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Effect of Operational Fertilization on Foliar Nutrient Content and Growth of Young Douglas-Fir and Pacific Silver Fir

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Abstract

Nitrogen concentration in current year needles of Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) showed a significant ($P \leq 0.05$) 1.9-fold increase after fertilization with sulfated urea (40-0-0-6), compared with a nonsignificant 1.3-fold increase in Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and a significant ($P \leq 0.05$) 2.5-fold increase in bracken fern (*Pteridium aquilinum* (L.) Kuhn.). Nitrogen concentration in needles of unfertilized Pacific silver fir (0.99 percent) indicated a deficiency of nitrogen, whereas the concentration in Douglas-fir (1.35 percent) was above threshold levels. Total sulfur concentration in needles ranged from 0.05 to 0.09 percent for both species, with no significant effect of fertilization. Fertilization resulted in increased needle surface area for Pacific silver fir.

Diameter growth of the trees, stand basal area growth, and volume growth were all increased by fertilization. More trees on the fertilized plots had broken tops, and rates of height growth for undamaged trees were greater for the fertilized plots; but the difference attributed to fertilization was not quite significant at the 5-percent level of probability.

Keywords: Foliar analysis, nitrogen fertilizer response, increment, Pacific silver fir, Douglas-fir.

Introduction

Most of the Wenatchee National Forest near Cle Elum, Washington, is in alternate sections interspersed with privately owned land, much of which has been clearcut. The effects of very large clearcuts on runoff, erosion, timing of peak streamflow, and fish and wildlife habitat, although largely undocumented, are thought to be substantial. A management objective for National Forests in this area is to accelerate the growth of newly established stands and reduce possible adverse post-harvest effects on the land and associated resources. Published literature (Miller and Fight 1979, Regional Forest Nutrition Research Project 1979) suggests that fertilization is one way to increase tree growth, but there has been little experience with fertilization in these particular Forests. In 1979 and 1980, a nitrogen-sulfur fertilizer was applied to about 2,000 acres of conifer stands in the Wenatchee National Forest west of Cle Elum. Sulfur was included in the formulation along with

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nitrogen because previous studies have shown a positive response to sulfur in eastern Washington and Oregon (Geist 1971, Klock and others 1971). The fertilization program was conducted by personnel of the Wenatchee National Forest. This study was done to determine if the nitrogen-sulfur fertilization increased tree growth.

Methods

The study areas are in the Wenatchee National Forest west of Cle Elum and southeast of Snoqualmie Pass in the Cascade Range in Washington. Elevation ranges from 2,400 to 3,500 feet. All aspects were represented. Slopes vary from 0 to 70 percent, but most slopes are 45 percent or less. Annual precipitation ranges from 60 to 95 inches per year, of which about 50 percent occurs as snow. Mean annual temperature is 39 °F; mean temperature is 24 °F in January and 57 °F in July. Soils in the study area are deep sandy loams or loamy sands formed in glacial till materials and are classified as medial-skeletal Typic Cryorthods.[1/] Study areas with these soil types were selected because they are relatively productive and are typical of forest soils in the fertilized area, and in the Cle Elum area in general.

Areas selected for fertilization were well-stocked clearcuts 50 to 60 acres in size, which had been planted with Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco).[2/] Other naturally occurring tree species included Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), western redcedar (*Thuja plicata* Donn), western white pine (*Pinus monticola* Dougl. ex D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and black cottonwood (*Populus trichocarpa* T. & T. ex Hook.). Most areas had been precommercially thinned, which left trees of sapling to small pole size. Understory vegetation consisted of vine maple (*Acer circinatum* Pursh), snowbrush (*Ceanothus velutinus* var. *velutinus* Dougl. ex Hook.), huckleberry (*Vaccinium* spp.), and bracken fern (*Pteridium aquilinum* (L.) Kuhn.).

Study plots were established in eight of the units to be fertilized. Two 1-acre square plots were established in each of the eight units. Within each 1-acre plot, four 1/20-acre square subplots were laid out with boundaries of the subplots parallel to the boundaries of the main plots. The outer boundaries of subplots were 38.5 feet within the boundaries of the 1-acre plots. One of the two 1-acre plots was randomly selected as a control in each unit, and corners were marked with weather balloons to assure that no fertilizer was applied to this plot. The rest of the unit (including the other 1-acre plot) was treated with sulfated urea (40-0-0-6) in pellet from, applied by helicopter. Fertilizer traps were placed in the corners of some plots to monitor actual application rates. The traps consisted of aluminum rings 2 square feet in area positioned 2 feet above the ground and supporting a plastic bag to catch the fertilizer pellets. Prescribed rates of fertilization for the eight units were based on soil texture, soil depth, and annual precipitation. Prescribed rates of nitrogen (N) ranged from 275 to 350 lb/acre, but actual rates were as high as 528 lb/acre[3/] (table 1). Fertilization was scheduled to be completed by early winter 1979, but inclement weather forced postponement of fertilization in units 6, 7, and 8 until July 1980.

[1/]Wenatchee Resource Inventory, 1976; on file at Wenatchee National Forest, Wenatchee, WA 98801.

[2/]Scientific names are from Garrison and others (1976).

[3/]We suspect that the helicopter pilots saw the fertilizer traps on some of the units and wanted to be certain that the prescribed rates were applied to the fertilized plots. In areas without traps it was impossible for the pilots to tell where the fertilized plot was located.

Table 1—Rates and dates of application of fertilizer to the 8 units studied[1]

Unit number	Date applied	Prescribed rate of application		Actual rate of application	
		Nitrogen	Sulfur	Nitrogen	Sulfur
		Pounds per acre			
1	11/17/79	275	41	—	—
2	11/18/79	300	45	—	—
3	11/17/79	300	45	—	—
4	11/20/79	300	45	399	60
5	11/20/79	300	45	528	79
6	7/8/80	300	45	—	—
7	7/8/80	300	45	434	65
8	7/15/80	350	53	261	39

[1]Fertilizer was sulfated urea (40-0-0-6) in pellet form.

Foliage Nutrient Content and Surface Area

Foliage samples were collected from Douglas-fir, Pacific silver fir, and one herbaceous species, bracken fern, for determination of nitrogen and sulfur content. Samples were collected from each of four pairs of fertilized and control plots in October and November of 1980 and 1984. Eight trees were sampled in each plot. Conifer foliage was collected from the upper portion of the south side of the crowns by use of a pole pruner. Needles and leaves were removed from the twigs, ovendried at 150 °F, and finely ground.

Nitrogen content (minus nitrate) was determined by a mercury catalyzed standard micro-Kjeldahl technique. Total sulfur was measured with a Leco high frequency induction furnace coupled to an automatic titrator following the method described by Tiedemann and Anderson (1971).[4]

Surface areas of needles from fertilized and control trees were compared for evaluation of possible increases in needle size in response to fertilization. Fifty needles were taken from each of the eight foliage samples collected from each control and each fertilized plot in 1984. Needles were taken from the midportion of the terminal growth extension of the twig. Surface areas (one side) of samples of 50 needles were measured with a Delta-T area measuring system.

A split-plot analysis of variance was used with the data for nitrogen and sulfur content of the foliage. Whole-plots are the control and fertilized treatments, whereas split-plots are time (1979, 1980, and 1984 for the trees and 1980 and 1984 for the bracken fern). Data for needle surface area were analyzed by a paired t-test.

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[4]The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Growth Measurements

Height and diameter of all trees on each subplot were measured before the start of the growing season in 1980 and again after five growing seasons. Diameters were measured to the nearest 0.1 inch with a diameter tape, and heights were measured to the nearest 0.5 feet with a height pole. Volumes for each tree were determined from the heights and diameters with the equations for second-growth Douglas-fir developed by Bruce and DeMars (1974).

The average diameter (the diameter equivalent to the average basal area, Dg), the average height, the basal area per acre, and the volume per acre were estimated for each of the 1-acre plots from data for the appropriate 1/20-acre subplots before treatment and five growing seasons after treatment. Periodic annual increments for height, average diameter, basal area per acre, and volume per acre were then determined. Percent inceases in annual growth rates for average diameter, basal area per acre, and volume per acre were calculated for each 1-acre plot by:

$$\text{Percent increase} = \frac{(100)\ (\text{periodic annual increment})}{\text{initial value}}.$$

Paired t-tests ($P \leqslant 0.05$) were used with values for controlled and fertilized plots from each area to test the hypothesis that fertilization did not increase the rate of tree growth. Analysis of covariance was also used for the periodic annual increments of basal area and volume; initial basal area was used as the covariate in the randomized block design. This analysis aids in the visualization of growth rates as a function of treatment and stand density.

Results and Discussion

Foliar Nutrients and Surface Area

Nitrogen concentration of Pacific silver fir needles for all foliage ages ranged from 0.95 to 0.99 percent for control plots and 1.13 to 1.84 percent for fertilized plots (table 2). Fertilization caused a significant increase ($P \leqslant 0.05$) in concentration of nitrogen in needles of silver fir in both 1979 and 1980, and nitrogen concentration in needles of fertilized trees was significantly higher ($P \leqslant 0.05$) in 1980 than in 1979. Year by treatment interaction was significant at the 0.05 level.

In Douglas-fir, nitrogen concentration in needles from control plots ranged from 1.15 to 1.36 percent in 1979, 1980, and 1984, compared with 1.18 to 1.80 percent in needles from fertilized plots. Fertilization apparently increased the nitrogen concentration in both 1979 and 1980, but differences were not significant. Foliage age differences also were not significantly different, nor was year by treatment interaction. Fertilization did result in a significant increase ($P \leqslant 0.05$) in nitrogen concentration in bracken fern collected in 1980.

The nitrogen concentration in Pacific silver fir needles in 1984, 5 years after fertilization, still was higher in fertilized trees than in the controls, but the difference was not significant. By 1984, there was no indication of a fertilizer effect on the nitrogen concentration in Douglas-fir needles. Nitrogen concentration in bracken fern, however, still was significantly higher ($P \leqslant 0.05$) for fertilized plots than for control plots.

Sulfur concentrations in Pacific silver fir needles of all ages from control and fertilized plots ranged from 0.05 to 0.07 percent. In Douglas-fir, sulfur concentrations were slightly higher, ranging from 0.07 to 0.09 percent. Within a given foliage age, there were no differences in sulfur concentrations between fertilized and control trees and no significant differences between years. Sulfur concentration in bracken fern collected in 1980, however, was significantly higher ($P \leqslant 0.05$) for fertilized plots than for control plots. Values for fertilized plots also were higher than those for controls in 1984, but the difference was not significant.

Table 2—Nitrogen and sulfur concentrations in foliage of Pacific silver fir and Douglas-fir trees and of bracken fern from control and fertilized plots

Fertilizer and year of foliage	Pacific silver fir[1] Control	Pacific silver fir[1] Fertilized[2]	Douglas-fir Control	Douglas-fir Fertilized[2]	Bracken fern[1] Control	Bracken fern[1] Fertilized
			Percent			
Nitrogen:						
1979	0.99	1.64*	1.36	1.65	—	—
1980	.99	1.84*	1.36	1.80	0.54	1.34*
1984	.95	1.13	1.15	1.18	.97	1.97*
Sulfur:[3]						
1979	.06	.07	.09	.09	—	—
1980	.06	.07	.08	.08	.06	.10*
1984	.05	.05	.07	.07	.05	.07

[1]*Indicates that the mean for the fertilizer treatment is significantly different ($P \leq 0.05$) from the mean for the control treatment.
[2]Samples collected in 1980 were divided into current year (1980) and previous year (1979) foliage. Only current year foliage was collected in 1984.
[3]Total sulfur.

Average needle surface area for Pacific silver fir from fertilized plots was 3.92 square inches per 50 needles compared with 2.82 square inches for control plots, an increase in surface area of 39 percent. The difference was not significant at the 0.05 level, but it was significant at the 0.06 level. For Douglas-fir, needle surface area for fertilized trees was 3.21 square inches per 50 needles compared with 2.91 square inches for control trees, with no significant difference.

The critical level of foliar nitrogen required for adequate growth is 1.15 percent for true firs and 1.20 percent for Douglas-fir (Powers 1983). By these criteria, nitrogen concentrations in 1979 and 1980 needles of Douglas-fir from unfertilized trees in our study were somewhat above threshold levels, whereas nitrogen concentrations in unfertilized Pacific silver fir indicated a deficiency. This may explain the 1.9-fold increase in foliar nitrogen concentration (1980 needles) in silver fir after fertilization compared with only a 1.3-fold increase in Douglas-fir. One concern about forest fertilization is that a large proportion of the added nutrients may be taken up by shallow-rooted vegetation rather than by trees. Bracken fern did in fact show the largest increase in foliar nitrogen (2.5-fold), but total loss to herbaceous vegetation depends on the amount of vegetation present.

Sulfur concentrations from 0.10 to 0.20 percent are considered adequate in foliage of conifer seedlings (Landis 1985). By this criterion, Douglas-fir and particularly Pacific silver fir trees in our study appear to be somewhat deficient in sulfur, but the low levels apparently are not unusual for forest trees. Will and Youngberg (1979), for example, reported a sulfur concentration of 0.06 percent for Pacific silver fir in central Oregon, and Clayton and Kennedy (1980) reported a sulfur concentration of 0.088 percent for current year needles of Douglas-fir in Idaho. Also, there was no increase in foliar sulfur concentration after fertilization in our study.

Similar results have been observed for Douglas-fir seedlings (Radwan and Shumway 1985). The lack of response in foliar concentration may be caused partly by a dilution effect resulting from increased foliar growth.

Growth Increment

The number of live trees per acre at the end of the 5-year monitoring period ranged from 150 to 325 (table 3). During this period there was very little mortality: 11 trees of the 697 trees on the 1/20-acre plots died. There was no evident relationship between mortality and fertilization. All stand characteristics and growth rates were calculated from data for trees alive 5 years after treatment. A total of 37 trees still living at the end of the 5 years (5.4 percent of the live trees) suffered damage. Seven of these trees were partially or completely girdled above the start of live crown, 4 were bent by snow, and 26 had broken tops. Twenty-four of the trees with broken tops were on fertilized plots, a significantly greater number (paired t-test, $P \leqslant 0.05$) than for the control plots. Miller and Pienaar (1973) reported increased breakage in fertilized Douglas-fir west of the Cascades in winter. They attributed the breakage to greater needle length which resulted in a larger accumulation of ice and snow and greater resistance to wind.

Initial average stand diameters ranged from 3.0 to 6.2 inches, and average heights ranged from 14.4 to 37.7 feet. Initial basal areas ranged from 9.4 to 56.3 square feet per acre and total volume ranged from 79.5 to 1,102 cubic feet per acre (table 3).

Fertilization significantly raised the percent increases in diameter growth and in growth of basal area and volume per acre. The average periodic annual increment for diameter was 0.33 inch for trees on control plots (an 8-percent annual increase) and 0.47 inch (a 12.1-percent annual increase) for trees on fertilized plots. The periodic annual basal area increment averaged 4.3 square feet per acre per year for the control plots (a 19.1-percent annual increase), and 6.1 square feet per acre per year (a 32.1-percent annual increase) for the fertilized plots. The average periodic annual volume increment for the control plots was 90.6 cubic feet per acre per year (a 32.4-percent annual increase), and 107.4 cubic feet per acre per year for the fertilized plots (a 48.4-percent increase). Adjusted means from analysis of covariance for periodic annual basal area growth (fig. 1) were 4.1 square feet per acre per year for the control plots and 6.4 square feet for the fertilized plots. Similar adjusted means for volume growth (fig. 2) were 81.7 and 116.3 cubic feet per acre per year. These adjusted means were significantly higher ($P \leqslant 0.05$) for the fertilization treatment.

Height growth of all trees on fertilized and control plots averaged 2.3 and 2.1 feet per year, respectively. Differences in these values were not significant. Because more trees experienced top damage on the fertilized plots, a comparison of treatments was made with the height growth of trees that displayed no apparent top damage. Differences between treatments were still not quite significant at the 5-percent level of probability.

Table 3—Some initial stand values for fertilized and control plots and stand values in the fall of 1984, 5 years after treatment[1]

		Control		Fertilized	
Stand parameter	Unit	Average	Range	Average	Range
Trees per acre	Number	220.0	150-270	229.4	150-325
Initial values:					
Dg[2]	Inches	4.4	3.0-6.2	4.0	3.2-5.3
Basal area	Square feet per acre	25.3	9.4-56.3	20.6	10.1-32.5
Height	Feet	22.0	14.4-37.7	20.7	15.3-27.5
Volume	Cubic feet per acre	345.9	79.5-1,101.8	243.3	88.1-503.3
1984 values:					
Dg	Inches	6.1	4.7-7.7	6.4	5.8-7.3
Basal area	Square feet per acre	46.8	21.8-87.9	51.5	33.8-71.0
Height	Feet	32.3	24.8-49.5	32.0	21.3-41.5
Volume	Cubic feet per acre	798.9	286.6-2,110.9	780.4	397.0-1,295.0

[1]Values are for trees alive in 1984.
[2]Diameter equivalent to initial average basal area.

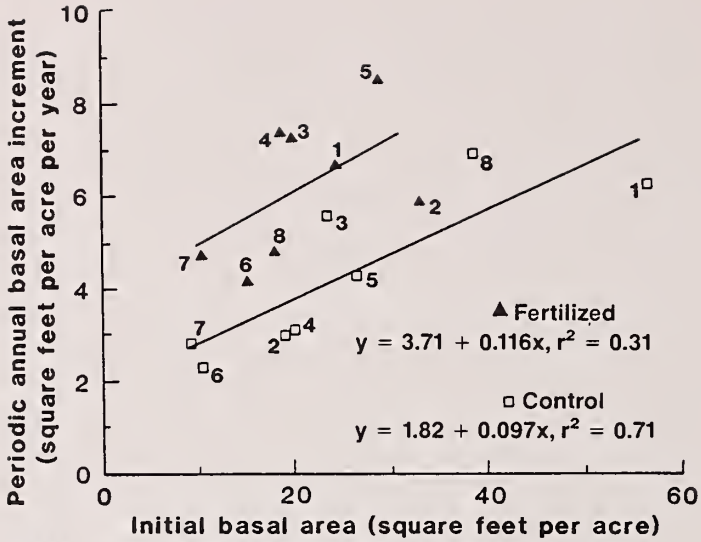

Figure 1.—Periodic annual basal area increment as a function of initial basal area for the fertilized and control plots. Numbers next to the plotted points refer to the locations. Slopes of the two regression lines are not significantly different, but the regression line for the fertilized plots is higher ($P \leq 0.05$) than the regression line for the control plots.

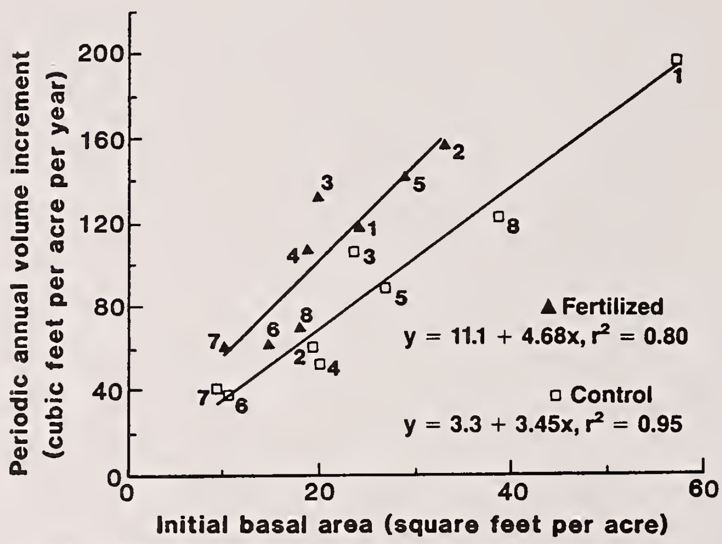

Figure 2.—Periodic annual volume increment as a function of initial basal area for the fertilized and control plots. Numbers next to the plotted points refer to the locations. Slopes of the two regression lines are not significantly different, but the regression line for the fertilized plot is higher ($P \leq 0.05$) than the regression line for the control plot.

Summary and Conclusions

Fertilization caused (1) a significant increase in the nitrogen concentration in the current and 1-year-old needles of Pacific silver fir the first growing season after treatment and in the foliage of bracken fern for the entire 5-year period, (2) a significant increase in the diameter growth of the trees as well as an increase in stand basal area and volume, and (3) an increase in top breakage. The increased top breakage after fertilization may not be particularly important, however, because of the relatively low numbers of trees damaged.

Growth rates will be remeasured at periodic intervals to determine how long the response to fertilization lasts. Other potential benefits besides increased tree growth need to be specifically identified. When total wood production after fertilization is available and values are placed on other possible benefits, an economic analysis can be made.

Conversions

1 inch = 2.540 centimeters
1 foot = 30.480 centimeters; 0.3048 meter
1 square inch = 6.452 square centimeters
1 square foot = 929 square centimeters; 0.0929 square meter
1 acre = 0.4047 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.0700 cubic meter/hectare
1 pound/acre = 1.1208 kilograms/hectare
5/9 (°F-32) = °C

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