Peter G. Mika

College of Forestry, Wildlife and Range Sciences

SEVENTH ANNUAL REPORT

Intermountain Forest Tree
Nutrition Cooperative

April 1987

College of Forestry, Wildlife
and Range Sciences
University of Idaho
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SUMMARY

Results based on analysis of four-year basal area, height, volume growth, and mortality for all Douglas-fir installations indicate the following:

(A) There were significant differences in response to the nitrogen treatments between geographic regions.

(B) Only central Washington continued to show statistically significant differences in response between treatments of 200 and 400 lbs per acre of nitrogen, the other regions did not.

(C) Gross basal area and volume growth response for both nitrogen treatments were significantly greater than the controls for all geographic regions. However, for net basal area and volume response, Montana and northeast Oregon did not show a significant response to either nitrogen treatment.

(D) Higher mortality caused by wind on the nitrogen treated plots (particularly the 400 lb treatment) localized in several installations in both northern Idaho and northeast Washington reduced the overall net growth responses to treatment for these regions.

(E) Foliar potassium levels are low for most soils in our region. The application of nitrogen resulted in even lower concentrations of potassium, often well below estimated inadequate levels. Potassium, in addition to nitrogen, may limit growth on many of our soils.

Introduction

This year's report includes estimates of four-year height, basal area, and volume growth response to nitrogen fertilization treatments as well as mortality estimates for all Douglas-fir installations of the IFTNC. Basal area growth response estimates are also provided for each two-year period (i.e., years 1 and 2 vs. years 3 and 4). Probabilities for obtaining a specified four-year growth response to nitrogen fertilization by region and soil parent material are also reported. New data, showing the effect of nitrogen fertilization on foliar potassium after treatment are presented.

Four-year Growth Response of all Douglas-fir Test Sites:

General Description of the Analysis

Ninety four installations were established in managed Douglas-fir stands (45 in both 1981 and 1982, and 4 in 1980). The distribution of these installations by geographic region and selected mensurational characteristics were provided to cooperators in previous annual reports. Each installation includes six plots, each plot a minimum of one-tenth acre in size. Nitrogen fertilization treatments were assigned to the plots randomly and applied in the fall. The treatments consisted of: (1) two plots with applications of 200 pounds per acre actual nitrogen, (2) two plots with applications of 400 pounds per acre actual nitrogen, and (3) two control plots. Urea was the nitrogen source. The diameters of all sample trees were measured before treatment and again after two and four growing seasons.

Four-year height increments and total heights were measured for all sample trees after the fourth growing season. Mortality was recorded by cause at each measurement period. Therefore, the following analyses are based on diameter (basal area), height, and volume growth for four years after treatment. Volume equations used are from the prognosis model for total cubic foot volume.

Experimental design models:

The design models took the form:

INC = f (region, installation within region, block within installation, treatment, BA, BA^2)

where INC = the growth occuring in 4 years;

Region = the geographic region of the cooperative;

Treatment = the level of nitrogen fertilizer applied;

BA = the basal area (ft^2/A at the time of treatment).

The model form was identical for all responses considered, including gross and net basal area increment (ft^2/A), gross and net volume increment (ft^3/A) and average per tree height increment (ft).

Growth responses reported here are smoothed estimates. The estimates are adjusted for initial basal area as indicated by the statistical model shown above and described in more detail in Tables 1 through 5 of the Technical Documentation Report.

Basal Area Growth Response:

Average basal area increment and response to the nitrogen treatments (adjusted to a common initial basal area of 150 ft^2/A) for both gross and net basal are increments are given in Table 1. The four-year gross basal area per acre increment for both the 200 and 400 lb nitrogen treatments were statistically different from the controls across all geographic regions. Only in northern Idaho and central Washington were the gross increments for the 400 lb treatment significantly greater than the 200 lb treatment. These results are the same as for the two-year basal area response (1984 IFTNC Annual Report). The results are very different for net basal area increment, as is clearly shown in Figure 1. There is no statistical difference in net basal area increment between either nitrogen treatment and the controls for the Montana and northeast Oregon regions. In central Idaho and northeast Washington the 200 lb treatments were significantly greater than the controls, but the 400 lb treatments were not. Both nitrogen treatments produced a significant net basal area growth response in northern Idaho and central Washington. In central Washington the 400 lb nitrogen treatment was also significantly greater

Table 1. Average four-year net and gross basal area growth response by region and treatment.[1]

Region	Treatment	Net Basal Area Increment: Total ft^2/acre	Net: Increase over control ft^2/acre	Net: Increase over control percent	Gross Basal Area Increment: Total ft^2/acre	Gross: Increase over control ft^2/acre	Gross: Increase over control percent
Northern Idaho	Control	22.4			22.5		
	200 # N	25.5	3.1	14.0	28.3	5.8	25.8
	400 # N	26.8	4.4	19.6	30.5	8.0	35.7
Montana	Control	11.6			13.0		
	200 # N	11.8	0.2 NS	1.7	15.5	2.5	19.1
	400 # N	11.7	0.1 NS	0.9	15.5	2.5	19.2
Central Idaho	Control	17.9			18.5		
	200 # N	21.1	3.2	17.4	21.4	2.8	15.3
	400 # N	20.3	2.4 NS	13.2	21.7	3.2	17.1
Northeast Oregon	Control	12.7			14.7		
	200 # N	13.2	0.5 NS	4.2	16.8	2.1	14.1
	400 # N	14.0	1.3 NS	10.4	17.8	3.1	20.6
Central Washington	Control	16.9			17.1		
	200 # N	21.6	4.7	27.8	22.2	5.1	29.8
	400 # N	24.0	7.1	42.1	24.9	7.8	45.5
Northeast Washington	Control	16.4			19.2		
	200 # N	19.4	3.0	18.6	22.4	3.2	16.5
	400 # N	16.2	-0.2 NS	-1.0	22.7	3.5	18.2
Overall	Control	16.8			17.9		
	200 # N	19.5	2.7	16.0	21.7	3.8	21.4
	400 # N	19.6	2.8	16.7	22.9	5.0	28.1

[1]Averages are adjusted to a common initial basal area of 150 ft^2/A.

NS = Not Significant (a = .1)

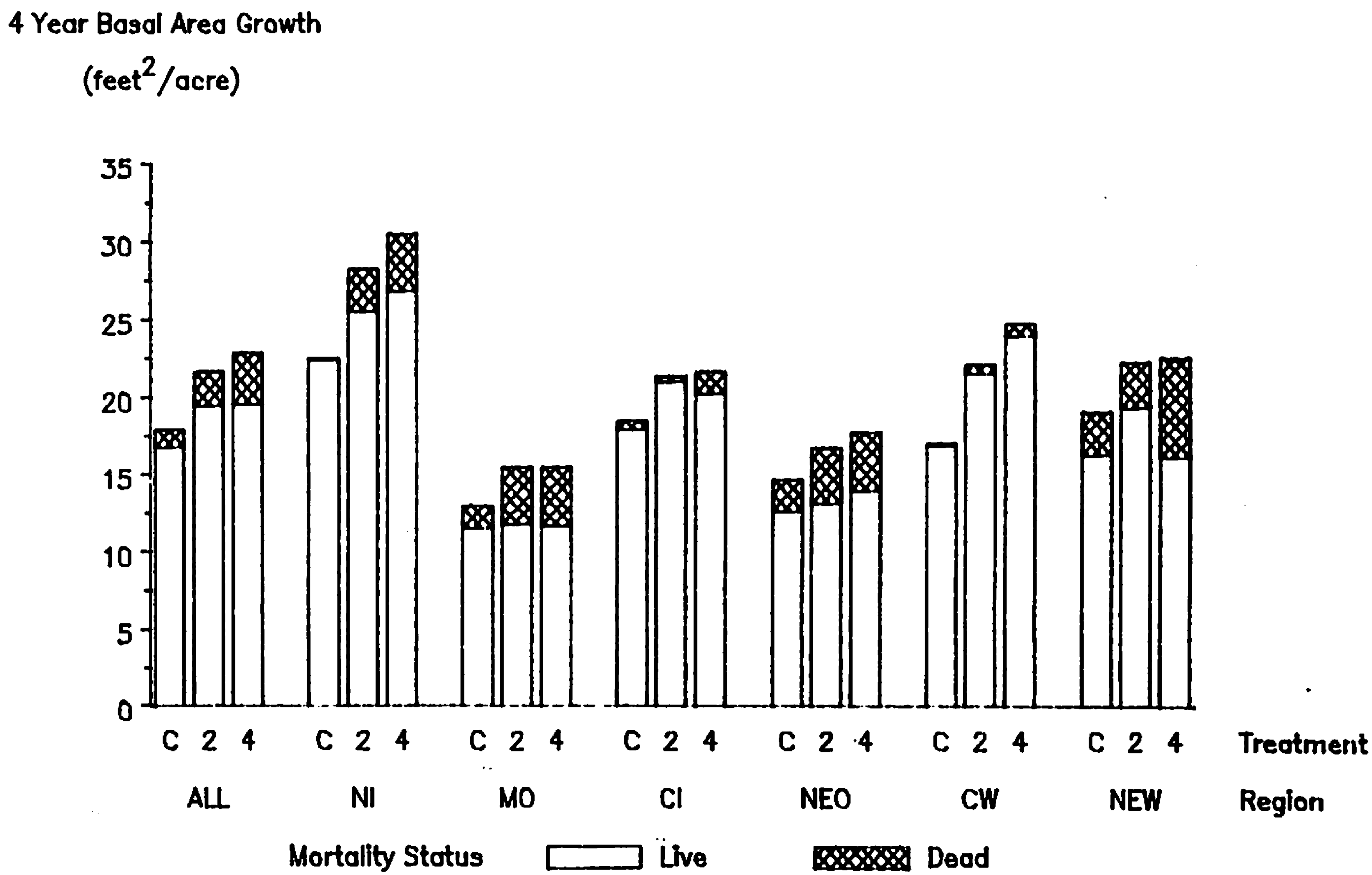

Figure 1. FOUR-YEAR BASAL INCREMENT BY REGION AND TREATMENT PARTITIONED INTO LIVE (NET) AND DEAD COMPONENTS.

than the 200 lb treatment. The reason for the different results for gross and net basal area growth response is fertilized plots had significantly higher mortality rates during years 3 and 4 than the control plots. Mortality will be discussed in detail in a later section of this report.

Several important points are evident in Table 1 and Figure 1. Central Washington continues to show the largest net growth response to both nitrogen treatments and the 400 lb treatment remains significantly greater than the 200 lb treatment. Also notice the large decrease from gross to net basal area response for the 400 lb treatment in all other geographic regions, particularly northeast Washington and northern Idaho.

<u>Height Increment Response</u>:

This analysis is based on average four-year height increment per tree. All fertilization treatments in all regions, except the 400 lb treatment in central Idaho showed significantly greater height growth than the untreated control plots. There was no difference in height increment between the 200 and 400 lb treatments, except for central Washington. These results are provided in Table 2 and shown in Figure 2.

Initial basal area was a significant covariate in the height increment analysis. As initial basal area per acre increases four-year height increment slowly decreases.

<u>Volume Growth Response</u>:

The results for net and gross volume growth response are similar to those for basal area growth. The net and gross volume growth estimates by region and treatment are given in Table 3 and shown in Figure 3. The gross volume per acre increments for both nitrogen treatments are significantly greater than

Table 2. Average four-year height increment response per tree by region and treatment.[1]

		Height Increment		
		Total	Increase over control	
Region	Treatment	ft/tree	ft/tree	percent
Northern Idaho	Control	4.6		
	200 # N	5.5	0.9	19.9
	400 # N	5.6	1.0	20.5
Montana	Control	2.7		
	200 # N	3.2	0.5	18.5
	400 # N	3.1	0.4	17.1
Central Idaho	Control	3.3		
	200 # N	3.7	0.4	14.4
	400 # N	3.4	0.2 NS	5.7
Northeast Oregon	Control	3.3		
	200 # N	3.7	0.4	10.5
	400 # N	3.7	0.4	11.0
Central Washington	Control	3.5		
	200 # N	4.4	0.9	27.6
	400 # N	4.7	1.2	35.4
Northeast Washington	Control	4.3		
	200 # N	4.7	0.4	7.9
	400 # N	4.7	0.4	9.0
Overall	Control	3.7		
	200 # N	4.3	0.6	17.1
	400 # N	4.3	0.6	17.7

[1]Averages are adjusted to a common initial basal area of 150 ft^2/A

NS = Not Significant (α = .1)

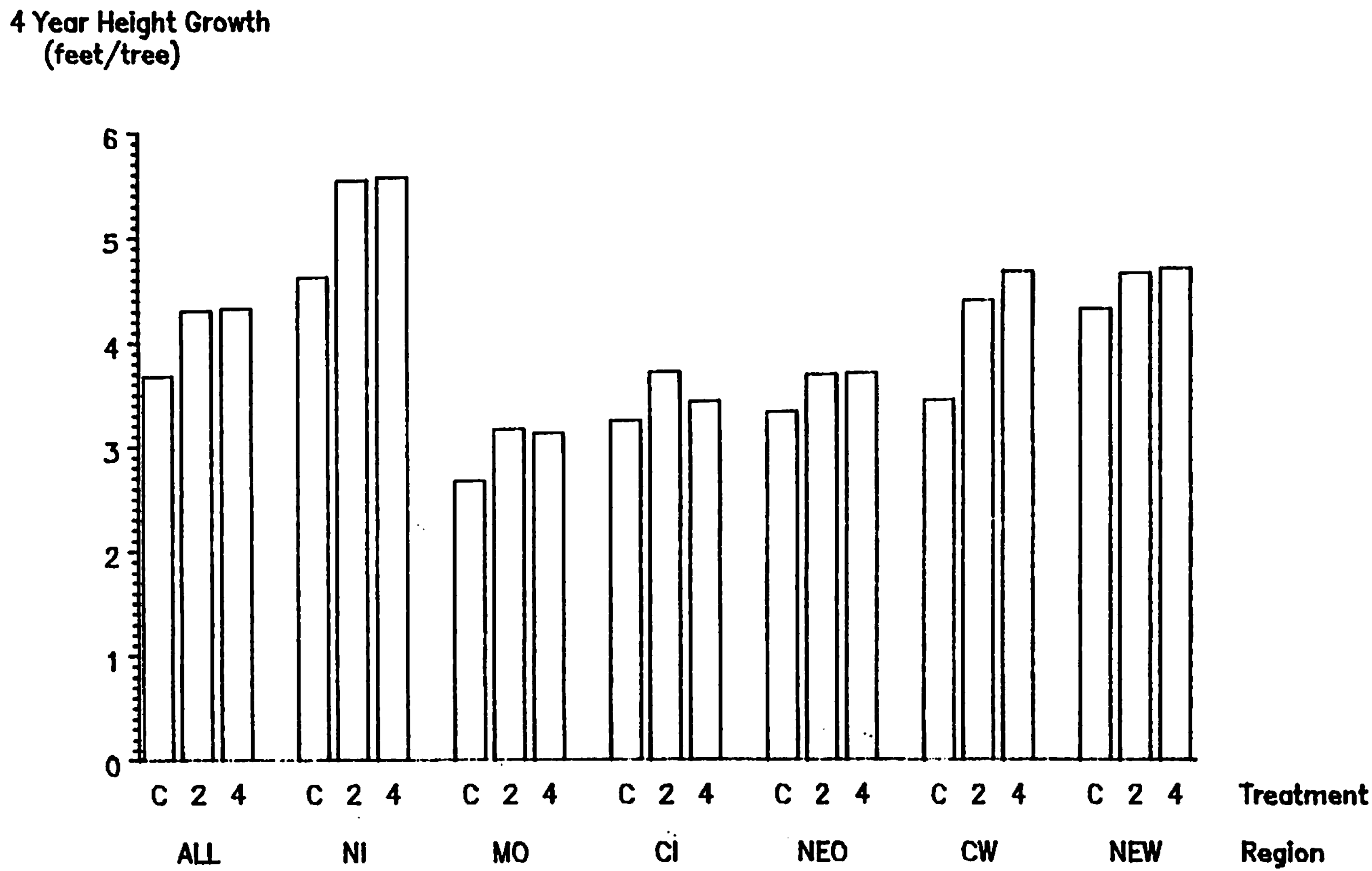

Figure 2. AVERAGE FOUR-YEAR HEIGHT GROWTH PER TREE BY GEOGRAPHIC REGION AND TREATMENT.

Table 3. Average four-year net and gross cubic foot volume growth response by region and treatment.[1]

Region	Treatment	Net Volume Increment: Total ft^3/acre	Net Volume Increment: Increase over control ft^3/acre	Net Volume Increment: Increase over control percent	Gross Volume Increment: Total ft^3/acre	Gross Volume Increment: Increase over control ft^3/acre	Gross Volume Increment: Increase over control percent
Northern Idaho	Control	868				– 849	
	200 # N	983	115	13.3	1033	184	21.7
	400 # N	1008	140	16.1	1085	236	27.9
Montana	Control	436			475		
	200 # N	465	29 NS	6.8	564	88	18.6
	400 # N	462	26 NS	6.1	558	83	17.4
Central Idaho	Control	635			651		
	200 # N	745	110	17.3	752	101	15.6
	400 # N	717	82	12.9	754	103	15.9
Northeast Oregon	Control	546			584		
	200 # N	541	-5NS	-0.9	640	56	9.5
	400 # N	540	-6 NS	-1.0	658	74	12.6
Central Washington	Control	654			660		
	200 # N	840	185	28.3	850	190	28.9
	400 # N	922	268	40.9	944	284	43.0
Northeast Washington	Control	548			718		
	200 # N	759	111	17.1	822	104	14.6
	400 # N	667	19 NS	2.9	825	107	14.9
Overall	Control	646			669		
	200 # N	748	102	15.7	799	130	19.5
	400 # N	748	102	15.8	830	161	24.1

[1]Averages are adjusted to a common initial basal area of 150 ft^2/A.

NS = Not Significant
(α = .1)

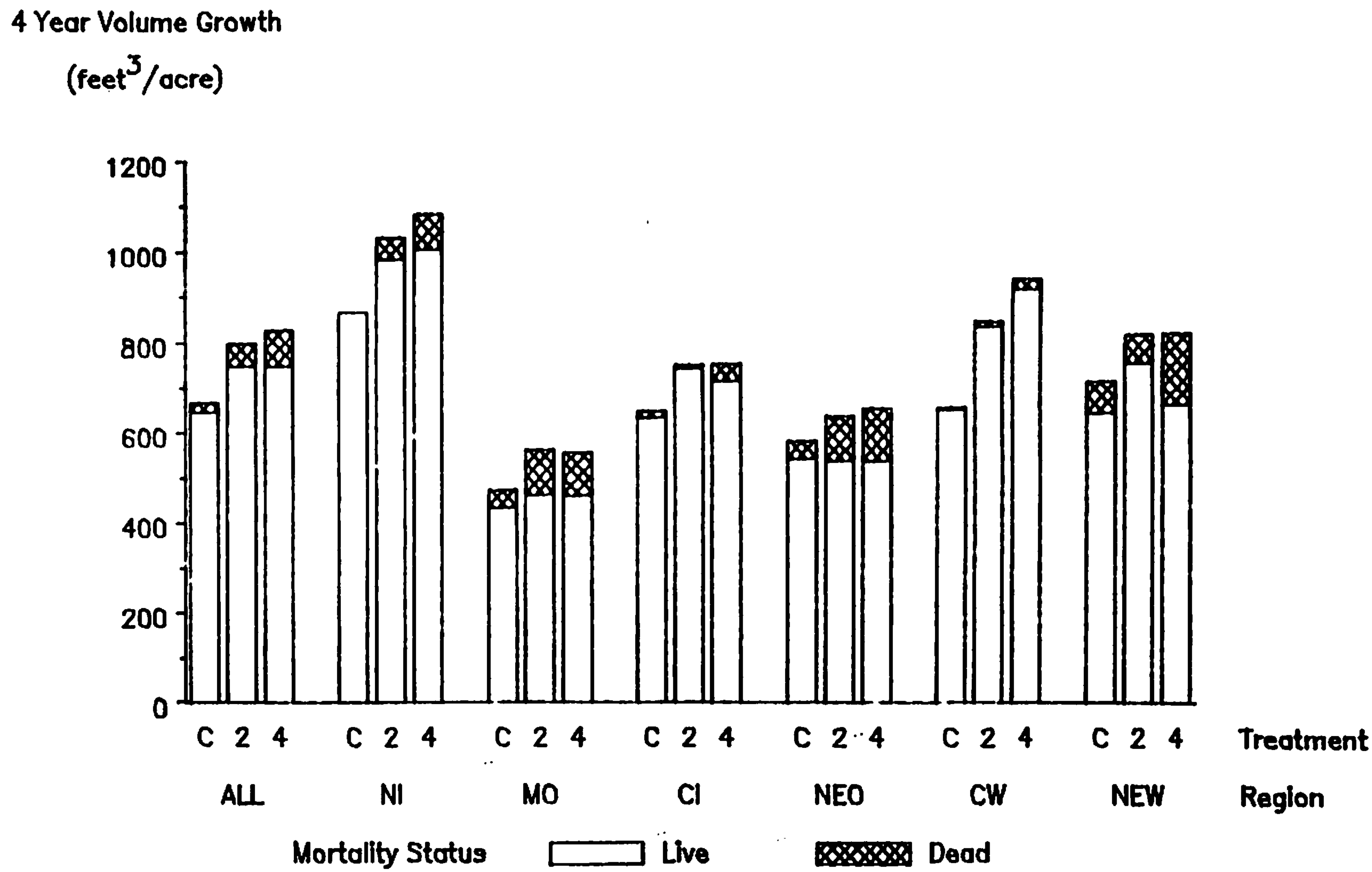

Figure 3. FOUR-YEAR VOLUME INCREMENT BY REGION AND TREATMENT PARTITIONED INTO LIVE (NET) AND DEAD COMPONENTS.

the controls across all geographic regions. Only in central Washington and northern Idaho is the gross volume growth for the 400 lb treatment significantly greater than the 200 lb treatment.

There is no statistical difference in net volume increment for the 400 lb treatments and the controls in northeast Washington, and no difference between either fertilizer treatment and the controls in Montana and northeast Oregon. Central Washington showed the greatest net volume growth response to both nitrogen treatments (200 lb N = 185 ft^3, 28.3%; 400 lb N = 268 ft^3, 40.9%). The net volume growth for the 400 lb treatment is significantly greater than the 200 lb treatment in central Washington.

Differences in Mortality Rates by Treatment:

Mortality rates differed significantly by nitrogen treatment. Basal area and the volume per acre mortality estimates by treatment and geographic region are given in Table 4. Most of the mortality occured during the second two-year period (i.e., years 3 and 4), and was significantly higher for the nitrogen treatments. The mortality rates were higher for the 400 lb treatment than the 200 lb, particularly in northeast Washington. Central Washington incurred the lowest mortality of any region. The distribution of mortality by cause and geographic region are provided in the Technical Documentation Report. The most common causes of mortality differed by region. In northern Idaho and northeast Washington the most common cause was wind (approximately 50 and 65% respectively). Although control plots sustained significant wind damage, the amount of wind-caused mortality on the fertilized plots was substantially higher particularly for the 400 lb treatment. Wind-caused mortality was localized at several installations in both of these

Table 4. Average four-year basal area and volume mortality rates by region and treatment.[1]

Region	Treatment	Basal Area Total ft²/A		Volume Total ft³/A
		--Years--		
		0-2	2-4	
Northern Idaho	Control	0.0	0.9	0
	200 # N	0.3	2.4	49
	400 # N	0.6	3.1	78
Montana	Control	0.5	1.0	39
	200 # N	1.4	2.4	98
	400 # N	0.3	3.6	96
Central Idaho	Control	0.4	0.3	16
	200 # N	0.6	0.0	7
	400 # N	0.2	1.0	37
Northeast Oregon	Control	0.7	1.6	39
	200 # N	1.0	3.0	99
	400 # N	1.4	2.4	118
Central Washington	Control	0.3	0.0	5
	200 # N	0.4	0.2	11
	400 # N	0.2	0.3	21
Northeast Washington	Control	0.4	2.6	70
	200 # N	0.2	2.5	63
	400 # N	0.4	6.3	158
Overall	Control	0.2	1.0	23
	200 # N	0.6	1.7	51
	400 # N	0.4	2.8	82

[1]Averages are adjusted to a common initial basal area of 150 ft^2/A.

regions. We might speculate that the tress on the fertilized plots had more foliage biomass and, if high winds hit a stand, the fertilized trees were more prone to windthrow. In other regions there was no consistent treatment-related frequent cause of mortality. However, in Montana and northeast Oregon, there were mortality factors apparently unrelated to treatment. A mountain pine beetle outbreak in Montana killed most of the Ponderosa pine component of two stands (as well as in the rest of the watershed). The mortality occured equally on both fertilized and control plots. Similarly, in northeast Oregon, spruce budworm heavily defoliated the Douglas-fir in all plots of one installation. These (and other) external factors that cause mortality unrelated to the experiment introduce unexplained variation in our attempts to predict net growth response to fertilization.

Duration of Response:

The data collected this year provides our first opportunity to look at duration of treatment response for all Douglas-fir installations. Since only diameters were remeasured after the first two-year growth period, the following analysis is based only on periodic basal area growth. Basal area increments for the first and second two-year periods are compared in Table 5. The gross and net basal area increments by treatment and region are shown in Figures 4 and 5 for the first two-year and the second two-year periods.

The gross and net basal area responses declined during years 3 and 4 compared to years 1 and 2 in all regions. The decline in response during the second two-year period was even more noticeable for net basal area increment. The only treatment in any region that produced a significant response in net basal increment for years 3 and 4 was the 400 lb treatment in central

Table 5. Average net and gross basal area response for each two-year period by region and treatment.[1]

		Basal area increment in the first two years						Basal area increment in the second two years					
		Net	Increase over control		Gross	Increase over control		Net	Increase over control		Gross	Increase over control	
Region	Treatment	ft^2/A	ft^2/A	percent	ft^2/A	ft^2/A	percent	ft^2/A	ft^2/A	percent	ft^2/A	ft^2/A	percent
Northern Idaho	Control	12.7			11.8			9.8			10.7		
	200#N	15.0	2.3	18.5	15.3	3.5	30.3	10.6	0.8NS	8.2	12.9	2.2	20.7
	400#N	15.6	2.9	23.3	16.2	4.4	37.4	11.3	1.5NS	15.4	14.3	3.6	33.8
Montana	Control	6.6			7.1			5.0			5.9		
	200#N	7.2	0.6NS	8.0	8.5	1.4	19.9	4.5	-0.5NS	-8.8	6.9	1.0	17.2
	400#N	8.4	1.8	26.7	8.6	1.5	21.2	3.3	-1.7NS	-33.6	6.9	1.0	16.2
Central Idaho	Control	8.6			9.0			9.2			9.4		
	200#N	10.2	1.6	18.7	10.7	1.7	19.8	10.7	1.5NS	16.4	10.5	1.1	11.5
	400#N	11.1	2.5	29.2	11.2	2.2	25.5	9.5	0.3NS	4.2	10.5	1.1	11.5
Northeast Oregon	Control	6.1			6.8			5.2			6.9		
	200#N	7.3	1.2NS	20.4	8.4	1.6	22.6	4.8	-0.4NS	-8.8	7.7	0.8	12.6
	400#N	7.5	1.4NS	23.7	9.0	2.2	31.4	5.5	0.3NS	5.5	7.9	1.0	15.7
Central Washington	Control	8.6			8.9			8.4			8.3		
	200#N	11.5	2.9	33.6	11.9	3.0	33.3	10.2	1.8NS	21.3	10.4	2.1	25.5
	400#N	13.1	4.5	51.7	13.3	4.4	49.0	11.3	2.9	35.4	11.6	3.3	40.1
Northeast Washington	Control	9.4			9.8			6.4			9.0		
	200#N	11.5	2.1	21.7	11.7	1.9	19.6	7.8	1.4NS	20.8	10.3	1.3	13.6
	400#N	11.6	2.2	22.4	12.0	2.2	22.2	3.9	-2.5NS	-38.8	10.3	1.3	13.6
Overall	Control	9.0			9.2			7.6			8.5		
	200#N	10.9	1.9	20.7	11.5	2.3	25.4	8.4	0.8NS	11.4	10.1	1.6	17.8
	400#N	11.7	2.7	29.8	12.2	3.0	32.4	7.8	0.2NS	3.3	10.6	2.1	24.2

[1] Averages are adjusted to a common initial basal area of 150 ft^2/A
NS = Not significant (α = .1)

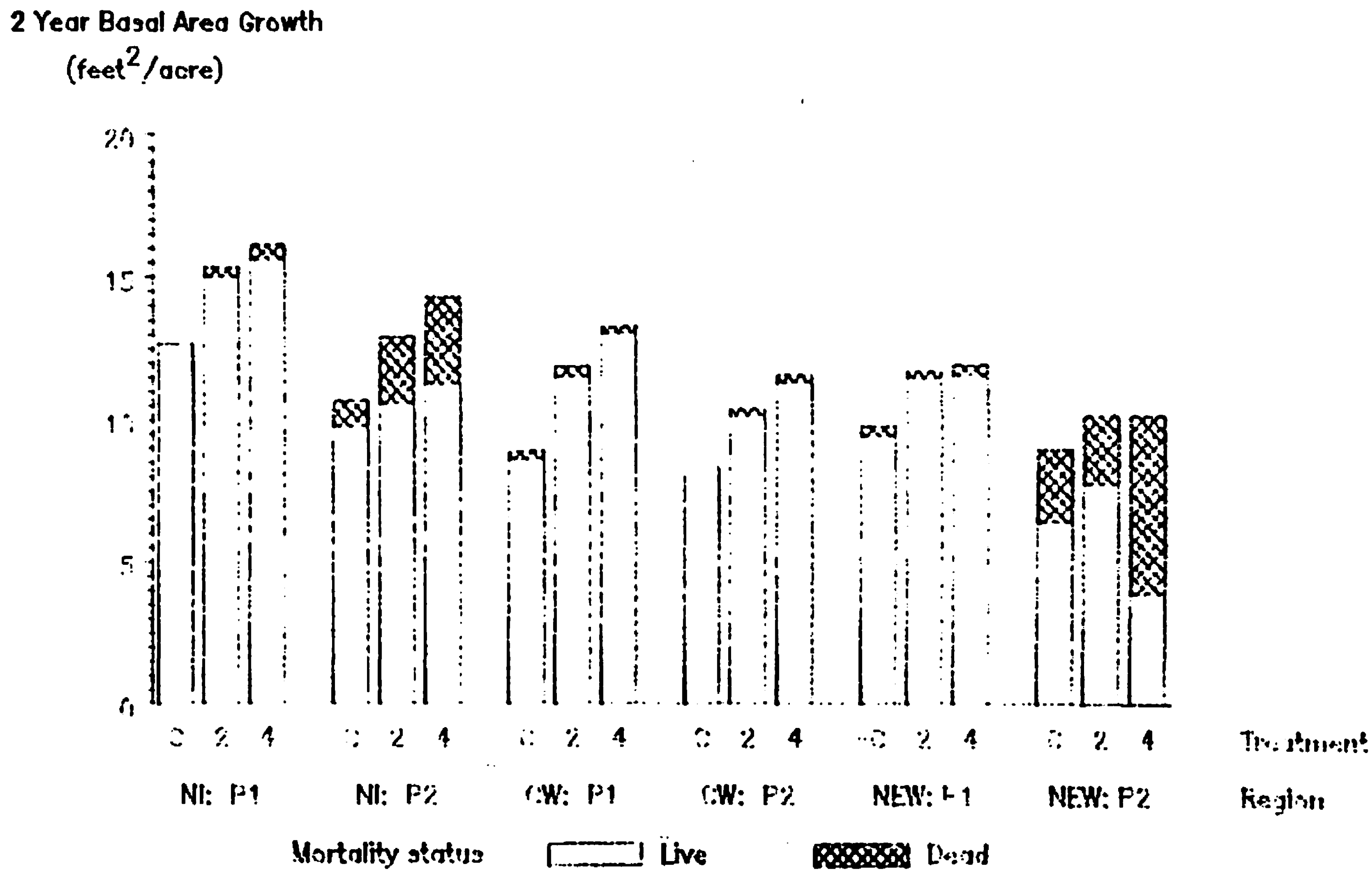

Figure 4. AVERAGE BASAL AREA INCREMENT BY TREATMENT FOR YEARS ONE AND TWO VERSUS YEARS THREE AND FOUR FOR NORTHERN IDAHO, CENTRAL WASHINGTON, AND NORTHEAST WASHINGTON.

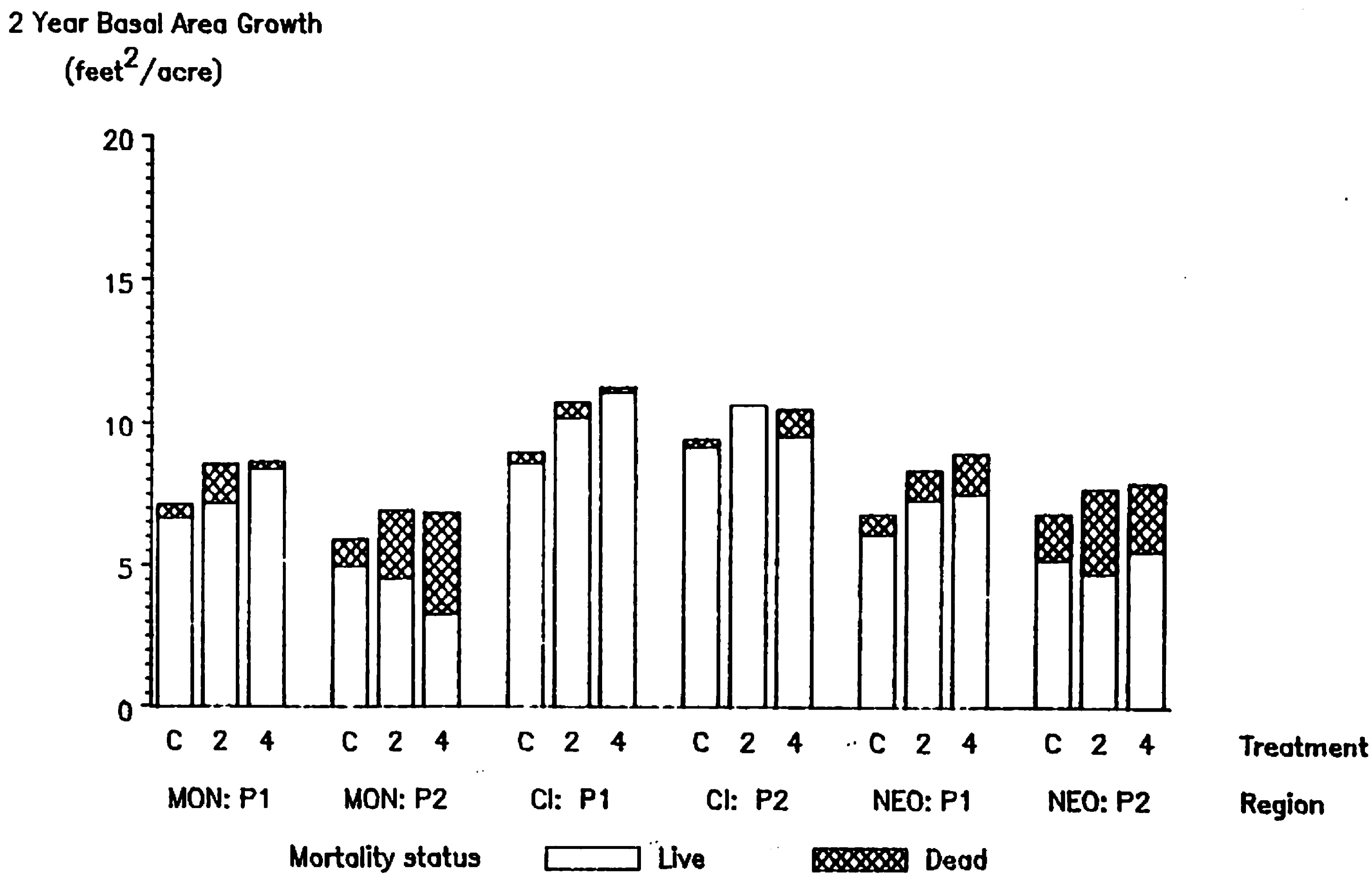

Figure 5. AVERAGE BASAL AREA INCREMENT BY TREATMENT FOR YEARS ONE AND TWO VERSUS YEARS THREE AND FOUR FOR MONTANA, CENTRAL IDAHO, AND NORTHEAST OREGON.

Washington. As mentioned previously, almost all mortality occured during the second two-year period.

Something else interesting can be seen in Figures 4 and 5 and Table 5. Both net and gross basal area increment for the untreated control plots declined during years 3 and 4 in every region except central Idaho and northeast Oregon. The reason for the decline in the growth rate of the control plots is not known (climatic variation?). However, the reduced "normal" untreated growth does explain some of the reduction in absolute growth response to the nitrogen treatments since the relative (percent) treatment response did not decline as sharply.

Variation in Growth Response to Nitrogen Fertilization Across Installations

So far in the discussion of results we have been comparing average responses by treatment and geographic region. This approach is useful for drawing general conclusions, but averages tell us nothing about the variation in response to nitrogen fertilization between installations. In every region some stands responded well to nitrogen fertilization and others did not respond at all. The variation in treatment response across the entire experiment is shown in Figure 6. This figure is the cumulative distribution of net four-year volume growth response to the nitrogen treatments. This information can be potentially useful to cooperators. For example, if an organization specified 100 ft^3/A (25 $ft^3/A/yr.$) (or any specified amount) as the minimum treatment response required to make an acceptable return on investment, then Figure 6 can be used to estimate the probability of obtaining at least this response for the population of managed Douglas-fir stands represented by our sample. The

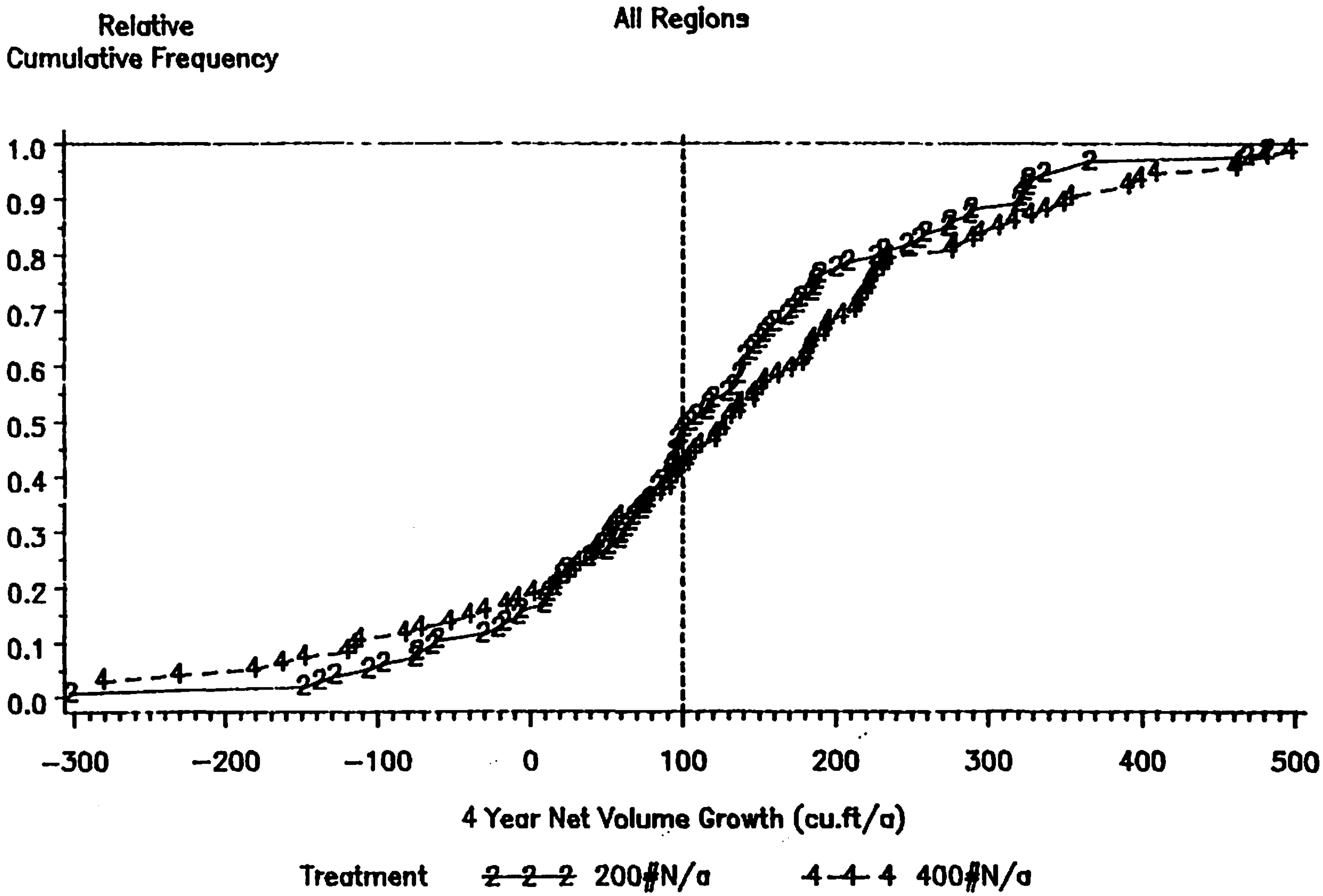

Figure 6. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR THE ENTIRE DOUGLAS-FIR EXPERIMENT.

solid vertical line in Figure 6 is located at 100 ft^3/A. Our data indicate that about 52% of the stands would produce a response greater than 100 ft^2/A for the 200 lb nitrogen treatment. Similarly for the 400 lb treatment the probability is about 57%. One of the IFTNC's objectives is to explain the variation in response to nitrogen fertilization so that operational treatments can be targeted at those stands with a high probability of "substantial" response. We can now explain much of the variation in response, at least preliminarily based on four-year results. The following example illustrates this process. We know that response to nitrogen fertilization is significantly different by geographic region. This is clearly shown in Figures 7 through 12 which provide the cumulative distribution of net four-year volume response for each geographic region. The probability of obtaining the previously specified response of 100 ft^3/A varies significantly by region and in some cases by nitrogen treatment. This is summarized in Table 6. The chances of obtaining at least this response to the 200 lb treatment are very good in central Washington, good in northern Idaho, and very small in Montana.

We also know that stand density and soil characteristics significantly affect response to nitrogen treatments. Within each region we can further refine the likelihood of obtaining the specified 100 ft^3/A response by using soil parent material as a predictor variable. These results are given in Table 7. In northern Idaho, the only installations (4) not producing a response greater than 100 ft^3/A are on ash/metasediments. Three of these stands sustained mortality caused by wind damage. The fact that they all occured on ash/metasediments is probably an artifact rather than a real parent material effect. Obviously, the likelihood of a substantial four-year response to fertilization with 200 lbs of nitrogen in northern Idaho is very high. Conversely, in Montana the chances of such a response is low. However, the

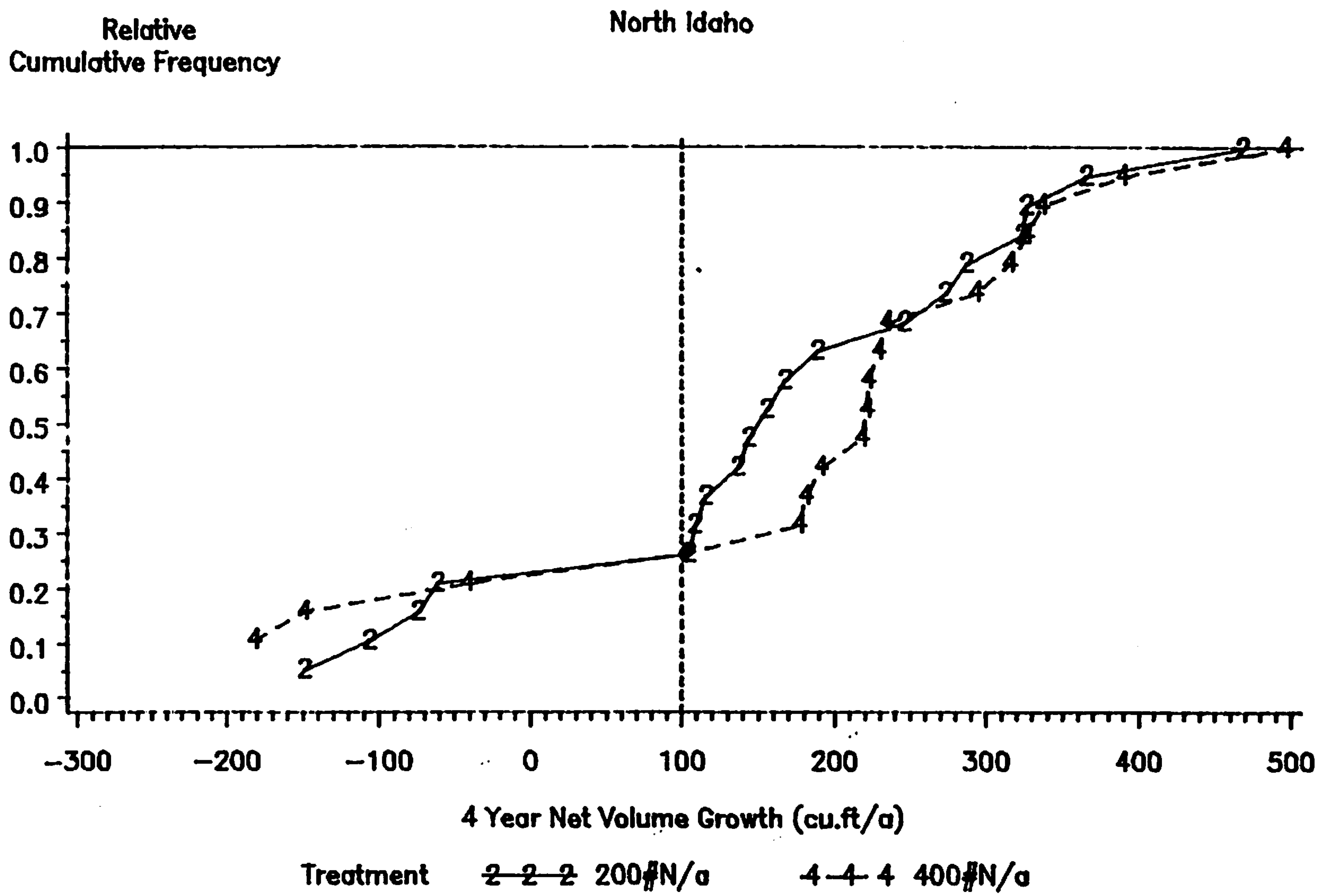

Figure 7. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR NORTHERN IDAHO.

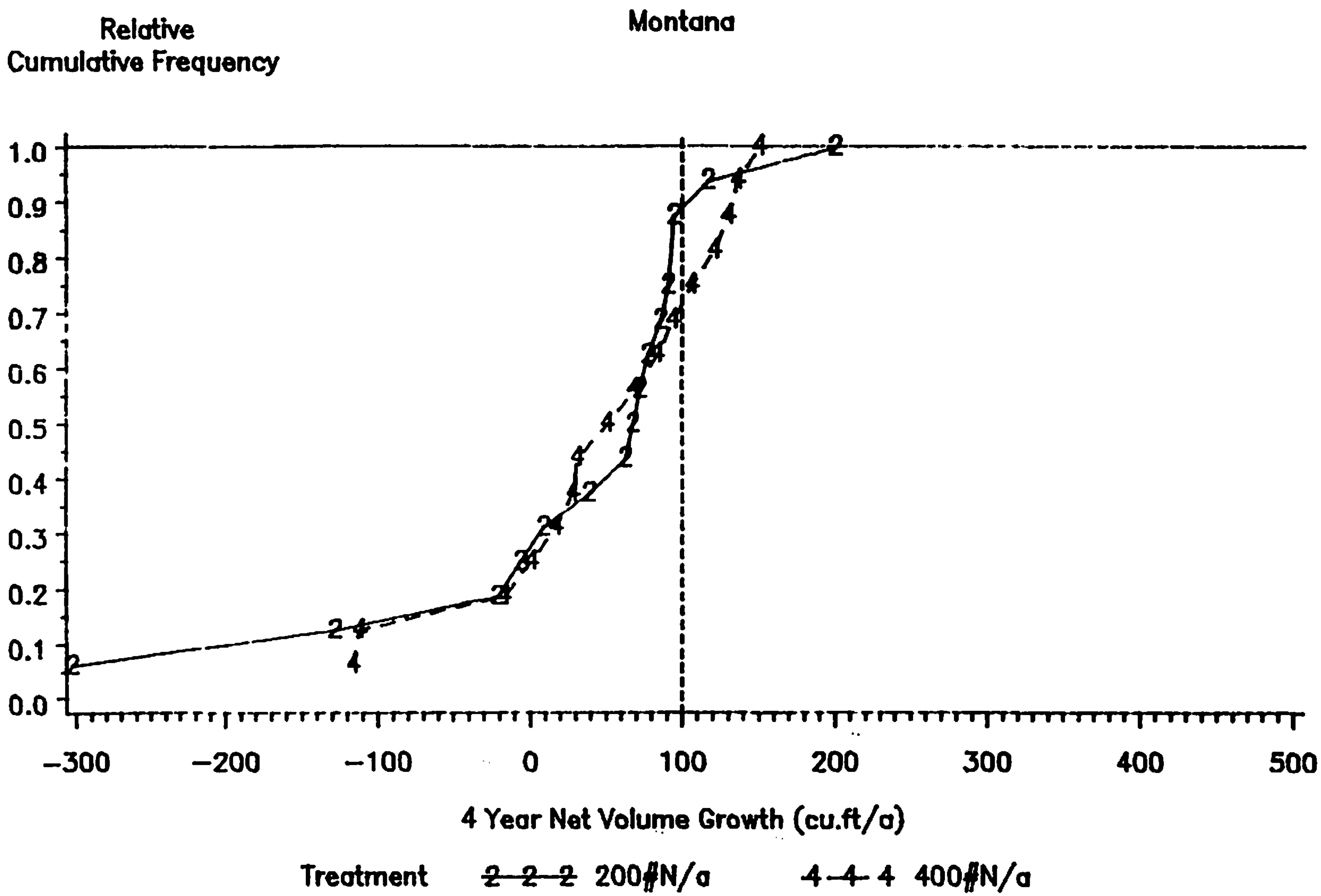

Figure 8. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR MONTANA.

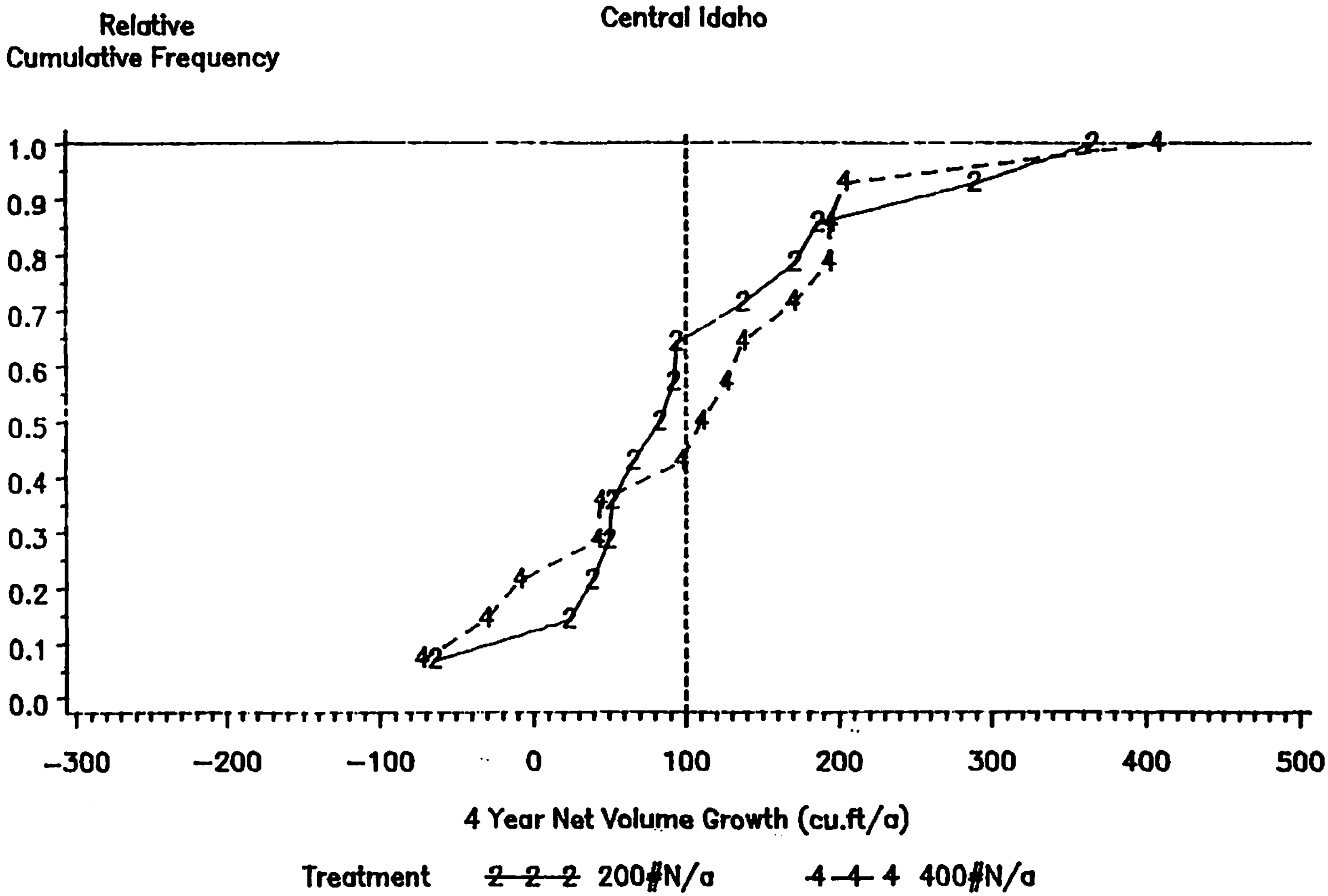

Figure 9. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR CENTRAL IDAHO.

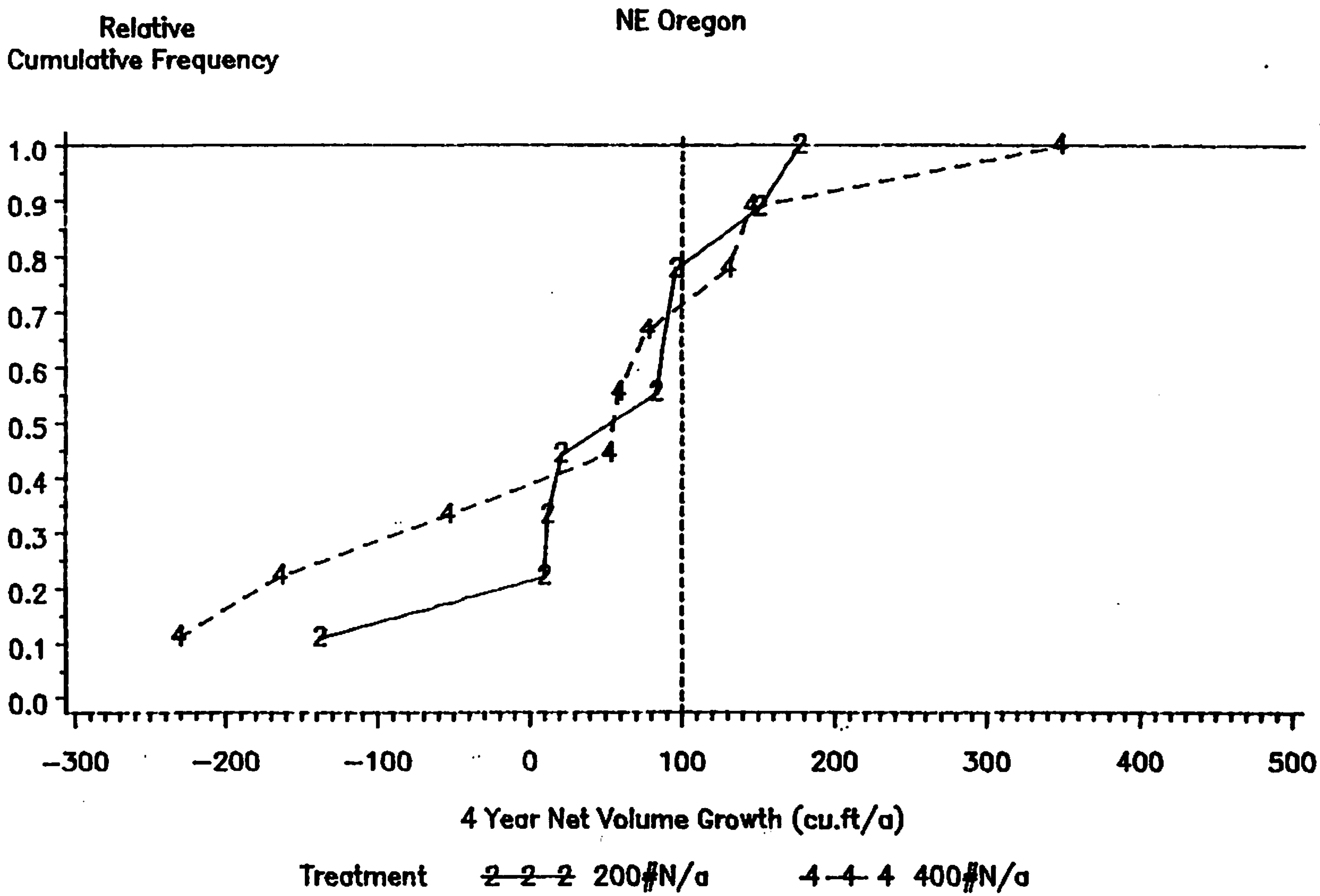

Figure 10. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR NORTHEAST OREGON.

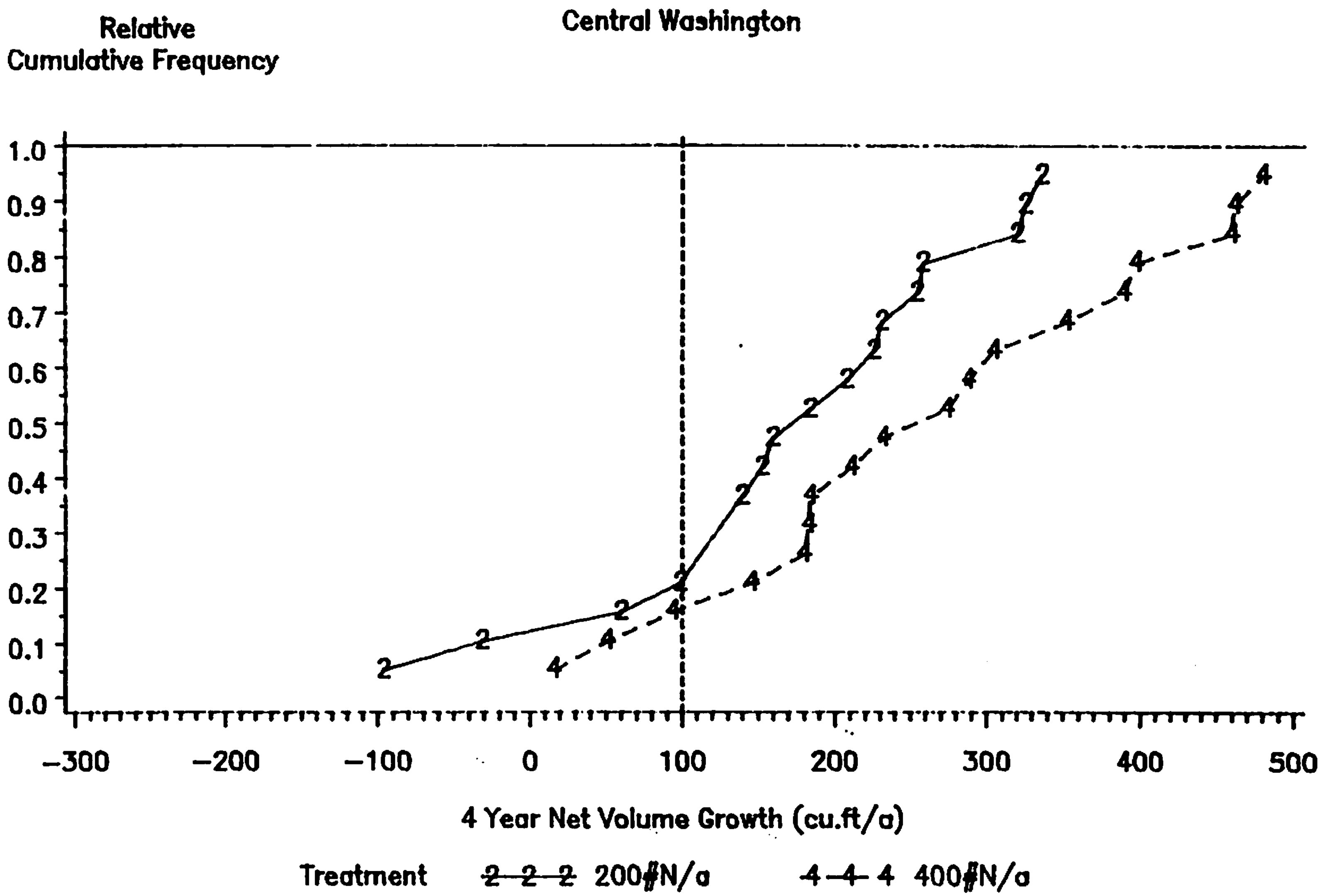

Figure 11. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR CENTRAL WASHINGTON.

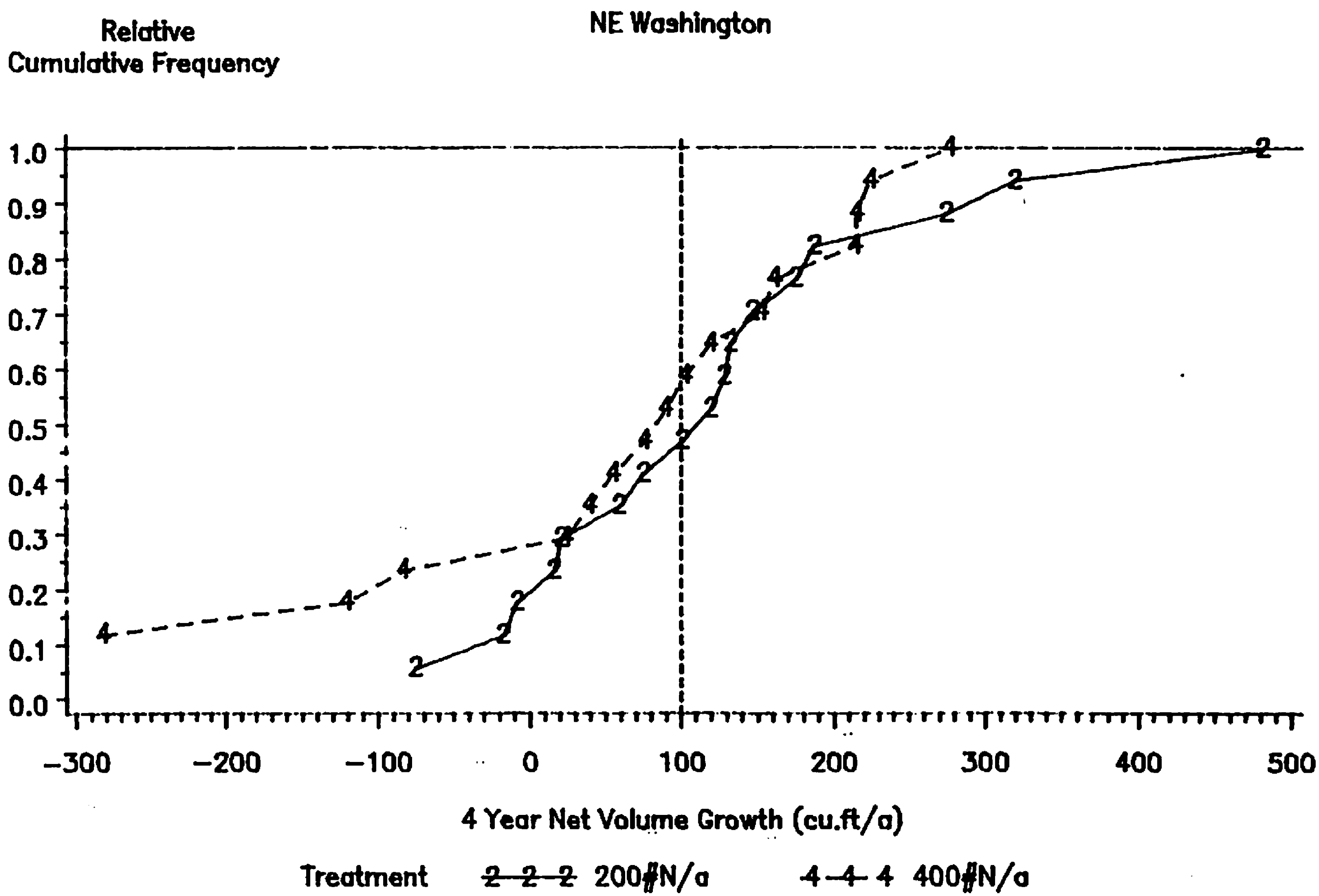

Figure 12. THE CUMULATIVE DISTRIBUTION OF NET FOUR-YEAR VOLUME GROWTH RESPONSE TO THE NITROGEN TREATMENTS FOR NORTHEAST WASHINGTON.

Table 6. The Probability of Obtaining a four-year Net Volume Response Greater than 100 Cubic feet per Acre by Geographic Region and Treatment.

Region	200#N	400#N
Northern Idaho	75%	78%
Montana	12%	20%
Central Idaho	36%	50%
Northeast Oregon	22%	33%
Central Washington	80%	84%
Northeast Washington	59%	40%
Overall	50%	55%

Table 7. The Number of Installations Producing a Net Volume Response of More than 100 ft^3/A to the 200 lb Nitrogen Treatment by Region and Parent Material.

Region	Parent Material	Number of Responding Stands (>100 ft^3/A)	Total Number of Stands	Percent of Stands Responding
Northern Idaho	Ash-loess	5	5	100%
	Ash/metasediments	8	12	67%
	Others	2	2	100%
Montana	Glacial till	1	4	25%
	Valley fill	1	4	25%
	Others	0	8	0%
Central Idaho	Granite	2	8	25%
	Basalt	3	6	50%
Northeast Oregon	Basalt	2	7	29%
	Others	0	2	0%
Central Washington	Basalt & Sandstone	10	10	100%
	Glacial till	3	5	60%
	Others	2	4	50%
Northeast Washington	Glacial till	9	15	60%
	Others	1	2	50%

probability would be improved somewhat by only fertilizing glacial tills and valley fill soils. For central Idaho, basalts are more likely to respond to nitrogen fertilization that granitic soils and the same situation is true for northeast Oregon. In central Washington 80% of the installations produced a net volume response greater than 100 ft^3/A. All ten of the stands located on basalt and sandstone soils responded more than 100 ft^3/A in four years to 200 lb of nitrogen. For northeast Washington, nearly all installations are on glacial tills, so there is no real improvement over the region's cumulative distribution (Figure 12 and Table 6). As a point of interest, in the "other" category in northeast Washington, the responding stand was on a basalt soil and the non-responder on granite.

The process we have been going through in this section of the report attempts to "screen-out" non-responding installations (i.e. those < 100 ft^3/A in four years). This is one of the major goals of the cooperative. The results suggest that we are fairly successful in the screening process using region and parent material. Naturally the average response to nitrogen fertilization is much higher for the responding stands in the population than for the overall average response. This is shown in Table 8, which gives the average net volume response by region for responding installations in a region. The purpose of the data in Table 8 is to illustrate what might be gained by applying what we know to "screen-out" non-responding stands.

The Relationship Between Other Mineral Nutrients and the Response to Nitrogen Treatments:

The post-treatment foliar nitrogen levels are given by treatment and soil parent material in Table 9. These values are derived from all 90 Douglas-fir installations established in 1981 and 1982. The average foliar nitrogen

Table 8. Average four-year net cubic feet volume growth response to the 200 pound nitrogen treatment for responding and all installations by region.

Region	Responding Installations 1] (>100 ft^3/A) ft^3/A	All Installations 1] ft^3/A
Northern Idaho	228	159
Montana	159	35
Central Idaho	229	113
Northeast Oregon	164	56
Central Washington	254	202
Northeast Washington	207	126
Overall	226	124

1] These responses are adjusted to individual installation average basal area rather than the overall average basal area of 150 ft^2/A.

Table 9. Average foliar nitrogen concentration by soil parent material and treatment.

Parent Material	Nitrogen Percent Control	200 lb	400 lb
Granite (10)	1.02	1.26	1.61
Ash-loess (8)	1.09	1.34	1.95
Basalt (20)	1.17	1.41	1.65
Glacial till (22)	1.10	1.38	1.78
Ash/metasediments (12)	1.14	1.38	1.82
Valley fill (3)	1.20	1.42	1.81
Colluvium (4)	1.06	1.33	1.74
Alluvium (3)	1.10	1.35	1.84
Sandstone (3)	1.41	1.41	1.81

concentration for the untreated control plots is only 1.1%. This is very low compared to results from studies in other regions. It has been suggested by some studies that significant response to nitrogen can be expected if foliar N levels are below 1.6%. Notice that the foliar N levels for the 200 lb nitrogen treatment, while significantly greater than the controls, do not reach 1.6%. It is only withthe 400 lb treatment that we approach this level. Why then wasn't the two-year growth response to the 400 lb treatment significantly greater than the 200 lb treatment based on all 90 installations? In the cases where additional nitrogen did not produce additional increment, it is likely some other factors limited growth. Central Washington produced the greatest response to both nitrogen treatments, and the 400 lb treatment was significantly greater than the 200 lb treatment. This is the kind of response pattern we would expect from a nitrogen limited forest system. However, the foliar nitrogen concentration values for the control plots in other regions were even lower than central Washington. This suggests that nitrogen also limits growth in the other regions. Central Washington is not the most productive of our IFTNC regions based on comparing untreated control height and volume increments (Tables 2 and 3). Central Washington ranks behind northern Idaho and northeast Washington and about the same as central Idaho in terms of productivity. Why does central Washington respond so well to nitrogen fertilization? One clear difference between central Washington and the other regions is in foliar potassium (K) concentrations before and after nitrogen fertilization. The average foliar K concentrations by region and treatment are given in Table 10. Central Washington control plots have foliar K concentrations well above the other regions and the K concentrations remain about the same after nitrogen treatments. Northern Idaho, Montana, and northeast Washington control plots are low in foliar K and show a noticeable

Table 10. Average foliar potassium concentration by geographic region and treatment.[1]

Region	Potassium concentration (PPM) -Treatment- Control	200lb.N	400lb.N
Northern Idaho	6316	6049	5625
Montana	6249	6056	6081
Central Idaho	6092	5928	6645
Northeast Oregon	6630	6823	6800
Central Washington	7210	7317	7248
Northeast Washington	6880	6297	6132
Overall	6568	6390	6366

[1] Estimated marginal foliar K concentration is 8000ppm.
Estimated inadequate foliar K concentration is 6000ppm.

drop in K concentrations after nitrogen treatments. In northern Idaho and Montana, the average values are at or below an estimated inadequate foliar K concentration of 6000 ppm (Webster & Dobkowski, 1983). Even though the installations in central Idaho and northeast Oregon do not exhibit the pattern of decline in foliar K after nitrogen treatments, the values are low and are well below the estimated marginal K concentration of 8000 ppm (Webster & Dobkowski).

Another way to analyze nutrient status is to examine balances between nutrients. Ingestad (1966) proposed a set of "standards" for nutrient ratios. In this approach other nutrients are expressed as a percent of nitrogen concentration in the foliage. These potassium/nitrogen ratios are given by region and treatment in Table 11. A ratio of 50 is low, and a value below 40 would be cause for concern. Notice that the average K/A ratios for the 400 lb nitrogen treatments in northern Idaho, Montana, and northeast Washington are all below 40.

The trends in foliar K concentrations and K/N ratios by nitrogen treatments are even more noticeable when compared by soil parent material. Average foliar K concentrations by soil parent material and nitrogen treatment are provided in Table 12. Ash-loess, glacial tills, ash/metasediments, and colluvium soils all begin with low K concentrations (the control plots) and show noticeable decreases with the nitrogen treatments. This is particularly true for ash-loess and colluviums given the 400 lb nitrogen treatments. The average K concentrations are well below the suggested inadequate level of 6000 ppm. The K decline for glacial tills would be even greater if the glacial till soils in central Washington were excluded; none of them showed a large decrease with nitrogen treatments! The other parent materials generally were low for the untreated control plots but remained at about the same level after

Table 11. Average ratios of foliar potassium and nitrogen concentrations by geographic region and treatment.[1]

Region	Ratio (K/N*100) -Treatment- Control	200 lb N	400 lb N
Northern Idaho	58	45	32
Montana	57	45	35
Central Idaho	60	46	41
Northeast Oregon	59	57	47
Central Washington	60	53	43
Northeast Washington	61	45	37
Overall	59	48	38

[1] Ingestad suggests that 65 is "optimal" and 50 is "marginal".

Table 12. Average foliar potassium concentrations by soil parent material and treatment.[1]

Parent Material	Potassium concentration (PPM) -Treatment- Control	200lb.N	400lb.N
Granite	5881	6345	6583
Ash-loess	6149	5704	5310
Basalt	6918	6634	6824
Glacial till	6680	6319	6202
Ash/metasediments	6524	6289	6111
Valley fill	6199	5571	6704
Colluvium	5985	6064	5369
Alluvium	6653	6778	6714
Sandstone	8127	8574	8381
Overall	6568	6390	6366

[1] Estimated marginal foliar K concentration is 8000ppm.
Estimated inadequate foliar K concentration is 6000ppm.

nitrogen treatments. Granites and valley fills (for the 400 lb nitrogen treatment) increased in foliar K concentrations after nitrogen treatments. The foliar K levels for sandstone soils are the highest we sampled in the study and remain high for all treatments (they are even above the suggested marginal concentration of 8000 ppm). Perhaps it is not a coincidence that these soils produced the highest average absolute and relative response to the nitrogen treatments in the entire experiment.

The average K/N ratios by parent material and nitrogen treatment (Table 13) clearly show the foliar K decreases after nitrogen fertilization. The nitrogen treatments produced a noticeable decrease in the foliar K/N ratios for all parent materials. The decrease is largest for ash-loess, ash/metasediments, glacial till, valley fill, and colluvium soils. The foliar K/N ratios remained at "acceptable" levels after nitrogen treatments for sandstones.

We have carefully examined the foliar concentrations and Ingestad ratios for the following other mineral nutrients: phosphorous, calcium, magnesium, zinc, manganese, boron, iron, and copper. Except for a few cases for boron and iron, none of the other nutrients suggested the kind of potential problem we may have with potassium.

The following is an interesting paraphrase taken from Jorgensen and Wells (1987): . . . . unlike nitrogen, the effects of potassium can persist over a longer time because it can be recycled with few leaching losses.

Developing a Predictive Model of Treatment Response

Development of a predictive model of response to nitrogen treatments based on four-year growth is still in progress as of this time. However, the results of this analysis will be available at the annual meeting of the IFTNC.

Table 13. Average ratios of foliar potassium and nitrogen concentrations by parent material and treatment.[1]

Parent Material	Ratio (K/N*100) -Treatment- Control	200 lb N	400 lb N
Granite	58	50	42
Ash-loess	57	43	29
Basalt	61	49	43
Glacial till	61	47	37
Ash/metasediments	57	46	34
Valley fill	52	39	37
Colluvium	57	46	32
Alluvium	61	50	38
Sandstone	59	61	49
Overall	59	48	38

[1] Ingestad suggests that 65 is "optimal" and 50 is "marginal".

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