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Ponderosa Pine Response to Nitrogen or Nitrogen Plus Potassium Fertilization

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INTRODUCTION

In 1985, the Intermountain Forest Tree Nutrition Cooperative (IFTNC) established 10 nitrogen (N) fertilization trials in stands dominate by ponderosa pine. The ponderosa pine trials were located throughout northeastern Oregon and central Washington and were an expansion of IFTNC Douglas-fir N fertilization trials established in the early 1980's. The focus of these fertilization trials was to study nutrition of commercial forests in the Intermountain Northwest, with the majority of the effort on studying the effect of N fertilization on growth and survival. In addition, evidence from IFTNC Douglas-fir trials (Mika and Moore 1990) and other research from the Inland Northwest suggested that elements other than N, particularly potassium (K), may also be limiting. In 1987, IFTNC members established 6 additional ponderosa pine trials in Montana to study the effects of N and K fertilization on tree growth and survival. This report provides 12 year (1985 sites) and 10 year (1987 sites) final response results for the ponderosa pine fertilization sites.

METHODS

The ten 1985 and six 1987 ponderosa pine study sites shown in Figure 1 are located in ecologically diverse areas throughout the Blue Mountains in northeastern Oregon, east slopes of the Cascade Mountains in central Washington and on west slopes of the Rocky Mountains in western Montana. Although they are ponderosa pine stands, they are situated on either Douglas-fir or grand fir habitat series types. The installations consist of six square 0.1 acre plots surrounded by buffer stripes. Plots were grouped into blocks of three plots based on tree and site similarities. The three treatments applied in each of two blocks for the 1985 installations include control, 200 lbs./ac. nitrogen (2N) and 400 lbs./ac. of nitrogen (4N). Treatments for the 1987 sites include control, 2N and 200 lbs. nitrogen plus 170 lbs./ac. of potassium (NK). Nitrogen was applied in the form of urea, and K in the form of murate of potash. Site characteristics are given in Table 1.

Table 1. Site characteristics at time of establishment for 1985 and 1987 ponderosa pine installations in northeast Oregon, central Washington and western Montana.

Site	**Elevation**	**Age**	**Veg. Series**	**Parent Material**
Northeast Oregon (Installations 291-295)				
Sardine Sprs. (291)	4450	89	DF	Basalt
Sparta Butte (292)	4100	99	DF	Basalt
Summit Salvage (293)	4000	46	GF	Basalt
Moses Cr. (294)	2950	80	DF	Basalt
Parker's Flat (295)	2950	33	DF	Basalt
Central Washington (Installations 296-300)				
Corral Cr. (296)	2900	37	GF	Sandstone
Upper Mud Cr. (297)	2800	74	DF	Granite
Lilly Lake (298)	3300	77	GF	Basalt
Lick Creek (299)	2500	76	GF	Sandstone
Sage Flat (300)	1900	88	GF	Basalt

Western Montana (Installations 301-306)				
Lubrecht (301)	4000	110	DF	Meta-sedimentary
Blue Mtn. (302)	3300	107	DF	Sedimentary
Four Mile Cr. (303)	3500	95	DF	Meta-Sedimentary
Hinchwood Cr. (304)	3200	79	GF	Sedimentary
Libby Plantation (305)	3000	43	GF	Sedimentary
Sedlak (306)	3000	75	GF	Sedimentary

Initial mensurational characteristics were taken in the fall at the time of establishment in 1985 and 1987. Diameter re-measurements are taken every two years and height re-measurements every four years. Final 12 year (1985 sites) and 10 year (1987 sites) measurements were taken in the fall of 1997. Installation 297 (Upper Mud Cr.) was destroyed by wildfire and is not represented in this summary report. Damages and mortality were noted during re-measurement. Tree volumes were estimated using regional species-specific volume equations (Wykoff et al. 1982). Detailed stand characteristics at time of establishment (1985, 1987) and re-measurement summaries are reported in IFTNC Technical Documentation Report, July, 1998.

For this document, differences in basal area (ft^2/ac.) and volume (ft^3/ac) growth response were examined. Analyses included estimation of response on the fertilized plots relative to control plots. All analyses were run as analysis of variance (GLM) procedures in the general linear models module of SAS (SAS Institute Inc. 1985). Individual installation basal area and volume growth response plus statistical models are given in IFTNC Technical Documentation Report, July, 1998. Average basal area increment to the fertilizer treatments was adjusted to a common initial basal area of 120 ft^2/ac. Fertilizer growth response was calculated by subtracting the model estimates of growth on the control plots from the estimates on the fertilized plots.

RESULTS AND DISCUSSION

Basal Area and Volume Growth Response for northeast Oregon and central Washington:

Twelve-year results for both geographic regions combined show that basal area per acre response on the 2N and 4N treatments was not significant for the net growth but was significant for gross (Table 2). Relative net basal area response (growth response on fertilized plots / growth on control plots) was only 0.5% for the 2N treatment and a negative 10.0% for the 4N treatment (Table 2). Relative gross basal area response was was fair with 2N and 4N treatments responding 9.9% and 11.2% over that of the controls, respectively (Table 2). Twelve-year net and gross cubic volume response was insignificant, with net volume for both N treatments responding negatively and gross volume only increasing slightly over that of the controls (Table 3).

The reason for different results between gross and net and the generally low combined region response may be better explained by looking at the individual region responses. For instance, there was no significant twelve-year net or gross response over the controls for either N treatment in northeast Oregon (Tables 4 & 5). In fact, northeast Oregon net response showed low or highly negative responses for both N treatments.

The cause for low net response in northeast Oregon was high mortality. This was particularly true on plots receiving the 4N treatment where increased mortality could be attributed to the treatment. Indeed, two northeast Oregon installations suffered moderate to high mortality (square death) on the plots receiving the 4N treatment. In contrast to the northeast Oregon sites, central Washington gross basal area and cubic volume response on the 4N treatment was significantly higher than that of the controls, with 19.7% and 13.8% increases, respectively (Tables 6 & 7). Even though net basal area and cubic volume response on those plots receiving the 2N treatment was negative or low, gross response was moderate with 11.3 and 8.2 % increases over that of the controls.

Table 2. Average twelve-year net and gross basal area growth response to nitrogen fertilization by treatment for ponderosa pine in C. Washington and N.E. Oregon[1] combined.

		Net Basal Area			**Gross Basal Area**		
		Increment	**Response**		**Increment**	**Response**	
Region	**Treatment**	**ft^2/acre**	**ft^2/acre**	**Percent**	**ft^2/acre**	**ft^2/acre**	**Percent**
C. WA. &	Control	39.9			43.6		
N.E. OR.	200#N	40.1	0.2 NS	0.5	47.9	4.3	9.9
	400#N	35.9	-4.0 NS	-10.0	48.5	4.9	11.2

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (p = .10).

Table 3. Average twelve-year net and gross projected cubic foot volume growth response to nitrogen fertilization by treatment for ponderosa pine in C. Washington and N.E. Oregon[1].

		Net Volume			**Gross Volume**		
		Increment	**Response**		**Increment**	**Response**	
Region	**Treatment**	**ft^3/acre**	**ft^3/acre**	**percent**	**ft^3/acre**	**ft^2/acre**	**percent**
C. WA. & N.E. OR.	Control	1970			2086		
	200#N	1929	-41 NS	-2.1	2179	93 NS	4.5
	400#N	1897	-73 NS	-3.7	2193	107 NS	5.1

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (p = .10).

Table 4. Average twelve-year net and gross basal area growth response to nitrogen fertilization by treatment for ponderosa pine in N.E. Oregon[1].

		Net Basal Area			**Gross Basal Area**		
		Increment	**Response**		**Increment**	**Response**	
Region	**Treatment**	**ft^2/acre**	**ft^2/acre**	**Percent**	**ft^2/acre**	**ft^2/acre**	**Percent**
N.E. OR.	Control	37.2			41.0		
	200#N	37.8	0.6 NS	1.6	44.6	3.6 NS	8.8
	400#N	21.7	-15.5 NS	-41.7	41.8	0.8 NS	2.0

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (p = .10).

Table 5. Average twelve-year net and gross projected cubic foot volume growth response to nitrogen fertilization by treatment for ponderosa pine in N.E. Oregon[1].

		Net Volume			Gross Volume		
		Increment	Response		Increment	Response	
Region	**Treatment**	**ft^3/acre**	**ft^3/acre**	**percent**	**ft^3/acre**	**ft^3/acre**	**Percent**
N.E. OR.	Control	1926			2055		
	200#N	1841	-85 NS	-4.4	2066	11 NS	0.5
	400#N	1538	-388 NS	-20.1	1978	-77 NS	-3.7

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (*p* = .10).

Table 6. Average twelve-year net and gross basal area growth response to nitrogen fertilization by treatment for ponderosa pine in C. Washington[1].

		Net Basal Area			Gross Basal Area		
		Increment	Response		Increment	Response	
Region	**Treatment**	**ft^2/acre**	**ft^2/acre**	**Percent**	**ft^2/acre**	**ft^2/acre**	**Percent**
C. WA.	Control	42.6			46.1		
	200#N	42.4	-0.2 NS	-0.5	51.3	5.2 NS	11.3
	400#N	50.0	7.4 NS	17.4	55.2	9.1	19.7

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (*p* = .10).

Table 7. Average twelve-year net and gross projected cubic foot volume growth response to nitrogen fertilization by treatment for ponderosa pine in C. Washington[1].

		Net Volume			Gross Volume		
		Increment	Response		Increment	Response	
Region	**Treatment**	**ft^3/acre**	**ft^3/acre**	**percent**	**ft^3/acre**	**ft^3/acre**	**percent**
C. WA	Control	2015			2117		
	200#N	2016	1 NS	0.1	2291	174 NS	8.2
	400#N	2256	241 NS	12.0	2409	292	13.8

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (*p* = .10).

Combined region gross basal area periodic annual increment (PAI) growth response to the N treatments was significant for the first three growth periods but insignificant in the fourth period (Table 8). Apparently, the effects of the N treatments declined during years 7-12. Net basal area PAI response was significant the first period then generally non-significant for growth periods two, three and four. The reason for the different results between gross and net basal area growth response is that the fertilized plots had significantly higher mortality rates, particularly during years 3-4 and 7 to 12 (Table 8).

Table 8. Average periodic annual increment basal area response to nitrogen fertilization for years 1-2, 3-4, 5-6 and 7-12 for ponderosa pine installations in C. Washington and N.E. Oregon combined.

	Net Response		Gross Response	
	ft^2/acre		ft^2/acre	
Periods	**200#N**	**400#N**	**200#N**	**400#N**
Years 1 -2	0.6	0.6	0.6	0.7
Years 3 - 4	-0.1 NS	-1.7 NS	0.6	0.7
Years 5 - 6	0.8 NS	0.9	0.5	0.6
Years 7 - 12	-0.5 NS	-1.2 NS	0.1 NS	0 NS

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant (*p* = .10).

Figure 2 shows the twelve-year net and gross basal area response by vegetation series and treatment for the ponderosa pine sites in northeastern Oregon and central Washington combined. Differences in response are noticeable between the Douglas-fir vegetation series and the grand fir vegetation series. Net and gross response was low or negative for both N treatments on the Douglas-fir types while the grand fir types showed moderate positive response to both N treatments. The significance of these results is that all but one of the non-responding Douglas-fir vegetation series types are located in the northeast Oregon region while all of the responding grand fir types are located in central Washington. Similarly, net and gross response for both N fertilizer treatments were different by parent material types (Figure 3). Basalt parent material types showed negative net basal area response and only a slight gross basal area response to both fertilizer treatments. Sandstone parent materials types, however, showed positive response to both fertilizer treatments and significantly so on the 4N treatment with a 17% increase in response over that of the controls. All of the northeast Oregon sites are located on negative or low response vegetation / parent material types. We believe differences in kinds of parent material and vegetation types where our test sites were located explain the response differences between Oregon and Washington.

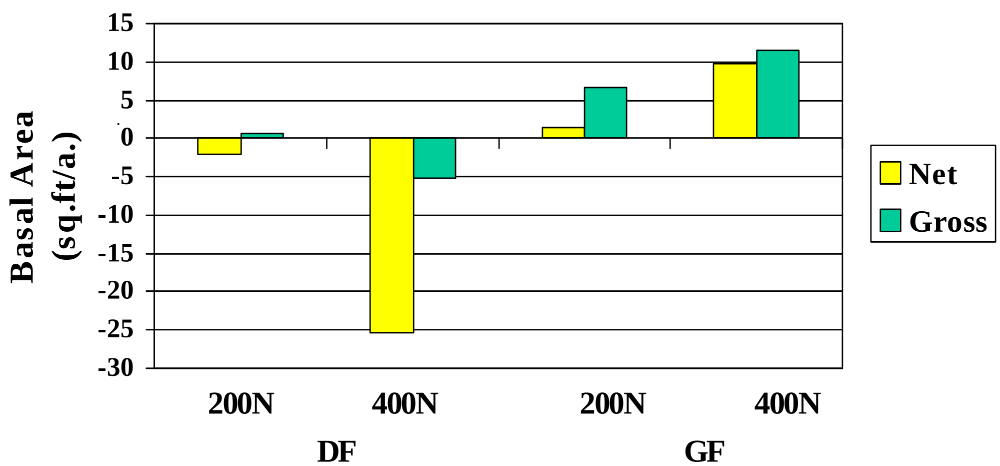

Figure 2. Twelve-year net and gross basal area response by vegetation series and treatment for ponderosa pine sites in northeastern Oregon and central Washington.

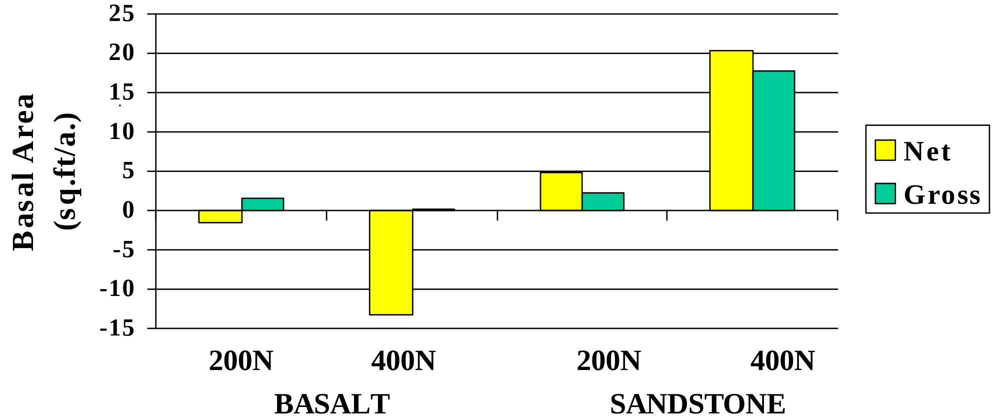

Figure 3. Twelve year net and gross basal area response by parent material and treatment for ponderosa pine sites in northeastern Oregon and central Washington.

Basal Area and Volume Growth Response for Montana:

In 1987 six additional ponderosa pine installations were established in Montana to test the K hypothesis developed in IFTNC Douglas-fir trials (see introduction). The treatments were different from the 1985 ponderosa pine trials with the 4N treatment being replaced with a treatment of 200 pounds per acre of N plus 170 pounds per acre of K (NK). Other than the treatment difference, the experimental set-up was identical to the IFTNC Douglas-fir and 1985 ponderosa pine trials.

Average ten-year net and gross results support the potassium hypothesis developed from the IFTNC Douglas-fir experiment (Mika and Moore 1990). The N alone treatment showed an average negative net response of 21% compared to control plot growth, however, when K is added to the fertilizer treatment a 1% response over that of the controls and a 22% K response over that of the N alone treatment was shown (Table 9). Gross basal area growth was significant for those plots receiving the NK treatment with a 10.4% growth increase over control plots and 8.5% K response over N alone plots (Table 9). Ten-year net and gross volume growth response followed the same trends as the basal area response (Table 10). Those plots that received the NK treatment showed a significant gross volume response of 10%. Clearly, this study shows that when K is added to the fertilizer mix response increases significantly.

Table 9. Average ten-year net and gross basal area growth response to nitrogen plus potassium fertilization by treatment for ponderosa pine in Montana[1].

		Net Basal Area			Gross Basal Area		
		Increment	Response		Increment	Response	
Region	**Treatment**	**ft^2/acre**	**ft^2/acre**	**Percent**	**ft^2/acre**	**ft^2/acre**	**percent**
Montana	Control	30.9			31.6		
	200#N	24.4	-6.5 NS	-21.0	32.2	0.6 NS	1.9
	200#N + 170#K	31.2	0.3 NS	1.0	34.9	3.3	10.4
	K effect		6.8 NS	22.0		2.7 NS	8.5

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant ($p = .10$).

Table 10. Average ten-year net and gross projected cubic foot volume growth response to nitrogen plus potassium fertilization by treatment for ponderosa pine in Montana[1].

		Net Volume			Gross Volume		
		Increment	Response		Increment	Response	
Region	**Treatment**	**ft^3/acre**	**ft^3/acre**	**Percent**	**ft^3/acre**	**ft^3/acre**	**percent**
Montana	Control	1557			1570		
	200#N	1432	-125 NS	-8.0	1638	68 NS	4.3
	200#N + 170#K	1608	51 NS	3.3	1727	157	10.0
	K effect		176 NS	11.3		89 NS	5.7

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant ($p = .10$).

Average PAI shown in Table 11 suggests the positive effect of the K amendment to the fertilizer treatment. All three periods show increased net and gross response on the NK treatment over that of the N alone treatment (Table 11). However, by period 3 (years 5-10) response declined on plots receiving the NK treatment. If N only is applied then net basal area response is negative. This same response trend can be seen for each period.

Table 11. Average periodic annual increment (PAI) basal area response to nitrogen plus potassium fertilization for years 1-2, 3-4 and 5-10 for ponderosa pine installations in Montana.

	Net Response ft^2/acre			Gross Response ft^2/acre		
Periods	**200#N**	**200#N + 170#K**	**K effect**	**200#N**	**200#N + 170#K**	**K effect**
Years 1 –2	-0.8 NS	0.5 NS	1.3 NS	0.1 NS	0.3	0.2 NS
Years 3 – 4	-0.6 NS	0.9 NS	1.5	0.6	0.9	0.3 NS
Years 5 – 10	-0.5 NS	-0.3 NS	0.2 NS	-0.1 NS	0.1 NS	0.2 NS

[1]Averages are adjusted to a common initial basal area of 120 ft^2/acre. NS = Not Significant ($p = .10$).

Figure 4 shows the ten-year mortality rates by cause for the ponderosa pine sites in Montana. Nearly all the mortality was caused by mountain pine beetle. This was especially true on the N alone treatment where mortality was significantly higher than on the NK treatment. Potassium added to the fertilizer mix lowered bark beetle mortality rates in the ponderosa pine. Perhaps the beetles were responding to some physiological or chemical differences in the trees that were fertilized with N only.

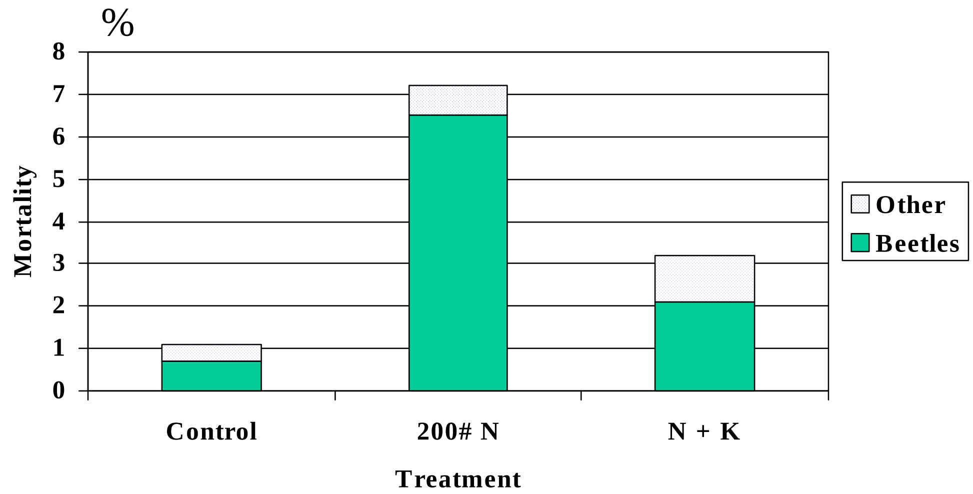

Figure 4. Ten-year mortality rates by treatment for the1987 ponderosa pine sites in Montana.

Net basal response by site and treatment versus pre-treatment foliar K/N ratios are shown in Figure 5. Based on findings by Ingestad and Lund (1979) the critical foliar K/N ratio for optimal growth is 0.65 (Figure 5). Values below this level have unbalanced K/N ratios. The majority of the low or negative (bark beetle mortality) basal area responses derive from N alone treatments and are associated with those sites that have pre-treatment foliar K/N ratios below 0.65. Mortality occurred (the large negative responders) when N alone was added to those sites that had poor K/N balance prior to treatment. Regardless of the pre-treatment foliar K/N value, when K is added to the fertilizer treatment, response tends to be positive. Interestingly, all the sites, except installation 303, with pre-treatment K/N ratios below the 0.65 K/N critical value were grand fir vegetation series types on sedimentary parent materials (installations 304, 305 and 306). Furthermore, two of the three low K/N ratio sites showed large differences in response between treatments (installations 305 and 306). When N alone was applied to these grand fir / sedimentary types, response was highly negative, however the addition of K to treatment reduced ease the negative response caused by bark beetle mortality. To further illustrate the K effect, Figure 6 shows the K net basal area response (K effect) versus foliar K/N ratios on the N only treated plots. Note that all of the N alone treatment K/N ratios are below the 0.65 recommended level and that net basal area K response clearly decreases as foliar K/N ratios increase. The installations showing large K response are grand fir vegetation series types on sedimentary rock types. In fact, three of the top four K responders are located grand fir / sedimentary types.

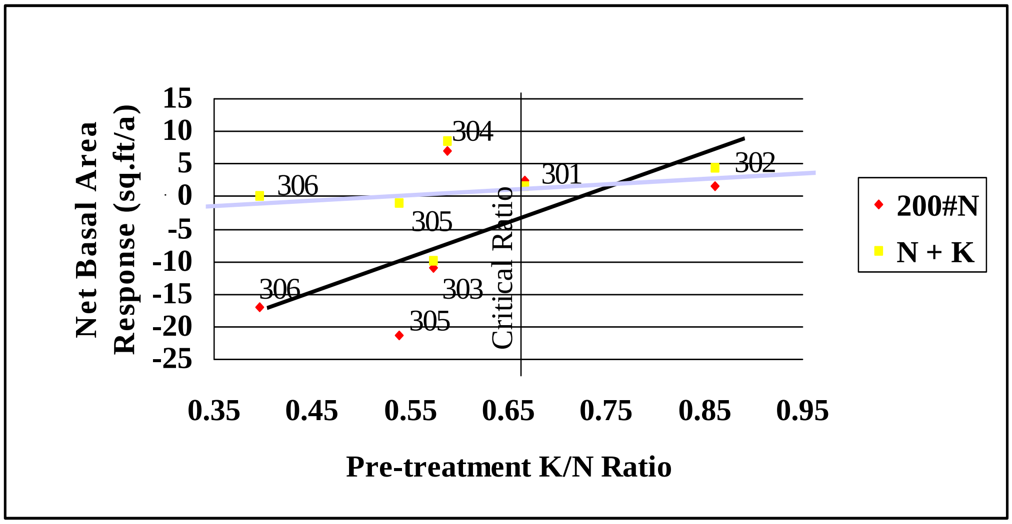

Figure 5. Ten-year net basal area response by treatment versus pre-treatment K/N ratio for ponderosa pine sites in Montana. Note: Points are labeled by installation number. Plotted lines are regression lines of best fit for the two treatments.

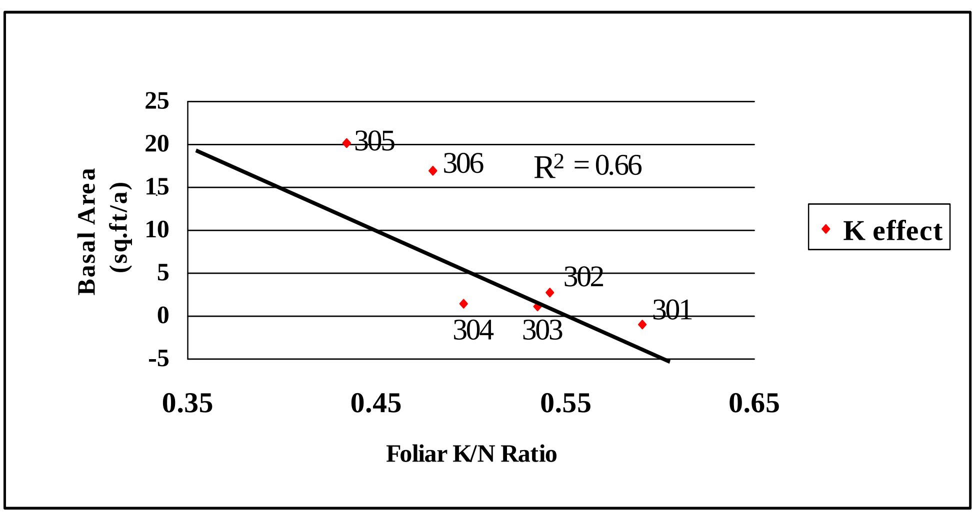

Figure 6. Ten-year K effect net basal area response versus foliar K/N ratio on nitrogen treated plots for ponderosa pine in Montana. Note: Points are labeled by installation number. Plotted line is regression line of best fit.

Ten-year basal area response differed by vegetation series and parent material types. Figure 7 shows response for the three vegetation / parent material types present in Montana. Gross basal area response did not differ significantly between treatments for the three vegetation and parent material types. Net basal area response, however, did show negative net basal area response for both treatments on the Douglas-fir / Meta-sedimentary types. This differed from the Douglas-fir / Sedimentary type which showed a positive net response to both treatments. The addition of K to the fertilizer treatment did not appear to make a significant difference, either positively or negatively, on these vegetation / parent material types. However, the addition of K to the fertilizer treatment did have a significant effect on the grand fir / sedimentary types, with a significant 42% K response over the N alone treatment. These results are similar to the results in Figures 5 and 6 in that the grand fir / sedimentary types seem to respond well to the addition of K to the fertilizer treatment.

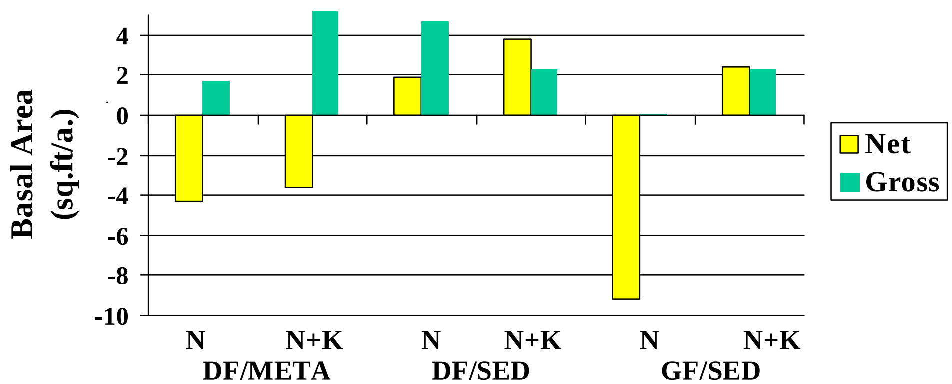

Figure 7. Ten-year net and gross basal area response by vegetation series/parent material and treatment for ponderosa pine sites in Montana. Note vegetation series and parent material types are: DF/META = Douglas-fir/Meta-sedimentary, DF/SED = Douglas-fir/Sedimentary and GF/SED = Grand fir/Sedimentary.

CONCLUSIONS

In 1985 the IFTNC established 10 sites in stands dominate to ponderosa pine. These sites were designed to test the response of two N fertilization treatments (200 lbs./ac. and 400 lbs./ac) in central Washington and northeastern Oregon. Twelve-year response to the N fertilization in these regions was quite different by vegetation series and parent material types. Central Washington sites, for instance, showed good N response on grand fir vegetation types and sandstone parent material types that we sampled there. Douglas-fir vegetation types and basalt parent material types that we sampled in Northeast Oregon showed low or negative N response. Negative response was especially apparent on those plots receiving the 4N treatment where mortality was high. To fully determine ponderosa pine fertilization response in these regions further investigations on different vegetation and parent material types need to be completed.

In Montana, IFTNC established an experiment testing the effect of N and N plus K fertilizers on growth and mortality of ponderosa pine. This experiment provided the first chance for the IFTNC to test a combined N plus K treatment at the start of an experiment. After 10 years there were large net growth differences between treatments. The N only treatment had significantly more mortality than the NK treatment. Potassium added to the fertilizer mix seemed to reduce mortality. Potassium response was related to foliar K/N ratios and substantiated the importance of K nutrition for tree growth and survival. Mortality occurred when N alone was added to those sites with a poor K/N balance prior to treatment. When K was added to the fertilizer mix, response was generally positive. Again, as in northeast Oregon and central Washington, site characteristics such as vegetation and parent material types had a strong effect on fertilization response. Grand fir vegetation series and sedimentary parent material types showed the highest response in the Montana region, especially when K was included in the fertilizer treatment.