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Two-Year Response of North Idaho Stands of Douglas-Fir and Grand Fir to Urea Fertilizer and Thinning

by David C. Scanlin
Howard Loewenstein
Franklin H. Pitkin

Forest, Wildlife and Range
ment Station

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University of Idaho
Moscow, Idaho 83843

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INTRODUCTION

In recent years, experiments throughout the world have demonstrated that application of some kinds of fer- 'izer can substantially increase the growth of forest :es. Not all applications were successful and not all cies responded in the same manner or to the same ree. The interest which has been generated in the sibility of widespread fertilization programs has sparked pooling of resources for investigation of fertilization tential in commercial forests. Organizations such as the ooperative Research In Forest Fertilization (CRIFF), oordinated by the University of Florida, and the Regional orest Nutrition Research Project, coordinated by the iiversity of Washington, are attempting to pinpoint the fects of specific fertilizer combinations within their ons. Industry is contributing heavily to these projects in hopes of obtaining specific information for making agement decisions.

In the northwest, various experiments utilizing nitro- n, the most universally deficient nutrient, have indicated onsiderable variability in growth response with several pecies. Miller and Pienaar (1973) demonstrated increased diameter, height and volume growth of a 35-year-old Douglas-fir stand during a 7-year period following application of 140, 280 and 420 pounds per acre of nitrogen (as ammonium nitrate). A study in a 50-year old-Douglas-fir stand showed that application of 100 and 200 pounds of urea nitrogen per acre produced only a 1.5 percent increase in volume growth over unfertilized stands over a 5-year period (Mitchell and Kellogg 1970). Preliminary results of the Regional Forest Nutrition Research Project suggest that Douglas-fir is responding much more to applications of nitrogen than is western hemlock (Regional Forest Nutrition Research Project 1974). Smaller scale experiments in Idaho indicate that both Douglas-fir and grand fir may respond to applications of nitrogen fertilizer (Loewenstein and Pitkin 1963 and 1971). Many other studies could be cited with varying results, but several reviews, such as Forest Fertilization: Theory and Practice published by the T.V.A. in 1968, as well as the articles by Armson (1967) and Lee (1968) are available for this purpose.

It was soon realized that in order to predict the quantitative response to fertilization of stands of timber in the Inland Empire (northern Idaho, western Montana and eastern Washington), as well as determine the qualitative changes within each tree and stand, many more fertilizer trials would be necessary. Sufficient interest was generated with industry, the Idaho Department of Public Lands and the USDA Forest Service to begin a major study of nitrogen fertilization in the area. Initial reaction favored utilizing two of the most important species in the area, Douglas-fir (*Pseudotsuga menziesii* Mirb.) and grand fir (*Abies grandis* [Dougl.] Lindl.), in thinned and unthinned stands. A variety of age classes was suggested for investigation, and it was also recommended that the area be classified according to the predominant geologic strata of the region.

The following report is a summary of the 2-year response of Douglas-fir and grand fir on three geologic rock-types to fertilization with 200 lbs/acre of urea nitrogen, and to thinning alone, as well as to the combination of thinning and fertilization.

PROCEDURES

Study Area and Candidate Stands.–The portion of Idaho north of the Salmon River was subdivided into three intermeshed units based on the character of the underlying rock (as obtained from geologic maps). These subdivisions in-

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The authors are, respectively, Research Assistant Professor and Professors of Forest Resources, College of Forestry, Wildlife and Range Sciences, University of Idaho.

clude: (1) Tertiary granitic rocks and granitic rocks of the Idaho Batholith, (2) Columbia River basalt, and (3) the Belt Series of metamorphosed sediments. Within each of these subdivisions, six stands of grand fir and six of Douglas-fir between the ages of 15 and 60 years were located. Restrictions as to uniformity of slope, aspect, soils and density made it difficult to find suitable sites and, in some cases, compromise was necessary. Originally, the study plan called for division of the two species on each rock-type into two age classes, 15-35 and 35-60 years, but as the sites were selected, a noticeable clustering of stand ages at both ends and the middle occurred. Age class, therefore, was not considered as a main effect in the data analysis.

Accessibility by existing roads was a stringent requirement, as technicians packed the 80-lb sacks of fertilizer to the individual plots from the nearest road by hand.

All effort was made to select stands which truly represented large commercial acreages of timber, so that response of these sites would adequately represent response on commercial stands.

Plot Design and Layout.—On acceptable sites (installations), eight one-tenth-acre square plots were marked off, allowing a buffer of approximately one chain or more between plots. Stand geography determined the actual placement of plots within the study site.

Thinning.—Four of the eight plots on each installation, selected at random, were thinned using a 15 x 15 ft spacing between leave trees as a general guideline. Due to great differences in tree sizes between installations, somewhat closer spacing on younger sites allowed more trees to be sampled, yet maintained freedom from competition of other crop trees.

Fertilization.—Pelleted urea fertilizer was applied at the rate of 200 lbs of actual nitrogen per acre to two of the four unthinned, and two of the four thinned plots (selected randomly). Application with a hand held mechanical spreader in a criss-cross fashion assured adequate distribution within the plot. A strip approximately 10 ft wide, fertilized at the same rate, served as a buffer to trees near the plot borders. Application was made in mid-spring and early summer of either 1972 or 1973, depending on the individual site. A few sites had a few inches of snow remaining on them at the time of fertilization; most, however, had no snow or snow only in a few small patches. In many cases rain followed fertilization within hours. Some installations may not have received rain for several days, though the relative humidity was generally high during this period.

The thinning and fertilizing combinations provided two replicates of four treatments within each installation: control (i.e., no thinning or fertilization), thinned only, fertilized only, and both thinned and fertilized.

Initial Measurements.—After establishment of plots, the initial diameter at breast height (recorded to hundredths of an inch), species, crown class and major defects were recorded for all trees within the plot which were greater than 2 inches in diameter (1 inch on the three youngest sites). In addition, approximately 10 trees of the major species, marked with paint bands, served as sample trees to provide more intensive measurements for response. Initially, these trees were to be selected by a computer program with probability proportional to basal area. However, many of the computer selected trees were deformed, diseased or otherwise poor for sampling to determine the potential for response to fertilization and thinning. Handpicking the sample trees with a preference for the dominant and codominant trees of the major species provided a suitable alternative. In addition to the above mentioned descriptors, the age, past 10-year radial increment at breast height (to hundredths of an inch), initial height (to tenths of a foot where possible), and crown ratio of the sample trees were recorded. If the plot contained considerable basal area of species other than the major species, additional measurements were made on a subsample of these trees also.

Site descriptors of elevation, aspect, slope, site index and habitat type provided additional information for analysis.

Growth Measurements.—Two growing seasons following treatment, all plots were remeasured for growth. Diameter growth was recorded as the difference between the 2-year diameter and the initial diameter. A new method was used in the measurement of height growth which allowed the height increment to be measured directly, independent of total height, as long as the leader nodes were clearl visible. A description of this method will be publishe separately.

Evaluation Procedures.—Processing of the data collected on each plot involved summarization through a computer program and statistical evaluation of the summary data.

Summarization included (1) calculation of average age of the stand, (2) total number of trees, (3) total basal area and volume per acre, (4) basal area and volume per acre by 2-inch diameter classes, (5) calculation of the diameter of the tree of average basal area, (6) total basal area and volume growth per acre, (7) basal area and volume growth for each diameter class, and (8) relative density of the stand. In addition, the program included several of the subprograms and much of the logic of other subprograms contained within the prognosis model developed by Albert Stage and his associates (Stage 1973). These subprograms served to (1) assign heights to all plot trees not measured for height by regressing sample tree heights on diameter or, alternatively, defaulting to coefficients characteristic of the species in northern Idaho; (2) predict diameter growth increment, given the crown competition factor (CCF) and habitat type of the stand and the species, diameter and percentile ranking of the individual tree; (3) predict height growth increment, given the habitat type of the stand and the species, diameter, height and diameter growth of the tree; (4) utilize sample tree data to calculate "calibration factors" which adjust the growth prediction equations to meet local conditions; (5) calculate volume from height and diameter; and (6) collect all pertinent calculations involving sample trees for statistical evaluation.

The prediction equations are estimates of how the trees will grow in diameter in an unaltered stand. These predictions can be made more accurate by adjusting them for local stand conditions (i.e., considering the pretreatment growth rates in the prediction equation). This is the function of the calibration factor in Stage's model. It is defined as the median deviation between expected and recorded growth rates. The diameter of the tree 10 years prior to treatment (determined from increment cores or past measurements) is used in the prediction equation and the expected growth of the tree is calculated and compared to the actual growth during the pretreatment period. When the expected growth exactly equals the actual growth, the calibration factor is 1.0; if growth is underestimated, the factor increases; if it is overestimated, the factor falls between 0.0 and 1.0. Multiplying the expected growth for the treatment period (as determined from the individual prediction equations for each species) by this pretreatment calibration factor adjusts the predicted growth to allow for differences in growth rates due to variation in stand density and other site factors.

A second calibration factor, computed from the deviation of the predicted increment from the true increment occurring during the treatment period, provides an estimate of the treatment effect. Quite likely, however, growth will be affected by climatic differences between the two periods of calibration. Such differences influence the control plots as well as the treated ones, so that comparison of the calibration factors from treated and untreated plots, calculated for the treatment period, should reflect differences in growth due to treatment. If the pretreatment calibration factor is not included in the prediction model, the calibration factor computed for the treatment period will not account for differences in initial growth rates between treatments except as those differences are expressed in terms of stand CCF and the diameter and percentile ranking of the trees.

A multiplicative calibration factor was obtained for height growth by dividing the deviation of the predicted value from the recorded value by the recorded value for each sample tree, adding this ratio to unity, and then finding the median of the resulting values.

Adjustment of the actual growth variables for differences in previous growth rates, initial size and age provide an alternative to the use of calibration factors. We shall restrict the 2-year analysis to covariant adjustment of the growth variables for past growth and age (wherever these variables show a significant effect on growth).

The Statistical Model.–The model for comparing the effects of rock-type (R), species (S), fertilization (F), and thinning (T), as well as the interactions of these factors among themselves and among and within installations (I), included adjustments for age (X_1), and for previous growth rate (X_2). Only diameter growth and basal area growth were corrected for past growth, since no past height growth increments were available. Variation in response among installations within the RS subclass (I:RS) is the error term for testing the effects of R, S, and RS, while the variation between plots treated alike within each installation (Reps: TFRS) is the error term for testing the remaining effects and interactions. The overall model, then, is as follows:

name ??

$$Y = \mu + R + S + RS + \beta_1 (X_1 - \bar{X}_1) + \underset{\text{(Error A)}}{I{:}RS} + T + F + \begin{bmatrix} TF \\ TR \\ TS \\ FR \\ FS \end{bmatrix} + \begin{bmatrix} TFR \\ TFS \\ TRS \\ FRS \end{bmatrix} + TFRS + \begin{bmatrix} TI{:}RS \\ FI{:}RS \\ TFI{:}RS \end{bmatrix} + \beta_2 (X_2 - \bar{X}_2) + \underset{\text{(Error B)}}{Reps{:}TFRS}$$

Response Distributions.–Regression of all growth variables on their respective cumulative values (i.e., diameter growth on diameter, height growth on height, etc.) for the various treatments were compared by the method suggested by Steel and Torrie (1960).

Total basal area and volume growth per acre were compared for each treatment over the range of basal areas and volumes contained within the study.

RESULTS AND DISCUSSION

Unadjusted Means.–Separation of response by species was not attempted at this stage because of the low number of replicates. The general trend of treatment response in diameter growth (Fig. 1) indicates that both thinning and fertilizing improved growth on most plots, while the combination of the two treatments caused a response much greater than either one alone. Since these responses represent comparisons of treatment means on the same site, the relative value of each response should be close to its true value. Noteworthy is the range of responses to treatments. A portion of this range could be explained if we assume that stands of larger diameter would not likely increase in diameter to the same extent as stands of small diameter. A comparison of basal area response may be more appropriate. The results of this comparison (Fig. 2) are quite similar, suggesting that the response in diameter growth may not be closely associated with initial diameter.

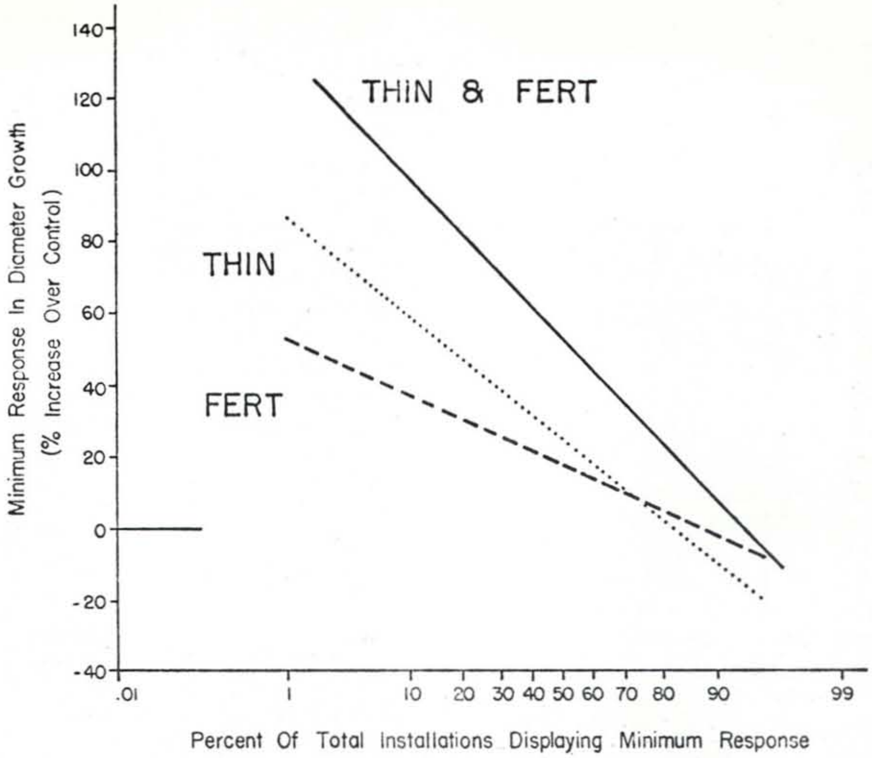

Fig. 1. Two-year diameter growth response of grand fir and Douglas-fir stands to thinning and fertilizing (200 lbs/acre "N").

The trend of height growth response (Fig. 3) suggests that thinning may retard height growth slightly (at least initially). Nitrogen fertilization in conjunction with thinning appears to cancel the negative effect on height growth, while fertilization of unthinned stands tends to increase height growth somewhat.

Trends in volume growth response (Fig. 4) are similar to those of basal area. Response to the combination of fertilization and thinning appears to be most favorable.

Regressions for Covariant Adjustment.–The variables of diameter growth and basal area growth were regressed on past diameter growth and past basal area growth, respectively. Additional regressions included dependent variables of diameter growth, basal area growth, height growth, volume growth, diameter growth calibration factor and height growth calibration factor on the independent variable, age. The two calibration factors showed no linear relationship with age, but all the other regressions were significant at the 1 percent level (Table 1).

Analysis of Variance.–Tests of significance from the overall analysis of variance for the variables diameter growth, basal area growth, height growth and volume growth support the suggestions based on the raw data and indicate several interesting interactions. First, all four variables were highly significant ($\alpha = .0001$) for both fertilizer and thinning effects. As neither rock-type nor species were important in themselves, these effects were combined; the resultant means (Table 2) clearly show that both fertilization and thinning increase growth in diameter, basal area and volume, but thinning reduces height growth while fertilization increases it.

Second, the interaction of thinning and fertilization was also highly significant for diameter growth ($\alpha = .0022$) and basal area growth ($\alpha = .0032$). The means for the various combinations (Table 3) indicate that thinning increases growth of these factors slightly more than does fertilization, but the combination of both is far better than either alone.

Third, both diameter and basal area displayed significant interactions of thinning with rock-type, but diameter growth also produced a significant ($\alpha = .0140$) interaction of thinning between species by rock-type subclasses. Since the latter breakdown of means is probably more useful, it is presented in Table 4. Clearly, diameter growth and basal area growth responses to thinning are much less for Douglas-fir on metamorphic sites than on granitic or basaltic sites. Response on metamorphic sites was also poorest in grand fir stands, but the difference is only minor when compared to that found with Douglas-fir. No explanation is offered at this time for the reduced response, but site and habitat factors not considered in this analysis may explain at least part of the effect.

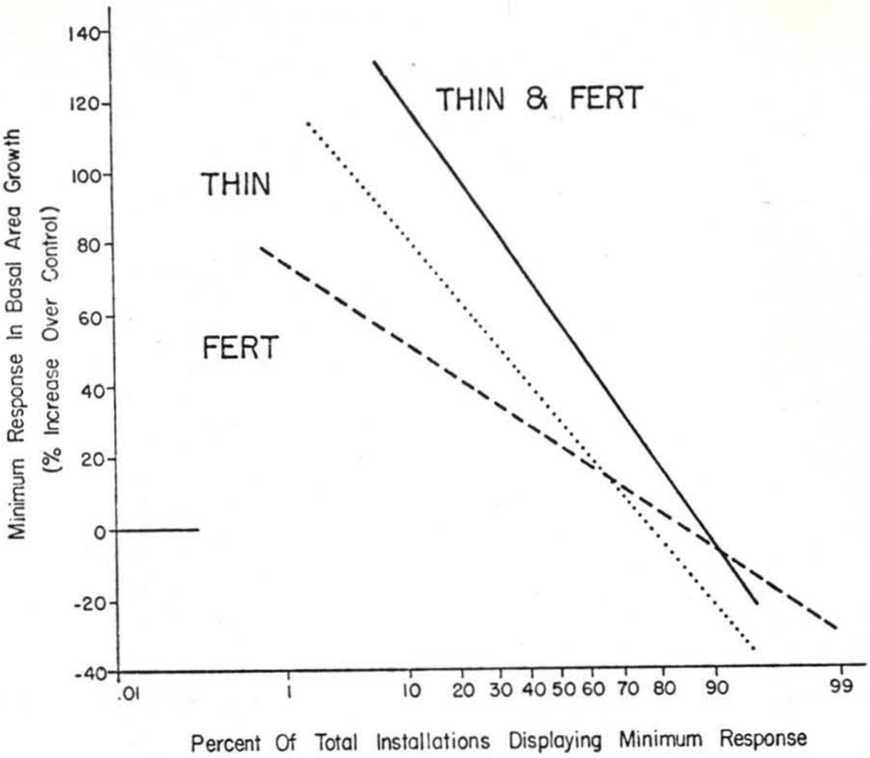

Fig. 2. Two-year basal area growth response of grand fir and Douglas-fir stands to thinning and fertilizing (200 lbs/acre "N").

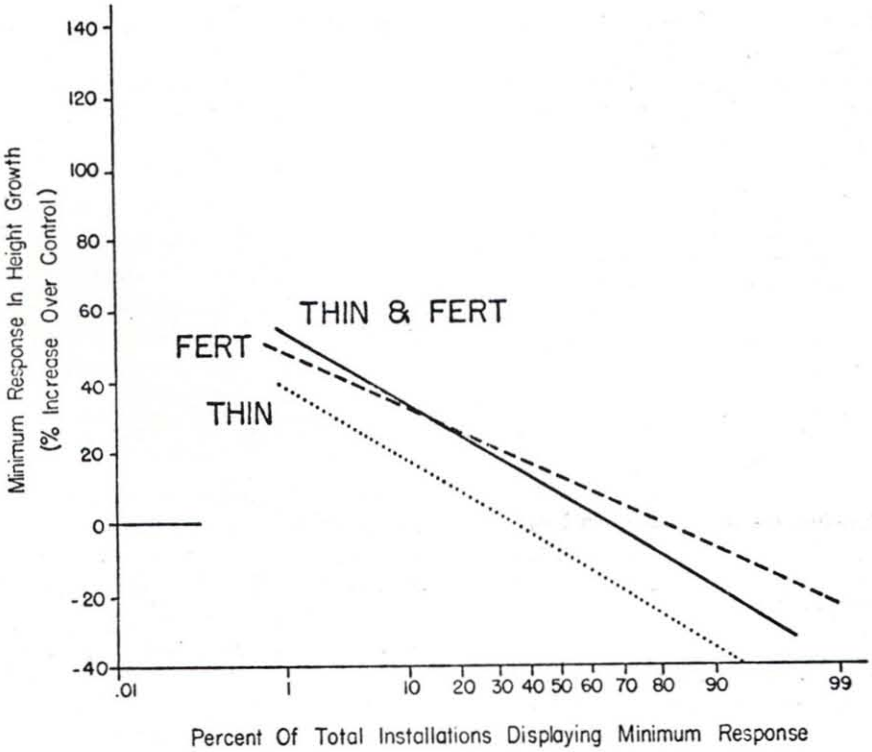

Fig. 3. Two-year height growth response of grand fir and Douglas-fir stands to thinning and fertilizing (200 lbs/acre "N").

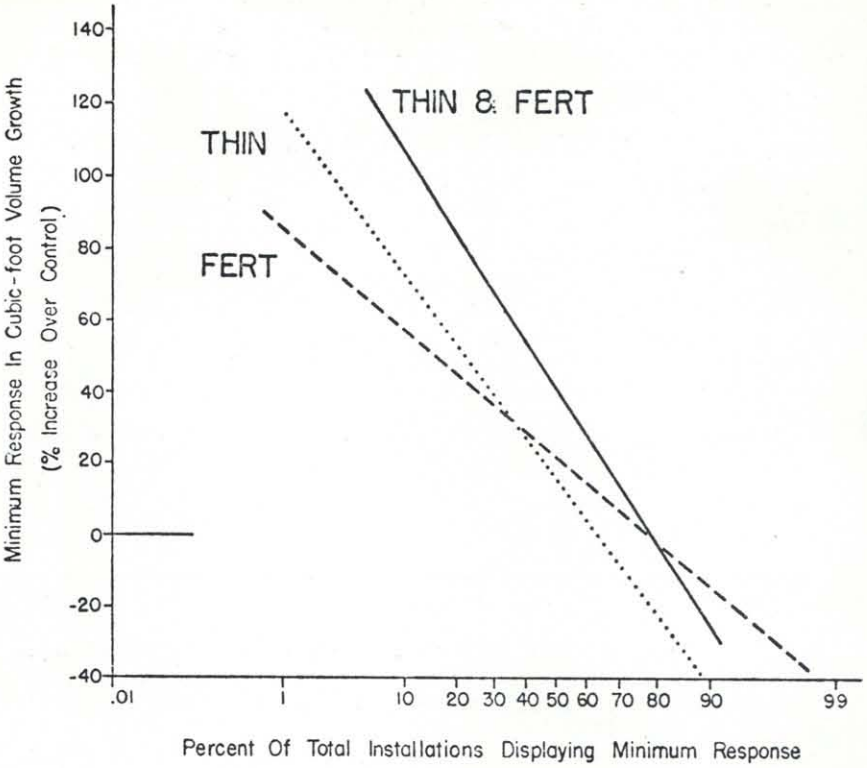

Fig. 4. Two-year cubic foot volume growth response of grand fir and Douglas-fir stands to thinning and fertilizing (200 lbs/acre "N").

Table 1. Regression statistics for adjusting growth variables for differences in past growth rate and age in the analysis of variance among treatments (all regressions were significant at the 1% level). Regressions include measurements of both Douglas-fir and grand fir.

Variable	Regr. Constant (α)	Regr. Coeff. for Past Growth (β_1)	Regr. Coeff. for Age (β_2)	R^2	Mean Growth ($\overline{Y}$)	Std. Dev. (S_y)	N
Diameter Growth (inch)	.48207	.09600	-.00556	.508	.42900	.09881	228
Basal Area Growth (inch^2)	.01953	.19741	-.00026	.690	.03650	.00876	288
Height Growth (ft)	3.54287	—	-.02098	.102	2.67220	.72638	288
Volume Growth (ft^3)	-.27518	—	.03762	.304	1.28620	.66390	288

Table 2. Growth means and response to thinning and fertilizing. Thinned stands were compared to unthinned stands, regardless of fertilizer level; likewise, fertilized stands were compared to unfertilized stands regardless of thinning level. Each mean was calculated from 144 plot means (from both Douglas-fir and grand fir stands), each based on about 10 sample trees.

Variable	Unfertilized	Fertilized	Response (%)	Unthinned	Thinned	Response (%)
Diameter Growth (inch)	.3977	.4603	15.7	.3869	.4712	21.8
Basal Area Growth (ft^2)	.0339	.0391	15.3	.0334	.0396	18.6
Height Growth (ft)	2.5075	2.8369	13.1	2.7907	2.5537	-8.5
Volume Growth (ft^3)	1.1624	1.4100	21.3	1.1966	1.3758	15.0

Table 3. Diameter growth (DG) and basal area growth (BAG) means for four combinations of thinning and fertilizing and the percent response of treated plots over the control. Each mean was calculated from 72 plot means (from both Douglas-fir and grand fir stands), each based on about 10 sample trees.

Variable	Control	Fertilized	Response (%)	Thinned	Response (%)	Thinned + Fertilized	Response (%)
DG (inch)	.3654	.4084	11.8	.4300	17.7	.5122	40.2
BAG (ft^2)	.0317	.0351	10.7	.0361	13.9	.0431	36.0

Table 4. Influence of species and rock-type on diameter growth (DG) and basal area growth (BAG) means and on response to thinning. Thinned stands were compared to unthinned stands regardless of fertilizer level. Each mean was calculated from 24 plot means, each based on about 10 sample trees.

		ROCK-TYPE								
		Granitic			Basaltic			Metamorphic		
Species	Variable	Unthin.	Thin.	Resp. (%)	Unthin.	Thin.	Resp. (%)	Unthin.	Thin.	Resp. (%)
Douglas-fir	DG (inch)	.3813	.5096	33.6	.3477	.4916	41.4	.4008	.4609	15.0
	BAG (inch^2)	.0335	.0422	26.0	.0318	.0421	32.4	.0344	.0376	9.3
Grand fir	DG (inch)	.3963	.4551	14.8	.4062	.4778	17.6	.3890	.4315	10.9
	BAG (inch^2)	.0337	.0392	16.3	.0326	.0385	18.1	.0320	.0346	8.1

Fourth, height growth displayed significant differences ($\alpha = .0120$) in thinning effect among the rock-types. The means (Table 5) suggest that thinning reduces height growth slightly on granitic and metamorphic sites, but the reduction is considerably greater on basaltic sites. Again, no explanation for these effects is apparent at this time.

Differences did occur in the response to thinning among installations within the species by rock-type subclasses for all variables. Some responses to thinning seem excessively large, others very small (even negative). The reasons for this have yet to be discovered, but the variability among sites within the rock-type by species subclass (as influenced by site index, aspect, slope, soil type, etc.) present factors for consideration.

Comparison of Regressions by Species and Treatment.—The statistics for regressions of 2-year diameter growth and height growth on initial diameter and height, respectively, indicated that little of the variation in growth (less than 5 percent for any treatment of either species) could be accounted for by the regression. Basal area and volume growth, however, are much more dependent on initial tree size, and comparisons among treatments (Table 6) may suggest trends that can be utilized in short-term projections of response. Noteworthy is the substantially greater proportion of growth variation attributed to tree size for grand fir as compared with that for Douglas-fir. This is most likely a reflection of the more tolerant nature of the former species, which allows a greater amplitude of response in relation to crown position, which is closely related to tree size. The actual regression lines of the two species for control plots do not differ markedly, although basal area growth for Douglas-fir is significantly greater than that for grand fir.

In terms of basal area growth response of Douglas-fir to treatments (Fig. 5), thinning appears to be most effective with trees of lower basal area, while fertilization tends to increase growth uniformly over a wider range of basal areas. Fertilization in conjunction with thinning, which displayed a dramatic response over all other treatments, tended to alleviate the difference in slope due to thinning. All regressions were significantly different ($\alpha = .0100$) in slope and/or mean basal area growth.

The responses of the three treatments over the control for grand fir (Fig. 6) were similar in that they all significantly increased the regression slopes as well as mean basal area growth. There was no statistical difference in the regressions for thinned and fertilized plots, but the regression of the combination of both treatments was significantly greater than that for either alone. In contrast to the thinning response of Douglas-fir, grand fir trees of larger basal area responded more favorably to thinning than did trees of smaller basal area. Response differences between the two species may reflect differences in stand structure and species tolerances as suggested above.

Both fertilizing alone and in conjunction with thinning significantly increased mean volume growth of Douglas-fir over the control (Fig. 7). In addition, fertilizing increased growth more than did thinning, and the combination was greater than either effect alone. While mean volume growth was greater in thinned stands compared with control stands, the effect of thinning decreased with increasing volume, producing a significant change in the regression slope. With grand fir (Fig. 8), all treatments resulted in significant increases in mean volume growth, but the effects were greater on the larger trees. Again, the combination of thinning and fertilizing proved superior to either treatment alone.

Comparison of Calibration Factors.—The trend of change due to treatment of the diameter growth calibration factor (using the 10 years prior to treatment as the pretreatment calibration period [Fig. 9]), follows closely that of the actual values of both diameter growth and basal area growth.

The analysis of variance of the diameter growth calibration factors indicated a significant difference ($\alpha = .0172$) among species. The means of this factor (0.960 for grand fir and 1.132 for Douglas-fir) revealed that, on the average, grand fir did not grow as fast as was predicted, and that Douglas-fir exceeded the predicted rate of growth. The difference between the species, however, does not necessarily suggest that grand fir grew less than did Douglas-fir, but reflects departure from the prediction equations for the species.

Table 5. Influence of rock-type on mean height growth (ft) and on response to thinning. Thinned plots were compared to unthinned plots regardless of fertilizer level. Each mean was calculated from 48 plot means (from both Douglas-fir and grand fir stands), each based on about 10 sample trees.

ROCK-TYPE								
Granitic			Basaltic			Metamorphic		
Unthinned	Thinned	Resp. (%)	Unthinned	Thinned	Resp. (%)	Unthinned	Thinned	Resp. (%)
2.808	2.658	-5.3	3.036	2.581	-15.0	2.528	2.421	-4.2

Table 6. Statistics for the regression of 2-year basal area growth (BAG) and volume growth (VG) on their respective cumulative values (BA and VOL) for four treatments of grand fir and Douglas-fir stands. BA and BAG are measured in square feet and VOL and VG are measured in cubic feet.

Species	Regression Y	vs X	Treatment	Regression Constant (α)	Regression Coefficient (β)	Coefficient of Determination (R^2)	Mean Growth (Y)	Standard Error of Y (S_y)	Mean Size (X)	Standard Error of X (S_x)	Standard Error of Regression ($S_{y \cdot x}$)	Sample Size (N)
Douglas-fir	BAG	BA	Control	.0198	.0341	.245	.032	.021	.360	.310	.019	313
			Fertilized	.0251	.0376	.191	.040	.024	.388	.275	.021	313
			Thinned	.0299	.0237	.124	.039	.021	.392	.315	.020	313
			Thin. + Fert.	.0369	.0281	.126	.049	.026	.411	.332	.025	313
	VG	VOL	Control	.4971	.0607	.560	1.011	.775	8.460	9.549	.515	313
			Fertilized	.7012	.0580	.424	1.221	.744	8.960	8.351	.566	313
			Thinned	.6868	.0489	.454	1.148	.737	9.436	10.147	.545	313
			Thin. + Fert.	.8472	.0576	.438	1.416	.922	9.880	10.602	.692	313
Grand fir	BAG	BA	Control	.0140	.0379	.620	.026	.019	.323	.405	.012	328
			Fertilized	.0131	.0547	.622	.030	.022	.310	.318	.014	328
			Thinned	.0155	.0529	.529	.033	.022	.336	.310	.015	328
			Thin. + Fert.	.0210	.0543	.510	.041	.026	.363	.346	.018	328
	VG	VOL	Control	.4237	.0674	.814	1.116	1.244	10.278	16.655	.536	328
			Fertilized	.3512	.0916	.825	1.248	1.315	9.795	13.050	.550	328
			Thinned	.4288	.0824	.735	1.274	1.192	10.247	12.395	.614	328
			Thin. + Fert.	.6266	.0833	.715	1.590	1.425	11.569	14.470	.761	328

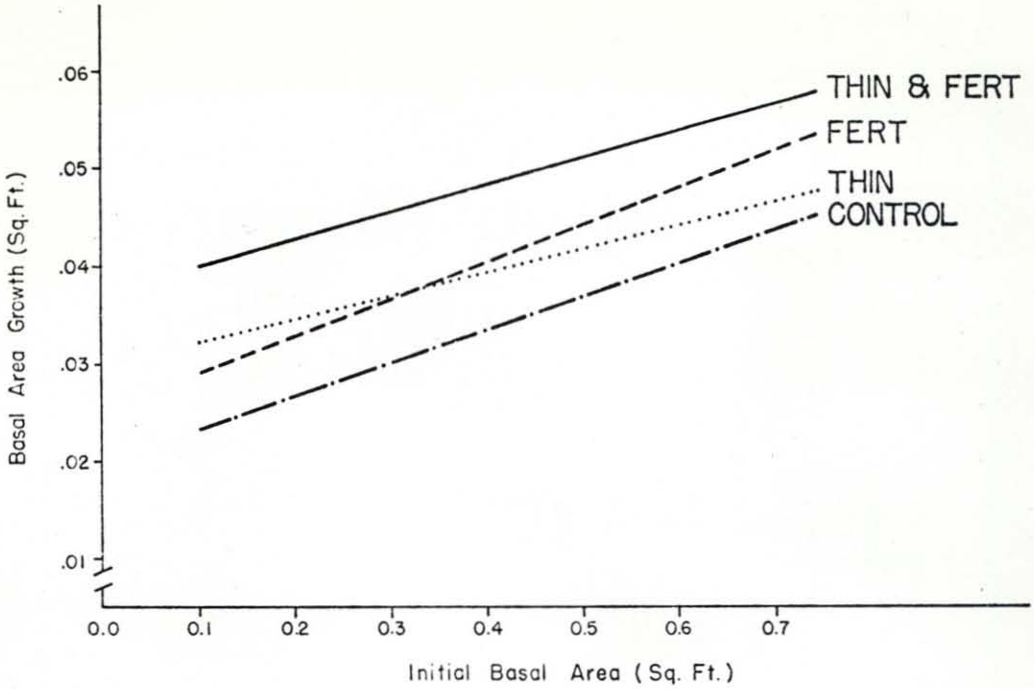

Fig. 5. Effect of fertilization and thinning on basal area growth distribution of Douglas-fir.

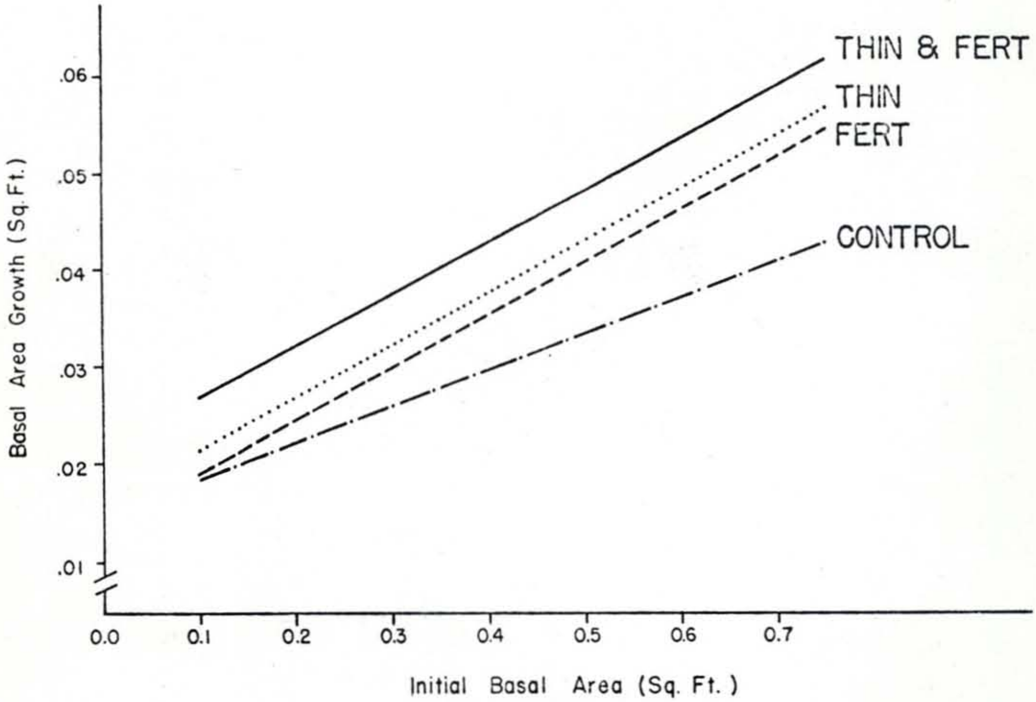

Fig. 6. Effect of fertilization and thinning on basal area growth distribution of grand fir.

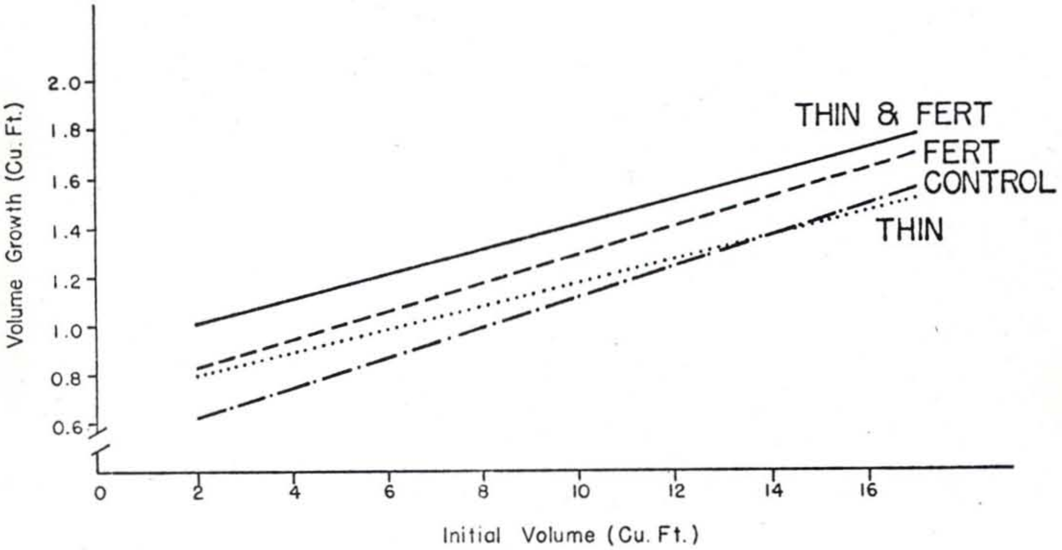

Fig. 7. Effect of fertilization and thinning on volume growth distribution of Douglas-fir.

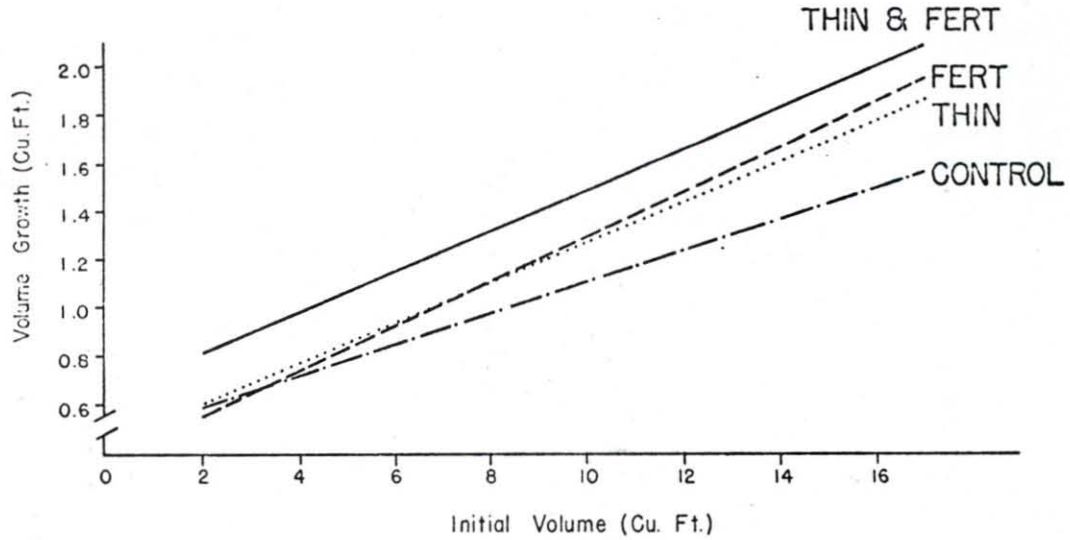

Fig. 8. Effect of fertilization and thinning on volume growth distribution of grand fir.

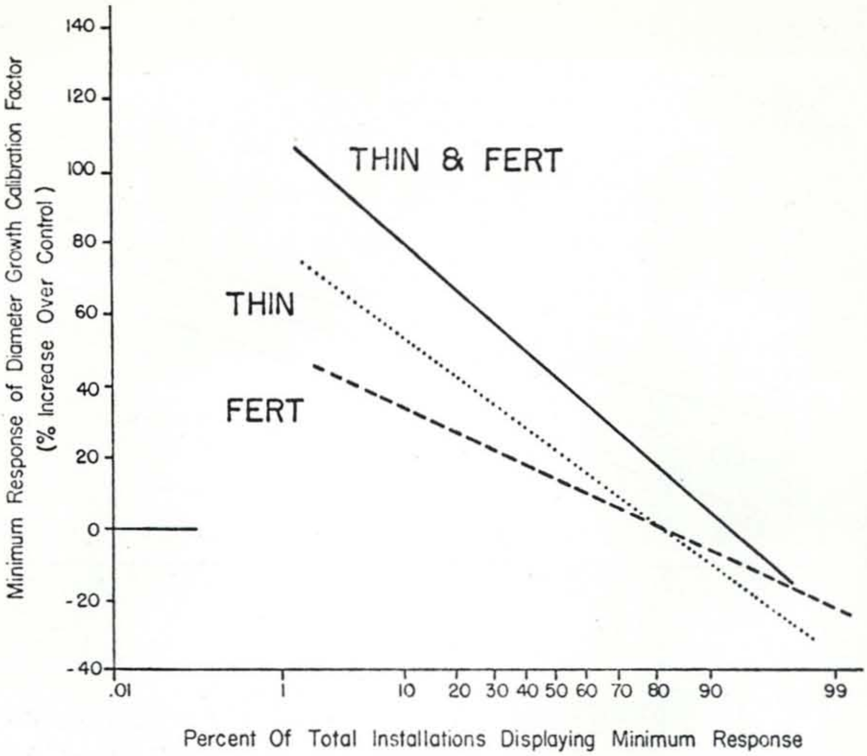

Fig. 9. Two-year response of the diameter growth calibration factor to thinning and fertilizing (200 lbs/acre "N") of grand fir and Douglas-fir stands.

As with the adjusted diameter growth means, the diameter growth calibration factor showed a significant interaction of species with rock-type in the effect of thinning. However, the thinning by fertilizer interaction within the same subclasses was also significant ($\alpha = .0399$). The means for the various combinations of thinning and fertilizing on each rock-type (Table 7) indicate that for Douglas-fir, fertilization of unthinned stands improved growth slightly on all rock-types, but thinning of unfertilized stands produced far less response on metamorphic sites than on granitic or basaltic sites. The combination of thinning and fertilizing had the greatest effect on the metamorphic sites where the response was four times that of either treatment alone. Substantial gains were made with this combination on the granitic and basaltic sites also. Grand fir displayed greater variation in the effects of fertilization of unthinned stands, with the greatest response occurring on metamorphic sites. Thinning of unfertilized sites produced substantially less response on granitic sites for this species. The combination proved far superior to either treatment alone on granitic and basaltic types, but was no better than fertilization alone on metamorphic types. Thinning alone had the greatest effect on basalt types for both species.

Significant differences in thinning effects among installations within rock-type by species subclasses suggest that at least a few of the sites reacted quite differently than others in the same class. Such differences may offset the general effect of the entire subclass. Subsequent analysis of 4-year data may indicate which sites differ markedly from supposedly similar sites and why.

Despite the interactions mentioned above, the overall effects of fertilization and thinning on the diameter growth calibration factor were very highly significant ($\alpha = .0001$). The overall mean calibration factors (including sites of both species) for stands that were unfertilized (0.9666), fertilized (1.1251), unthinned (0.9340), and thinned (1.1576), show the positive effect of both treatments on diameter (actually basal area) growth.

An interesting point of interpretation was discovered in attempting to describe the effects of thinning on the diameter growth calibration factor. Since this factor requires the use of the crown competition factor, the value of which changes during the thinning process, and since the CCF of the stand before thinning was not available, the factor was calculated for the treatment period without incorporating the adjustment for pretreatment growth. The relative density of the stand at the start of the treatment period was used so that thinned stands would be comparable to unthinned stands. The rationale behind this was that the prediction model would provide estimates of

Table 7. Influence of species and rock-type on the diameter growth calibration factor means for four combinations of thinning and fertilizing and on the response of the treated plots over the control (N = 12).

Rock-Type	Control	Fertilized	Resp. (%)	Thinned	Resp. (%)	Thinned + Fertilized	Resp. (%)
			DOUGLAS-FIR				
Granitic	0.930	1.033	11.0	1.149	23.5	1.313	41.2
Basaltic	0.904	1.013	12.0	1.207	33.5	1.292	42.9
Metamorphic	1.002	1.086	8.4	1.135	13.3	1.513	51.0
			GRAND FIR				
Granitic	0.797	0.944	18.4	0.832	4.4	1.078	35.3
Basaltic	0.882	0.992	12.5	1.221	38.4	1.416	60.5
Metamorphic	0.713	0.912	27.9	0.826	15.8	0.907	27.2

growth based on conditions immediately after treatment, but before any growth occurred. This manner of comparing diameter growth calibration factors of thinned and unthinned stands does not provide an estimate of the effect of thinning; rather, it indicates departure of each stand from the model for the given conditions. For example, suppose an unthinned stand had a calibration factor (calculated for the treatment period) of 0.850, and a thinned stand produced a factor of 0.700. The interpretation would not be that thinning produced a negative effect on diameter growth, but that during the treatment period, the control stand growth was overestimated by 17.6 percent (i.e., [1.0-0.85]/0.85 = 0.176). The calibration factor of the thinned stand must be adjusted by this same amount (i.e., 0.700*1.176 = 0.816). This adjusted factor, then, should be interpreted as the degree to which the thinned stand approached the average growth of stands having the same CCF, but which have been growing under similar conditions for some time. It would be unreasonable to expect that the adjusted factor should exceed 1.0, even though growth was accelerated by the thinning, because the crown characteristics of a recently thinned stand would be inferior to those of a naturally occurring stand having the same CCF, or of a stand that had been thinned at some distant time in the past.

The intepretation of the calibration factor immediately changes when the expected growth has taken into account the pretreatment growth rate. Given the CCF of the thinned stand but the growth rate of the stand prior to thinning, the model predicts the growth for a stand of low density that would be growing more slowly than would be expected for that density, site index and habitat type because the density is underestimated. Comparison of this expected growth with the actual growth after thinning produces the calibration factor, which when compared with that of an unthinned stand, would provide an estimate of the thinning effect. This estimate would probably be a low estimate of the actual effect because of the low density figure used in the calculation of the expected growth (Stage, pers. comm.).

The trend of the response of the diameter growth calibration factor when pretreatment growth is not taken into account (Fig. 10) is quite different from that which utilizes the pretreatment increments (Fig. 9). If the former were interpreted in the same manner as the latter, the erroneous conclusion would be drawn that fertilization alone increased diameter growth the most, and that thinning alone had a greater effect than thinning in conjunction with fertilizing. Obviously, this is contrary to all the other data presented thus far.

Although the trend of the effects of thinning and fertilizing on the height growth calibration factor (Fig. 11) is similar to that of the actual height growth values, the curves have been shifted downward (especially those including the effects of thinning), indicating less response than was suggested by the actual growth figures. The reason for this is that the height growth prediction equation uses concurrent diameter growth as the basic predictor of height increment. Thus, if a treatment enhances diameter growth, only a change in height growth not accounted for by the change in diameter increment would be detected. Since thinning tended to increase diameter growth, the model predicted a corresponding increase in height growth. The tendency, however, was toward reduced height growth; this inflated the discrepancy between the actual and the expected values, accounting for the apparently greater shift in the response curves of thinned stands.

A significant difference ($\alpha = .0421$) in the height growth calibration factors between species (1.540 for Douglas-fir and 0.832 for grand fir) suggests that height increment was underestimated for Douglas-fir and overestimated for grand fir. It should be noted that past height increments were not used to adjust the prediction equations; therefore, the calibration is for the treatment period only. Had pretreatment increments been available, it is likely that the predictions of height growth during the treatment period would have been more accurate.

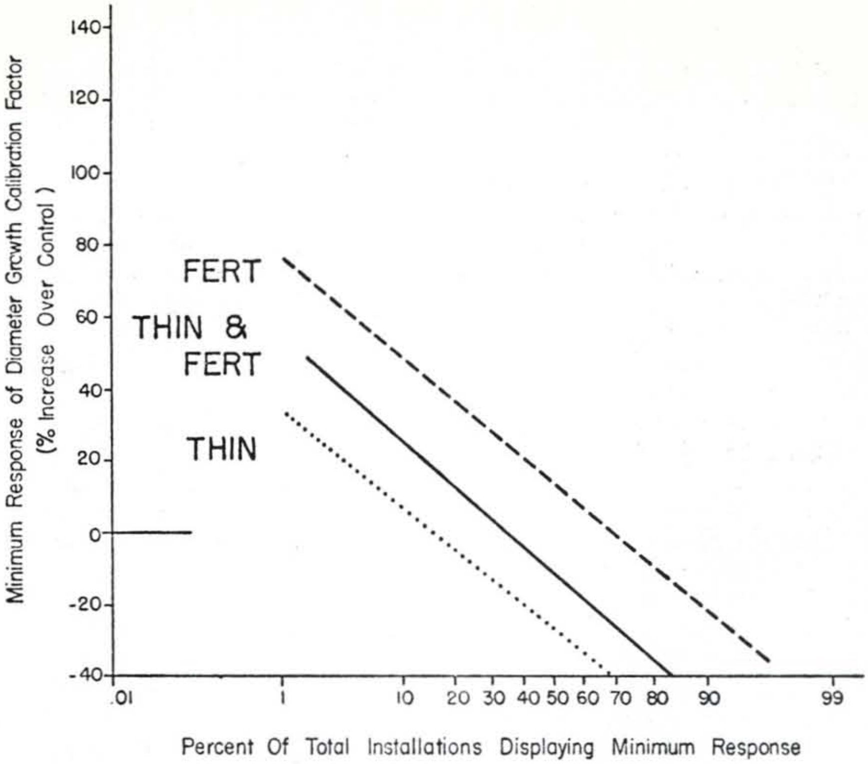

Fig. 10. Two-year response of the diameter growth calibration factor (calculated without including the pretreatment calibration factor) to thinning and fertilizing (200 lbs/acre "N") of grand fir and Douglas-fir stands.

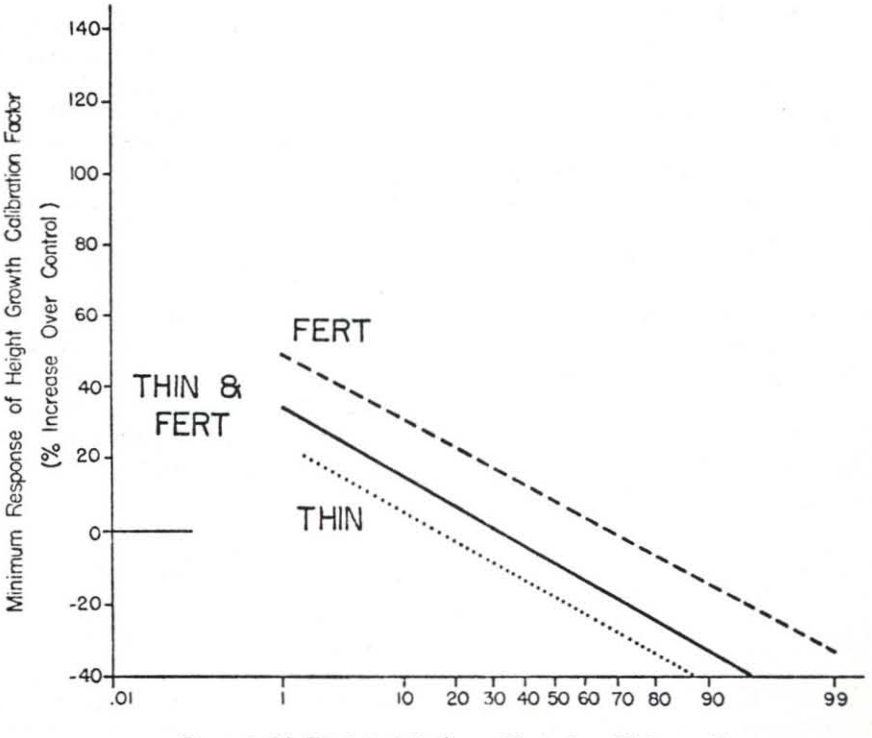

Fig. 11. Two-year response of the height growth calibration factor to thinning and fertilizing (200 lbs/acre "N") of grand fir and Douglas-fir stands.

The effect of thinning on the height growth calibration factor among the species by rock-type subclasses was significantly different ($\alpha = .0034$). The relationships among the means (Table 8) suggest that, except for grand fir stands on metamorphic sites, height growth was overestimated for the 2-year period following thinning. The underestimate of the grand fir increment on metamorphic sites may be partially attributed to the fact that the growth prediction models are based on trees greater than 5 inches in diameter and the metamorphic sites contain two very young and dense grand fir stands. Therefore, the model may have produced erratic results on these sites which could have influenced the overall mean for the subclass.

Although the thinning by fertilizing interaction for both the height and diameter growth calibration factors was not of notable significance, the means for these combinations for each species are presented in Table 9 so that the effect of each treatment on these factors may be considered independently of other treatment effects.

Examination of Scatter Diagrams.—Plots of growth observations against age and past growth indicate that trees under the age of 30 may behave differently than trees beyond that age. Also, many of the sample trees in the youngest stands were too small to have growth rates for the entire 10-year period before treatment. These trees were eliminated from the regression of diameter growth on past diameter growth. This probably resulted in inaccurate predictions of growth for small trees. These irregularities will be more intensively evaluated when the 4-year response is examined.

Response of Entire Plots.—Thus far, the discussion has been confined to the statistical analysis of data collected from a subsample of the trees on each one-tenth acre plot. In order to provide some indication of the total effect of nitrogen fertilization in stands consisting predominantly of Douglas-fir or grand fir, the 2-year basal area and volume growth means for all trees (regardless of species) on each plot were expressed as precentages of the initial basal area and volume, respectively. The average basal area and volume per acre for the unthinned and thinned portions of each installation were obtained and the resulting arrays were divided into 25 ft^2 basal area and 1000 ft^3 volume classes. Within each class, average percent growth of plots which were neither thinned nor fertilized was compared with that of plots which were fertilized only; likewise, average percent growth of plots that were thinned only was compared with that of plots which were both thinned and fertilized.

In general, basal area growth may be increased by 8 to 28 percent within 2 years following nitrogen fertilization (Table 10) of unthinned stands, and by 3 to 31 percent when the same treatment is applied to thinned stands. The range of volume growth responses (Table 11) shows considerably more variation, including some negative effects. These likely are caused by false assumptions of equal stocking on treated and untreated stands, as well as complications arising from consideration of hardwood species and residual old-growth trees which may affect the overall growth mean of particular plots. It appears likely, however, that growth increases of 30 percent or more may be expected to occur when fertilizer is applied to a wide variety of stand conditions.

SUMMARY

Analysis of the growth of trees subjected to one of four treatments (control, thinned, fertilized with 200 lb/acre of nitrogen, and both thinned and fertilized) in Douglas-fir and grand fir stands on three rock-types (granitic, basaltic and metamorphic) indicates that substantial gains in growth may be realized within the short period of 2 years.

In general, thinning appears to produce a slightly greater growth response than does fertilization when considered on a tree-by-tree basis, while the combination of thinning and fertilization is considerably better than either alone on the average. Choice of thinning or fertilization must take cost into account as well as the specific management objectives. Both of these considerations are beyond the scope of this paper.

The difference in response between the two species suggests that each species should be evaluated separately for the effects of silvicultural treatment. Also, very young stands may require separate analysis from pole and sawlog-size stands. The statistical use of calibration factors produced in Stage's prognosis model (Stage 1973) indicated a difference in response between species, but did not

Table 8. Influence of species and rock-type on mean height growth calibration factor and response to thinning. Thinned stands were compared to unthinned stands regardless of fertilizer level (N = 24).

	ROCK-TYPE								
	Granitic			Basaltic			Metamorphic		
Species	Unthinned	Thinned	Resp. (%)	Unthinned	Thinned	Resp. (%)	Unthinned	Thinned	Resp. (%)
Douglas-fir	1.443	1.400	-2.9	1.265	0.925	-26.8	2.220	1.985	-10.6
Grand fir	0.812	0.658	-19.0	0.784	0.552	-29.6	1.021	1.165	+14.1

Table 9. Influence of species on the calibration factor means of diameter growth (DGCF) and height growth (HGCF) for four combinations of thinning and fertilizing and on the response of treated plots over the control (N = 36).

Species	Variable	Control	Fertilized	Resp. (%)	Thinned	Resp. (%)	Thinned + Fertilized	Resp. (%)
Douglas-fir	DGCF	0.945	1.044	10.5	1.164	23.2	1.373	45.3
	HGCF	1.622	1.663	2.5	1.392	-14.2	1.482	-8.6
Grand fir	DGCF	0.798	0.949	18.9	0.960	20.3	1.134	42.1
	HGCF	0.833	0.912	9.5	0.761	-8.6	0.822	-1.3

Table 10. Effect of fertilization on the basal area growth in unthinned and thinned plots in variously stocked stands of Douglas-fir and grand fir.

	Basal area/Acre of Stand (ft^2)					
	25	75	125	175	225	275
	Unthinned Stands					
Number of plots	3	4	19	24	16	6
%BA growth/acre (unfert. plots)	40.8	21.1	11.5	7.3	5.9	3.6
%BA growth/acre (fert. plots)	42.3	25.2	13.3	9.0	7.1	4.6
% increase over unfert. plots	8.7	19.4	15.6	23.3	20.3	27.8
	Thinned Stands					
Number of plots*	17	37	13	4	1	
%BA growth/acre (unfert. plots)	25.5	12.6	6.4	3.7	2.9	
%BA growth/acre (fert. plots)	26.4	15.5	8.4	4.5	3.4	
% increase over unfert. plots	3.5	23.0	31.2	21.6	17.2	

* Based on basal area of the plot after thinning.

Table 11. Effect of fertilization on volume growth in unthinned and thinned plots in variously stocked stands of Douglas-fir and grand fir.

	Volume/Acre of Stand								
	500	1500	2500	3500	4500	5500	6500	7500	8500
	Unthinned Stands								
Number of plots	6	12	14	8	13	6	7	4	2
% volume growth/acre (unfert. plots)	60.4	23.6	19.1	13.6	18.7	10.5	11.2	12.2	8.1
% volume growth/acre (fert. plots)	62.5	26.4	18.0	19.8	22.5	11.0	14.6	12.9	5.8
% increase over unfert. plots	3.5	11.9	-5.8	45.6	20.3	4.8	30.3	5.7	- 28.4
	Thinned Stands								
Number of plots*	22	22	13	5	8	2			
% volume growth/acre (unfert. plots)	32.3	20.9	16.0	11.7	7.1	6.8			
% volume growth/acre (fert. plots)	38.7	22.8	18.8	1.87	8.8	5.9			
% increase over unfert. plots	19.3	9.1	17.5	59.8	23.9	- 13.2			

* Based on volume of plot after thinning.

suggest any thinning/fertilizing interactions, whereas the opposite effects were indicated with the covariant analysis of actual growth rates. These differences may be partly attributed to the inclusion of site and habitat factors in the former analysis, whereas at this point, the latter approach did not include these factors, except as they relate to the geologic rock-type. Also, in comparing calibration factors of thinned and unthinned stands, the crown competition factors (CCF) of the thinned stands were underestimated; this may have caused underestimation of the treatment effect. Other differences may be attributed to the application of the calibration technique to stands which were outside the range of data from which the prediction equations were derived (namely those stands which contained a high proportion of trees under 5 inches in diameter). At the time of this writing, changes in the prognosis model have been implemented to provide better estimates for these trees. However, with the 4-year response data close at hand, reevaluation of the 2-year data is not justified.

The interpretation of the calibration factor with respect to treatment effects may be critical, depending on the options used in its calculation. The analysis of the 4-year results of this study will incorporate the use of predicted diameter growth in place of actual diameter growth in the calculation of expected height growth. This will allow use of the calibration factor to estimate treatment effects directly, rather than indicating only effects beyond what would be expected from the effect on diameter growth. In the case of the diameter growth calibration factor, the CCF used in its calculation for thinned stands should utilize (in the absence of prethinning CCF of the same stand) an average CCF based on unthinned stands in the same area.

Finally, growth means for the various combinations of thinning and nitrogen fertilization indicate a wide assortment of responses to these treatments. The ability to determine which stands have the greatest potential for response and the application of fertilizer to, or the thinning of, only those stands will greatly increase the percentage of stands responding to the treatments as well as the overall average response.

Indiscriminate application of fertilizer can be very costly, but fertilization of stands which have a high potential for response may be well worth the costs of application. It is the goal of this study to determine the factors which control the response to these treatments. The 4-year analysis will include many factors related to site productivity, including vegetation and soil analysis.

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