Nitrogen and Potassium Concentrations after Fertilization on Mixed Conifer Stands in North Central Washington.

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Summary

Post fertilization foliar nitrogen and potassium concentrations and needle weights were examined for Douglas-fir (Pseudotsuga menzeisii), lodgepole pine (Pinus contorta) and ponderosa pine (Pinus ponderosa) in north central Washington. Foliar nitrogen concentration was found to increase and foliar potassium concentration to remain the same or decrease following fertilization. Lodgepole pine showed the most efficient uptake for both nitrogen and potassium. Potassium to nitrogen ratios decreased following treatment. Needle weights for lodgepole pine increased following fertilization. Foliar magnesium, boron, iron and zinc levels were also examined for lodgepole pine and ponderosa pine occurring on pumice soils versus glacial till soils. Response to treatment varied widely, but expected nutrient deficiencies due to pumice soils did not materialize except for lodgepole pine magnesium levels on untreated plots. Boron and iron showed unexpected increases on pumice soils following combined nitrogen and potassium treatment, leading us to suspect that some other soil layer may underlie the pumice soil.

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Methods

Study Area

This study was located on the Okanogan National Forest in north central Washington. Eight study sites were distributed evenly throughout the area on both the east and west sides of the Okanogan River. The sites were split between the Winthrop and Twisp Ranger Districts, except for one site on the Chelan District. Figure 1 shows the installation locations. The stands selected were younger stands in recently burned areas, and the intent was to determine whether fertilizing these stands would help hasten the rotation and bring them into production sooner by increasing growth rates and decreasing mortality rates.

Species studied were lodgepole pine (Pinus contorta), Douglas-fir (Pseudotsuga menzeisii) and ponderosa pine (Pinus ponderosa). Lodgepole pine alone was examined on three installations. Ponderosa pine alone was examined on two installations. Of the remaining three installations, one included ponderosa pine in combination with lodgepole pine, and the other two had Douglas-fir in combination with lodgepole pine.

Elevations for the eight installations ranged from 2900 to 5500 feet above sea level. Vegetation series were Douglas-fir and subalpine fir (Abies lasiocarpa). Parent material was glacial till, except for two installations with pumice soils. Three of the installations had ash layers, three had granite, and one had lacustrine soils. Table 1 shows the installation names, elevations, vegetation series, parent materials and species studied. Plot summary reports are included in Appendix A.

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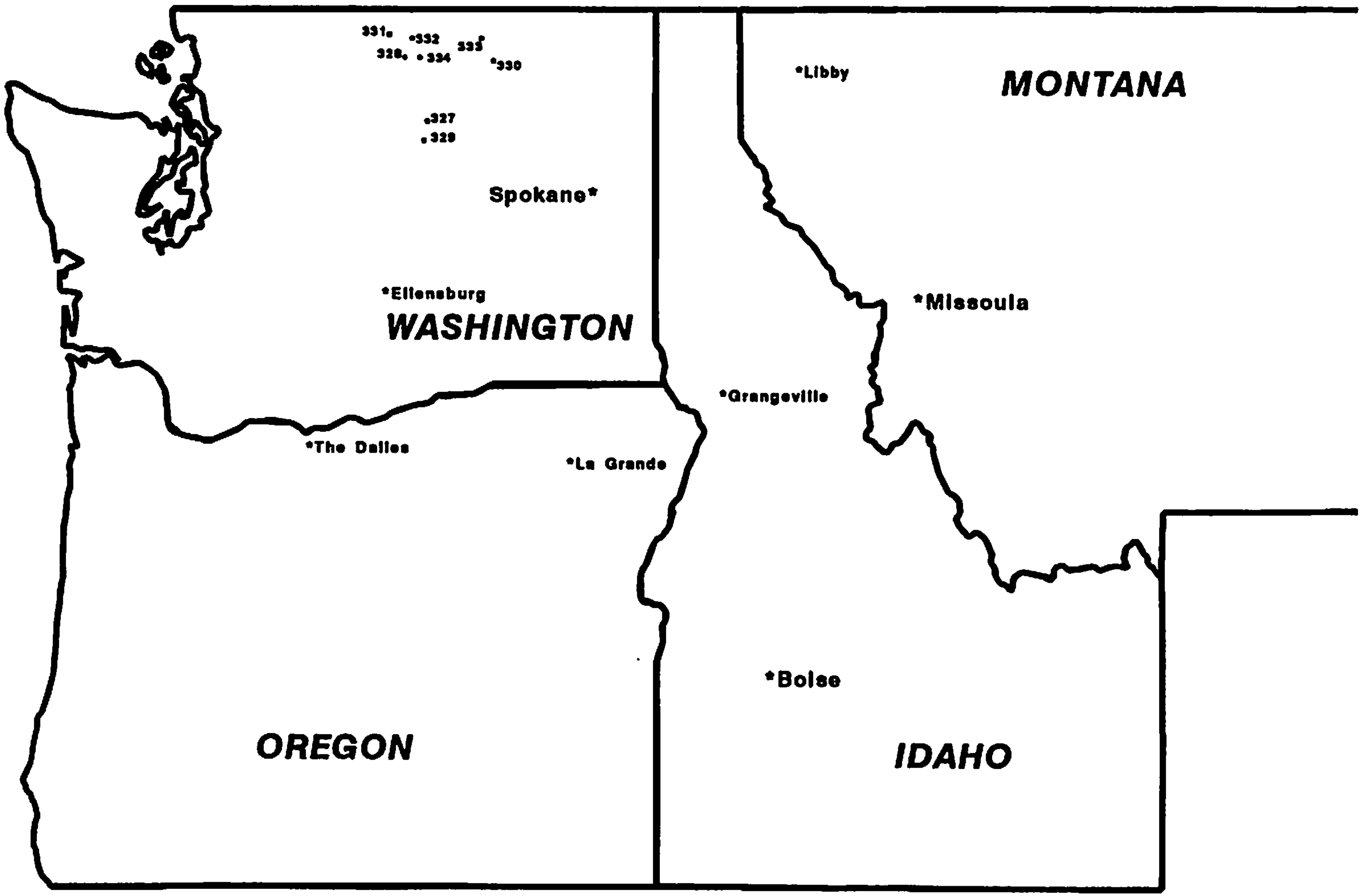

Mixed Species Okanogan Study Site

Table 1. Site characteristics for eight mixed conifer study sites located on the Okanogan National Forest in north central Washington.

Site	Elevation	Veg. Series	Parent Material
Benson Creek (327)	3360	PSME	Pumice
Blue Thin (328)	5200	ABLA	Ash/Glacial Till
Cooper Creek (329)	5500	PSME	Pumice/Granite
Lost Thin (330)	2900	PSME	Ash/Glacial Till
Black Pine (331)	5200	ABLA	Glacial Till/Granite
South Boulder (332)	4950	ABLA	Glacial Till/Granite
Bonaparte (333)	4250	ABLA	Ash/Glacial Till
Granite Creek (334)	4050	PSME	Glac.Till/Lacustrine

Design and Treatments

The eight study sites were established in 1993. Each installation consisted of six square plots 0.1 acre in size, with 20 to 40 foot buffer strips around them. For treatment, the plots were grouped into two blocks of three plots based on tree and site similarities. The three treatments included the control (C), 200 lbs (225 kg/ha) Nitrogen (N), and 200 lbs Nitrogen + 200 lbs Potassium (N+K). Nitrogen was applied in urea form, and potassium as potash (KCl). Treatment occurred in the fall of 1993.

Measurements

Initial measurements were taken in the fall of 1993. All live trees taller than 4.5 feet (1.35 m) were tagged and numbered. Measurements included diameter, height, crown ratio and defect. Diameters will be remeasured every two years on all trees, and any incidence of damage or mortality and the probable cause will be noted. Heights will be remeasured every four years.

Foliage samples were taken one year after treatment, in the fall of 1994. Two trees from each of the two most dominant species represented on each installation were selected for collection. Western larch (Larix occidentalis) was present as a dominant species on several of the installations, but was not tested because foliage had been shed by this time. At present, no satisfactory method for foliage collection and testing has been developed for western larch.

Climbers collected foliage from the third whorl of each tree. Current season foliage was clipped, placed in plastic bags, and stored in ice-cooled containers. In the laboratory, samples were oven-dried at 70 degrees centigrade for 24 hours, needles were separated from stems, and the separated needles were redried at 70 degrees centigrade for another 24 hours. Foliage was ground in preparation for chemical analysis.

Chemical analyses were performed for nitrogen (N), potassium (K), phosphorus (P), aluminum (Al), boron (B), calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mn), and zinc (Zn). Average concentrations and needle weights for each species examined are given by site in Appendix B.

Data Analyses

Tree foliar nutrient data were examined using analysis of variance. Six independent variables were examined, including foliar nitrogen (N) concentration, foliar N content, foliar potassium (K) concentration, foliar K content, K/N ratio, and needle weight. Two stages of analyses were performed. The first stage examined each of the three species individually for differences between installations using the following model:

(1) $Y_i = u + I_i + e_{ij}$, where:

Y_i = the observation from the *i*th installation
u = the experimental mean
I_i = the fixed effect from the *i*th installation
e_{ij} = experimental error

Results were considered significant at $p=0.05$ for lodgepole pine, which appeared on six installations, and $p=0.10$ for ponderosa pine and Douglas-fir, which appeared on three and two installations respectively.

If installation effects were found, site data was examined to determine whether vegetation series or parent material could explain the difference. If either of these factors was able to explain an effect, then similar installations were grouped for subsequent analysis. If neither of these factors was able to explain an effect, then installation was retained during the second stage of analysis. This stage compared species, sites and treatment responses for each of the six independent variables mentioned above using the following model:

(2) $Y_{ijk} = u + T_i * S_j * E_k + e_{ijk}$, where:

Y_{ijk} = the observation from the *k*th installation or group effect on the *j*th species on the *i*th treatment
u = the experimental mean
T_i = the effect of the *i*th treatment
S_j = the effect of the *j*th species
E_k = the effect of the *k*th installation or group
e_{ijkl} = the experimental error

General linear contrasts for these models were obtained using the general linear models procedure of the Statistical Analysis System (SAS Institute Inc. 1985).

An additional set of analyses was performed to compare the effects of pumice parent material, which occurred on two installations, and glacial till parent material, which occurred on the other six installations. Lodgepole pine and ponderosa pine occurred on the two installations with pumice parent material. The two glacial till installations containing Douglas-fir and were dropped from analysis since there were no Douglas-fir on pumice parent material with which to compare. This left a total of four installations with glacial till parent material tested against two installations with pumice parent material. Data for each species were grouped according to their occurrence with glacial till or with pumice parent material. Model 2 above was used for analysis of these data, with parent material effect used for E_k. The independent variables N, K, and K/N ratio were again used, and Mg, B, Fe, and Zn were also examined due to concerns regarding their concentration levels in trees on pumice soils (Ballard and Carter 1986, Will 1978, Barrett and Youngberg 1970, Will and Knight 1968, Will 1978).

For each species studied, critical and adequate nutrient concentration levels are presented in Table 2. If nutrients were present at levels below critical, trees were considered deficient in those nutrients. If nutrients were present at levels above adequate, trees were considered to have sufficient quantity for growth and functioning. Any level between critical and adequate was considered marginal.

Table 2. Critical and adequate foliar nutrient concentrations for three conifer species. Values are shown as ranging from critical (low) to adequate (high), with values in between considered marginal.

Foliar Nutrient Concentration	Douglas-fir[a]	Lodgpole Pine[b]	Ponderosa Pine[c]
N (%)	1.40-1.60	1.20-1.55	0.95-1.15
K (%)	0.60-0.80	0.40-0.55	0.48-0.70
P (%)	0.12-0.15	0.12-0.15	0.08-0.15
Ca (%)	0.15-0.25	0.06-0.10	0.05-0.30
Mg (%)	0.08-0.12	0.07-0.10	0.05-0.15
Mn (ppm)	15-25	4-25	4-25
Fe (ppm)	25-60	25-50	25-50
Zn (ppm)	10-15	10-15	10-15
B (ppm)	10-15	10-20	10-20
Mo (ppm)	0.1[*]	0.1[*]	0.1[*]

[*] Molybdenum is considered deficient in concentrations below 0.1 ppm and sufficient in concentrations above 0.1 ppm.

[a] From Webster and Dobkowski (1983)

[b] Based on Ballard and Carter (1986)

[c] Based on Powers (1988), Powers (1983), Zinke and Stangenberger (1979), and Boyer (1978)

Results and Discussion

Foliar Nitrogen

Results from Model 1 above indicated that for Douglas-fir, no significant differences ($p=.10$) occurred between installations, so installations 331 and 333 were grouped for nitrogen analysis. Lodgepole pine showed no differences between 331 and 333 ($p=.05$), so this group was both analyzed for response to fertilization and for comparison of lodgepole pine with Douglas-fir. On other installations, lodgepole pine showed differences between installations, therefore installations 328, 332 and 334 were individually examined. Ponderosa pine showed no differences between installations ($p=.10$), and therefore installations 327 and 330 were grouped. Installation 329 was examined separately in order to compare lodgepole pine with ponderosa pine. Analysis of variance information for foliar N concentration is presented in Table 3, followed by foliar N content in Table 4.

For Douglas-fir, the untreated plots indicate that the stand was below critical levels for nitrogen before fertilization. Addition of N or N+K succeeded in bringing the N concentration levels up to well above adequate. Examination of foliar N contents showed that Douglas-fir tended to take up nitrogen following fertilization. Lodgepole pine showed results similar to those for Douglas-fir, with foliar N concentrations on untreated plots below critical levels. However on the fertilized plots, while foliar N concentrations increased to above critical, they did not exceed adequate levels. These results are consistent with previous findings for lodgepole pine showing that while fertilization does increase foliar nutrient concentrations, these concentration levels are still considered deficient (Shaw and Moore 1994). Examination of foliar N contents for lodgepole pine show that N contents

Table 3. Average nitrogen concentrations (%) in current foliage by site, treatment and species.

Site & Treatment	Nitrogen Concentration (%)						Species [a] Contrasts	
	N(%)	% Response		N(%)	% Response		% Change by species	
327&330	PP							
C	1.27							
N	1.58		24					
N+K	1.43		14					
328	LP							
C	0.95							
N	1.27	**	34					
N+K	1.56	*	65					
329	LP			PP				
C	1.02			1.21				19
N	1.63	*	59	1.52		25		- 7
N+K	1.57	*	54	1.69	**	39		8
331&333	DF			LP				
C	1.09			1.09				0
N	1.61	*	49	1.35	*	24	**	-16
N+K	1.67	*	54	1.48	*	36		-11
332	LP							
C	1.14							
N	1.77	*	55					
N+K	1.71	*	50					
334	LP							
C	1.19							
N	1.31		11					
N+K	1.65	*	40					

Note: Means in rows are foliar nitrogen concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the nitrogen concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Species Contrast column indicates a significant difference between foliar nitrogen concentrations for the two species by treatment, using the same significance levels as listed above. The number in this column represents the percent difference between two species by treatment, with the first species as a basis for relative comparison.

Table 4. Average nitrogen content of current foliage by site, treatment and species.

Site & Treatment	Nitrogen Content (g/50 needles)					Species [a] Contrasts
	N(g)	% Response		N(g)	% Response	% Change by species
327&330	PP					
C	.0419					
N	.0559	*	33			
N+K	.0606	*	47			
328	LP					
C	.0111					
N	.0171		54			
N+K	.0274	*	147			
329	LP			PP		
C	.0136			.0420		* 209
N	.0302	*	122	.0505	20	* 67
N+K	.0256	**	88	.0520	24	* 103
331&333	DF			LP		
C	.0042			.0114		171
N	.0060		43	.0171	50	* 185
N+K	.0063		50	.0228	* 100	* 262
332	LP					
C	.0132					
N	.0313	*	137			
N+K	.0209		58			
334	LP					
C	.0161					
N	.0240		49			
N+K	.0312	*	94			

Note: Means in rows are foliar nitrogen contents for each species. Within each site means in columns are contents for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the nitrogen content indicates a significant difference in content between that treatment and the control. Percent differences between control and treatment contents are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Species Contrast column indicates a significant difference between foliar nitrogen contents for the two species by treatment, using the same significance levels as listed above. The number in this column represents the percent difference between two species by treatment, with the first species as a basis for relative comparison.

increased, often significantly, following application of N alone or N plus K, indicating that lodgepole is able to take up nitrogen following treatment. Ponderosa pine appeared least likely to show increased foliar N concentrations in response to fertilization. On control plots, ponderosa pine showed N concentrations well above adequate given requirements for the species. While fertilization did result in increased foliar nitrogen levels, it would appear that nitrogen was not limiting in ponderosa pine even before fertilization, which may be why it was less likely to show foliar response to treatment. Examination of foliar N contents for ponderosa pine showed a tendency to take up nitrogen following treatment. This uptake was significant for ponderosa pine on installations 327 & 330.

Species comparisons were made between Douglas-fir and lodgepole pine, and between ponderosa pine and lodgepole pine. Douglas-fir and lodgepole pine on control plots showed the same N concentrations, but Douglas-fir increased twice as much in N concentration as lodgepole pine after N fertilization, and increased 50% more in foliar N on the N+K treatment. However, while Douglas-fir did show greater foliar N concentrations than lodgepole after fertilization, a comparison of N contents shows that lodgepole pine took up more N than Douglas-fir following N fertilization, and significantly more N following N+K fertilization. This indicates that lodgepole pine was more efficient at N uptake than Douglas-fir. Compared to lodgepole, ponderosa pine started out with higher foliar N concentrations, but the increase in N concentration was much less than for lodgepole after both fertilization treatments. As a result, lodgepole and ponderosa pine had very comparable nitrogen concentrations following fertilization. An examination of N contents shows that due to its greater needle size, ponderosa pine maintained a greater N content than lodgepole both before and after treatment. However, ponderosa pine N content still showed a much lower rate of uptake than lodgepole pine N content.

Foliar Potassium

Statistical analysis using Model 1 showed that for Douglas-fir foliar potassium concentration, there were no significant differences between installations 331 and 333. Similarly, no significant differences were found between these two installations for lodgepole pine. Therefore, they were combined for subsequent analysis. No significant differences were found for lodgepole pine on installations 328, 332 and 334, so these were retained as a group for analysis. For ponderosa pine, installations 327 and 330 were similar, so they also were grouped for analysis. Installation 329 was examined separately in order to compare lodgepole pine with ponderosa pine. Analysis of variance information for K concentration is given in Table 5, and K content details are given in Table 6.

Critical and adequate foliar potassium concentrations for each species are shown in Table 2. Foliar K concentrations for Douglas-fir and lodgepole pine on untreated plots are approximately at adequate levels. Potassium concentrations for ponderosa pine on untreated plots are slightly above reported adequate levels. This suggests that potassium was not a limiting factor for any species before fertilization. Neither lodgepole pine nor ponderosa pine showed any foliar K concentration response to treatment. An examination of foliar K contents for these two species shows that there was a tendency towards K uptake following treatment, and this uptake was significant for ponderosa pine on installations 327 & 330 following application of N plus K. Douglas-fir K concentrations decreased to well below pre-treatment levels after N fertilization, but remained higher, though still below pre-

Table 5. Average potassium concentrations (%) in current foliage by site, treatment and species.

Site & Treatment	Potassium Concentration (%)					Species [a] Contrasts
	K(%)	% Response		K(%)	% Response	% Change by species
327&330	PP					
C	0.70					
N	0.71		1			
N+K	0.75		7			
328,332 &334	LP					
C	0.56					
N	0.55		-2			
N+K	0.60		7			
329	LP			PP		
C	0.59			0.89		* 51
N	0.71		19	0.83	- 7	17
N+K	0.72		21	0.82	- 8	14
331&333	DF			LP		
C	0.98			0.61		* -38
N	0.78	*	-21	0.58	- 5	* -26
N+K	0.87		-11	0.63	3	* -27

Note: Means in rows are foliar potassium concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the potassium concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Species Contrast column indicates a significant difference between foliar potassium concentrations for the two species by treatment, using the same significance levels as listed above. The number in this column represents the percent difference between two species by treatment, with the first species as a basis for relative comparison.

Table 6. Average potassium content of current foliage by site, treatment and species.

Site & Treatment	Potassium Content (g/50 needles)				Species Contrasts[a]
	K(g)	% Response	K(g)	% Response	% Change by species
327&330	PP				
C	.0225				
N	.0253	12			
N+K	.0313	* 39			
328,332&334	LP				
C	.0070				
N	.0090	29			
N+K	.0094	34			
329	LP		PP		
C	.0080		.0299		* 274
N	.0130	** 63	.0277	-7	* 113
N+K	.0119	49	.0251	-16	* 111
331&333	DF		LP		
C	.0037		.0066		78
N	.0029	-22	.0074	12	* 155
N+K	.0033	-11	.0093	* 41	* 181

Note: Means in rows are foliar potassium contents for each species. Within each site means in columns are contents for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the potassium content indicates a significant difference in content between that treatment and the control. Percent differences between control and treatment contents are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Species Contrast column indicates a significant difference between foliar potassium contents for the two species by treatment, using the same significance levels as listed above. The number in this column represents the percent difference between two species by treatment, with the first species as a basis for relative comparison.

treatment levels, after fertilization with both N and K. These results are consistent with previous findings (Shaw and Moore 1994, Mika and Moore 1991) and may be explained in part by growth dilution, which is a decrease in K concentration resulting from the growth flush induced by N fertilization (Jarrel and Beverly, 1981). Growth dilution was apparent after an examination of foliar K content for Douglas-fir showed that the decrease in potassium following fertilization was not significant.

These results indicated that potassium fertilization was not successful in raising foliar K concentration levels. Mika and Moore (1991) offer several suggestions as to why K fertilization does not result in increased potassium concentration, one of which is that K may be allocated to other portions of the tree which are undergoing active growth, such as phloem, fine roots, or flowering. This explanation could be relevant here, particularly considering that foliar K concentration levels were initially adequate. The same study found that the response of K foliage concentrations to fertilization is difficult to predict. Even though K uptake is not reflected by increased foliar concentrations, the addition of K still seems to show a positive response in the long term.

Species comparisons were made between Douglas-fir and lodgepole pine and between ponderosa pine and lodgepole pine. Douglas-fir foliar potassium concentration initially was significantly higher than lodgepole pine. However, after fertilization, Douglas-fir K concentration decreased proportionately more than lodgepole pine. Even so, Douglas-fir K concentrations after fertilization were significantly greater than lodgepole pine. These results are consistent with previous findings (Shaw and Moore 1994). An examination of untreated foliar K contents for these species shows no significant difference between them. However, lodgepole pine K content increased following fertilization with N alone, and significantly increased following application of N plus K, while Douglas-fir K contents tended to decrease following treatment. As a result, after fertilization lodgepole pine foliar K content was significantly greater than Douglas-fir foliar K content, indicating that lodgepole pine was more effective at K uptake than Douglas-fir. On installation 329 containing both lodgepole and ponderosa pine, lodgepole showed significantly lower foliar K concentrations than ponderosa on the control plots. In response to both treatments, however, lodgepole showed an average 20% increase in K concentration, while ponderosa pine decreased an average 8%. Thus, following treatment, the differences between lodgepole and ponderosa were insignificant, although ponderosa pine foliar K concentrations were still higher. An examination of K contents for this installation showed ponderosa pine with significantly greater K content, as to be expected given the larger needle weights. However, K content again tended to decrease in ponderosa pine following both fertilization treatments, while lodgepole K content increased following both treatments, with a significant increase for the N application. This indicated that the lodgepole pine was able to take up potassium following fertilization, while ponderosa on the same site was not. It should be noted that installation 329 occurred on pumice soil. Youngberg and Dyrness (1965) found that for ponderosa pine on pumice soils, additions of K did not give any response. Will and Knight (1968) suggest that for pumice parent materials, K supply is adequate for many trees regardless of fertilizer additions. These findings concur with our results, which indicate that foliar K concentrations for lodgepole and ponderosa pine on pumice soils were not deficient and did not change after N or N+K fertilization.

Foliar K/N Ratio

Foliar K/N ratio was examined for each species as a measure of nutrient balance which may be related to tree biochemical status. Tree biochemistry is important to tree resistance to insect and disease attack. The K/N ratios were analyzed using the same installation groupings as for the potassium analysis. Analysis of variance details are given in Table 7.

Ingestad (1967, 1979) suggested that for all conifers a foliar potassium to nitrogen concentration ratio of 50% would be critical, while a ratio of 65% would be optimal. For Douglas-fir, the K/N ratio on untreated plots was well above optimal; however, after fertilization with N alone or N plus K, the foliar K/N ratio dropped to critical levels. For lodgepole pine on all installations, the K/N ratio on untreated plots was barely above critical, and this ratio decreased to below critical levels on fertilized plots. For ponderosa pine on installations 327 & 330, the untreated plots showed foliar K/N ratios just below adequate, and after fertilization, these ratios dropped to critical levels. Ponderosa pine on installation 329 started out with a greater K/N ratio, but with the addition of N or N+K dropped to levels similar to those on installations 327 & 330.

These results are consistent with previous findings (Shaw and Moore 1994). For the current study, nitrogen fertilization appears to drive the K/N ratio, while the addition of potassium along with nitrogen does not seem to have an effect. This relates in part to the previous discussion of K wherein foliar K concentrations do not show response to K fertilization, although K may still be being taken up and allocated to other functions within the tree. Ericsson and Kahr (1993) suggest that actual critical levels of the K/N ratio may in

Table 7. Average K/N ratio by site, treatment and species.

Site & Treatment	K/N Ratio				Species [a] Contrasts
	K/N	% Response	K/N	% Response	% Change by species
327&330	PP				
C	58.8				
N	48.7	-17			
N+K	52.6	- 9			
328,332 &334	LP				
C	52.2				
N	39.7	* -25			
N+K	38.0	* -27			
329	LP		PP		
C	58.8		74.8		** 29
N	43.1	** -27	54.6	* -27	28
N+K	45.9	-22	50.8	* -32	13
331&333	DF		LP		
C	90.3		56.3		* -38
N	51.0	* -43	45.8	** -18	-10
N+K	53.4	* -41	42.4	* -23	** -21

Note: Means in rows are foliar potassium to nitrogen ratios for each species. Within each site means in columns are ratios for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the ratio indicates a significant difference between the control and treatment ratios. Percent differences between control and treatment ratios are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Species Contrast column indicates a significant difference between ratios for the two species by treatment, using the same significance levels as listed above. The number in this column represents the percent difference between ratios for the two species by treatment, with the first species as a basis for relative comparison.

fact be lower than 50% for growth, but that for other physiological processes to occur, the 65% or greater ratio is preferable.

Species comparison showed significant differences on untreated plots, as would be expected given the variation in N and K concentrations discussed previously. For the Douglas-fir/lodgepole pine comparison, lodgepole on untreated plots had foliar K/N ratios significantly lower than those of Douglas-fir. Addition of N alone caused a greater decrease in the Douglas-fir K/N ratio than for lodgepole, resulting in no difference between the two species following N application. Following fertilization with N plus K, Douglas-fir foliar K/N ratios decreased the same amount as N fertilization, but lodgepole showed a greater decrease. Thus, following fertilization with N plus K, lodgepole once again had a significantly lower K/N ratio than Douglas-fir. For those installations where ponderosa and lodgepole pine grew on the same control plots, ponderosa pine had a K/N ratio 29% greater than lodgepole. After N fertilization, both species showed a 27% decrease in K/N ratio. After N + K fertilization, ponderosa pine showed a 32% decrease while lodgepole showed a 22% decrease. Generally, ponderosa pine maintained greater K/N ratios than lodgepole pine, both before and after treatment.

Needle Weights

Initial analysis showed no differences in needle weight between the two Douglas-fir installations, but since lodgepole pine needle weights on those installations did differ, they were analyzed separately. Other lodgepole pine installations were grouped for comparison, except for installation 329 where it occurs in combination with ponderosa pine. The remaining two ponderosa pine installations also showed differences and were analyzed separately. Analysis of variance information is shown in Table 8.

Lodgepole pine needle weights for installations 328, 332 & 334 showed a significant positive response to N and N+K fertilization. On installation 331, where lodgepole pine appeared in combination with Douglas-fir, no significant weight change occurred. Lodgepole pine on installation 333, which also occurred in combination with Douglas-fir, was more consistent with the other installations. Ponderosa pine needle weights did tend to increase in weight in response to treatment, but the only significant increase was for the N+K treatment on installation 330. Douglas-fir needle weights did not show any response to treatment.

Pumice vs. Glacial Till Parent Materials

Nitrogen

Analysis of variance results for this comparison are found in Table 9. Both species on both parent material types responded well to fertilization. No significant differences were found between foliar N concentrations on either parent material type for either species, regardless of treatment. The only exception was that ponderosa pine on pumice showed significantly lower N concentrations than ponderosa on glacial till after N fertilization. Youngberg and Dyrness (1970) report that nitrogen does tend to be a limiting element in pumice soils, though we did not find this to be a problem.

Potassium

Analysis of variance information for this comparison is found in Table 10. For lodgepole pine, untreated foliar K concentrations were the same for both parent material

Table 8. Average needle weight (g/50 needles) of current foliage by site, treatment and species.

Site & Treatment	Needle Weights (g/50 needles)					
	Weight		% Change	Weight		% Change
327	PP					
C	3.04					
N	3.45		13			
KN	3.40		11			
328,332 &334	LP					
C	1.23					
N	1.64	*	35			
KN	1.58	**	2			
329	LP			PP		
C	1.34			3.32		
N	1.89	**	41	3.33		0.1
KN	1.62		21	3.06		- 8
330	PP					
C	3.44					
N	3.49		2			
KN	4.99	*	45			
331	DF			LP		
C	0.398			1.00		
N	0.395		-0.6	0.89		-11
KN	0.410		3.0	1.16		17
333	DF			LP		
C	0.360			1.12		
N	0.350		- 3	1.64		46
KN	0.347		- 4	1.88	*	67

Note: Means in rows are foliage weights for each species. Within each site means in columns are weights for control (C), nitrogen (N) and nitrogen plus potassium (N+K) treatments. An asterisk next to the weight indicates a significant difference between the control and treatment weights. Percent differences between control and treatment weights are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

Table 9. Average foliar nitrogen concentrations (%) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type: Glacial Till		Pumice		Parent Material[a] Contrasts
Species	N(%)	% Response	N(%)	% Response	% Change by Parent Material
LP					
C	1.09		1.02		- 6
N	1.46	* 35	1.62	* 59	11
N+K	1.64	* 52	1.58	* 54	- 4
PP					
C	1.38		1.18		-14
N	1.77	* 27	1.47	* 23	** -17
N+K	1.44	31	1.56	* 3	8

Note: Means in rows are foliar nitrogen concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the nitrogen concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar nitrogen concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

Table 10. Average foliar potassium concentrations (%) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type: Glacial Till		Parent Material Type: Pumice		Parent Material[a] Contrasts	
Species	K(%)	% Response	K(%)	% Response		% Change by Parent Material
LP						
C	0.560		0.595			6
N	0.554	-2	0.710	19	*	28
N+K	0.602	7	0.724	21	**	20
PP						
C	0.681		0.811		**	19
N	0.733	7	0.788	-2		8
N+K	0.701	3	0.813	1		16

Note: Means in rows are foliar potassium concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the potassium concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar potassium concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

types. However, upon application of N and N+K treatments, foliar K concentrations became significantly greater for the lodgepole on pumice soils versus those on glacial till. Conversely, for ponderosa pine, control K concentrations were significantly higher on pumice than on glacial till, but following treatment showed no significant differences by parent material type. Several studies have indicated that fertilizer additions to pumice soils show no effect on ponderosa or radiata pine (Youngberg and Dyrness 1965, Will and Knight 1968). Further investigation of the response for lodgepole pine may be warranted.

Foliar K/N Ratio

Analysis of variance information for this comparison is found in Table 11. Generally, K/N ratios were higher for lodgepole pine on pumice than for lodgepole pine on glacial till, though not significantly so. Lodgepole pine K/N ratios tended to decrease following fertilization on both parent material types. Ponderosa pine also showed higher K/N ratios on pumice than on glacial till, and in this case the differences were significant for both the control and N treatment levels. Ponderosa pine on glacial till showed only a slight decrease (2%) following N+K treatment, while ponderosa on pumice showed a greater decrease (24%); however the ponderosa on pumice still showed a greater K/N ratio than on glacial till.

Magnesium

Analysis of variance information is given in Table 12. Critical and adequate levels for Mg are shown with other nutrients in Table 2. Magnesium is reported to be a deficient element on pumice soils (Will 1978, Will 1966, Barrett and Youngberg 1970). In this study foliar Mg concentration was significantly lower for lodgepole pine on pumice parent material

Table 11. Average ratios of foliar potassium to nitrogen (K/N) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type				Parent Material[a] Contrasts	
	Glacial Till		Pumice			
Species	K/N	% Response	K/N	% Response		% Change by Parent Material
LP						
C	0.522		0.588			12
N	0.397	* -25	0.431	** -26		21
N+K	0.379	* -27	0.460	-22		21
PP						
C	0.500		0.712		*	42
N	0.422	-15	0.549	* -22	**	30
N+K	0.490	- 2	0.536	* -24		9

Note: Means in rows are foliar potassium to nitrogen ratios for each species. Within each site means in columns are ratios for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the ratio indicates a significant difference between the control and treatment ratios. Percent differences between control and treatment ratios are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar K/N ratios on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between ratios for the two species by treatment, with the response on glacial till as a basis for relative comparison.

Table 12. Average foliar magnesium concentrations (%) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type				Parent Material[a] Contrasts	
	Glacial Till		Pumice			
Species	Mg(%)	% Response	Mg(%)	% Response		% Change by Parent Material
LP						
C	0.115		0.091		*	-21
N	0.097	* -11	0.069	-23	*	-29
N+K	0.103	- 5	0.079	-14	*	-23
PP						
C	0.100		0.085			-15
N	0.099	-.2	0.095	13		- 4
N+K	0.112	12	0.088	4	*	-21

Note: Means in rows are foliar magnesium concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the magnesium concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar magnesium concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

than on glacial till. While Mg concentrations for lodgepole were adequate on glacial till, they were only marginal on pumice. Addition of N or N+K to lodgepole on pumice resulted in a further decrease in Mg, though this decrease is not significant. For ponderosa pine, Mg concentrations did not significantly differ between parent material types, though concentrations tended to be lower on the pumice soils. Concentrations in both cases were marginal for ponderosa pine. The N+K treatment did result in glacial till having a significantly greater Mg level than the same treatment on pumice soil. In other work, potassium fertilization on pumice soils has been shown to result in high K/Mg ratios in the soil, which may result in greater Mg deficiencies in the trees (Will and Knight 1968).

Boron

Analysis of variance information for boron is given in Table 13, and critical and adequate foliar nutrient concentrations in Table 2. Boron is reported to be a problem nutrient on volcanic soils (Ballard and Carter 1986, Will 1978). However, we found that not only were B concentrations near or above reported adequate levels, but that both species showed greater B concentrations on pumice than on glacial till soils. For ponderosa pine, neither the addition of N or N+K resulted in significant differences from untreated levels. However, for lodgepole pine, the addition of combined N and K fertilizers showed a significant (.0001) increase in foliar B concentration, which was a 48% increase over the control concentration.

Zinc

Analysis of variance information for zinc is given in Table 14, and nutrient level information in Table 2. For lodgepole pine on untreated plots, foliar Zn concentration was

Table 13. Average foliar boron concentrations (ppm) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type				Parent Material[a] Contrasts	
	Glacial Till		Pumice			
Species	ppm	% Response	ppm	% Response		% Change by Parent Material
LP						
C	19.88		24.17			22
N	18.7	-2	23.05	-5		23
N+K	19.80	1	35.92	48	*	81
PP						
C	21.00		19.50			-7
N	20.85	-1	21.34	8		2
N+K	19.52	-7	19.41	2		-1

Note: Means in rows are foliar boron concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the boron concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$
** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar boron concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

Table 14. Average foliar zinc concentrations (ppm) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type: Glacial Till			Pumice		Parent Material[a] Contrasts	
Species	ppm		% Response	ppm	% Response		% Change by Parent Material
LP							
C	54.39			43.83		**	-19
N	49.28		-4	49.50	13		-.4
N+K	55.14		5	54.40	24		- 1
PP							
C	47.85			43.66			- 8
N	47.32		- 1	45.26	3		- 4
N+K	59.40	**	24	45.81	5	*	-22

Note: Means in rows are foliar zinc concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the zinc concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar zinc concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

significantly lower on the pumice installations than on the glacial till. However, in response to fertilization, Zn levels increased greatly on pumice soils and only slightly on glacial till soils, resulting in similar Zn concentrations for both parent material types following treatment. For ponderosa pine, on the other hand, Zn concentrations were about the same on untreated plots for both parent material types. However, while no changes resulted from the N treatment on either parent material, the N+K treatment caused foliar Zn concentrations to increase significantly on glacial till, but show no change on pumice. As a result, Zn concentrations were significantly lower on pumice soils following N+K fertilization.

<u>Iron</u>

Analysis of variance and critical nutrient levels for Fe are shown in Tables 15 and 2, respectively. Lodgepole pine Fe concentrations on the glacial till soils were at critical levels, while on pumice soils Fe concentrations were significantly greater, and were at adequate levels. On both parent materials, Fe concentration tended to increase after N or N+K fertilization. For lodgepole pine on pumice, the increase was highly significant ($p=.0001$) following N+K fertilization. For ponderosa pine on untreated plots, Fe concentrations on glacial till soils were not different from pumice soils. Fertilization caused Fe concentrations to drop from marginal to critical for ponderosa pine on glacial till, and also to become significantly lower than Fe concentrations on pumice, which remained marginal following fertilization. Barrett and Youngberg (1970) state that Fe may be a crucial element for ponderosa pine on pumice soils. However we found that for both ponderosa and lodgepole pine, foliar Fe concentrations were greater on pumice than on glacial till soils, although they were still below adequate levels.

Table 15. Average foliar iron concentrations (ppm) by site, treatment and species for lodgepole pine and ponderosa pine on pumice and glacial till parent materials.

Species & Treatment	Parent Material Type: Glacial Till		Pumice		Parent Material[a] Contrasts	
Species	ppm	% Response	ppm	% Response	% Change by Parent Material	
LP						
C	22.84		29.97		**	31
N	24.21	13	34.67	16	*	43
N+K	26.17	21	43.50	* 45	*	66
PP						
C	32.98		32.53			-1
N	25.95	-21	34.31	5	**	32
N+K	26.03	-21	32.64	1		25

Note: Means in rows are foliar iron concentrations for each species. Within each site means in columns are concentrations for control (C), nitrogen (N), and nitrogen plus potassium (N+K) treatments. An asterisk next to the iron concentration indicates a significant difference between the control and treatment concentrations. Percent differences between control and treatment concentrations are also listed. Asterisks have the following significance:

* $p \leq 0.05$

** $p \leq 0.10$

[a] An asterisk in the Parent Material Contrasts column indicates a significant difference between foliar iron concentrations on the two parent materials for that species and treatment, using the same significance levels as listed above. The number in this column represents the percent difference between concentrations for the two species by treatment, with the response on glacial till as a basis for relative comparison.

Conclusions

Response of foliar nutrient levels and needle weights to N and N+K treatments varied greatly by species and treatment. Generally, fertilization resulted in increased foliar N concentration levels for all species studied, with Douglas-fir showing the greatest concentration after fertilization, followed by lodgepole pine and then ponderosa pine. Comparison of foliar N contents showed that lodgepole pine was the most efficient of the three species in nitrogen uptake. Foliar potassium concentrations overall did not show a great response to fertilization; Douglas-fir showed a significant decrease while lodgepole and ponderosa pine stayed about the same. A comparison of species showed that following treatment, Douglas-fir K concentration decreased significantly more than lodgepole, while lodgepole K decreased significantly more than ponderosa. Examination of K contents showed that lodgepole pine was the most efficient in K uptake, followed by ponderosa pine and then Douglas-fir. Foliar potassium to nitrogen (K/N) ratios tended to decrease in response to both treatments. Douglas-fir showed the most dramatic decrease from above adequate to critical levels, followed by ponderosa pine with average ratios decreasing from adequate to critical levels, followed by lodgepole pine dropping from critical to below critical. Species comparisons indicated that after treatment, Douglas-fir foliar K/N ratio decreased more than lodgepole, but still maintained a higher K/N ratio overall. Lodgepole pine and ponderosa pine decreased about the same relative amount after fertilization, with ponderosa having a greater K/N ratio than lodgepole. An examination of needle weights showed that lodgepole and ponderosa pine needles increased in weight following treatment, though the increase was significant only for lodgepole. Douglas-fir needle weights did not increase after fertilization.

Overall, fertilization did affect foliar nutrition regimes of the three species studied. Nitrogen concentrations were raised from critical to adequate, and potassium levels for lodgepole and ponderosa pine were maintained at adequate levels. Douglas-fir foliar potassium concentrations were decreased to below critical levels. Some of the decrease in K concentrations may be explained through growth dilution effects. Future biochemical analysis should help explain where potassium is going in these trees. A combination of the increased N concentrations and equal or decreased K concentrations following treatment resulted in K/N ratios dropping to critical or below critical levels. Depending on results of biochemical analysis, we may be able to predict whether we will see increased susceptibility to root problems on the treated plots as a result of N fertilization.

Expected nutrient deficiencies due to pumice soils did not materialize. Nitrogen concentrations did not show any differences due to parent materials. Potassium concentrations and K/N ratios were greater on pumice than on glacial till, though still below adequate levels. Boron, iron and zinc concentrations were not deficient on pumice soils, nor were their concentration levels significantly different from the glacial till soils. The lodgepole pine on pumice soils which received the N+K treatment showed highly significant increases in boron and iron levels. The only element to show the expected deficiency due to pumice soil was magnesium in lodgepole pine, which showed significantly lower levels than lodgepole on glacial till.

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Appendix A: Plot Summary Reports

PLOT SUMMARY REPORT

INSTALLATION 327 BENSON CREEK

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T32N R23E SECTION 35 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	N+K	CON	CON	N+K	200#N	200#N
SITE CHARACTERISTICS:						
SLOPE (%)	11	11	15	12	12	8
ASPECT (DEGREES)	160	166	180	162	142	180
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	230	220	250	230	220	190
LIVE BASAL AREA (SQ.FT/A)	89.9	93.0	84.8	88.1	89.9	71.8
CROWN COMPETITION FACTOR	82	82	77	78	78	68
RELATIVE DENSITY INDEX	30.9	31.4	30.2	30.4	30.6	24.9
SITE HEIGHT (FT)	47.6	50.5	43.6	45.4	44.3	44.9
MEAN DIAMETER (IN)	8.5	8.8	7.9	8.4	8.7	8.3
AVERAGE CROWN RATIO (%)	69	66	64	61	68	62
AVERAGE CROWN LENGTH (FT)	28.2	24.9	24.0	22.8	25.9	24.4
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	9.0	3.0	5.4	2.1	0.0	19.9
PONDEROSA PINE	91.0	97.0	94.6	97.9	100.0	80.1

PLOT SUMMARY REPORT

INSTALLATION 328 BLUE THIN

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T33N R23E SECTION 19 MERIDIAN: WILLAMETTE

	PLOT NUMBER 1	2	3	4	5	6
TREATMENT	200#N	N+K	CON	N+K	200#N	CON
SITE CHARACTERISTICS:						
SLOPE (%)	34	35	34	33	43	27
ASPECT (DEGREES)	214	214	213	199	199	200
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	300	340	280	250	240	260
LIVE BASAL AREA (SQ.FT/A)	39.8	41.1	39.8	38.9	52.6	49.6
CROWN COMPETITION FACTOR	46	47	45	44	57	55
RELATIVE DENSITY INDEX	17.9	18.9	17.6	16.8	20.9	20.4
SITE HEIGHT (FT)	42.7	35.0	37.9	42.3	44.6	38.5
MEAN DIAMETER (IN)	4.9	4.7	5.1	5.3	6.3	5.9
AVERAGE CROWN RATIO (%)	42	44	45	54	59	53
AVERAGE CROWN LENGTH (FT)	14.5	14.8	15.7	20.4	24.4	21.6
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	1.0	0.0	0.0	0.0	0.0	0.0
LODGEPOLE PINE	99.0	100.0	100.0	100.0	100.0	100.0

PLOT SUMMARY REPORT

INSTALLATION 329 COOPER CREEK

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T29N R22E SECTION 15 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	CON	N+K	200#N	CON	200#N	N+K
SITE CHARACTERISTICS:						
SLOPE (%)	20	10	15	17	14	20
ASPECT (DEGREES)	162	148	162	168	190	168
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	370	450	440	460	340	370
LIVE BASAL AREA (SQ.FT/A)	17.8	19.0	18.6	21.2	17.7	18.2
CROWN COMPETITION FACTOR	20	22	22	25	20	21
RELATIVE DENSITY INDEX	10.3	11.4	11.1	12.4	10.1	10.5
SITE HEIGHT (FT)	17.3	19.2	18.7	20.4	16.8	16.2
MEAN DIAMETER (IN)	3.0	2.8	2.8	2.9	3.1	3.0
AVERAGE CROWN RATIO (%)	83	81	82	82	81	82
AVERAGE CROWN LENGTH (FT)	10.0	9.4	9.5	9.6	9.5	9.8
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	0.0	0.0	0.0	0.1	0.0	1.7
LODGEPOLE PINE	37.3	36.4	45.2	51.0	34.2	24.5
PONDEROSA PINE	62.7	63.6	54.8	48.9	65.8	73.8

PLOT SUMMARY REPORT

INSTALLATION 330 LOST THIN

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T35N R30E SECTION 25 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	N+K	200#N	CON	CON	200#N	N+K
SITE CHARACTERISTICS:						
SLOPE (%)	2	3	2	2	2	2
ASPECT (DEGREES)	100	100	129	130	130	130
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	170	140	160	140	170	180
LIVE BASAL AREA (SQ.FT/A)	88.6	100.9	94.7	92.4	100.8	89.2
CROWN COMPETITION FACTOR	76	84	79	77	86	77
RELATIVE DENSITY INDEX	28.3	29.8	29.3	27.9	31.2	28.9
SITE HEIGHT (FT)	49.3	63.8	56.2	60.3	64.9	51.9
MEAN DIAMETER (IN)	9.8	11.5	10.4	11.0	10.4	9.5
AVERAGE CROWN RATIO (%)	73	54	56	60	65	60
AVERAGE CROWN LENGTH (FT)	29.9	30.9	28.3	32.4	33.1	27.1
SPECIES COMPOSITION (% OF BA)						
PONDEROSA PINE	100.0	100.0	100.0	100.0	100.0	100.0

PLOT SUMMARY REPORT

INSTALLATION 331   BLACK PINE

REGION: CENTRAL WASHINGTON   OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T36N R19E SECTION 1   MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	N+K	200#N	CON	CON	200#N	N+K
SITE CHARACTERISTICS:						
SLOPE (%)	30	40	38	44	32	27
ASPECT (DEGREES)	229	229	229	229	229	210
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	200	290	330	240	210	230
LIVE BASAL AREA (SQ.FT/A)	43.8	30.9	37.4	36.9	46.4	46.5
CROWN COMPETITION FACTOR	47	37	44	42	52	50
RELATIVE DENSITY INDEX	17.4	14.7	17.5	16.0	18.4	18.8
SITE HEIGHT (FT)	41.2	33.1	38.1	37.1	38.0	44.6
MEAN DIAMETER (IN)	6.3	4.4	4.6	5.3	6.4	6.1
AVERAGE CROWN RATIO (%)	82	80	78	86	86	83
AVERAGE CROWN LENGTH (FT)	26.9	19.5	18.6	24.1	29.4	31.9
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	0.0	14.9	18.2	11.0	11.6	0.0
SUBALPINE FIR	3.4	0.0	0.0	0.0	3.7	0.0
LODGEPOLE PINE	94.8	80.3	73.5	83.9	80.8	96.1
ENGELMANN SPRUCE	1.8	4.8	8.3	5.1	3.9	3.9

PLOT SUMMARY REPORT

INSTALLATION 332 SOUTH BOULDER

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T36N R22E SECTION 24 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	200#N	N+K	200#N	N+K	CON	CON
SITE CHARACTERISTICS:						
SLOPE (%)	5	10	10	5	8	16
ASPECT (DEGREES)	210	185	22	30	5	195
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	800	1210	790	630	830	900
LIVE BASAL AREA (SQ.FT/A)	36.0	31.8	32.5	36.8	30.7	32.5
CROWN COMPETITION FACTOR	44	40	41	45	39	41
RELATIVE DENSITY INDEX	21.2	21.5	19.6	20.4	19.0	20.3
SITE HEIGHT (FT)	22.0	21.9	25.8	24.4	23.6	23.6
MEAN DIAMETER (IN)	2.9	2.2	2.7	3.3	2.6	2.6
AVERAGE CROWN RATIO (%)	84	84	83	86	82	82
AVERAGE CROWN LENGTH (FT)	12.8	10.0	12.3	15.1	11.4	11.5
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	0.0	0.0	0.0	0.0	0.0	0.0
WESTERN LARCH	1.9	5.7	0.0	0.0	0.0	4.3
LODGEPOLE PINE	95.4	93.1	100.0	100.0	100.0	95.2
PONDEROSA PINE	2.7	1.2	0.0	0.0	0.0	0.5

PLOT SUMMARY REPORT

INSTALLATION 333 BONAPARTE
REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.
LEGAL DESCRIPTION: T39N R30E SECTION 33 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	N+K	N+K	200#N	200#N	CON	CON
SITE CHARACTERISTICS:						
SLOPE (%)	15	16	15	14	15	15
ASPECT (DEGREES)	320	320	341	280	300	280
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	390	520	450	670	650	640
LIVE BASAL AREA (SQ.FT/A)	30.9	27.9	31.0	31.3	34.7	38.4
CROWN COMPETITION FACTOR	32	30	33	33	37	41
RELATIVE DENSITY INDEX	15.8	15.7	16.4	18.3	19.6	21.1
SITE HEIGHT (FT)	25.2	25.7	24.3	27.2	29.9	24.0
MEAN DIAMETER (IN)	3.8	3.1	3.6	2.9	3.1	3.3
AVERAGE CROWN RATIO (%)	85	81	82	82	82	82
AVERAGE CROWN LENGTH (FT)	15.3	12.2	13.2	12.3	12.8	13.0
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	1.0	2.9	0.3	0.7	1.2	0.3
SUBALPINE FIR	0.0	0.0	0.0	0.0	0.2	0.0
WESTERN LARCH	92.9	59.3	68.1	81.0	79.9	66.4
LODGEPOLE PINE	6.1	37.8	31.6	18.3	18.6	33.3
ENGELMANN SPRUCE	0.0	0.0	0.0	0.0	0.0	0.0

PLOT SUMMARY REPORT

INSTALLATION 334 GRANITE CREEK

REGION: CENTRAL WASHINGTON OWNERSHIP: OKANOGAN N.F.

LEGAL DESCRIPTION: T35N R23E SECTION 12 MERIDIAN: WILLAMETTE

	PLOT NUMBER					
	1	2	3	4	5	6
TREATMENT	N+K	CON	200#N	200#N	CON	N+K
SITE CHARACTERISTICS:						
SLOPE (%)	20	8	18	7	12	15
ASPECT (DEGREES)	4	4	26	2	24	24
MENSURATIONAL CHARACTERISTICS:						
AT TIME OF TREATMENT (*)						
LIVE TREES PER ACRE	270	290	510	380	300	270
LIVE BASAL AREA (SQ.FT/A)	92.9	77.2	86.7	99.2	99.8	92.1
CROWN COMPETITION FACTOR	86	70	81	89	88	85
RELATIVE DENSITY INDEX	33.0	29.2	36.7	37.7	35.7	32.7
SITE HEIGHT (FT)	67.9	66.0	73.1	78.6	75.8	72.2
MEAN DIAMETER (IN)	7.9	7.0	5.6	6.9	7.8	7.9
AVERAGE CROWN RATIO (%)	72	73	78	77	74	76
AVERAGE CROWN LENGTH (FT)	27.8	20.2	16.9	22.6	25.2	29.7
SPECIES COMPOSITION (% OF BA)						
DOUGLAS-FIR	21.1	12.6	25.4	1.0	0.0	6.9
SUBALPINE FIR	0.0	0.0	0.0	0.0	0.5	0.0
WESTERN LARCH	59.6	77.5	54.3	79.5	81.0	92.5
LODGEPOLE PINE	19.2	10.0	20.4	19.5	17.8	0.7
ENGELMANN SPRUCE	0.0	0.0	0.0	0.0	0.6	0.0

Appendix B: Foliar Nutrient Concentrations Summary Reports

Foliar Nutrient Concentrations Summary Report

Installation 327 BENSON CREEK
Region: Central Washington
Legal Description : T32N R23E Section 35

Ownership: USFS, Okanogan N.F.
Meridian: Willamette

Species: PONDEROSA PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	CONT	CONT	2N+2K	2N	2N
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.580	1.250	1.075	1.295	1.460	1.360
Phosphorus (%)	0.166	0.162	0.142	0.160	0.177	0.141
Potassium (%)	0.826	0.667	0.798	0.787	0.904	0.586
Calcium (%)	0.159	0.125	0.117	0.095	0.085	0.162
Magnesium (%)	0.107	0.099	0.087	0.080	0.098	0.101
Manganese (ppm)	95.0	111.0	83.9	99.6	64.9	141.0
Zinc (ppm)	56.45	49.45	37.65	42.00	46.15	40.35
Iron (ppm)	35.55	34.55	36.90	33.75	35.55	40.30
Boron (ppm)	22.65	20.20	27.55	21.10	23.40	29.85
Copper (ppm)	3.435	2.775	2.430	2.780	3.575	2.125
Aluminum (ppm)	143.0	170.0	225.5	135.8	170.5	250.0
Molybdenum (ppm)	0.539	0.379	0.680	0.262	0.572	0.477
Sodium (ppm)	67.2	64.7	47.0	43.7	53.7	128.8
NEEDLE WEIGHT (g/100 needles)	3.926	2.798	3.302	2.871	2.992	3.912

Foliar Nutrient Concentrations Summary Report

Installation 328 BLUE THIN
Region: Central Washington
Ownership: USFS, Okanogan N.F.
Legal Description : T35N R23E Section 19
Meridian: Willamette

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N	2N+2K	CONT	2N+2K	2N	CONT
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.065	1.220	0.900	1.900	1.470	0.990
Phosphorus (%)	0.109	0.119	0.104	0.140	0.135	0.122
Potassium (%)	0.575	0.556	0.574	0.582	0.602	0.551
Calcium (%)	0.180	0.199	0.211	0.176	0.189	0.169
Magnesium (%)	0.095	0.120	0.103	0.093	0.083	0.092
Manganese (ppm)	98.7	96.2	121.0	102.5	134.0	87.5
Zinc (ppm)	40.30	64.20	50.05	54.05	57.00	46.35
Iron (ppm)	24.20	24.25	26.25	22.65	27.60	28.10
Boron (ppm)	14.25	22.15	28.70	25.55	22.25	26.15
Copper (ppm)	3.870	6.210	2.800	2.945	3.165	2.905
Aluminum (ppm)	392.5	499.0	593.0	588.0	556.0	523.5
Molybdenum (ppm)	0.860	0.913	0.971	0.746	0.630	0.802
Sodium (ppm)	69.0	69.4	61.9	37.9	57.4	62.4
NEEDLE WEIGHT (g/100 needles)	1.335	1.697	1.208	1.788	1.352	1.160

Foliar Nutrient Concentrations Summary Report

Installation 329 COOPER CREEK
Region: Central Washington
Legal Description : T29N R22E Section 15

Ownership: USFS, Okanogan N.F.
Meridian: Willamette

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	CONT	2N+2K	2N	CONT	2N	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.050	1.550	1.870	0.990	1.380	1.600
Phosphorus (%)	0.130	0.153	0.184	0.135	0.131	0.140
Potassium (%)	0.609	0.705	0.871	0.583	0.551	0.744
Calcium (%)	0.179	0.144	0.155	0.177	0.150	0.265
Magnesium (%)	0.090	0.064	0.084	0.092	0.055	0.093
Manganese (ppm)	74.0	65.6	67.3	77.2	44.0	103.3
Zinc (ppm)	44.30	49.95	58.60	43.35	40.40	58.85
Iron (ppm)	29.85	37.00	35.75	30.10	33.60	50.00
Boron (ppm)	20.70	26.65	25.90	27.65	20.20	45.20
Copper (ppm)	2.940	2.930	3.125	3.310	2.120	5.505
Aluminum (ppm)	432.0	418.5	480.0	535.0	419.5	602.0
Molybdenum (ppm)	0.594	0.532	0.872	0.696	0.571	0.788
Sodium (ppm)	71.5	64.9	92.3	64.2	57.3	100.3
NEEDLE WEIGHT (g/100 needles)	1.538	1.683	1.684	1.139	2.107	1.553

Species: PONDEROSA PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	CONT	2N+2K	2N	CONT	2N	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.400	1.630	1.475	1.025	1.565	1.750
Phosphorus (%)	0.185	0.188	0.184	0.161	0.152	0.161
Potassium (%)	0.931	0.873	0.799	0.849	0.866	0.771
Calcium (%)	0.146	0.146	0.111	0.092	0.159	0.172
Magnesium (%)	0.091	0.081	0.090	0.063	0.092	0.083
Manganese (ppm)	61.2	60.0	42.1	36.5	66.6	56.6
Zinc (ppm)	46.20	39.35	45.40	41.35	49.15	45.45
Iron (ppm)	30.80	25.25	32.80	27.85	28.60	36.00
Boron (ppm)	15.65	14.90	17.15	14.60	14.95	19.00
Copper (ppm)	3.715	3.410	3.430	3.170	5.505	3.045
Aluminum (ppm)	342.5	211.0	197.5	189.0	258.0	318.5
Molybdenum (ppm)	0.394	0.363	0.487	0.460	0.433	0.734
Sodium (ppm)	43.3	35.9	71.4	63.6	64.4	70.1
NEEDLE WEIGHT (g/100 needles)	4.440	3.212	3.773	2.207	2.884	2.901

Foliar Nutrient Concentrations Summary Report

Installation 330 LOST THIN
Region: Central Washington
Ownership: USFS, Okanogan N.F.
Legal Description : T35N R30E Section 25
Meridian: Willamette

Species: PONDEROSA PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	2N	CONT	CONT	2N	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.470	1.540	1.335	1.435	1.995	1.400
Phosphorus (%)	0.244	0.220	0.227	0.200	0.202	0.179
Potassium (%)	0.682	0.644	0.778	0.584	0.823	0.720
Calcium (%)	0.124	0.092	0.080	0.115	0.093	0.101
Magnesium (%)	0.120	0.109	0.096	0.103	0.090	0.103
Manganese (ppm)	93.5	66.5	63.8	118.2	55.1	59.6
Zinc (ppm)	67.05	42.80	46.85	48.85	51.85	51.75
Iron (ppm)	25.65	23.25	36.10	29.85	28.65	26.40
Boron (ppm)	20.85	19.90	21.30	20.70	21.80	18.20
Copper (ppm)	4.870	2.935	4.110	3.985	4.115	4.835
Aluminum (ppm)	106.0	57.5	147.1	99.4	104.2	122.7
Molybdenum (ppm)	0.602	0.833	0.899	1.075	1.182	0.885
Sodium (ppm)	109.5	58.2	64.1	62.9	40.2	68.6
NEEDLE WEIGHT (g/100 needles)	5.080	3.151	3.144	3.730	3.838	4.917

Foliar Nutrient Concentrations Summary Report

Installation 331 BLACK PINE
Region: Central Washington
Legal Description : T36N R19E Section 1
Ownership: USFS, Okanogan N.F.
Meridian: Willamette

Species: DOUGLAS-FIR

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	2N	CONT	CONT	2N	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.450	1.540	1.140	1.100	1.300	1.470
Phosphorus (%)	0.180	0.212	0.209	0.208	0.185	0.160
Potassium (%)	0.696	0.919	0.961	1.050	0.829	0.805
Calcium (%)	0.506	0.255	0.432	0.260	0.330	0.340
Magnesium (%)	0.079	0.107	0.100	0.120	0.074	0.085
Manganese (ppm)	129.0	171.5	232.0	161.7	174.7	120.5
Zinc (ppm)	11.70	25.50	19.95	26.95	19.05	17.00
Iron (ppm)	30.85	26.95	25.70	25.75	36.80	17.90
Boron (ppm)	22.45	29.55	21.25	16.55	23.95	15.45
Copper (ppm)	3.765	2.390	2.480	3.110	3.545	2.595
Aluminum (ppm)	231.0	218.0	218.5	167.5	243.5	158.0
Molybdenum (ppm)	0.194	0.286	0.194	0.195	0.295	0.219
Sodium (ppm)	123.0	70.3	58.9	59.7	69.4	51.9
NEEDLE WEIGHT (g/100 needles)	0.361	0.418	0.376	0.421	0.374	0.459

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	2N	CONT	CONT	2N	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.295	1.435	1.210	0.890	1.265	1.710
Phosphorus (%)	0.165	0.132	0.137	0.119	0.133	0.143
Potassium (%)	0.613	0.634	0.624	0.466	0.506	0.851
Calcium (%)	0.221	0.157	0.174	0.212	0.153	0.145
Magnesium (%)	0.128	0.073	0.102	0.083	0.103	0.077
Manganese (ppm)	167.5	95.9	105.9	142.5	119.5	102.5
Zinc (ppm)	46.00	41.90	40.75	36.40	40.80	37.30
Iron (ppm)	25.90	25.75	26.25	30.70	27.15	18.65
Boron (ppm)	18.35	24.75	27.90	17.70	16.10	23.00
Copper (ppm)	2.470	2.660	3.250	2.335	2.515	2.755
Aluminum (ppm)	479.0	370.0	504.0	932.0	713.0	260.0
Molybdenum (ppm)	0.630	0.458	0.525	0.837	0.639	0.490
Sodium (ppm)	69.2	83.4	45.1	53.7	62.0	53.2
NEEDLE WEIGHT (g/100 needles)	1.147	0.891	0.906	1.086	0.890	1.177

Foliar Nutrient Concentrations Summary Report

Installation 332 SOUTH BOULDER
Region: Central Washington
Legal Description : T36N R22E Section 24

Ownership: USFS, Okanogan N.F.
Meridian: Willamette

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N	2N+2K	2N	2N+2K	CONT	CONT
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.900	1.590	1.640	1.830	1.085	1.200
Phosphorus (%)	0.162	0.137	0.135	0.129	0.118	0.146
Potassium (%)	0.571	0.687	0.647	0.593	0.545	0.658
Calcium (%)	0.176	0.195	0.168	0.179	0.133	0.205
Magnesium (%)	0.116	0.104	0.097	0.108	0.102	0.109
Manganese (ppm)	103.9	126.0	101.8	104.6	108.6	125.5
Zinc (ppm)	58.65	51.70	51.65	49.15	45.00	52.25
Iron (ppm)	33.90	25.30	24.90	31.05	17.65	16.70
Boron (ppm)	19.95	19.05	22.60	14.30	15.55	19.05
Copper (ppm)	2.135	2.665	2.980	4.170	2.290	2.720
Aluminum (ppm)	508.0	443.5	398.0	508.0	649.0	580.0
Molybdenum (ppm)	0.600	0.574	0.478	0.603	0.650	0.556
Sodium (ppm)	73.9	48.6	76.0	146.5	61.0	58.6
NEEDLE WEIGHT (g/100 needles)	2.062	1.295	1.504	1.166	1.069	1.233

Foliar Nutrient Concentrations Summary Report

Installation 333 BONAPARTE
Region: Central Washington
Legal Description : T39N R30E Section 33
Ownership: USFS, Okanogan N.F.
Meridian: Willamette

Species: DOUGLAS-FIR

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	2N+2K	2N	2N	CONT	CONT
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.815	1.935	1.750	1.855	1.100	1.010
Phosphorus (%)	0.239	0.220	0.232	0.225	0.208	0.163
Potassium (%)	1.039	0.955	0.647	0.720	1.015	0.904
Calcium (%)	0.329	0.313	0.260	0.323	0.412	0.333
Magnesium (%)	0.117	0.102	0.106	0.115	0.134	0.096
Manganese (ppm)	106.5	83.4	78.2	98.8	81.5	84.3
Zinc (ppm)	19.35	25.25	24.05	25.85	29.70	17.75
Iron (ppm)	20.70	30.90	35.15	30.15	28.60	18.15
Boron (ppm)	27.75	28.85	28.60	20.20	21.55	20.60
Copper (ppm)	2.780	2.810	4.915	4.590	6.905	3.745
Aluminum (ppm)	116.5	120.5	83.8	96.8	69.2	47.7
Molybdenum (ppm)	0.549	0.499	0.444	0.401	0.501	0.448
Sodium (ppm)	73.5	60.4	87.9	67.5	68.1	57.8
NEEDLE WEIGHT (g/100 needles)	0.268	0.427	0.334	0.366	0.466	0.256

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	2N+2K	2N	2N	CONT	CONT
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.355	1.575	1.445	1.250	1.050	1.200
Phosphorus (%)	0.135	0.123	0.121	0.131	0.138	0.163
Potassium (%)	0.505	0.558	0.635	0.553	0.700	0.660
Calcium (%)	0.211	0.159	0.189	0.179	0.132	0.170
Magnesium (%)	0.098	0.078	0.099	0.088	0.087	0.121
Manganese (ppm)	61.1	63.0	93.0	69.1	68.8	61.0
Zinc (ppm)	52.90	48.00	44.75	54.85	53.40	65.20
Iron (ppm)	7.95	22.45	15.55	22.30	32.35	37.35
Boron (ppm)	20.85	19.60	21.30	19.95	22.35	26.70
Copper (ppm)	2.680	4.095	3.365	7.410	5.875	5.595
Aluminum (ppm)	72.6	136.0	101.4	81.9	214.5	70.8
Molybdenum (ppm)	1.011	0.659	0.576	0.789	0.839	1.530
Sodium (ppm)	42.0	81.4	47.4	67.2	65.3	67.4
NEEDLE WEIGHT (g/100 needles)	1.723	2.038	1.422	1.857	1.144	1.100

Foliar Nutrient Concentrations Summary Report

Installation 334 GRANITE CREEK

Region: Central Washington — Ownership: USFS, Okanogan N.F.

Legal Description : T35N R23E Section 12 — Meridian: Willamette

Species: LODGEPOLE PINE

	PLOT NUMBER					
	1	2	3	4	5	6
Treatment	2N+2K	CONT	2N	2N	CONT	2N+2K
Foliar Nutrient Concentrations:						
Nitrogen (%)	1.410	1.045	1.360	1.210	1.325	2.140
Phosphorus (%)	0.126	0.127	0.116	0.111	0.119	0.188
Potassium (%)	0.604	0.462	0.489	0.327	0.576	0.581
Calcium (%)	0.160	0.200	0.100	0.206	0.152	0.139
Magnesium (%)	0.089	0.161	0.076	0.133	0.126	0.106
Manganese (ppm)	130.0	164.5	112.0	176.0	143.0	143.0
Zinc (ppm)	50.10	75.15	34.15	58.60	57.55	68.10
Iron (ppm)	20.05	21.90	14.10	17.00	26.45	41.30
Boron (ppm)	18.05	15.40	16.20	15.20	14.45	19.70
Copper (ppm)	3.125	2.370	2.550	1.710	2.990	2.670
Aluminum (ppm)	310.0	468.0	198.0	172.0	371.0	330.0
Molybdenum (ppm)	0.456	0.567	0.404	0.296	0.529	0.455
Sodium (ppm)	101.1	64.7	67.1	37.4	77.1	61.9
NEEDLE WEIGHT (g/100 needles)	1.635	1.243	1.929	1.643	1.453	2.223