Table 2. Random plot SI_{25} (m) descriptive statistics by habitat type.

Habitat type	Mean	Standard deviation	Sample size
PIPO/ARPA	3.6	0.96	31
PIPO/ARNO	4.8	1.09	31
PIPO/PUTR	4.7	0.84	30
PIPO/QUGA	5.6	1.41	57
PIPO/SYOR	5.9	1.07	23

as seed source, time elapsed since last disturbance, and type of disturbance. For example, shrub species characteristic of the PIPO/ARPA habitat type (*Ceanothus* and *Arctostaphylos*) tend to germinate rapidly and resprout after fire disturbance (Daubenmire 1959). *Purshia tridentata* usually does not resprout after a fire but may be reestablished by rodents caching *Purshia* seeds (West 1968, Sherman and Chilcote 1972). Therefore the habitat type of a given site may not be entirely dependent on environmental conditions; it may also depend on site history and chance.

Although there was considerable site index variation within habitat types, the best sites ($SI_{25} > 7.2$ m) occurred only in the PIPO/QUGA and PIPO/SYOR habitat types.

In a related study (Verbyla 1988), we sampled the best ponderosa pine sites (according to Dixie National Forest silviculturists) within the Dixie National Forest. Randomly selected plots within these areas were always identified as PIPO/QUGA, PIPO/SYOR or habitat types within the Douglas Fir (*Pseudotsuga menziesii* [Mirb.] Franco) or White Fir (*Abies concolor* [Gord. and Glend.] Lindl ex Hildebr.) series. We found habitat types useful, when combined with soils information, in predicting prime versus nonprime ponderosa pine sites (Verbyla 1988). Therefore within-series habitat type may be useful in other areas if they are used with other site information.

CONCLUSIONS

1. The best ponderosa pine sites ($SI_{25} > 7.2$ m) sampled within the ponderosa pine series only occurred in PIPO/QUGA or PIPO/SYOR habitat types.
2. The range of SI_{25} within any one habitat type was broad. Therefore habitat type should not be used alone in predicting the best ponderosa pine sites.

□

LITERATURE CITED

Daubenmire, R. F. 1959. Plants and environment. A textbook of plant autecology. Wiley, New York, 422 p.

Daubenmire, R F, and J B Daubenmire 1968 Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Wash. Agric Exp. Stn., Pullman, WA.

Mathiasen, R. L., Blake, E. A., and C. B. Edminster. 1986. Estimates of site potential for Douglas-fir based on site index for several southwestern habitat types. Great Basin Nat 46:277–280.

———. 1987. Estimates of site potential for ponderosa pine based on site index for several southwestern habitat types. Great Basin Nat 47:467–472.

Monserud, R. A. 1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat. For. Sci 30:943–965.

Oliver, W. W. 1972. Height intercept for estimating site index in young ponderosa pine plantations and natural stands. USDA For Serv. Res. Note PSW-276.

Pfister, R. D., and S. F. Arno. 1980. Classifying forest habitat types based on potential climax vegetation. For. Sci. 26:52–70.

Roe, A. L. 1967. Productivity indicators in western larch forests. USDA For. Serv. Res Note INT-59. 4 p.

Sherman, R. J., and W. W. Chilcote. 1972. Spatial and chronological patterns of *Purshia tridentata* as influenced by *Pinus ponderosa*. Ecology 53:294–298.

Verbyla, D. L. 1988. A new approach to site quality modeling. Ph.D. diss., Utah State Univ., Logan. 112 p.

West, N. E. 1968. Rodent-influenced establishment of ponderosa pine and bitterbush seedlings in central Oregon. Ecology 49:1009–1011

Youngblood, A. P., and R. L. Mauk. 1985. Coniferous habitat types of central and southern Utah. USDA For. Serv. Gen. Tech. Rep INT-87.

Effects of Nitrogen Fertilization on Growth of Grand Fir and Douglas-Fir Stands in Northern Idaho[1]

Bahman Shafii, *College of Agriculture,* **James A. Moore,** *College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow 83843, and* **John R. Olson,** *Potlatch Corporation, Lewiston, ID.*

*ABSTRACT. A study of nitrogen fertilization response in thinned and unthinned stands of grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziesii*) in northern Idaho showed that the application of one urea nitrogen treatment applied at a rate of 200 lb N/ac resulted in a significantly higher average basal area growth over a 6-year post-treatment period. Nitrogen fertilization also resulted in a significant height increment increase over the same period. Fourteen years after treatment, fertilization had increased average tree size, in terms of total cubic volume, by 14% in unthinned and by 23% in thinned stands. A comparison of thinned and unthinned stands suggested an increase in tree size (>300%) over the same period without significant reduction in average total cubic volume per acre. Patterns of stand development were altered by nitrogen fertilization.*

West. J. Appl. For. 4(2):54–57, April 1989.

[1] This research was supported by Potlatch Corporation, Lewiston, ID, and the Intermountain Forest Tree Nutrition Cooperative, located at the College of Forestry, Wildlife and Range Sciences, University of Idaho. College of FWR Experiment Station contribution no. 460.

Silviculturists thin and fertilize to enhance growth, alter species composition, adjust spacing, and improve stem quality of developing forest stands. Fertilization is most often used to increase stand growth rate. Depending on a stand's site quality and nutritional status, nitrogen fertilization can accelerate tree growth, yielding higher stand volumes at a given age, or provide a reduction of the rotation age (Powers 1980, Miller 1981).

The magnitude, duration, and distribution of response to nitrogen fertilizer for forest stands located in the Pacific Northwest has been frequently investigated (e.g., Waring and Youngberg 1972, Cochran 1979, Miller et al 1979, Brix 1981, RFNRP 1987, IFTNC 1987), but little information is available for grand fir.

This article summarizes an analysis of average growth response to nitrogen fertilization and thinning in Northern Idaho grand fir and Douglas-fir stands utilizing plot-based analysis of variance procedures (Shafii and Moore 1986). The objectives of the analysis were to evaluate 6-year gross and net basal area and height growth response to urea in thinned and unthinned stands composed predominantly of grand fir and Douglas-fir, and to compare periodic (2-year) basal area growth response over time to assess duration of nitrogen response in thinned and unthinned stands. Net total cubic foot volume was also computed and treatments compared after 14 years.

METHODS

Source of Data and Experimental Setting

Data from 25 permanent-plot nitrogen fertilization research installations located thoughout northern Idaho were combined from three separate research studies for this analysis. Data sources were selected based on the duration of post-treatment measurements and a predominance (percent basal area >50%) of grand fir and Douglas-fir.

A University of Idaho McIntire-Stennis (MS-16) study provided data from 13 nitrogen fertilization and thinning installations that were established in the early 1970s (Scanlin et al. 1978). These sites provided 14 years of post-treatment stem height (a subsample) and diameter measurements for all trees. Measurements were obtained every 2 years (from 1971 to 1979), and the last measurement was conducted in 1985. All tree heights were measured at the end of the growth period; however, only approximately 20% of tree heights were measured at the beginning of the experiment. Initial heights for unmeasured trees were predicted using the following height/diameter breast height relationship, estimated separately for each plot:

$$H = e^{[b_0 + b_1 * (1/DBH)]}$$

The same procedure was followed for all three data sources. Individual tree total cubic volume was estimated using species specific volume equations given in Prognosis (Wykoff et al. 1982). Each installation contained eight one-tenth acre square plots, four of which were thinned to a 15′ × 15′ spacing regardless of initial density, and four were left unthinned No prethinning records were available, and thus, acutal thinning intensity is unknown. Urea nitrogen fertilizer was applied, randomly, at time of plot establishment at a rate of 200 lb of N/ac to two thinned and two unthinned plots.

Five additional installations were supplied from an Intensive Timber Culture (ITC) project established in 1977 by the University of Idaho in cooperation with USDA Forest Service Intermountain Research Station. Each was established to test thinning and combined thinning/urea fertilization treatments and provided 10 years of post-treatment diameter and height (subsample) data. These sites were operationally thinned to spacings ranging from 10′ × 10′ to 15′ × 15′ one year prior to the application of the nitrogen treatments.

A third data set was composed of seven permanent research installations provided by Potlatch Corporation. Six years of post-treatment growth measurements (diameter, a subsample of height, and damage) were available from these sites. Only thinned and unthinned 1/10th ac control plots and those receiving the 200 lb N(urea)/ac application were included in this analysis.

A total of 147 one-tenth acre plots were selected from the three data sources, MS-16, ITC, and Potlatch for this analysis. The distribution of selected mensurational characteristics by data source is provided in Table 1. The study areas are second-growth even-aged stands composed primarily of grand fir and Douglas-fir.

Statistical Analysis

The following experimental model was used in the 6-year gross and net basal area growth response analysis:

$$\begin{vmatrix} GBA \\ NBA \end{vmatrix} = f(Inst,\ Trt,\ BA,\ P\text{-}BAGF), \qquad (1)$$

where

GBA = gross basal area increment (ft²/ac),
NBA = net basal area increment (ft²/ac) = *GBA* − mortality,
Inst = installation,
Trt = treatment: control, nitrogen alone, thinning, and thinning + nitrogen,
BA = total initial basal area (ft²/ac), and,
P-BAGF = grand fir basal area as a percentage of initial total basal area.

Statistically, this model is a multivariate analysis of covariance with standard underlying linear model assumptions. Installation and treatment terms represent classification variables, while *BA* and *P-BAGF* represent continuous covariates. The nature of this type of model allows investigation of the overall effect of nitrogen fertilization on both net and gross basal area increments. Growth responses provided are "smoothed" estimates in that they are adjusted for initial basal area (*BA*) and species composition (*P-BAGF*).

A 6-year height increment (*Ht. Inc.*) model was also specified and tested:

$$Ht.\ Inc. = f\,(Inst,\ Trt,\ BA) \qquad (2)$$

which represents a univariate analysis of covariance with terms defined as before. Only those trees with actual measured heights at the beginning of the study were used in this height growth analysis.

For 14-year periodic basal area growth and volume response analysis, only data from the MS-16 study were used as the other studies did not encompass a 14-year post-treatment measurement period. Two models were used for the analysis of periodic gross and net basal area growth over the entire 14-year post-treatment period and for each separate growth period. The model developed for thinned stands resembled that of the 6-year basal area response. The model for unthinned stands, though similar, included a term for the interaction of fertilizer treatment and initial basal area (*Trt* * *BA*) to investigate the changes of treatment effect across varying stand density. Basal area for thinned stands represented post-thinning densities, and was not significantly related to growth immediately following treatment. Both models produced statistically similar fits of the data (R^2 = 0.77 and 0.79, respectively).

Table 1. Distribution of mensurational characteristics for three data sources used in the analysis of thinning and fertilization response.

	MS-16	ITC	Potlatch
	Mean and (Range)		
Number of installations	13	5	7
Breast height age	42	52	56
	(21 to 77)	(19 to 84)	(38 to 96)
Site index[1] (feet	58	59	68
base age 50)	(30 to 90)	(40 to 80)	(50 to 80)
Dbh (in.)	6.3	6.6	10.3
	(1.0 to 19.5)	(0.5 to 20.2)	(2.9 to 18.9)
Basal area (ft²/ac)	122.3	113.1	181.9
	(18.7 to 314.3)	(22.0 to 208.8)	(96.4 to 262.9)
Percent grand fir[2]	53.9	44.0	23.0
	(4 to 95)	(4 to 78)	(3 to 46)

[1] Grand fir site index (Stage 1959).
[2] Percentage of total basal area composed of grand fir. Stands with small amounts of grand fir were predominantly Douglas-fir.

RESULTS

Six-year Basal Area Growth Response

Results of 6-year basal area response to nitrogen fertilization are

Table 2. Average 6-year gross and net basal area growth response to nitrogen fertilization.

	Gross		Net	
Treatment	Response (ft^2/ac)	Percent	Response (ft^2/ac)	Percent
Unthinned	4.8[1]	18.3	4.0	16.8
Thinned	6.5	19.3	6.4	25.1

[1] Response is the increase in basal area growth due to fertilization. All response estimates were statistically significant (α = .10).

summarized in Table 2. Fertilizer significantly ($\alpha = 0.1$) increased growth in both thinned and unthinned stands. Average gross and net basal area response was higher for thinned stands as compared to unthinned stands over the 6-year post-treatment period.

Thinning treatment did not appear to proportionately affect adjusted average height growth (ft/tree) as much as basal area growth (Table 3). Nitrogen fertilization results in a significant increase in height growth in both thinned and unthinned plots over the 6-year post treatment period, however (11.5% and 16.2%, respectively).

Fourteen-year Periodic Basal Area Growth and Volume Response

The pattern of gross and net basal growth response to nitrogen fertilization for thinned and unthinned stands is illustrated in Figure 1. The estimates provided in Figure 1 are from the two statistical models described above and are adjusted to the average initial basal area for each treatment. This procedure along with higher mortality on nonfertilized plots during certain growth periods produced greater net response than gross for some growth periods. The average annual basal area response along with percent response are shown for each growth period. The first four periods are 2 years, while the last period is 6 years. The fertilization effect in thinned stands begins slightly lower than that of unthinned stands during the first period (Figure 1). Notice that the maximum percent fertilization response in GBA for both thinned and unthinned stands occurs in the second 2-year growth period with slightly lower response for the unthinned stands. The fertilization effect becomes insignificant after the third period. During the third period, for unthinned stands, the fertilization effect drops to less than one-half that estimated in the previous period and is only one-third of the effect for the corresponding thinned plots during the same period. Periodic NBA growth response in thinned stands resembled that of GBA, with the maximum occurring in years 3 and 4 with declining (insignificant) treatment effect after 6 years. Periodic NBA response in unthinned stands was greater than thinned stands during the first four years (Figure 1).

Periodic basal area growth for thinned and unthinned stands showed different growth patterns over the 14-year post-treatment period. For the untreated stands, net basal area per acre growth was relatively constant for the first 8 years and then declined for the next 6 years (4 4 vs. 2.6 ft^2/ac/yr for the first 8 vs. the last 6 years). Initially, the thinned stands grew slower than the untreated stands, but by years 5 through 8 their growth rates were approximately equal. During the last 6 years, thinned stands were growing at an average rate of 5.8 ft^2/ac/yr. This is substantially higher than the untreated stands during the same period (2.6 ft^2/ac/yr), and the growth is concentrated on far fewer trees in the thinned stands Lower growth in early years for thinned stands results from less growing stock (i.e., thinning removed, on the average, approximately 70% of initial number of trees per acre); and a shift of resources to crown development and expansion to fill unoccupied released space. Similarly, unthinned stand with much higher densities are under higher

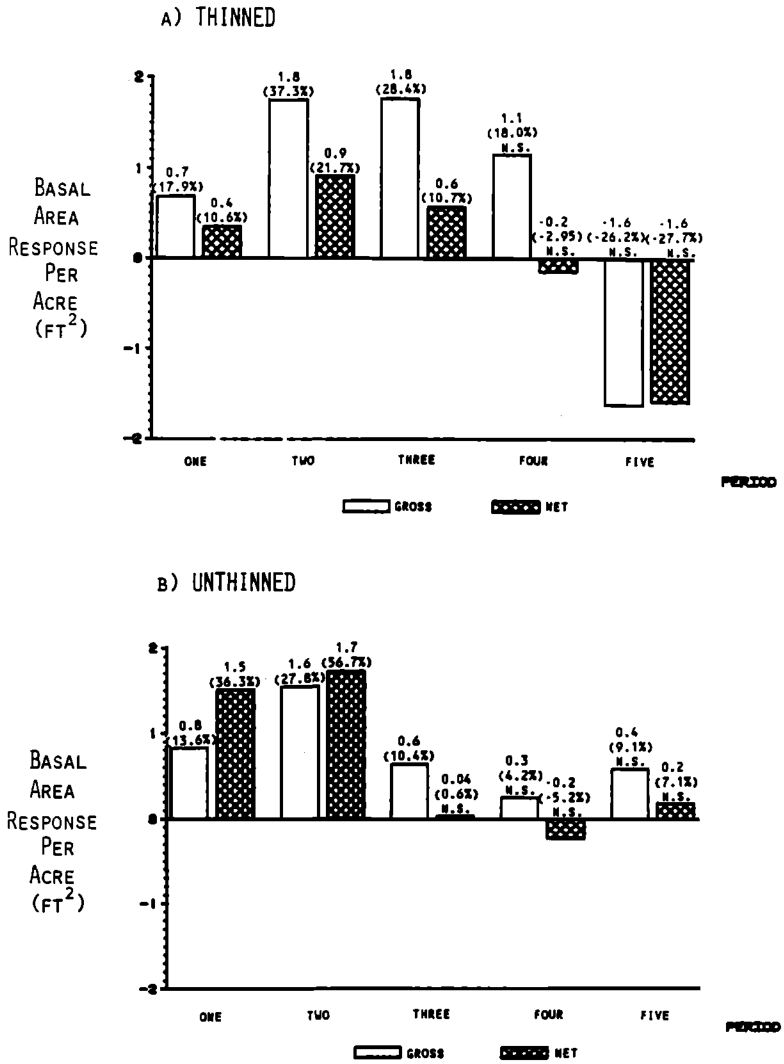

Figure 1. Average annual gross and net basal area response to nitrogen fertilization in (a) thinned and (b) unthinned stands. (N.S. = nonsignificant, α = .10). The fifth growth period is 6 years rather than 2 years.

Table 3. Average 6-year height growth response to nitrogen fertilization.

	Response (ft/tree)	Percent
Unthinned	1.2[1]	16.2
Thinned	0.8	11.5

[1] Response is the increase in height growth due to fertilization. Response estimates were statistically significant (α = .10).

Table 4. Average 14-year net cubic volume per acre, trees per acre, and cubic volume per tree.

Treatment	Volume/ac (ft^3)	Trees/ac	Volume/tree (ft^3)
No treatment	2358	954	2.5
Fertilized	2369	847	2.8
Thinned	2439	296	8.2
Thinned and fertilized	2477	244	10.2

levels of competition and have smaller less efficient crowns in their later years resulting in decreased basal area increment.

The different growth patterns for the various treatments result in the average 14-year ending net cubic volumes for thinned and unthinned plots summarized in Table 4. By the end of the 14-year post-treatment period all treatments produce approximately the same average total volume. Average cubic volume per tree, however, shows an interesting progression: no treatment = 2.5; fertilized only = 2.8; thinned only = 8.2; and thinned plus fertilized = 10.2. Thinning increased average tree size without significant reduction in average total cubic volume per acre.

DISCUSSION

Thinned and unthinned stands of Douglas-fir and grand fir in Northern Idaho appear to respond initially in average basal area growth to nitrogen fertilization 6 years following treatment. The basal area response estimates for the two periods for the unthinned plots are higher than those reported for the IFTNC (1986) Douglas-fir trials located in the same region. Duration of basal area response, however, is short-lived (4 years) in unthinned stands, perhaps due to high density, which probably did not allow for an increase in foliar biomass after treatment. It is probable that nitrogen continues to influence stand dynamics and subsequent development beyond the four-year period. Nitrogen fertilization in unthinned Douglas-fir and grand fir stands reduced average density by about 100 trees per acre over the 14-year post-treatment period. This contributes to an increase in the average tree size relative to the untreated stands. Additional treatment related mortality was concentrated in the smaller size classes. The lightly thinned stands showed trends similar to unthinned stands.

Nitrogen applied to thinned stands produced both lower average absolute and relative response during the first 4 years following treatment as compared to fertilized unthinned plots. However, duration of response appears to be longer than in unthinned stands and remains significant after 6 years.

A negative though nonsignificant fertilization response noted in thinned stands during later periods (years 9–14) may be related to inital differences in stand structure. Thinning type and intensity differed both within and between installations studied. Some stands were only lightly thinned while others were thinned heavily, and some received mechanical thinning while others were thinned either from below or from above in order to achieve strict spacing objectives. These initial structural differences influence mortality, and in turn, tree size distributions. The results show increased variability in response in later years, which we feel can be attributed to initial stand conditions and consequent differences in mortality patterns. Shifts in volume increment distribution across diameter classes (from lower to upper diameter classes) were observed quite frequently within individual installations. Distribution of fertilization response increment within a stand was addressed in a separate study using an individual tree modeling approach (Shafii et al. 1988). Fertilizer response, evaluated on an individual tree basis, produced larger trees after 14 years in both thinned and unthinned stands. This results from two factors; larger trees in a stand showed more absolute fertilization response than smaller trees (Shafii 1988), and higher mortality rates were observed for smaller size classes in fertilized stands. Nitrogen fertilization, particularly in thinned stands, is an effective treatment to increase grand fir and Douglas-fir growth in northern Idaho. The results of this study also illustrate that thinning concentrated growth on residual crop trees, reduced mortality and, consequently, thinned stands produced approximately the same total volume as unthinned stands after 14 years. □

LITERATURE CITED

Brix, H. 1981. Effects of thinning and fertilization on branch and foliage production in Douglas-fir. Can. J. For. Res. 11:502–511.

Cochran, P. H. 1979. Response of thinned ponderosa pine to fertilization. USDA For. Serv. Res. PNW-339. 8 p.

Intermountain Forest Tree Nutrition Cooperative (IFTNC). 1986. Sixth Ann. Rep. FWR. Exp. Stn., Univ. of Idaho, Moscow. 42 p.

Intermountain Forest Tree Nutrition Cooperative (IFTNC). 1987. Seventh Ann. Rep. FWR. Exp. Stn., Univ. of Idaho, Moscow. 39 p.

Miller, H. G. 1981. Forest fertilization: Some guiding concepts. Forestry 54:157–167.

Miller, R. E., D. L. Reukema, and R. L. Williamson. 1979. Response to fertilization in thinned and unthinned Douglas-fir. P. 109–115 in Proc. Forest Fertilization Conference, Gessel, S. P., R. M. Kenady, and W. A. Atkinson (eds.). Inst. For. Resour. Contrib. No. 40. Univ. of Washington, Seattle.

Powers, R. F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest trees. Soil Sci. Soc. Am. J. 44:1314–1320.

Regional Forest Nutrition Research Project (RFNRP). 1987. Bienn. Rep. 1984–1986. Coll. of For. Resour., Univ. of Washington, Seattle. 35 p.

Scanlin, D., H. Loewenstein, and F. Pitkin. 1978. Forest fertilization cooperative project status report. FWR. Exp. Stn., Univ. of Idaho, Moscow. 153 p.

Shafii, B. and J. A. Moore. 1986. Growth response analysis of Grand-fir and Douglas-fir stands to nitrogen fertilization and thinning. Interim Rep. to Potlatch Corp. FWR. Exp. Stn., Univ. of Idaho, Moscow. 120 p.

Shafii, B. 1988. Quantification of thinning and fertilization treatment response for forest stands in northern Idaho. Ph.D. diss., College of FWR, Univ. of Idaho, Moscow. 82 p.

Shafii, B., J. A. Moore, and J. D. Newberry. 1988. Individual tree growth response models for managed stands in Northern Idaho. Can. J. For. Res. (In prep.).

Stage, A. R. 1959. Site index curves for grand fir in the Inland Empire. USDA For. Serv. Res. Note INT-71. 4 p.

Waring, R. H., and C. T. Youngberg. 1972. Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Sci. 46:67–74.

Wykoff, W. R., N. L. Crookston, and A. L. Stage. 1982. User's guide to the stand prognosis model. USDA For. Serv. Gen. Tech. Rep. INT-133. 112 p.