Six-year growth response of the Umatilla and four-year growth response of the Okanogan mixed conifer stands to N, N+K and N+S fertilization

Mariann T. Garrison

James A. Moore

Peter G. Mika

Terry M. Shaw

Intermountain Forest Tree Nutrition Cooperative

Technical Report

April 1998

Six-year growth response of the Umatilla and four-year growth response of the Okanogan mixed conifer stands to N, N+K and N+S fertilization

Introduction

Two studies to examine the effects of fertilization on mixed conifer stands were designed and established by the Intermountain Forest Tree Nutrition Cooperative (IFTNC) in the early 1990's. The first study was located on the Umatilla National Forest in northeastern Oregon and southwestern Washington, and was established in the fall of 1991. The second study was located on the Okanogan National Forest in north central Washington, and was established in the fall of 1993. Each study consisted of eight installations.

All installations on both studies were located in mixed conifer stands. Elevations for the Umatilla study ranged from 4500 to 5500 feet, and vegetation series included grand fir (Abies grandis) and subalpine fir (Abies lasiocarpa). Parent materials on the Umatilla sites were basalts. The Okanogan elevations ranged from 2900 to 5500 feet, and vegetation series included Douglas-fir (Pseudotsuga menziesii) and subalpine fir (Abies lasiocarpa). Parent materials on the Okanogan were primarily granitic and sedimentary types. Site characteristics for the eight installations at each study area are shown in Table 1. Also included are locations for the Umatilla study and dominant species groupings for the Okanogan study, which were used during analyses.

Methods

The eight installations on each National Forest were set up in the fall of the establishment year. Each installation consisted of 6 plots 0.1-ac in size, surrounded by a 20-ft buffer. The six plots at each installation were grouped into two blocks of three based on tree and site similarities. Three treatments were then applied to the three plots in each block.

The treatments for the Umatilla were a control (C), 200 lb/ac nitrogen (N), and 200 lb/ac N+100 lb/ac S (N+S). The treatments for the Okanogan included the control (C), 200 lb/ac nitrogen (N), and 200 lb/ac N plus 170 lb/ac potassium (N+K). Treatment information is also included in Table 1. Nitrogen was applied as urea, sulfur as ammonium sulfate, and potassium as murate of potash. On the Umatilla sites receiving the N+S treatment, a portion of the N came from the ammonium sulfate, and the remainder from urea.

Table 1. Site characteristics for sixteen mixed conifer study sites located on the Umatilla and Okanogan National Forests.

Umatilla Study: Established 1991. Treatments: C, N, N+S				
Location	Site	Elevation	Veg.Series	Parent Material
1 (NE)	313: Pomeroy #1	5500	ABLA	Grand Ronde Basalt
	314: Pomeroy #2	5000	ABGR	Grand Ronde Basalt
2	315: Tollgate #1	4500	ABGR	Lower Yakima Basalt
	316: Tollgate #2	5500	ABGR	Lower Yakima Basalt
3	320: Ukiah	4800	ABGR	Upper Yakima Basalt
4 (SW)	317: Heppner #1	4780	ABGR	Picture Gorge Basalt
	318: Heppner #2	4800	ABGR	Picture Gorge Basalt
	319: Heppner #3	4800	ABGR	Picture Gorge Basalt
Okanogan Study: Established 1993. Treatments: C, N, N+K				
Dominant Species	Site	Elevation	Veg.Series	Parent Material
Ponderosa	327: Benson Cr.	3360	PSME	Gneiss
	330: Blue Thin	2900	ABLA	Granite
Lodgepole	328: Cooper Cr.	5200	ABLA	Mixed, Metadiorite
	331: Lost Thin	5200	ABLA	Mix: volcanic/sandstone
	332: Black Pine	4950	ABLA	Biotite granodiorite
Western larch	333: S.Boulder	4250	ABLA	Mixed, metamorph./seds.
	334: Bonaparte	4050	PSME	Granodiorite
Mixed	329: Granite Cr.	5000	PSME	Biotite granodiorite

Initial measurements were taken on all sites at the time of installation during the fall of the establishment year. All live trees taller than 4.5 ft (dbh) were tagged and measured for height, diameter and defect. Two years later, diameters were remeasured, and any incidence of mortality and probable cause were noted. Four years after establishment, diameters and heights were remeasured, damages or mortality noted, and ingrowth recorded. This four-year

measurement occurred in the fall of 1995 for the Umatilla sites, and in the fall of 1997 for the Okanogan sites. Six years after establishment, diameters were remeasured on the Umatilla sites. This took place in the fall of 1997. Six-year measurements are scheduled for 1999 for the Okanogan sites. Mensurational data are summarized in the appendices for both National Forests.

Tree volumes for these sites were estimated using regional species-specific volume equations (Wykoff et al. 1982). Since tree heights were measured as part of the four-year measurement on the Okanogan, these values were used for volume estimates. Tree heights for the six-year Umatilla analysis were estimated by projecting the annual growth rate from the year-four height measurements, and this height estimate was used to make six-year volume estimates. The analyses and results of the four- and six-year responses to fertilization of the Okanogan and Umatilla Forests, respectively, are reported here.

Differences in gross volume increment (GVI) between treatments and across installations were examined for both studies. For the Okanogan study, relative gross volume increment as a percentage of initial volume was also examined (RGVI), as well as height increment (HG). These values were calculated as follows:

$$GVI = (Volume_n - Volume_0) \quad (1)$$
where n = years since establishment

$$RGVI = (GVI/Volume_0)*100 \quad (2)$$

$$HG = (Height_n - Height_0) \quad (3)$$
where n = years since establishment

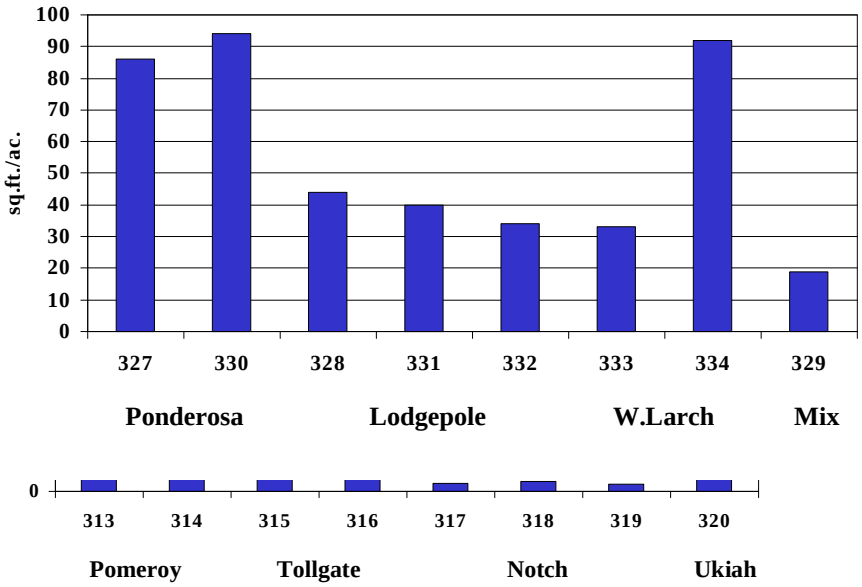
Geographic locations were included in the Umatilla analysis, and dominant species groupings in the Okanogan analysis. All analyses were run as analysis of variance (ANOVA)

procedures in the general linear models module of SAS (SAS Institute Inc. 1985). Results were considered significant at p=.10.

Results and Discussion

Average initial basal area conditions for the Umatilla study are shown by installation within location in Figure 1a. This same information is portrayed for the Okanogan N.F. by

Figure 1b: Initial basal areas for the Okanogan mixed conifer study



installation within dominant species type in Figure 1b. This information was included to show initial conditions for both study areas, and will also be used later in analysis as a covariate.

Gross Volume Increment (GVI)

Gross volume growth over the time period since establishment (GVI) for both studies was calculated as described previously. The volume increments for each study were analyzed for overall treatment effects using the following model:

GVI = f(installation, block(installation), BA_0, treatment)

Treatment responses were also calculated per individual installation, and adjusted to initial basal area (BA_0). Results of overall treatment effects are given in Tables 2a and 2b for the Umatilla and Okanogan studies, respectively.

On the Umatilla study, the eight study sites were situated in four geographic locations which run northeast to southwest. This geographic location was found to have a significant effect, and was therefore used for further analysis. Similarly, the Okanogan sites were classified as having one of four dominant species in the overstory. This species classification was also found to be significant and was used for further analysis. The following ANOVA models were used in determining differences by location or dominant species:

Umatilla:

GVI = f(location, installation(location), BA_0, treatment, location*treatment)

Okanogan:

GVI = f(dominant species, installation(dominant species), BA_0, treatment)

Location-level and dominant species-level volume growth estimates were adjusted to initial basal areas. Tables 2a and 2b show the results of this analysis by location for the Umatilla and by dominant species group for the Okanogan. Installation-level values are illustrated by location and dominant species in Figures 2a and 2b, respectively.

Table 2a. Gross six-year volume growth for the Umatilla National Forest study sites by geographical location.

Location	Treatment	Growth (ft3/ac)	Contrast (ft3/ac)	%

1 (Pomeroy)	Control	735			
	200N	872	N-Control	138	19
	200N+100S	930	NS-Control	196	27
			NS-N	58	7
2 (Tollgate)	Control	1163			
	200N	1225	N-Control	62	5
	200N+100S	1295	NS-Control	132	11
			NS-N	70	6
3 (Ukiah)	Control	508			
	200N	449	N-Control	-59	-12
	200N+100S	461	NS-Control	-47	-9
			NS-N	12.3	3
4(Heppner)	Control	259			
	200N	221	N-Control	-39	-15
	200N+100S	272	NS-Control	13	5
			NS-N	52	23
Overall	Control	635			
	200N	663	N-Control	28	4
	200N+100S	716	NS-Control	**81	13
			NS-N	**53	8

**Comparison of overall treatment effects significant at p= .05

Table 2b. Gross four-year volume growth for the Okanogan National Forest study sites by dominant species.

Dominant Species	Treatment	Growth (ft3/ac)	Contrast (ft3/ac)		%
Ponderosa	Control	363			
	200N	385	N-Control	22	6
	200N+170K	424	NK-Control	61	17
			NK-N	39	10
Lodgepole	Control	273			
	200N	357	N-Control	84	31
	200N+170K	417	NK-Control	144	53
			NK-N	59	17
W. Larch	Control	383			
	200N	416	N-Control	33	9
	200N+170K	411	NK-Control	28	7
			NK-N	-6	-1
Mix	Control	231			
	200N	277	N-Control	46	20
	200N+170K	256	NK-Control	26	11
			NK-N	-21	-7
Overall	Control	318			
	200N	369	N-Control	51	16
	200N+170K	397	NK-Control	**80	25
			NK-N	28	7

**Comparison of overall treatment effects significant at p= .05

Figure 2a. Six-year volume response by location for installations on the Umatilla National Forest

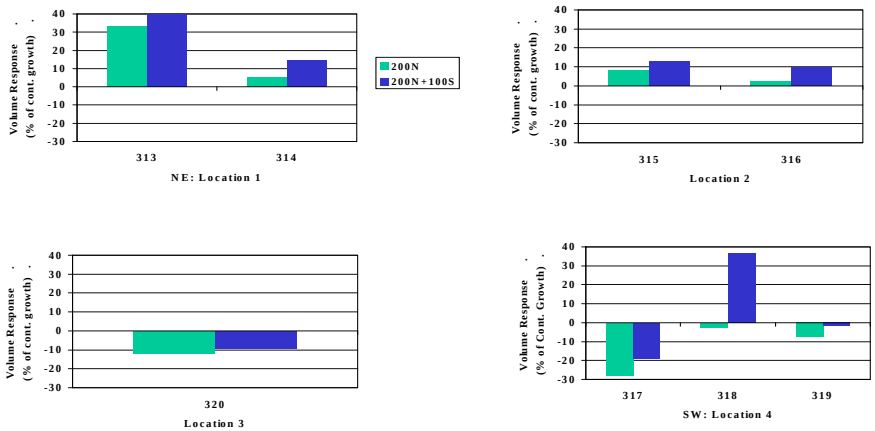
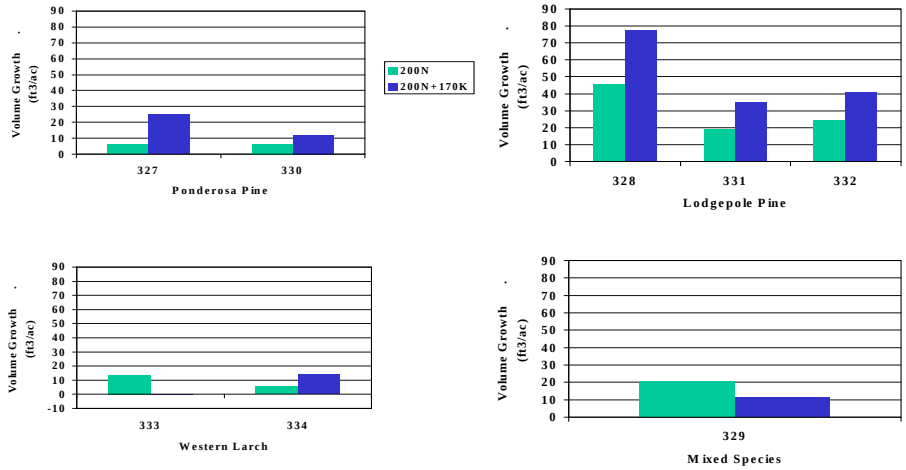


Figure 2b. Four-year volume response by dominant species for installations on the Okanogan National Forest



Results for overall treatment effects from Table 2a indicated that the Umatilla sites showed positive responses of 28% and 81%, respectively, to N and N+S fertilization, although only the N+S response was significant. The N response was insignificant due to the variation across installations, as shown in Figure 2a. This variation was also apparent in the analysis by geographic location, shown in Table 2a. The northeastern sites responded well to N fertilization while the southwestern sites showed negative responses. However, all sites responded better to N+S fertilization than to N-alone, and the N+S response was positive in most cases. Analysis of gross volume increment by location indicated that again, the northeastern sites responded better than the southwestern sites to N+S fertilization. The reasons for the linear trend in response by geographic location are unclear, and confounded by various factors. Moisture, elevation, tree size, and parent material type all vary across this gradient. Installations 317, 319 and 320 all responded negatively to both fertilization treatments, contributing to the poor overall response of the southwestern sites. The reasons for the poor response at these sites are uncertain, however compaction is thought to be a problem on at least one of these sites. The overall better response of all sites to N+S fertilization indicated that the Umatilla sites may be S-limited. Foliar nutrient analyses for the Umatilla also indicated a potentially S-limiting situation, showing that foliar S levels were deficient prior to fertilization, and increased following N+S fertilization (Shaw and Moore 1994).

Analysis of overall treatment effects for the Okanogan sites showed significant, positive responses of 51% and 80% to N and N+K fertilization, respectively (Table 2b). While there was no significant difference between the N

and N+K treatments, the N+K plots tended to show greater volume increases than the N-alone plots. Figure 2b illustrates the positive responses of all installations to fertilization, and the trend towards greater volume responses on the N+K than the N-alone treatments. The Okanogan sites were also classified according to dominant species and analyzed for gross volume response. These results are shown in Table 2b. Generally, the pine stands showed the greatest response to fertilization, and showed greater volume growth following N+K fertilization than N alone. The mixed species and larch stands responded positively to both fertilization treatments, but responded better to N than to N+K. The larch group showed the poorest overall response, and this response was variable between the two larch sites, as illustrated in Figure 2b. This variation may be due to site characteristics, as the two sites differ in parent material and vegetation series. The variation in response of the two larch-dominated stands may also be related to tree size and competition factors, as the trees on Installation 333 are significantly smaller than those on 334. Similarly, the overall variation in responses by dominant species group may be related to parent material, vegetation series, elevational, moisture, and/or tree size differences. The pine-dominated sites may also be K-limited, judging from their response to K fertilization. The mixed and larch sites, however, showed more variable responses, indicating that K may not be a limiting factor on all sites. The consistently positive N responses indicated that all sites were N-limited.

Relative Gross Volume Increment (RGVI)

The large differences in tree size between sites on both the Okanogan and Umatilla National Forests (see Figures 1a and 1b) resulted in wide differences in

gross volume increments across those sites. In order to try and alleviate some of this tree size effect, relative gross volume increment was also examined for both National Forests. The calculation of RGVI was explained previously in the analysis section, but essentially is a measure of the growth on fertilized plots as percent of initial volume. Analysis of RGVI for the Umatilla National Forest indicated that there were no significant differences by location, installation or treatment. Again, the Umatilla sites are extremely variable, which may explain the lack of significance or even trends in terms of RGVI. Because of the lack of significance of any factors, the results of this analysis are not shown. The Okanogan National Forest, however, did show significance both for overall treatment effects and for differences by dominant species group. The following model was used to estimate overall treatment effects on RGVI for the Okanogan:

RGVI = f(installation, block(installation), BA_0, treatment, installation*treatment)

To estimate effects of dominant species, this model was used:

RGVI=f(dominant species, installation(dominant species), BA_0,treatment, dominant species*treatment)

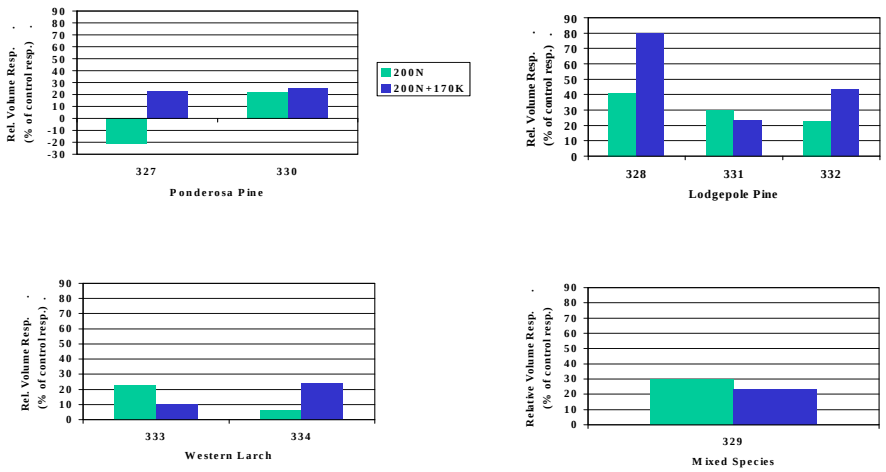
Since initial basal area (BA_0) remained a significant variable in both models, the RGVI estimates were adjusted using BA_0. Table 3 shows the results of the RGVI analysis for the Okanogan National Forest by dominant species. Figure 3 illustrates the installation-specific responses by dominant species type.

Table 3. Relative four-year volume growth increment for the Okanogan National Forest study sites by dominant species.

Dominant Species	Treatment	Growth (ft3/ac)	Contrast (ft3/ac)		%
Ponderosa	Control	20.9			
	200N	20.8	N-Control	-0.1	-0.5
	200N+170K	25.9	NK-Control	5.0	23.9
			NK-N	5.1	24.5
Lodgepole	Control	51.5			
	200N	66.1	N-Control	14.6	28.3
	200N+170K	75.5	NK-Control	24.0	46.6
			NK-N	9.4	14.2
W. Larch	Control	63.0			
	200N	75.8	N-Control	12.8	20.3
	200N+170K	70.6	NK-Control	7.6	12.1
			NK-N	-5.2	-6.9
Mix	Control	168.4			
	200N	218.5	N-Control	50.1	29.8
	200N+170K	207.9	NK-Control	39.5	23.5
			NK-N	-10.6	-4.9
Overall	Control	61.3			
	200N	76.2	N-Control	**14.9	24.3
	200N+170K	78.5	NK-Control	**17.2	28.1
			NK-N	2.3	3.0

**Comparison of overall treatment effects significant at p= .05

Figure 3. Four-year relative volume response by stand type for the Okanogan National Forest



The results for relative volume growth analysis on the Okanogan National Forest did not differ substantially from the gross volume growth results in terms of response to fertilization. There is still an overall positive response to both N and N+K fertilization, and these responses are significant, as seen in Table 3. The responses by dominant species group are also shown in Table 3, and follow the same trends as for gross volume response. Examination of Figure 3 shows that there is some variation within dominant species groups. The pine sites still show an overall stronger response to N+K fertilization than to N-alone. One of the ponderosa sites showed a negative response to N fertilization, resulting in a slightly negative N response for the ponderosa-dominated sites. One of the lodgepole sites showed a slightly greater response to N than to N+K fertilization, however the lodgepole sites still showed an overall stronger response to N+K than to N-alone.

The western larch and mixed conifer groups also showed similar responses here as they did for gross volume growth, with stronger responses to N than to N+K. The two larch-dominated stands showed opposing responses, with one site having a stronger response to N, and the other responding better to N+K. Again, this may be related to site characteristics or tree size effects. The mixed-species site responded better to fertilization by N alone than to N+K.

Height Growth

Height growth was analyzed for the Okanogan National Forest since 1997 was a height-measurement year for these sites. Heights were not measured on the Umatilla National Forest this year; the Umatilla is due for height measurements again in 1999. The four-year height growth increment (HG) for the Okanogan National Forest was analyzed for overall treatment effects using the following model:

HG = f(install, treatment)

To estimate the effects of dominant species, this model was used:

HG = f(dominant species, installation(dominant species), treatment, dominant species*treatment)

The results for height growth analyses by dominant species group are shown in Table 4. A graphical representation of the mean treatment responses by installation within dominant species group is shown in Figure 4.

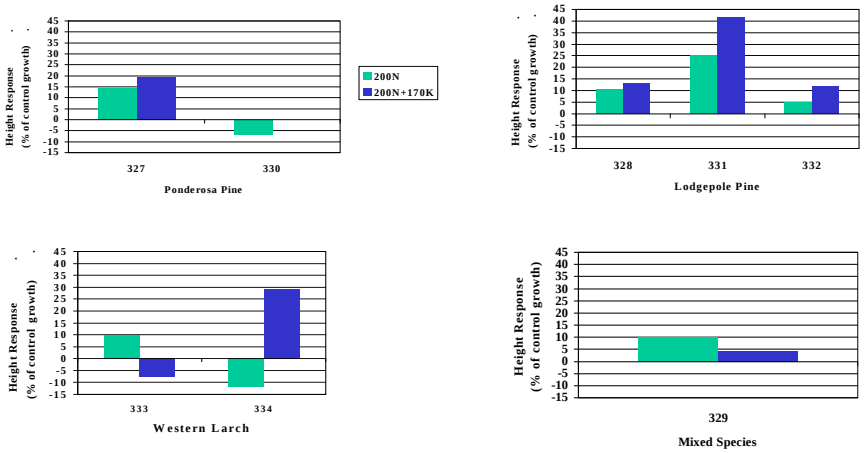
Table 4. Four-year height growth increment for the Okanogan National Forest study sites by dominant species.

Dominant Species	Treatment	Growth (ft3/ac)	Contrast (ft3/ac)	%

Ponderosa	Control	5.1			
	200N	5.2	N-Control	0.1	2.0
	200N+170K	5.5	NK-Control	0.4	7.8
			NK-N	0.3	5.8
Lodgepole	Control	3.9			
	200N	4.4	N-Control	0.5	12.8
	200N+170K	4.7	NK-Control	0.8	20.5
			NK-N	0.3	6.8
W. Larch	Control	3.4			
	200N	3.0	N-Control	-0.4	-11.8
	200N+170K	4.3	NK-Control	0.9	26.5
			NK-N	1.3	43.3
Mix	Control	5.0			
	200N	5.6	N-Control	0.6	12.0
	200N+170K	5.0	NK-Control	0.0	0.0
			NK-N	-0.6	-10.7
Overall	Control	4.4			
	200N	4.7	N-Control	0.3	6.8
	200N+170K	4.9	NK-Control	**0.5	11.4
			NK-N	0.2	4.3

**Comparison of overall treatment effects significant at p= .05

Figure 4. Four-year height response by dominant species for installations on the Okanogan National Forest



Analysis of four-year height growth increment for the Okanogan National Forest indicated that overall, there were positive responses of 7% and 11% to N and N+K

fertilization, respectively. This response was significant (p=.05) for the N+K treatment. As was the case with volume growth, the pine sites showed stronger height growth responses to N+K than to N-alone. One of the ponderosa sites showed a negative height growth response to N, and no response to N+K; the other responded positively to both treatments. All of the lodgepole sites showed positive responses to both fertilization treatments, with stronger N+K than N responses. Height growth in the larch-dominated stands did not behave similarly to volume growth. While volume growth showed generally greater responses to N than N+K for the larch stands, height growth response was better following N+K fertilization, and there was no response to N-alone. In Figure 4, the two larch sites showed opposing responses, with the N-responding site showing a negative response to N+K, and the N+K-responding site showing a negative response to N-alone. The opposing response pattern may indicate that some site-specific factors are influencing nutrient dynamics on those sites. Height response on the mixed species site responded in a similar fashion as volume growth, showing a greater response to N-alone than to N+K fertilization.

Conclusions

Volume and height growth analyses for the Umatilla and Okanogan National Forests showed that overall, the stands responded well to N fertilization, and responded even better when N was supplied along with another nutrient such as S or K. These response patterns indicated that while all sites appeared to N-limited, many of these sites were also either S- or K-limited. Individual responses varied across installations on both National Forests. The Umatilla study sites responded differently according to their geographical location, with the northeastern sites responding well to fertilization, and the southwestern sites responding

poorly. The Okanogan sites also had variable responses, however in this case the variation appeared to be related to the dominant overstory species on each site rather than geographic location. The stands dominated by ponderosa and lodgepole pine tended to show stronger responses to fertilization than those dominated by western larch or mixed species. Between the two National Forests, a variety of parent material types and vegetation series occurred, which may help explain some of the variation in results across installations. Differences in tree size may also have affected how each stand responded to fertilization.

Literature Citations

SAS Institute Inc., 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute Inc., Cary NC p433-506.

Shaw, T.M. and J.A. Moore, 1994. Nitrogen, sulfur and potassium concentrations after fertilization on mixed conifer stands in northeast Oregon and southeast Washington. IFTNC Technical Report, 15p.

Wykoff, W.R., N.L. Crookston and A.R. Stage, 1982. User's guide to the Stand Prognosis Model. USDA For. Serv. Gen. Tech. Rep. INT-133.