limits

concentrations from the 5th percentile to the 48th percentile. The multi-nutrient fertilizer treatment was successful in improving K and B concentration rankings but not SO_4-S.

<u>Ion-Resin Exchange Capsules</u>

Ion-exchange resin capsule technology provides a methodology to determine soil nutrient availability similar to that available to plants. Ion-resin capsules at Vanstone detected significant ($p \leq 0.10$) adsorption differences by treatment and depth level for NO_3-N, K and B (Table 6). NO_3-N adsorption in the upper "A" level depth at the organic matter/mineral soil interface increased over five fold on the N-Only treatment and over four fold for the multi-nutrient treatment. Increase of NO_3-N adsorption on the fertilized plots continued through all depth levels for both treatments but only the N-Only treatment was significant. The multi-nutrient treatment improved K adsorption significantly over control adsorption at the "A" level depth. Multi-nutrient treatment K adsorption declined at the "B" level at 6", and then increased insignificantly above the controls at levels "C" and "D", indicating either upper soil level retention and lower level K leaching through the soil profile or increased soil solution K uptake by plants at the

Table 6 – Comparisons of treatment mean resin adsorption quantities (µg cm^{-2}) in different nutrients sampled at four soil depths and under three levels of fertilizer

Resin Capsule Placement Level	Treatment	NO_3-N	NH_4-N	K	S	B
A	**Control**	2.8a	66.1a	24.3a	21.4a	0.37a
Organic/Mineral	**N Only**	16.4b	56.9a	10.2a	17.6a	0.33a
Interface	**N+K+S+B**	11.7b	64.9a	56.2b	24.3a	0.68b
B	**Control**	3.6a	58.2a	19.7a	17.6a	0.43a
Master	**N Only**	13.9b	56.0a	33.9a	19.9a	0.36a
Horizon B1 @ 6”	**N+K+S+B**	5.7a	57.9a	13.8a	17.9a	0.39a
C	**Control**	2.5a	59.8a	6.9a	19.0a	0.35a
Master B1/B2	**N Only**	11.1b	61.4a	15.7a	18.1a	0.27a
Interface @ 18”	**N+K+S+B**	5.0a	51.8a	18.9a	22.2a	0.34a
D	**Control**	4.1a	57.9a	2.5a	18.2a	0.28a
Master Horizon	**N Only**	13.9b	61.8a	7.0a	18.2a	0.23a
B2 @ 24”	**N+K+S+B**	5.5a	50.3a	8.5a	20.8a	0.24a

§ Treatment means for a given variable followed by the same letter were not statistically significant by treatment at the 90% confidence level using linear contrasts of the SAS GLM procedure.

“B” level. Boron also showed significantly increased adsorption for the multi-nutrient treatment over control at the “A” level. However, B may have been retained in the upper “A” level because multi-nutrient B adsorption was below control adsorption in all lower levels, “B” at 6”, “C” at 18” (master horizon interface) and “D” at 24”. Ion-resin capsules did not detect any strong treatment adsorption response at any level for NH_4-N and SO4-S.

Reasons for insignificant treatment response for NH_4-N and SO4-S could be related to the time when resin capsules were placed in the soil profile and the duration of placement. Capsule placement was in the early summer (June) with little or no significant precipitation during the time period between placement and extraction in mid October. Ground solution nutrients may have been limited. Additionally, fertilizer application treatments took place over four-years prior to capsule placement. It is possible that over this period of time large proportions of fertilizer nutrients would have been made unavailable through plant uptake and ground water leaching or would have been retained in the soil in a form that was unavailable to resin capsules.

Ion-exchange resin capsule adsorption levels differed by nutrient along the soil depth profile (Figures 3a-3e). NO_3-N adsorption for both fertilizer treatments were highest at the "A" placement level (organic/mineral interface), then incrementally declined through placement levels "B" and "C" " from 0 – 24" belowground and then increased slightly near the bottom of the soil profile or "D" placement level at 24" (Figure 3a). Since resin capsules absorb nutrients in solution, the u-shaped pattern could be due to higher plant nutrient uptake in the B and C placement levels, thus decreasing soil solution nutrients available to the capsules. Control NO_3-N adsorption patterns were generally the same by depth. Additionally, no strong differences were detected for NH_4-N or S ion adsorption levels by depth for any treatments (Figures 3b and 3c). Potassium and B absorption values showed similar absorption patterns by depth and treatment with both the control and the N-Only treatment showing uniform values throughout the soil profile (Figures 3d and 3e). Multi-nutrient treatment K and B absorption declined with soil depth. Potassium values were more than six times higher at the "A" level than the "D" level and more than three times higher for B.

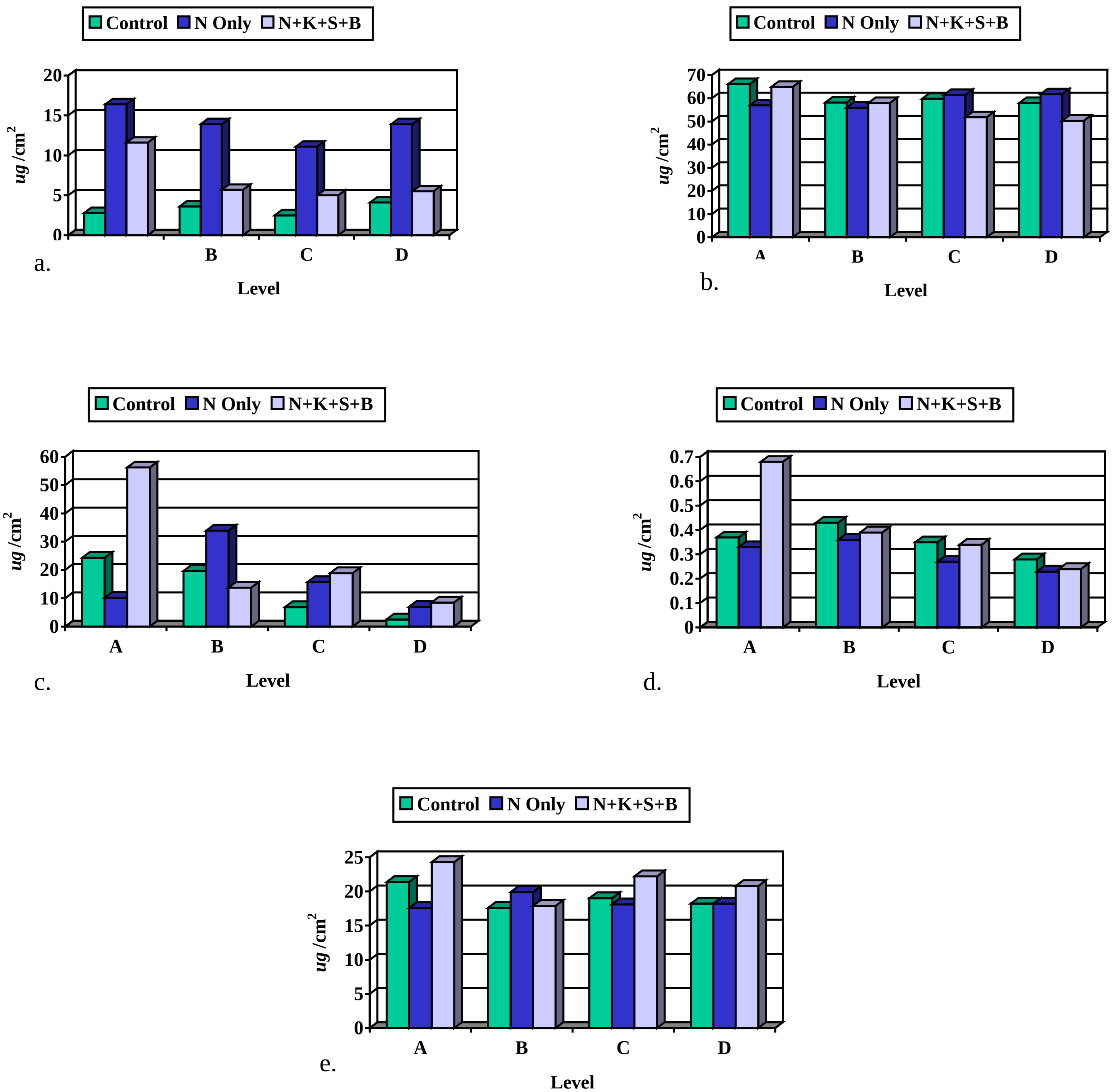

Figure 3. Resin adsorption quantities for NO3-N (a), NH4-N (b), K (c), SO4-S (d) and B (e) at different soil depths under three fertilization treatments at Vanstone northeast Washington

Soil Strength

Soil strength (density) measured by a Rimiks cone probe penetrometer was not significantly different around live trees as compared to dead trees on the site, except at 20cm belowground (Table 7). In general, soil strength was slightly higher under live trees compared with that under dead trees and soil strength measurements tended to increase with soil depth. Even though these results suggest that soil strength was not closely associated with western larch mortality, it is the opinion of field observers that the accurate measurement using the cone penetrometer in glacial till or soils with high concentrations of large coarse fraction may be difficult to obtain. In addition, field observations at the site support the theory that the site was highly disturbed from past logging practices, suggesting high soil disturbance.

Table 7 – Soil strength around live and dead trees in western larch stands at 10, 20, and 30 cm in the soil horizon at Vanstone, northeast Washington

Depth (cm)	Tree status	Soil density (kPa)	P > t
10	**Live**	1143	0.29
	Dead	1094	
20	**Live**	2020	0.02
	Dead	1840	
30	**Live**	2069	0.42
	Dead	2002	

CONCLUSIONS

The N+K treatment was most effective in reducing western larch mortality and improving stand growth relative to the control and to the other two fertilizer treatments over the four-year period. Factors contributing to differences in western larch mortality and stand productivity remain unclear but possible causes could be related to nutrient and water relationships plus past management practices that markedly affected tree mortality and growth during years 3 and 4 of this study. As indicated in the previous reports (Shaw et al. 1998, Xiao et al. 2001), stand growth potential in marginal environments (more than one limiting factor) is often determined by the more severe factor. Limited soil water supply at Vanstone could have greatly increased western larch mortality in N only and N+K+S+B treatments relative to the control and the N+K treatments. The results suggest that future fertilization silvicultural prescriptions in marginal environments may need to consider prevailing stand conditions, which may be different from environments with only one limiting factor such as insufficient soil nutrient supply.

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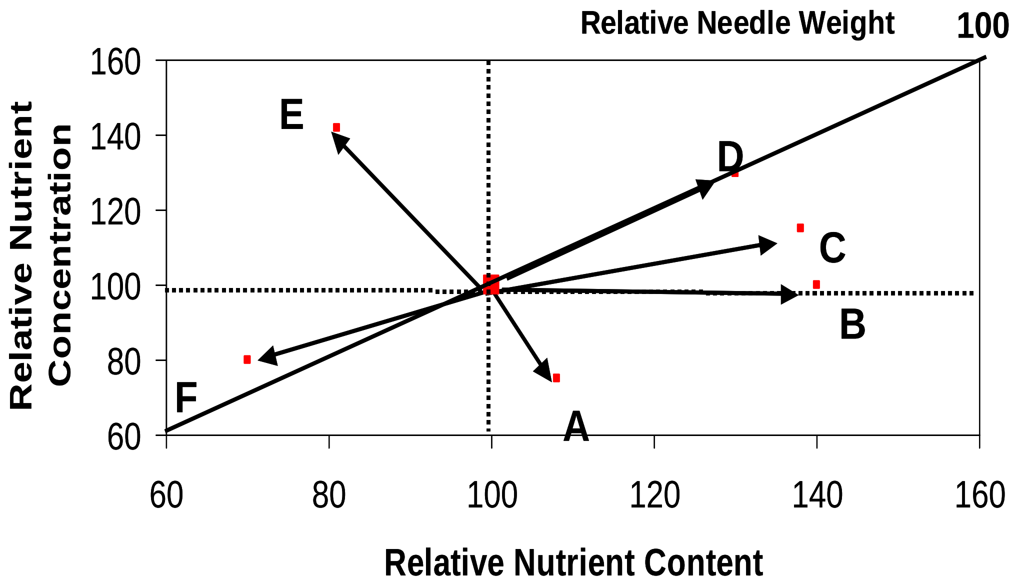
APPENDIX A

Table A1 – Plot mensurational characteristics for all live trees in the fall, 1999 (establishment) and July, 2004 (4.5 years after establishment) for Vanstone Western Larch multi-nutrient fertilization test site located on Boise timberlands in northeast Washington

MENSURATIONAL CHARACTERISTICS																				
Block	**1**				**2**				**3**				**4**				**5**			
Plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TRT	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
	Fall/1999																			
TPA	140	140	150	150	180	130	170	190	200	150	180	160	180	140	200	150	160	180	190	200
BA	10.4	10.5	10.4	11.1	15.3	9.2	11.7	15.2	11.5	14.9	8.7	13.7	7.9	7.4	8.9	8.4	8.0	10.4	7.8	7.4
CCF	11.0	11.2	11.9	13.4	16.1	9.5	12.5	16.5	13.5	16.7	11.4	14.7	8.8	8.7	11.5	9.8	8.9	11.2	8.7	9.0
RDI	5.4	5.4	5.5	5.8	7.7	4.8	6.2	7.8	6.4	7.2	5.1	6.9	4.7	4.2	5.3	4.7	4.6	5.8	4.7	4.6
QDBH	3.7	3.9	3.6	3.7	3.9	3.6	3.5	3.8	3.3	4.3	3.0	4.0	2.8	3.1	2.9	3.2	3.0	3.3	2.7	2.6
	July/2004																			
TPA	140	110	140	130	180	130	170	190	200	140	180	150	180	140	200	120	160	180	190	140
BA	17.7	16.1	18.6	18.4	26.3	19.3	24.3	30.5	21.6	25.8	19.5	24.9	16.8	16.3	20.2	15.9	16.6	22.6	18.8	13.3
CCF	17.9	16.5	20.8	20.9	26.3	18.8	24.4	31.0	23.5	27.1	23.1	25.3	17.4	17.6	23.7	17.5	17.0	22.8	19.4	15.3
RDI	8.0	7.0	8.1	7.9	11.9	8.5	10.7	13.0	10.0	10.5	8.8	10.5	8.1	7.4	9.3	6.9	7.9	10.3	9.0	6.3
QDBH	4.8	5.2	5.2	5.4	5.1	5.1	5.1	5.4	4.6	5.9	4.8	5.5	4.2	4.8	4.6	5.1	4.4	4.8	4.3	4.4
	Establishment % Basal Area by Species																			
WL	98	97	80	70	79	100	97	94	87	84	67	92	98	91	82	90	98	98	98	91
DF			20	30			3	6	10	13	20	8		9	18	10	2	2	2	9
LP					21				3	3	13									
GF	2	3											2							

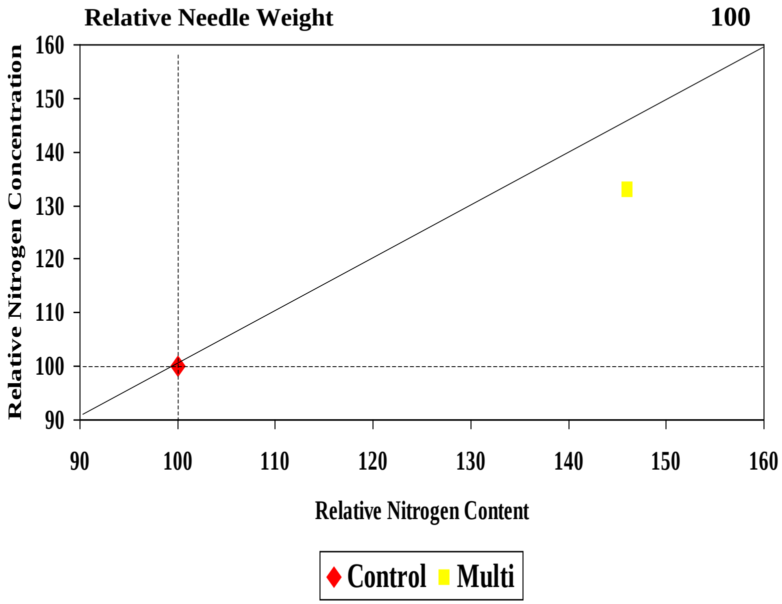
TRT – Treatment, TPA – Trees Per Acre, BA – Basal Area (sq/ft/ac), CCF – Crown Competition Factor, QDBH – Quadratic Mean Diameter, Relative Density Index. Treatments: 0 = Control; 1 = N-Only; 2 = N+K; 3

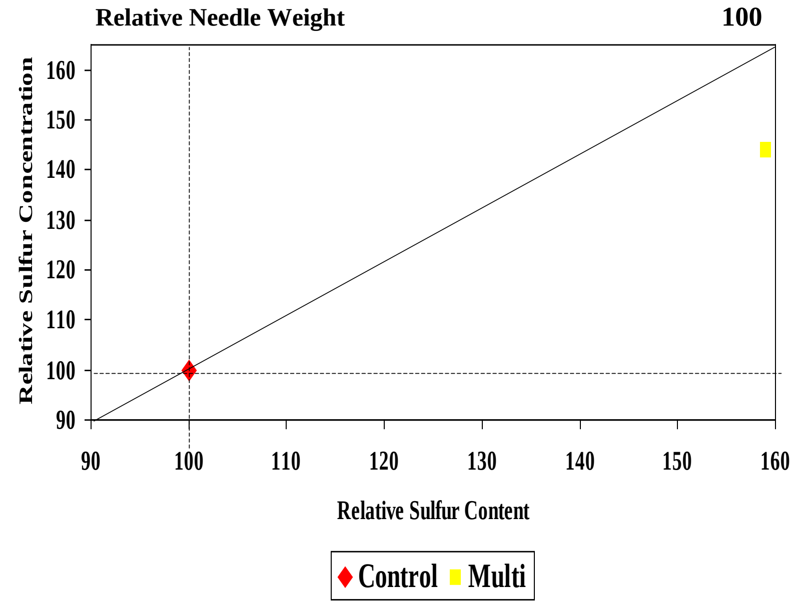
APPENDIX B

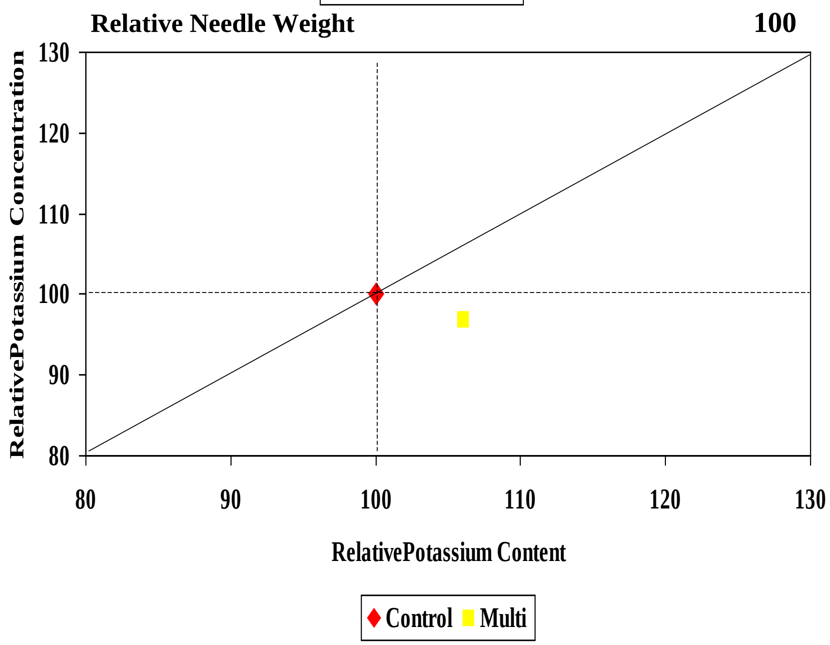


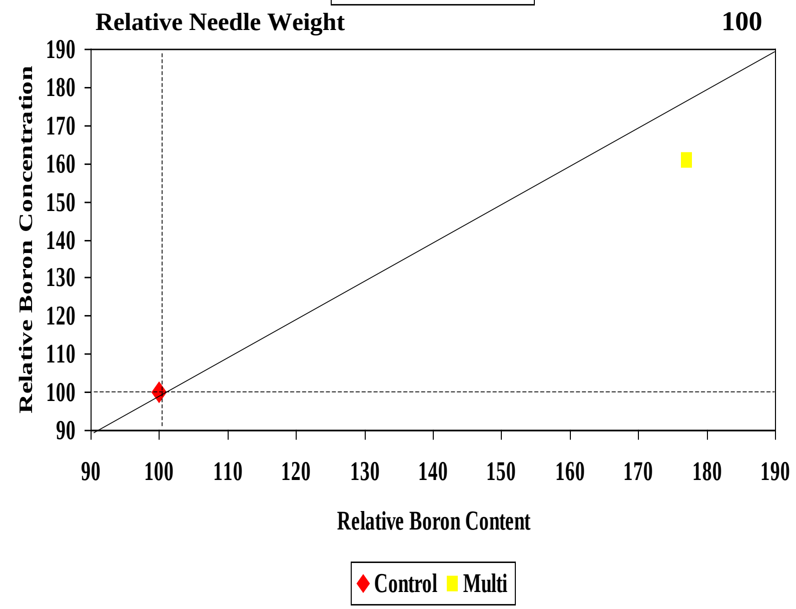
Vector analysis schematic chart showing various diagnostic shifts. Each shift is denoted by a capital letter (A through F). Shift interpretations are shown in Table ___. Nitrogen, sulfur, potassium and boron vector analysis for western larch at Vanstone, northeast Washington.

Relative Needle Weight	Relative Nutrient Concentration	Relative Nutrient Content	Shift	Interpretation	Possible Diagnosis
+	-	+/-	A	Dilution	Non-Limiting
+	-	0	A	Dilution	Non-Limiting
0	-	-/0	A	Dilution	Non-Limiting
+/0	0	+/0	B	Unchanged	Non-Limiting
+	+	+/0	C	Deficiency	Limiting
0	+	+/0	D	Luxury	Non-toxic
-	+	+/-	E	Excess	Toxic
-	+	0	E	Excess	Toxic
-	0	-	E/F	Excess	Toxic/Antagonistic
-	-	-	F	Excess	Antagonistic









Nitrogen, sulfur, potassium and boron vector analysis for western larch at Vanstone, northeast Washington.