VOLUME GROWTH AND VOLUME
GROWTH RESPONSE AFTER FERTILIZATION
OF UNTHINNED DOUGLAS-FIR STANDS

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This report is a publication of the Regional Forest Nutrition Research Project, a cooperative program initiated in 1969 to provide forest managers with accurate growth data for managed stands of Douglas-fir and western hemlock in western Oregon and western Washington. Over 30 Pacific Northwest forest industry companies, state and federal agencies, and fertilizer manufacturers provide support and direction for the Project. The RFNRP Report Series is intended to enhance communication of forest fertilization research results within the RFNRP community. Prepared to meet internal RFNRP needs, reports in the series may be descriptions of work in progress as well as final statements of research results.
SUMMARY

Volume growth response to single and multiple nitrogen fertilizer applications in second-growth unthinned Douglas-fir installations is analyzed for six two-year growth periods. The installations contained replicated treatments of 0, 200, and 400 lbs N/A applied as urea. A second application of 200 lbs N/A was applied to one plot of each initial treatment before the fifth two-year growing period. These data are also used to examine volume growth by treatment for trends over time to aid in the interpretation of the volume growth response results. In addition, temperature and precipitation records are presented for the twelve-year period. These data are used to subjectively evaluate the effect of temperature and precipitation on volume growth and volume growth response. The main results are:

1. Responses to the initial treatments are significant \((p < 0.10)\) for the first four two-year periods, and in the final, sixth period. Responses are not significant \((p > 0.25)\) in the fifth period.

2. Responses to refertilization (responses due solely to the second application of fertilizer) are significant \((p < 0.10)\) for the two growth periods for which data are available. Growth responses to the refertilization in the first two-year period following refertilization are comparable to growth responses in the first two-year period following initial fertilization. However, responses to the refertilization declined somewhat in the second period following fertilization, while responses to the initial fertilization increased in the second period.

3. It is possible the insignificant responses to the initial fertilization in the fifth period were caused by unusually dry, warm weather.

4. The duration of response to one application of urea applied at either 200 lbs N/A or 400 lbs N/A is at least twelve years.
INTRODUCTION

This report examines the issue of volume growth response and volume growth to multiple nitrogen (N) applications in unthinned Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) stands in western Washington and Oregon, using data of the Regional Forest Nutrition Research Project (RFNRP). Past RFNRP reports have answered many questions regarding growth response of Douglas-fir to one application of urea-N. However, several important questions remain: How long, for example, would the effects of one fertilization last? Would these same well-stocked stands respond to a second fertilization? How might growth response to a second fertilization compare to growth response from the initial fertilization? The objective of this paper is to answer these questions.

Growth responses to single applications of N fertilizer and second applications of N fertilizer are analyzed. Gross volume periodic annual increments are examined over time in order to better understand response trends. Regional precipitation and temperature data are also presented and discussed as to their influence on growth patterns, since these variables are acknowledged to influence tree growth (Salo 1974; Brubaker 1980).

METHODS

Description of Stands

The data were collected from 60 installations located in well-stocked, second-growth stands. Each installation contained six 0.1-acre or larger plots, with at least 80% Douglas-fir by basal area. Initially, average stand conditions were:
Site index (feet, 50-year basis)  118
Breast height age (years)  30
Stems/A  720
Basal area (square feet/A)  200

Treatment Design

Initial fertilizer applications were replicated treatments of 0, 200, and 400 lbs N/A (ON, 2N, 4N) applied as urea at each installation. A second application consisted of 200 lbs N/A applied to one randomly selected replicate of each initial treatment (02, 22, 42) at each installation after eight growing seasons. Thus, installation responses are based on data from two plots per treatment for the first eight growing seasons and one plot thereafter. Refertilization was applied at each installation in order to retain wide geographical coverage for growth response and to avoid unnecessary introduction of location effects. For more information about the treatment design, see Hazard and Peterson (1984).

Measurement Schedule

Installations were measured every two years during the dormant season. For logistical reasons, approximately half of the total number of installations were established, fertilized, and measured in the fall of 1969, and will be referred to as the "first half" in this study. The remainder of the installations, established, fertilized, and measured in the fall of 1970, will be called the "second half". Two-year measurements from the respective first and second halves were subsequently combined, creating one two-year growth period for the total sample. This scheme is illustrated in Figure 1. Note that the combined two-year growth period actually spans three growing seasons. For example, period 1 includes the
growing seasons of 1970 and 1971 from the first half plus the growing season of 1971 again and that of 1972 from the second half, each of which is a two-year period of growth.

**Mensurational Techniques**

Plots which received two fertilizer applications (treatments 22 and 42) may contain some residual response, or carry-over, from the initial fertilization. Therefore, the growth data from these plots are compared to growth data from plots fertilized once (treatments 2N and 4N) in order to isolate the growth response from refertilization only. In this study, response to the second fertilization only will be referred to as response to refertilization.

Growth responses for stands fertilized both initially and subsequently are partitioned as follows:

<table>
<thead>
<tr>
<th>Response Type</th>
<th>Data Source (treatment)</th>
<th>Data Source (treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First fertilization</td>
<td>Actual growth rate of stand treated once (2N or 4N) minus</td>
<td>Growth rate as in an untreated stand (ON)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2N - ON or 4N - ON</td>
</tr>
<tr>
<td>Second fertilization</td>
<td>Actual growth rate of stand treated twice (22 or 42) minus</td>
<td>Growth rate as in stand treated once</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22 - 2N or 42 - 4N</td>
</tr>
</tbody>
</table>

Growth response estimates are determined using covariance analysis with total gross volume periodic annual increment (PAI) as the dependent variable.
Since growth response is the difference between PAIs of treated and control stands, it is important to examine PAI trends, as well as growth response trends. Therefore, gross volume PAIs are plotted by treatment across two-year periods. In addition, PAIs for the first and the second halves are plotted against their corresponding growing seasons to help pinpoint the year or years in which abnormal growth might have occurred.

**Precipitation and Temperature Data**

Precipitation and temperature observations are available for western Oregon and western Washington in the form of divisional averages (U.S. Environmental Data Service, 1969-1984). Divisional averages have been found to correlate more closely with growth data from an installation than do observations from an individual weather station nearest a given installation (Blasing and others 1981). And, since RFNRP data are collected over geographical areas (provinces) which are similar to the weather divisions, divisional data were judged to be acceptable for this study. The boundaries of these divisions and the location of individual weather stations are illustrated in Figure 2. Since the total annual precipitation and average annual temperature of the divisions varied considerably over time, average deviations from normal were collected for each division. Normal temperature and precipitation are based on all available weather records. A negative deviation indicates a drier or cooler year than average, for precipitation and temperature respectively, and positive deviations indicate a year wetter or warmer than the average year. Data from the eight divisions were then averaged for a regional estimate. Average deviations were also calculated for the growing season and the dormant season. The growing season is defined as the five-month period from May through September (Griffith 1950).
RESULTS

Volume growth responses to single and repeated fertilizations for each of the six two-year periods are displayed in Figure 3. The estimates with standard errors and significance levels are tabulated by two-year period in Table 1.

Growth Response to Initial Fertilization

Growth responses to initial fertilization are significant \( p < 0.001 \) for both treatments through four growth periods. Growth response declined in period five, followed by an increase in period six. Although growth response is not significantly greater than zero for either treatment in period five, it is significantly \( p < 0.10 \) greater than zero in period six.

Growth Response to Refertilization

The second application of nitrogen fertilizer produced significant growth responses in both periods five and six (Table 1, Figure 3). Growth responses to the refertilization plus carry-over do, however, decline from period five to period six. Growth responses for the 22 and 42 treatments do not differ significantly from each other.

Precipitation and Temperature Data

Mean temperature and mean total precipitation for the region for 1969-1984 are presented in Table 2. The means are a useful reference point for comparison with the average deviations. During 1969-1984, average total precipitation in a calendar year was 66 inches, 11 inches of which fell during the growing season, May through September. Average
temperature for a calendar year was approximately 50°F, 60°F during the growing season, and 43°F during the dormant season.

Average deviations from the normal precipitation and temperature are graphed by calendar year in Figures 4 and 5, respectively. The dashed horizontal line represents normal. Generally, precipitation was above normal except for the years 1976-1980. The driest years were 1976 and 1978 at approximately fifteen inches below normal. Temperatures during years 1976-1980 were basically above normal, but for the other years were below normal.

Growing season precipitation (Figure 6) was near normal from the time of installation establishment to 1976. In 1977 and 1978, precipitation was about five inches above normal. Precipitation was also above normal for the years 1981, 1983, and 1984. Growing season temperatures (Figure 7) were below or slightly above normal except for the 1979 growing season. The temperature during that season was 1.2°F above normal.

Dormant season precipitation and temperature are presented in Figures 8 and 9, respectively. The horizontal axis represents the year following the dormant season. For example, the data point corresponding to year 1969 is the deviation from normal which occurred during October, 1968 through April, 1969, the seven months preceding the growing season of 1969. Dormant season precipitation was above normal except for the period beginning in October of the years 1972, and 1976 through 1980. The winter of 1976-1977 was the driest at 28 inches below normal. Dormant season temperatures were at least 0.5°F below normal from 1970 through 1975. They were little more than 1.0°F above normal for two years, and then 1.5°F below normal in winter, 1978. Temperatures were 1.0
and 2.0°F above normal in 1979 and 1980. Temperature was then below normal in 1981, but above normal during the rest of the period.

**PAIs of Initial Fertilization**

A peculiar feature of Figure 10 is the lower average PAIs for the treated plots for period five. The average PAI for the control is also lower at this time in comparison to control PAIs of periods four and six, but the decrease is less than the decreased growth on the treated stands.

Figures 11 and 12 illustrate PAI trends for the first half and second half installations, respectively, by the year of the first growing season in a measurement period. The growth trend of the first half of the installations is very similar to that of all installations combined. Only 4N plots exhibit a lower PAI in the next to the last measurement period for the second half in Figure 12.

**PAIs of Refertilized Plots**

The PAIs of the controls, fertilized, and refertilized plots from the first half are illustrated by two-year period in Figures 13 and 14. Plots were not retreated until the 1977-1978 dormant season, so for the first eight years all treated plots had received only one application. Thus, the PAIs for the plots receiving the initial fertilization only, and the treated plots that were given a second application are the same until that time. After refertilization, PAIs for both the 22 and 42 treatments increased markedly over the two, two-year periods prior to retreatment.
DISCUSSION

Comparison of Second Fertilization to Initial Fertilization

Growth responses to the refertilization in the first two-year period following refertilization are comparable to the growth responses in the first two-year period following initial fertilization. Unlike responses in the second period following the initial fertilization, however, responses to refertilization declined after the first two-year growth period. This is inferred from the increased "residual" responses from initial fertilization in period six. However, the responses to refertilization are still significant (p < 0.10).

Duration of Response

Prior to the sixth measurement period, it appeared from the low responses in period five that duration of response to an initial treatment of either 200 or 400 lbs N/A was eight years. However, responses during the sixth two-year period were somewhat greater than responses in the fourth period. In addition, preliminary analysis of data from period seven indicated response levels similar to those of period six. It was hypothesized that the low response in period five was the result of adverse weather conditions.

Precipitation and Temperature Effects

Indeed, the period of low response occurred during unusually dry, warm weather. Period five included the growing seasons from the years 1978, 1979, and 1980. These years were in the midst of a drier than normal period accompanied by higher-than-normal temperatures. Since one
of the most important factors limiting tree growth in the Pacific Northwest is drought (Brubaker 1980), it seems reasonable to expect lower growth levels in drier years. Also, warm summer temperatures are generally not conducive to growth of Douglas-fir (Salo 1974). If the low response in period five was due mostly to this abnormally dry, warm period, duration of response could be at least twelve years, and perhaps even fourteen years.

Further investigation into weather and growth trends seemed worthwhile given the preceding observations. The FAI graphs for initial fertilization reveal that the trends of the first half (Figure 11) followed the trends of all installations (Figure 10) more closely than the trends of the second half (Figure 12). Therefore, the growth of 2N and 4N plots in period five (years 1978-1979) of the first half is noticeably lower than in periods four and six, while the growth of the second half in period five (1979-1980) is similar to growth in the two adjacent periods. Since lower growth occurred for both treatments and the controls in the 1978-1979 period, and for treatment 4N in the 1979-1980 period, the year of poorest growing conditions appeared to be 1979.

The precipitation and temperature data suggest that low response in period five was at least due in part to weather. The winter of 1978-1979, colder and drier than normal, followed several years of low precipitation. The 1979 growing season was the warmest during the lifetime of the project, at 1.2°F above normal. Precipitation at that time was slightly below normal. No other year (between 1968 and 1984) had this particular combination of temperature and precipitation. Nineteen-eighty appeared to be a better year for growth with cooler summer temperatures and greater precipitation during the preceding dormant season than 1978. Although
precipitation was greater in 1978 than 1980, much of this came in September after most growth had occurred.

Thus, it seems reasonable that lower growth in the 1978–1980 combined period was at least partly due to poor weather conditions, and that growth in 1978–1979 was affected more than growth in 1979–1980. This is in agreement with Barclay and others (1982) in British Columbia. They reported that low observed height and diameter increments in Douglas-fir in 1978 corresponded to a period of low summer rainfall. It appears that weather did not adversely affect response to reapplication. Since the timing of precipitation also influences response to fertilization (Heilman and others 1982), it could be that precipitation fell at an opportune time after retreatment.
CONCLUSIONS

Determination of duration of response to a single application of nitrogen fertilizer is not easy for the response pattern obtained in this study. Certainly, the duration of response for both 2N and 4N treatments is at least eight years. It appears that unusual weather may have played a role in the insignificant response in the fifth two-year growth period. If this is true, duration of response is at least twelve years for both treatments. Unfortunately, our data is not adequate to conclusively prove a link between response to nitrogen fertilizer and weather.

Responses to the refertilization are comparable to responses to initial fertilization in the first two-year growth period following fertilization. In the second two-year growth period following fertilization, responses to the refertilization decline, but responses to initial treatment increase. This decline is particularly true for 42 plots. These findings suggest that response trends from refertilization do not mirror those from initial fertilizations.
LITERATURE CITED


Table 1. Response (± standard error) estimates of total gross volume increment for each two-year period, with levels of statistical significance; cu ft/ac/yr (min. d.b.h. = 1.55 inches)

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<th>3</th>
<th>4</th>
<th>5</th>
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Table 2. Mean precipitation and temperatures for the region for years 1969-1984.

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<th>Period</th>
<th>Precipitation (inches)</th>
<th>Temperature (°F)</th>
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<tr>
<td>Growing season</td>
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<tr>
<td>Dormant season</td>
<td>55</td>
<td>28-79</td>
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</table>
Figure 1. Years of measurements of first and second halves of installations.

* Installations established and first measured in the fall of these years
Figure 2. Location of weather stations and divisions of similar weather in western Washington and Oregon.
Figure 3. Estimated total gross volume growth response for each two-year growth period of unthinned Douglas-fir (cu ft/A/yr; min d.b.h. = 1.55 inches); from Table 1.
Figure 4. Average deviations by year from the mean precipitation (in) for January through December.

Figure 5. Average deviations by year from the mean temperature (°F) for January through December.
Figure 6. Average deviations from the mean precipitation (in) for the growing season only (May–Sept.).

Figure 8. Average deviations from the mean precipitation (in) for the dormant season only (Oct.–April).

Figure 7. Average deviations from the mean temperature (°F) for the growing season only (May–Sept.).

Figure 9. Average deviations from the mean temperature (°F) for the dormant season only (Oct.–April).
Figure 10. Gross volume PAI for unthinned stands for all installations.
Figure 11. Cross volume PAI for unthinned stands from first half treated with one fertilization only.

Figure 12. Cross volume PAI for unthinned stands from second half treated with one fertilization only.
Figure 13. Gross volume PAI for unthinned stands from first half only for refertilized 2N treatment.

Figure 14. Gross volume PAI for unthinned stands from first half only for refertilized 4N treatment.