RESPONSE OF A 110-YEAR-OLD DOUGLAS-FIR STAND TO UREA AND AMMONIUM NITRATE FERTILIZATION

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ABSTRACT

Basal area response to 150 pounds of nitrogen per acre applied as urea or ammonium nitrate was monitored on 1/5-acre plots for 4 years in a recently thinned, 110-year-old, site II, Douglas-fir stand. Nitrogen fertilization significantly increased growth. Basal area increment was increased 59 percent over the controls by ammonium nitrate and 37 percent by urea. The difference in response between urea and ammonium nitrate was statistically significant. Crown class had a highly significant influence on basal area growth of individual trees; however, the increases in growth due to fertilization were not significantly different by crown class.

KEYWORDS: Nitrogen fertilizer response, increment (basal area), urea, ammonium nitrate, Douglas-fir, Pseudotsuga menziesii.
More than 1 million acres of coniferous forests in western Washington and Oregon have been fertilized with nitrogen (N) since 1966. Urea fertilizer (46-percent N) has been used almost exclusively. Ammonium nitrate (34-percent N) has also been used as a nitrogen source, but it is more costly because of its somewhat higher initial cost and the higher cost of application associated with its lower nitrogen content. The relative effectiveness of these two nitrogen sources for increasing tree growth may depend on specific site conditions because different forms of nitrogen are subject to different transformations and fates within forest ecosystems (Wollum and Davey 1975). For example, urea applied to the forest floor is more likely to volatilize or to become temporarily immobilized in living or dead organic matter than is ammonium nitrate (Knowles 1975). Ammonium nitrate, however, is more subject to losses by leaching.

We present the initial results of a fertilizer trial which compared the responses to urea and ammonium nitrate in a recently thinned, 110-year-old, site II, Douglas-fir stand. In this stand, 4-year basal area response to ammonium nitrate was significantly greater than response to urea.

THE STUDY AREA AND TREATMENT

The Fall Creek study area is in the western Cascade Range about 30 miles southeast of Eugene, Oregon, on the Willamette National Forest. The elevation is about 1,800 feet; the topography is gently sloping and the aspect generally northern. Soil texture ranges from silt loam to clay loam in the surface horizons and from clay loam through loam in the subsoils. Annual precipitation averages 70 inches.

Douglas-fir is the dominant species in the study area—93 percent of the basal area is in Douglas-fir. Western redcedar (Thuja plicata Donn) and western hemlock (Tsuga heterophylla (Raf.) Sarg.) are common associates, especially in the lower crown classes. Prior to the 1974 growing season, the Douglas-fir averaged 111 years old with a site index (100-year base) of 168 or site II. The stand had been commercially thinned in the summer of 1973, the year before fertilization. About 70 square feet of basal area per acre were removed in a low thinning (fig. 1); the average diameter of the cut trees was less than the average diameter of the original stand. Average stand characteristics among treatments were similar before and after thinning (table 1).

We measured growth on 12 circular, 1/5-acre plots to compare three treatments: 150 pounds of nitrogen per acre as urea granules, 150 pounds of nitrogen per acre as ammonium nitrate, and 150 pounds of nitrogen per acre as ammonium nitrate with 100 pounds of urea applied in a second broadcast application at the end of the growing season. The results show that ammonium nitrate is more effective than urea in increasing tree growth in this site II stand. The relative effectiveness of these two nitrogen sources may depend on specific site conditions because different forms of nitrogen are subject to different transformations and fates within forest ecosystems (Wollum and Davey 1975). For example, urea applied to the forest floor is more likely to volatilize or to become temporarily immobilized in living or dead organic matter than is ammonium nitrate (Knowles 1975). Ammonium nitrate, however, is more subject to losses by leaching.

Figure 1.--About one-quarter of the basal area of this 110-year-old stand was subsequently removed in thinning prior to fertilization.
nitrate prill, and no nitrogen (control). The plots were selected for uniformity and lack of thinning damage from 22 plots that had been systematically located in the study area in the 1940's. We randomly assigned four plots to each treatment.

The fertilizers were applied by hand on March 27, 1974, to 1/2-acre plots centered on the 1/5-acre measurement plots. This provided a 30-foot-wide treated buffer for the fertilized plots. At the time of application, the soil was moist and the weather cool and drizzly; moreover, 5 inches of rain fell during the week after fertilization. Under these conditions, nitrogen losses by volatilization of urea were probably minimized; however, losses by leaching of ammonium nitrate were probably increased.

MEASUREMENTS AND ANALYSES

On the study plots, all trees 1.6 inches and larger in diameter were numbered and tagged. Diameter at breast height, crown class, and tree condition were recorded for each tree prior to fertilization and again 4 years after fertilization. In addition, 18 dominant trees, equally distributed among the treatments, were measured for height. The height and corresponding diameter measurements of the 18 trees were

Table 1--Stand characteristics in the Fall Creek study plots before fertilization

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control</th>
<th>Ammonium nitrate</th>
<th>Urea</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site index (100-year base)</td>
<td>169</td>
<td>172</td>
<td>162</td>
<td>168</td>
</tr>
<tr>
<td>Volume (cubic feet per acre to a 4-inch top)</td>
<td>11,600</td>
<td>12,400</td>
<td>12,000</td>
<td>12,000</td>
</tr>
</tbody>
</table>
| d/D[

1/ The ratio, d/D, is the ratio of the quadratic mean diameter of cut trees to that of all trees before cutting.

2/ Figures above the slash describe the stand after thinning and before fertilization (spring, 1974); figures below the slash describe the stand before thinning (spring, 1973).

3/ Diameter of the tree of mean basal area (quadratic mean diameter).
used to determine a mean tarif\(^1\) number for the stand at the start and end of the measurement period. We estimated plot volume (to a 4-inch top, d.i.b.) by multiplying basal area of the plot by the stand tarif number; we estimated gross volume growth by multiplying gross basal area growth by the tarif number corresponding to the midpoint of the treatment period.

We analyzed the effects of fertilization on 4-year gross basal area growth. Although forest managers are primarily interested in volume growth, we had too small a sample of heights to provide a sensitive measure of response in volume growth. We assumed, however, that in this mature stand differences in basal area growth reflect comparable differences in volume growth because the slow height growth indicated that basal area growth was the major component of volume growth. No statistical analyses were made of volume growth; the data on volume and volume growth have been included for the reader's information.

We examined effects of treatments on mean annual basal area growth using analysis of variance with the response data adjusted by covariance for differences in initial basal area (i.e., basal area after thinning). Orthogonal comparisons tested fertilization versus no fertilization and urea versus ammonium nitrate. In addition, we were interested in examining the effect of crown class on response to treatment. We investigated this by analyzing the experiment as a split plot design

\(^1\) The tarif number is the number of cubic feet in a tree of basal area 1.0; it is derived from the relationship between diameter and height (Turnbull et al. 1970).

with fertilization as the main plot treatment and crown class the split plot treatment. Split plot analysis assumes that the split plot treatments, crown class in this case, are independent of each other. In general, crown classes are not independent and, in fact, are in direct competition for the site's resources. We assumed for this analysis, however, that 4-year growth by one crown class would not be a major factor influencing the 4-year growth of trees in another crown class. In our analyses, we used the 5- and 1-percent probability levels to judge results as significant or highly significant.

RESULTS AND DISCUSSION

There was a significant increase in gross basal area growth after fertilization; moreover, growth with ammonium nitrate was significantly greater than growth with urea. When treatment means were adjusted for differences in initial basal area, the annual basal area increment on ammonium nitrate plots averaged 59 percent higher than that on the control plots; annual basal area increment on the urea plots was 37 percent more than on the controls (table 2). During the 4-year period, gross basal area growth was 5.4 square feet per acre more on the ammonium nitrate plots than on the control plots; gross basal area growth on the urea plots was 3.4 square feet per acre more than on the control plots. The comparable 4-year increases in volume growth were 296 and 184 cubic feet per acre, respectively.

Gross growth was only slightly different from net growth. On all plots, two suppressed western hemlock trees died during the 4-year period, and two western hemlock trees were added as ingrowth.
Table 2—Mean annual growth per acre at Fall Creek, based on 4-year data

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Basal area growth</th>
<th>Volume growth&lt;sup&gt;1/&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square feet&lt;sup&gt;2/&lt;/sup&gt;</td>
<td>Percent</td>
</tr>
<tr>
<td>Control</td>
<td>2.30</td>
<td>100</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>3.65</td>
<td>159</td>
</tr>
<tr>
<td>Urea</td>
<td>3.15</td>
<td>137</td>
</tr>
</tbody>
</table>

<sup>1/</sup>Volume growth = basal area growth x average tarif number.

<sup>2/</sup>Means adjusted by covariance analysis for initial differences in basal area.

Crown class had a highly significant influence on basal area growth of individual trees (fig. 2). Over all treatments, the average dominant

![Crown Class Chart](chart.png)

Figure 2.—Average annual basal area growth at Fall Creek by crown class and treatment, 4-year basis.
tree grew more than the average codominant tree; this relationship extended through the lower crown classes. The increases in growth due to fertilization, though, did not differ significantly by crown class. This experiment probably did not provide a sensitive test of crown class-fertilizer interactions, however, because: (1) there were very few trees in the intermediate crown class, (2) western hemlock and western redcedar trees were included in the analysis, and (3) the recent thinning probably released trees differentially.

The results from this study may be compared with the results of another urea and ammonium nitrate trial we reported previously (Miller and Harrington 1979). That trial was in an unthinned, 80-year-old, site I, Douglas-fir stand near McCleary, Washington. In the McCleary trial, we found that 200 pounds of nitrogen per acre increased volume growth 20 percent or about 280 cubic feet per acre during a 4-year period and that urea and ammonium nitrate did not differ significantly in their effect on volume growth.

We can only speculate why urea fertilization was less effective than ammonium nitrate in the Fall Creek trial. Immobilization of urea in the forest floor was probably a major factor. Although we have no direct measures of differences between the forest floor at the two locations, we observed a thicker forest floor in the older stand used in the Fall Creek study. Thus we can assume that the area had a greater potential for temporary immobilization of urea. Moreover, the lower dosage applied at Fall Creek (150 versus 200 pounds per acre) would have been less likely to compensate for this immobilization. Differences in volatilization of urea or leaching of ammonium nitrate were probably not major factors in determining the differential response. Both areas had moist, cool soil and wet, cool weather during and after application which probably minimized volatilization losses. In addition, we have no basis for suspecting that conditions at McCleary would have encouraged greater leaching of ammonium nitrate and thereby have reduced its effectiveness at that location.

The Fall Creek and McCleary studies have demonstrated that fertilization can increase growth in mature stands. Moreover, the 4-year results from the Fall Creek study indicate that the effectiveness of fertilization may depend on the nitrogen source used. We recommend consideration of nitrogen fertilization to increase growth in postrotation-age Douglas-fir; however, we prefer to await longer term growth data from this study and from other studies before recommending specific nitrogen sources.

**CONCLUSIONS**

In this recently thinned, 110-year-old, site II, Douglas-fir stand:

1. Four-year basal area growth was significantly increased by nitrogen fertilization; 150 pounds of N per acre as ammonium nitrate increased basal area increment 59 percent over the controls, and 150 pounds of N per acre as urea increased basal area increment 37 percent. This represented 4-year increases in gross basal area growth of 5.4 and 3.4 square feet per acre, respectively.

2. Response to ammonium nitrate was significantly greater than response to urea.

3. The influence of crown class on basal area growth of individual trees was highly significant. The
increases in growth due to fertilization, however, did not differ significantly by crown class.

LITERATURE CITED

Knowles, R.


Turnbull, K. H., Gene Roy Little, and Gerald E. Hoyer.

METRIC EQUIVALENTS

1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.06997 cubic meter/hectare
1 stem/acre = 2.471 stems/hectare
1 inch = 2.54 centimeters
1 pound/acre = 1.1204 kilogram/hectare
1 mile = 1.613 kilometer
1 foot = 0.3048 meter
1 acre = 0.4048 hectare

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