Six Year Fertilizer Response of Managed Second-Growth Douglas-fir Stands in the Inland Northwest

Peter G. Mika and James VanderPloeg

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INTERIOR DOUGLAS-FIR
THE SPECIES AND ITS MANAGEMENT

SYMPOSIUM PROCEEDINGS

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SIX-YEAR FERTILIZER RESPONSE OF MANAGED SECOND-GROWTH DOUGLAS-FIR STANDS IN THE INTERMOUNTAIN NORTHWEST

Peter G. Mika and James VanderPloeg

ABSTRACT

Growth data collected from 94 Douglas-fir sites in six geographic regions of the Intermountain Northwest were used to determine six-year growth response of managed Douglas-fir stands to two rates of nitrogen fertilizer. Fertilizer rates were 200 and 400 pounds nitrogen per acre in the form of urea. An analysis of covariance model was used to estimate treatment effects and differences in growth among regions, adjusting for site differences in initial basal area per acre.

Response to the nitrogen treatments differed significantly among geographic regions. Gross basal area and volume growth on fertilized plots were significantly greater than growth on controls for all geographic regions, but only in northern Idaho and central Washington was gross response significantly greater on 400-lb/ac N plots than on 200-lb N plots. Net basal area and volume growth on treated plots in Montana, central Idaho and northeast Oregon were not significantly greater than the controls for either nitrogen treatment. Analysis of two year periodic basal area increment indicated that, while response did decline through time, treated plots continued to grow more than control plots six years after treatment.

Mortality rates were influenced by nitrogen treatments; treated plots tended to suffer more mortality than controls. Causes of mortality differed by region, but wind or snow damage, root rots, and bark beetles were the most common.

Keywords: Nitrogen fertilization, stand growth estimates, *Pseudotsuga menziesii*

INTRODUCTION

As an intermediate silvicultural prescription, forest fertilization comes closest to a true medical prescription. It deals directly with the nutrient status of the forest through the application of a predetermined dosage of fertilizer—a shot of vitamins if you will. And, like much of medicine in this country, fertilization is often thought of as a remedy (take 200 lbs/ac and call me in ten years) rather than a preventative or growth enhancing treatment. This reactionary mentality regarding forest fertilization comes about for several reasons. First, the visual impact is relatively small, even though response may be terrific. Compared to the immediate and usually drastic visual impact obtained from treatments such as thinnings, prescribed burns or even herbicide applications, fertilization is boring. It is easier to justify expenses on activities where the end result is easily seen, whether the treatment fulfills its objective or not. Second, nutrient deficiencies are impossible to quantify without soil or foliar chemical analysis. Even when visual symptoms appear on the trees, they are often attributed to insect or disease problems. And finally, fertilization is considered somewhat risky. Not enough is known about the where, when and what of fertilization to make it a comfortable low-risk treatment.

In 1980, a group of public and private forestry organizations formed a cooperative to study the nutrition of commercial forest tree species of the Intermountain Northwest of the United States. This group, the Intermountain Forest Tree Nutrition Cooperative (IFTNC), decided to concentrate the majority of its initial effort on studying the effect of nitrogen (N) fertilization on growth and survival of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), the tree species of most wide spread interest in the area due to its ubiquity, large existing volumes, growth potential, and commercial value. To accomplish this task the IFTNC established a series of nitrogen fertilizer trials throughout the area.

Over 30 years ago, coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) was shown to respond to nitrogen fertilization (Gessel and Walker 1956); since then further aspects of its response have been well documented (Gessel 1968; Steinbrenner 1981; Brix and Ebell 1969; Brix 1971, 1981, 1983; Harrington and Miller 1979; Barclay *et al.* 1982; Miller *et al.* 1986). However, little has been published on the response of the Rocky Mountain variety to nitrogen amendments or on the variation in response across the wide range of conditions found in the Intermountain Northwest. In this paper we discuss the response of Rocky Mountain Douglas-fir to nitrogen fertilization, including variation among and within geographical regions and duration of the response.

METHODS

Study Area, Population, and Design

The Intermountain Northwest shown on the map in Figure 1 is a large, ecologically diverse area stretching from the eastern slopes of the Cascade Mountains in Washington to the western slopes of the Rocky Mountains in Montana and from the Canadian border in the north to the Snake River plain in southern Idaho. From 1980-1982, the IFTNC established 94 fertilizer trials (installations) in this area. By design, these installations fall in six geographic regions: central Washington, northeast Washington, north Idaho, western Montana, central Idaho, and northeast Oregon. The distribution of installations is shown in Figure 1.

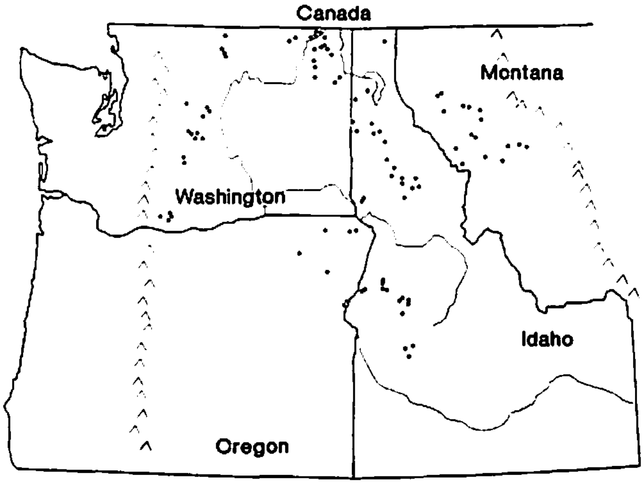

Figure 1.—The Intermountain Northwest region. Points on the map indicate the location of the 94 Douglas-fir fertilizer installations established by the Intermountain Forest Tree Nutrition Cooperative.

Installations were located in second-growth, even-aged, managed Douglas-fir stands. Most stands had been thinned 5-12 years previously; other stands were unthinned, but naturally well-spaced. Stands were selected to cover a range of stand densities, tree ages and sizes, and site productivities (Table 1). The stands are dominated by Douglas-fir; on average, 87% of the basal area was Douglas-fir. Other species contributing substantial basal area include ponderosa pine (*Pinus ponderosa* Dougl.), lodgepole pine (*P. contorta* Dougl.), western larch (*Larix occidentalis* Nutt.), and grand fir (*Abies grandis* [Dougl.] Forbes). Species of minor importance include western redcedar (*Thuja plicata* Donn.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western white pine (*P. monticola* Dougl.), and Engelmann spruce (*Picea engelmannii* Parry).

Table 1.—Averages and ranges for site and stand characteristics across the 94 fertilizer installations at the initiation of the experiment.

Characteristic	Mean	Minimum	Maximum
Elevation (feet	3580	1500	5900
DF Site Index[1] (ft@ 50 yrs)	68.6	40.6	96.4
Age (years)	65	27	100
Basal Area in DF (%)	87.3	27.7	100.0
Quadratic Mean Diameter (in)	10.3	6.1	16.7
Trees per acre	267	103	702
Basal Area (ft^2/ac)	141	48	272
Total Volume (ft^3/ac)	3695	740	8320

[1]Monserud (1984).

Each installation consists of six square plots from 0.1-0.2 acre in size. The plots each contain at least ten Douglas-fir sample trees and were selected to minimize among-plot variation in terrain, vegetation composition, tree stocking, and tree size. Plots were grouped into two blocks of three plots based on similarity of these features to further reduce variation. Three fertilizer treatments—0, 200, and 400 pounds per acre of nitrogen—were randomly assigned to the plots within each block. Nitrogen in the form of urea was applied in the late fall utilizing hand-held spreaders. All fertilized plots were surrounded by a treated buffer strip to reduce edge effects.

Data Collection and Compilation

All live plot trees were tagged and measured for heights and diameters at the time of treatment. Every two years diameters have been remeasured on all trees and any incidence of damage or mortality along with probable cause has been noted. Heights were remeasured four years after treatment on all trees. At six years, heights were measured on a stratified random sample of plot trees. Six-year heights for unmeasured trees were estimated using plot-specific regression equations for 6-year height based on 4-year height and 6-year diameter growth. Tree volumes were estimated using regional species-specific volume equations (Wykoff *et al.* 1982). Basal areas and total volumes were summed over all trees (not just Douglas-fir) to obtain plot totals.

One year after treatment, dormant season foliage samples were obtained from two dominant or co-dominant Douglas-fir trees on each plot for 85 of the 94 installations (16 per installation, 1020 total). Foliage was collected from the third whorl from the top of each tree by climbing. Current season foliage was clipped, placed in plastic bags, and stored in ice-cooled containers while in the field. In the laboratory, samples were stored at -18°C until they could be dried. Shoots were oven-dried at 70°C for 24 hours, needles were separated from stems, and removed needles were redried at 70°C for an additional 24 hours. Foliage was ground in a Wiley mill in preparation for chemical analysis.

Foliar nitrogen levels were determined using a standard micro-Kjeldahl procedure (Bremner and Mulvaney 1982). Needles were digested with sulfuric acid and the digestate was distilled with steam. Total nitrogen concentration was recorded as a percentage per unit of dry needle weight.

Statistical Analysis

Statistical analysis was conducted to estimate fertilizer effects on total plot tree growth using a split plot analysis of covariance model; in this study, whole plots correspond to installations and split plots are fertilizer treatment plots. The particular model fit was (after Federer 1955):

$$Y_{hijk} = \mu + R_h + \beta_1 X_{hi.} + \beta_2 X^2_{hi.} + I_{i(h)} + B_{j(i\,h)} + F_k + RF_{hk} + \beta_3 X_{hijk} + \beta_4 X^2{}_{hijk} + \beta_3 F_k X_{hijk} + \beta_4 F_k X^2{}_{hijk} + e_{hijk} \qquad [1]$$

where Y_{hijk} is the six year growth for the split plot (ie. the k̲t̲h̲ fertilizer treatment in the j̲t̲h̲ block of the i̲t̲h̲ installation within the h̲t̲h̲ region), μ is the overall mean effect, R_h is the effect due to the h̲t̲h̲ region, $I_{i(h)}$ is a whole plot random effect due to the i̲t̲h̲ installation within the h̲t̲h̲ region, $B_{j(i\,h)}$ is a nested random effect due to the j̲t̲h̲ block of the i̲t̲h̲ installation within the h̲t̲h̲ region, F_k is the split plot effect due to the k̲t̲h̲ fertilizer treatment, RF_{hk} is the interaction effect between region and fertilizer, X_{hijk} is the basal area per acre at the start of the experiment for the split plot, X_{hi} is the installation (whole plot) initial basal area per acre, β_1 and β_2 are regression coefficients for the whole plot regression of growth on initial basal area, β_3 and β_4 are regression coefficients for the split plot regression of growth on initial basal area, $\beta_3 F_k$ and $\beta_4 F_k$ are regression coefficients for the split plot regression of growth on the interaction of fertilizer treatment with initial basal area, and e_{hijk} is a random split plot error effect.

Parameter estimates, adjusted means, and contrasts of interest for the model above were obtained using the general linear models procedure (PROC GLM) of the Statistical Analysis System (SAS Institute Inc. 1985). Regression coefficients obtained by fitting equation [1] were used to adjust treatment plot growth rates for differences in initial basal area per acre. Growth response to fertilization was then calculated by subtracting adjusted growth on control plots from similar growth on fertilized plots. These adjusted fertilizer response rates are the values presented throughout the rest of this paper. For individual installations, growth was adjusted to the average initial basal area for each installation; for comparisons across regions, growth was adjusted to 150 ft² per acre initial basal area.

Duration of response was analyzed using a repeated measures analysis of covariance utilizing the REPEATED option of PROC GLM in SAS (SAS Institute Inc. 1985). Tests of sphericity indicated that a univariate split-split plot analysis of covariance model was appropriate for the data, where fertilizer split plots were further split based on time period. As above, the model parameter estimates were used to adjust plot growth values for differences in initial basal area.

RESULTS AND DISCUSSION

Nitrogen Levels in the Trees

The fertilizer treatments were successful in getting additional nitrogen into the trees. Average foliar nitrogen concentration in percentage by weight of dormant season foliage one year after treatment for the various region and treatment combinations is shown in Figure 2. Consistent dosage-dependent increases in foliar N associated with nitrogen fertilization were found across all regions.

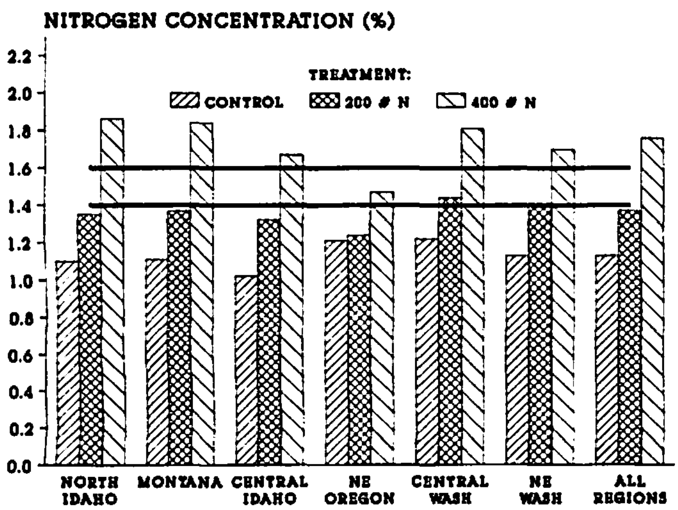

Figure 2.—Average dormant season foliar nitrogen concentrations (percent by weight) for the various combinations of geographic region and fertilizer treatment. The horizontal lines at 1.4 and 1.6% represent inadequate and marginal thresholds, respectively, for Douglas-fir growth (van den Driessche 1979; Webster and Dobkowski 1983).

The horizontal lines at 1.6% and 1.4% concentrations represent marginal and inadequate thresholds, respectively, found for Douglas-fir in western Washington (van den Driessche 1979; Webster and Dobkowski 1983). Trees with foliar N concentrations between marginal and inadequate thresholds can be expected to show growth reductions of 5-15% while trees with concentrations less than 1.4% could show reductions of more than 15%, assuming that nitrogen was the sole factor limiting growth. Untreated trees had inadequate average nitrogen concentrations across all regions. Addition of 200 lb/ac of nitrogen increased foliar N levels, but only to marginal levels. Only with the addition of 400 lbs/ac of N were foliar nitrogen concentrations able to reach adequate levels. Based on these results we would expect to see substantial tree growth gains from additions of 200 lbs/ac nitrogen and even greater increases from 400 lbs/ac fertilizer rates.

Average Gross Growth Response

Analysis of growth data for the six years following treatment shows that trees do respond to nitrogen fertilization. Average gross basal area growth (treatment means) and response to the nitrogen treatments (contrasts between treatment means) are given in Table 2. Growth differences between treated and control plots are considered to be fertilizer response while those between 400- and 200-lb/ac N plots indicate any response associated with increasing the rate of fertilization. Values have been adjusted to a common initial basal area of 150 ft²/ac using equation [1]. Tests on the treatment contrasts indicated that six-year growth on both the 200- and 400-lb/ac nitrogen treatments was significantly greater than that on controls for all geographic regions; significance levels for the tests are shown within parentheses in the table. Across all regions, growth increased by 17.6% when treated with 200 lbs/ac of N and by 24.5% with 400 lbs of N. However, only in northern Idaho and central Washington were the gross increments for the 400-lb treatment significantly greater than the 200-lb treatment. The large magnitude of response in these two regions resulted in a significant ($p=0.001$) difference of 1.7 ft²/ac between the two nitrogen treatments for all regions combined. In the other regions there was a small, nonsignificant trend of increased response with increased N rate.

The pattern of results for gross volume growth response shown in Table 3 is identical to that of basal area growth. In all regions, fertilized trees grew more on the average than unfertilized trees; across all regions, growth increased by 16.1% and 20.9% on plots fertilized with 200 lbs and 400 lbs/ac nitrogen, respectively. In northern Idaho and central Washington treated plots grew over 200 ft³/ac more than control plots in six years. Additionally, trees on 400-lb plots grew more than those on 200 lbs plots, but not across all regions: in northern Idaho and central Washington the higher N rate increased growth significantly, but significant increases were not obtained in any other region.

Average Net Growth Response

The results are different for net basal area increment (Table 4). There is no statistical difference in net basal area increment between either nitrogen treatment and the control for the Montana, central Idaho, and northeast Oregon regions. In northeast

Table 2.—Six-year response in gross basal area by region and treatment. Values in parentheses represent significance levels for tests that the treatment contrasts are equal to zero.

		Growth Basal Area			
		Growth		Response	
Region	Treatment	ft²/ac	Contrast	ft²/ac	Percent
Northern Idaho	Control	33.6			
	200 # N	40.1	200-0	6.5 (.001)	19.4
	400 # N	43.6	400-0	10.0(.001)	29.8
			400-200	3.5(.001)	8.8
Montana	Control	18.6			
	200 # N	21.5	200-0	2.9(.003)	15.6
	400 # N	21.6	400-0	3.0(.002)	16.3
			400-200	0.1(.888)	0.6
Central Idaho	Control	25.4			
	200 # N	28.7	200-0	3.3(.003)	13.0
	400 # N	29.3	400-0	3.9(.001)	15.3
			400-200	0.6(.588)	2.1
Northeast Oregon	Control	20.2			
	200 # N	22.9	200-0	2.7(.044)	13.3
	400 # N	23.9	400-0	3.6(.011)	18.0
			400-200	0.9(.504)	4.1
Central Washington	Control	24.3			
	200 # N	30.5	200-0	6.2(.001)	25.5
	400 # N	34.2	400-0	9.9(.001)	40.5
			400-200	3.6(.001)	11.9
Northeast Washington	Control	26.6			
	200 # N	30.3	200-0	3.7(.001)	13.9
	400 # N	30.8	400-0	4.2(.001)	15.7
			400-200	0.5(.617)	1.6
Overall	Control	25.4			
	200 # N	29.9	200-0	4.5(.001)	17.6
	400 # N	31.6	400-0	6.2(.001)	24.5
			400-200	1.7(.001)	5.8

Washington, the 200-lb/ac 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, and the 400-lb/ac N treatment growth rate was also significantly greater than the 200-lb growth rate for these two regions. Central Washington shows the largest net growth response to both nitrogen treatments. Also notice the large decrease from gross to net basal area response for the 400-lb/ac treatment in all other geographic regions, particularly northeast Washington.

As with basal area results, there is no statistical difference in net volume increment for the 400-lb/ac nitrogen treatments and the controls in northeast Washington, and no difference between either fertilizer treatment and the controls in Montana, central Idaho, and northeast Oregon (Table 5). Central Washington showed the greatest net volume growth response to both nitrogen treatments (200 lbs/ac N = 201 ft³, 21.8%; 400 lbs/ac N = 319 ft³, 34.5%). The net volume growth for the 400-lb/ac treatment is significantly greater than the 200 lbs treatment in northern Idaho and central Washington.

Duration of Response

The duration of fertilizer response was examined by analyzing the change in periodic basal area increments through time; since height measurements had not been taken every two years good periodic volume growth estimates were not available. Gross and net basal area increments for the first, second, and third 2-year periods are compared in Table 6; values are averages by treatment and region adjusted to a common initial basal area of 150 ft²/ac.

Gross basal area response has declined for each successive 2-year period in all regions. In years 1 to 2 and 3 to 4 all regions showed significant ($p<0.1$) positive response to fertilization for both 200- and 400-lb/ac N treatments. In years 5-6, although all regions showed a positive response, the 200-lb/ac N response was only statistically significant ($p<0.1$) in northern Idaho and central Washington. Gross basal area growth on the 400-lb/ac N treatment continued to be significantly greater ($p<0.1$) than the controls during years 5-6 across all regions, except for northeast Oregon ($p=0.168$). Northern Idaho and central Washington were the only regions to show a significant ($p<0.1$) increase in gross growth when the application rate changed from 200 to 400 lbs/ac.

Table 3.—Six-year response in gross volume by region and treatment. Values in parentheses represent significance levels for tests that the treatment contrasts are equal to zero.

		Gross Volume			
		Growth		Response	
Region	Treatment	ft³/ac	Contrast	ft³/ac	Percent
Northern Idaho	Control	1310			
	200 # N	1517	200-0	207(.001)	15.8
	400 # N	1608	400-0	298(.001)	22.7
			400-200	91(.005)	6.0
Montana	Control	689			
	200 # N	793	200-0	104(.002)	15.1
	400 # N	792	400-0	103(.003)	15.0
			400-200	-1(.977)	-0.1
Central Idaho	Control	924			
	200 # N	1048	200-0	124(.001)	13.4
	400 # N	1058	400-0	134(.001)	14.5
			400-200	9(.807)	0.9
Northeast Oregon	Control	802			
	200 # N	883	200-0	81(.082)	10.1
	400 # N	887	400-0	85(.089)	10.5
			400-200	3(.945)	0.4
Central Washington	Control	962			
	200 # N	1201	200-0	239(.001)	24.9
	400 # N	1333	400-0	371(.001)	38.6
			400-200	131(.001)	10.9
Northeast Washington	Control	1027			
	200 # N	1154	200-0	127(.001)	12.5
	400 # N	1156	400-0	129(.001)	12.6
			400-200	3(.940)	0.2
Overall	Control	977			
	200 # N	1134	200-0	157(.001)	16.1
	400 # N	1181	400-0	204(.001)	20.9
			400-200	47(.009)	4.1

Table 4—Six-year response in net basal area by region and treatment. Values in parentheses represent significance levels for tests that the treatment contrasts are equal to zero.

		Net Basal Area			
		Growth		Response	
Region	Treatment	ft²/ac	Contrast	ft²/ac	Percent
Northern	Control	32.2			
Idaho	200 # N	35.7	200-0	3.3(.098)	10.3
	400 # N	39.3	400-0	7.0(.001)	21.7
			400-200	3.7(.067)	10.3
Montana	Control	16.4			
	200 # N	16.7	200-0	0.4(.860)	2.3
	400 # N	16.4	400-0	-0.0(.995)	-0.1
			400-200	-0.4(.856)	-2.1
Central	Control	24.3			
Idaho	200 # N	26.3	200-0	2.1(.381)	8.5
	400 # N	26.3	400-0	2.1(.379)	8.5
			400-200	-0.0(.998)	-0.0
Northeast	Control	16.0			
Oregon	200 # N	14.7	200-0	-1.3(.647)	-8.1
	400 # N	16.9	400-0	0.9(.776)	5.5
			400-200	2.2(.086)	14.9
Central	Control	23.0			
Washington	200 # N	27.9	200-0	4.9(.014)	21.2
	400 # N	31.2	400-0	8.2(.001)	35.8
			400-200	3.4(.086)	12.0
Northeast	Control	21.9			
Washington	200 # N	25.4	200-0	3.5(.099)	15.8
	400 # N	20.5	400-0	-1.4(.501)	-6.4
			400-200	-4.9(.019)	-19.2
Overall	Control	23.1			
	200 # N	25.6	200-0	2.5(.020)	10.9
	400 # N	26.3	400-0	3.2(.004)	13.9
			400-200	0.7(.534)	2.7

The decline in net basal area response to the fertilizer treatments is even more pronounced than for gross basal area. The only treatment in any region that produced a significant net basal area response for years 5 and 6 was the 400-lb/ac nitrogen treatment in northern Idaho ($p=0.016$). Mortality is variable by treatment, region, and time period, and this variation contributes to the non-significant treatment effect for net basal area.

Both net and gross basal area increments for the untreated control plots were lowest in years 5 and 6 for all geographic regions except northern Idaho. For Montana, central Washington, and northeast Washington, there have been successive declines in control plots growth for each 2-year period. This decline in growth rate of the control plots is likely associated with increasingly droughty climatic conditions, particularly during years 5 and 6; this may explain some of the reduction in nitrogen response in those years.

Differences in Mortality Rates

The pattern of response differed for gross and net growth because fertilized plots had higher mortality rates. Volume per acre mortality rate estimates by period, treatment and geographic region are given in Table 7. Most mortality occurred during the second and third two-year periods and was higher for the nitrogen treatments. For most regions, the middle period (i.e., years 3 and 4) had the highest mortality rate. The mortality rates were higher for the 400-lb/ac treatment than for the 200-lb, particularly in northeast Washington. Northeast Oregon has incurred substantial treatment related mortality for both nitrogen levels. Central Idaho showed the lowest mortality levels.

The distribution of mortality by cause and geographic region are provided in Table 8. The most common causes of mortality differed by region. In northern Idaho and northeast Washington the most common cause was wind or snow damage. Although control plots sustained significant wind damage, the amount of wind-caused mortality on the fertilized plots was substantially higher for the 400-lb/ac treatment. Wind-caused mortality was localized at several installations in both of these regions. Root

Table 5.—Six-year response in net volume by region and treatment. Values in parentheses represent significance levels for tests that the treatment contrasts are equal to zero.

		Net Volume			
		Growth		Response	
Region	Treatment	ft³/ac	Contrast	ft³/ac	Percent
Northern	Control	1304			
Idaho	200 # N	1423	200-0	119(.066)	9.1
	400 # N	1529	400-0	225(.001)	17.3
			400-200	106(.102)	7.4
Montana	Control	625			
	200 # N	668	200-0	43(.529)	6.8
	400 # N	658	400-0	32(.633)	5.2
			400-200	-10(.880)	-1.5
Central	Control	889			
Idaho	200 # N	982	200-0	94(.217)	10.5
	400 # N	970	400-0	81(.281)	9.1
			400-200	-12(.870)	-1.3
Northeast	Control	705			
Oregon	200 # N	648	200-0	-57(.537)	-8.1
	400 # N	664	400-0	-41(.681)	-5.8
			400-200	17(.866)	2.6
Central	Control	923			
Washington	200 # N	1124	200-0	201(.002)	21.8
	400 # N	1242	400-0	319(.001)	34.5
			400-200	118(.061)	10.5
Northeast	Control	905			
Washington	200 # N	1036	200-0	131(.053)	14.5
	400 # N	893	400-0	-12(.861)	-1.3
			400-200	-143(.033)	-13.8
Overall	Control	920			
	200 # N	1024	200-0	104(.003)	11.3
	400 # N	1041	400-0	121(.001)	13.2
			400-200	17(.624)	1.7

Table 6.—Average gross and net basal area growth for each two-year period by region and treatment.

		Periodic Basal Area Increment (ft²/ac*yr)					
		Gross BAI Years			Net BAI Years		
Region	Treatment	1-2	3-4	5-6	1-2	3-4	5-6
Northern Idaho	Control	5.9	5.3	5.6	6.3	4.9	5.0
	200 # N	7.7	6.5	5.9	7.5	5.3	5.1
	400 # N	8.1	7.2	6.6	7.8	5.6	6.3
Montana	Control	3.6	2.9	2.8	3.3	2.5	2.4
	200 # N	4.3	3.5	3.0	3.6	2.3	2.3
	400 # N	4.3	3.4	3.0	4.2	1.6	2.3
Central Idaho	Control	4.5	4.7	3.5	4.4	4.6	3.2
	200 # N	5.4	5.2	3.8	5.2	5.3	3.0
	400 # N	5.6	5.2	3.8	5.5	4.7	3.0
Northeast Oregon	Control	3.7	3.7	2.7	3.4	3.0	1.7
	200 # N	4.3	4.1	3.0	3.9	2.8	0.8
	400 # N	4.7	4.2	3.1	4.0	3.0	1.5
Central Washington	Control	4.4	4.2	3.6	4.3	4.2	3.1
	200 # N	5.9	5.3	4.2	5.7	5.8	3.6
	400 # N	6.6	5.9	4.6	6.4	5.8	3.6
Northeast Washington	Control	5.0	4.6	3.7	4.8	3.4	2.8
	200 # N	5.9	5.2	4.0	5.7	4.1	2.9
	400 # N	6.1	5.2	4.1	5.9	2.3	2.1
Overall	Control	4.6	4.3	3.8	4.5	3.8	3.2
	200 # N	5.8	5.1	4.1	5.5	4.3	3.4
	400 # N	6.1	5.3	4.4	5.8	4.0	3.4

rot-caused mortality was higher for both nitrogen treatments in northeast Oregon and for the 400-lb/ac N treatment in northeast Washington. In Montana and northeast Oregon, there were mortality factors apparently unrelated to treatment such as mountain pine beetle in lodgepole and ponderosa pine and spruce budworm in Douglas-fir and grand fir. 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.

Average Stand Diameter Response

Over a short time period, the loss of a few trees on fertilized plots can erase per acre response due to fertilization. However, over a longer time horizon, mortality may not be "bad" depending on which size class within a stand is most affected.

Our data suggests that nitrogen fertilization produces two different types of treatment-related mortality. The first type, which can be called "nutrient-related" mortality, was discussed in the previous section. The second mortality type can be called "competition-related". Larger trees within a stand respond more to fertilization than smaller trees. Over time this would accelerate crown differentiation within a stand with resulting increased mortality rates for smaller trees in subordinate corwn positions—in effect, a thinning from below. The combination of greater fertilization response for larger trees and a fertilization thinning-effect produced the treatment related differences in average stand diameter shown in Table 9.

The increase in average stand diameter resulting from both nitrogen treatments was significantly different from the controls for all geographic regions except northeast Oregon. The 400-lb/ac N treatment was also significantly greater than the 200-lb N treatment for northern Idaho, central Washington, and northeast Washington. The effects of the two treatments are consistent across geographic areas (with the exception of northeast Oregon), and these results suggest that even in those regions where net per acre response is not significant, the nitrogen treatments are having significant effects within stands.

Variation in Growth Response Across Installations

Average responses by region and treatment are useful for making general comparisons and conclusions, but, since we intentionally selected installations to cover a broad range of site and stand conditions, it would be unlikely that all installations would respond to nitrogen fertilization. Understanding why sites and stands do or do not respond is important to devising an effective operational fertilization or nutrient management program.

Table 7.—Average percent mortality by region, treatment, and period. Values are cubic foot volume losses expressed as percentages of gross total volume at year six.

		Percent Loss by Period			
		Years			
Region	Treatment	1-2	3-4	5-6	6-year Total
Northern Idaho	Control	0.01	0.57	0.55	1.13
	200 # N	0.19	0.84	0.88	1.91
	400 # N	0.40	1.24	0.46	2.10
Montana	Control	0.42	0.79	0.46	1.67
	200 # N	0.98	1.69	0.20	2.87
	400 # N	0.15	1.98	0.60	2.73
Central Idaho	Control	0.15	0.37	0.19	0.71
	200 # N	0.17	0.00	0.73	0.90
	400 # N	0.07	0.17	0.61	0.85
Northeast Oregon	Control	0.75	0.97	1.19	2.91
	200 # N	0.77	1.40	2.61	4.78
	400 # N	0.96	1.69	2.55	5.20
Central Washington	Control	0.46	0.21	0.57	1.24
	200 # N	0.13	0.14	1.12	1.39
	400 # N	0.30	0.00	1.20	1.50
Northeast Washington	Control	0.22	1.71	1.02	2.95
	200 # N	0.20	1.27	0.89	2.36
	400 # N	0.20	2.98	2.20	5.38
Overall	Control	0.33	0.75	0.67	1.75
	200 # N	0.39	0.89	1.15	2.43
	400 # N	0.39	1.34	1.31	3.04

Table 8.—Average six-year percent mortality by region, treatment, and cause. Values are the amount of cubic foot volume lost to mortality expressed as a percentage of the gross total volume.

		Percent Cubic Foot Volume Loss by Cause					
Region	Treatment	Competition	Bark Beetle	Root Rot	Wind/ Snow	Other	Total
Northern Idaho	Control	0.19	0.00	0.36	0.47	0.11	1.13
	200 # N	0.19	0.03	0.68	0.41	0.59	1.91
	400 # N	0.16	0.00	0.41	1.38	0.15	2.10
Montana	Control	0.01	1.54	0.00	0.08	0.03	1.67
	200 # N	0.00	2.34	0.00	0.48	0.05	2.87
	400 # N	0.04	1.28	0.00	0.79	0.63	2.73
Central Idaho	Control	0.01	0.51	0.00	0.07	0.12	0.71
	200 # N	0.00	0.29	0.45	0.17	0.00	0.90
	400 # N	0.00	0.11	0.09	0.31	0.35	0.85
Northeast Oregon	Control	0.03	0.00	1.36	1.08	0.44	2.91
	200 # N	0.00	0.10	2.23	0.31	2.14	4.78
	400 # N	0.00	1.84	1.80	0.32	1.24	5.20
Central Washington	Control	0.02	0.45	0.53	0.24	0.00	1.24
	200 # N	0.05	0.49	0.03	0.57	0.25	1.39
	400 # N	0.01	0.38	0.26	0.79	0.07	1.50
Northeast Washington	Control	0.06	0.01	0.58	2.16	0.14	2.95
	200 # N	0.21	0.29	0.54	1.14	0.18	2.36
	400 # N	0.17	0.60	1.33	3.00	0.27	5.38
Overall	Control	0.07	0.41	0.46	0.69	0.12	1.75
	200 # N	0.11	0.57	0.62	0.61	0.52	2.43
	400 # N	0.08	0.62	0.64	1.30	0.39	3.04

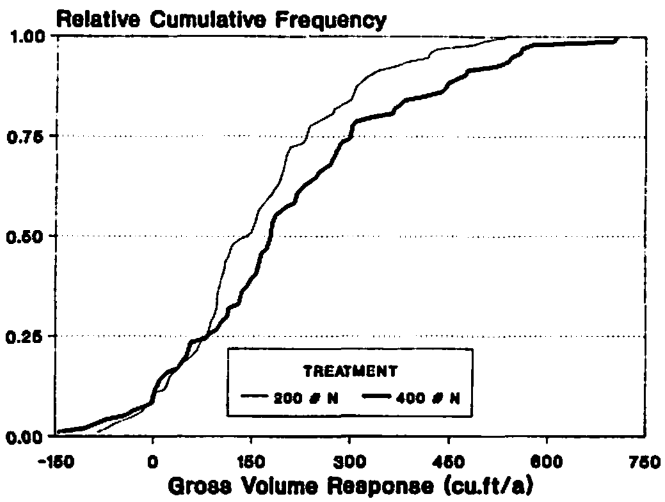

Figure 3.—The relative cumulative frequency distribution of six year gross volume response (ft³/ac) across all regions by fertilizer treatment. Values on the vertical axis are the proportions of the entire sample that were less than or equal to a particular response value on the horizontal axis.

In every region some stands responded well to nitrogen fertilization while others responded negligibly or even negatively. The variation in treatment response across the entire experiment is shown in Figure 3. Within-installation growth differences attributable to differences in initial stand density have been removed using equation [1]. Values are presented in an empirical cumulative distribution function: the vertical axis indicates the proportion of all installations that responded less than or equal to a particular gross volume response value shown on the horizontal axis. For example, of all the 200-lb/ac treatments approximately half of them responded less than 150 ft³/ac and about 90 percent responded less than 300 ft³/ac.

One interesting characteristic is the increasing difference in the response patterns for the 200-lb/ac N and the 400-lb N treatments at high response levels. Perhaps the installations represented in this portion of the sample are limited by nitrogen alone and thus produce additional volume response to the higher nitrogen treatment.

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

Table 9.—Six-year response in average stand diameter by region and treatment. Values in parentheses represent significance levels for tests that the treatment contrasts are equal to zero.

		Change in Stand Quadratic Mean Diameter			
		Growth		Response	
Region	Treatment	inches	Contrast	inches	Percent
Northern Idaho	Control	1.10			
	200 # N	1.29	200-0	0.19 (.001)	17.3
	400 # N	1.42	400-0	0.32 (.001)	29.5
			400-200	0.13 (.004)	10.4
Montana	Control	0.60			
	200 # N	0.68	200-0	0.08 (.078)	14.5
	400 # N	0.75	400-0	0.15 (.002)	26.2
			400-200	0.07 (.159)	10.2
Central Idaho	Control	0.86			
	200 # N	0.99	200-0	0.13 (.017)	15.4
	400 # N	0.95	400-0	0.10 (.074)	11.4
			400-200	-0.03 (.544)	-3.4
Northeast Oregon	Control	0.96			
	200 # N	0.94	200-0	-0.02 (.773)	-2.0
	400 # N	0.99	400-0	0.03 (.693)	2.9
			400-200	0.05 (.504)	5.1
Central Washington	Control	0.93			
	200 # N	1.14	200-0	0.21 (.001)	22.6
	400 # N	1.25	400-0	0.32 (.001)	34.3
			400-200	0.11 (.017)	9.6
Northeast Washington	Control	0.91			
	200 # N	1.06	200-0	0.15 (.003)	16.2
	400 # N	1.16	400-0	0.25 (.001)	27.1
			400-200	0.10 (.041)	9.4
Overall	Control	0.90			
	200 # N	1.04	200-0	0.14 (.001)	15.6
	400 # N	1.12	400-0	0.22 (.001)	24.4
			400-200	0.08 (.002)	7.6

"substantial" response. Other analysis indicates we can explain much of the variation in response using factors such as geographic region, soil parent material, soil mineralizable nitrogen levels, tree crown ratio, and tree foliar potassium status.

The 75th percentile of the response distribution may be a good estimate of the expected response to nitrogen treatments if we were successful in using what we have learned to target responding stands in an operational fertilization program. The value of the 75th percentile for gross volume response by geographic region is provided in Table 10. The 75th percentile response for the 200-lb/ac N treatments range from a low of 147 ft^3 in northeast Oregon to a high of 342 ft^3 in northern Idaho. For the 400 lbs/ac N treatment, the range was from 173 ft^3 in Montana to a high of 540 ft^3 in central Washington. The difference in the 75th percentile for the two treatment response distributions in central Washington was 232 ft^3. This may indicate that for central Washington (and perhaps northern Idaho) the 400 lbs N treatment may produce a response of longer duration.

Table 10.—The 75th percentile of gross volume per acre response by region and treatment.

Region	200 # N	400 # N
Northern Idaho	342	444
Montana	157	173
Central Idaho	204	250
Northeast Oregon	147	182
Central Washington	308	540
Northeast Washington	201	198
Overall	235	302

In closing, past efforts of the IFTNC have resulted in a better understanding of the nutritional status of Douglas-fir in the Intermountain region. Response of Douglas-fir stands to nitrogen fertilization in a wide variety of site conditions has been quantified. Using predictive models, expected fertilizer response can be estimated and much of the risk reduced. Future analysis will be directed toward determining response by species, distribution of response within a stand and the relationship of response to tree nutritional status.

The results of this project and many others presented at this symposium during the past few days emphasize the need for overall ecosystem management. We, as foresters, can have a major impact on future productivity of the forest ecosystem through our management practices. A more thorough understanding of these relationships is absolutely essential if we are to manage properly.

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