Introduction

Over the past two decades a network of nearly 1,000 fertilizer plots have been superimposed over the variety of edaphic, climatic, and stand conditions existing in our western hemlock forests. These plots, along with a few associated investigations, provide the base for examining the relationship of response to such factors as geographic location, soils, site quality, stand conditions, and fertilizer variables. Although much remains unknown, a limited understanding of hemlock response to fertilizer has begun to emerge.

Relationship of Response to Geographic Location, Soils, and Site Quality

The network of nearly 1,000 plots covers a wide range of geographic locations, soils, and site qualities. Examining the responses by geographic location reveals that hemlock installations in coastal Oregon and Washington have generally failed to respond to fertilizer; whereas installations in inland Washington and installations on Vancouver Island have often responded favorably. Coastal installation in Washington and Oregon are those occurring within about 50 miles of the coast. Inland Washington installations are those occurring in the eastern portion of the Puget Basin and at lower elevations on the west slopes of the Cascades. The Cooperative Regional Forest Nutrition Research Project (RFNRP), supervised by the University of Washington, has established 28 installations in unthinned hemlock. Seventeen of these are situated in the coastal zone, ranging from the midpoint of the Oregon coast north to the Strait of Juan de Fuca. The remaining 11 installations are in the Washington inland zone, situated between Bellingham to the north and Morton to the south. At each installation, in addition to unfertilized control plots, nitrogen dosages of 200 pounds and 400 pounds per acre as urea were tested on duplicate plots.

Basal area responses, four years after fertilization, are summarized in Figure 1. The term response throughout this paper will refer to the difference in growth on treated and untreated plots. In Figure 1, and in most of those which follow, response is in terms of percent. The bars represent average responses for the two different dosages of nitrogen in the three different geographic zones. Responses recorded at each individual installation are plotted along the lines within each bar. Generally the inland installations were more responsive, with average response for 200 pounds of nitrogen being 14 percent. On the average, response to 200 pounds of nitrogen per acre is the same or greater than response to 400 pounds.

Typically, a wide range of responses were recorded for each dosage and in many instances, negative responses were recorded. These negative responses occur when growth on fertilized plots at an installation is less than growth on control plots. Whether this lesser growth on fertilized plots is the result of a toxic effect of the fertilizer or is the result of differences in soil or stand

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characteristics between fertilized and control plots (resulting in different growth rates) has not been determined.

Results from installations of the Regional Forest Nutrition Research Project are reinforced by results of a similar network of installations belonging to Weyerhaeuser Company. The Weyerhaeuser Installations differ from those of the regional project in that the dosages applied are 100, 300, and 500 pounds of nitrogen per acre as urea, and these dosages are not replicated at the individual installations. There are 16 coastal installations ranging from just north of Montesano to slightly south of Raymond, Washington. About one-half of the coastal installations were established during the winter.

Regardless of the year established, these coastal installations generally responded unfavorably to additions of nitrogen (Figure 2). Again, the range of responses recorded within the different dosages was very large. For each dosage the number and magnitude of positive and negative responses were about balanced; however, on the average only the 300-pound dosage applied in the winter of 1970-1971 produced a positive response.

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Figure 2. Gross basal area responses for unthinned coastal hemlock for Weyerhaeuser empirical installations.

Fertilization/Weyerhaeuser
COASTAL RESPONSES

Basal area response (percent)

<table>
<thead>
<tr>
<th>Nitrogen (lb./acre)</th>
<th>-40</th>
<th>-30</th>
<th>-20</th>
<th>-10</th>
<th>0</th>
<th>+10</th>
<th>+20</th>
<th>+30</th>
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Winter of 1970 - 71 —— establishment —— 1971 - 72

Seven of the Weyerhaeuser Installations are at Inland locations scattered between Enumclaw in the south and Monroe in the north. Although these installations were established later than the coastal installations, the responses are clearly more favorable than are the coastal responses (Figure 3). However, the range of responses is large and several negative responses have been recorded. The relationship between dosage and response was inconsistent for 100 and 300 pounds of nitrogen, but for both sets of installations, 300 pounds was superior to 500 pounds.

A third geographic location is represented by results of a single installation on the north end of Vancouver Island. This Installation has a site Index of about 115 feet on a 50-year basis and, at the time of fertilization, the trees were 60 to 70 years old. The percent increases in basal area growth (Figure 4) are for a 6-year period following fertilization. These responses and others reported for younger hemlock stands on Vancouver Island are comparable to responses recorded for Inland hemlock in Washington.

Figure 3. Gross basal area responses for unthinned Inland hemlock for Weyerhaeuser empirical installations.

Fertilization/Weyerhaeuser
INLAND RESPONSES

Basal area response (percent)

<table>
<thead>
<tr>
<th>Nitrogen (lb./acre)</th>
<th>-25</th>
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<th>+10</th>
<th>+25</th>
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Winter of 1971 - 72 —— establishment —— 1972 - 73

Figure 4. Gross basal area response for unthinned hemlock on Vancouver Island in British Columbia, Canada.

Fertilization/6 Growing seasons
VANCOUVER ISLAND RESPONSES

Basal area response (percent)

<table>
<thead>
<tr>
<th>Nitrogen (lb./acre)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
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<tbody>
<tr>
<td>N100</td>
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<tr>
<td>N300</td>
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In contrast to geographic location, no clear trend has emerged in the relationship of response to soils or site quality. Responses of the Weyerhaeuser Installations were examined in light of the soil type and parent material on which the installations occurred.
Sixteen different soil types were represented. Parent materials represented included sedimentary rock, basalt, glacial till on the southwest slopes of the Olympic Mountains, young alluvium, glacial gravels, glacial tills with impervious subsoils, and volcanic ash. This assortment of soils and parent materials presents a wide spectrum of soil conditions such as nutrient and moisture status. However, from this assortment, no trends between soil conditions and response have yet been established.

Site qualities for the network of the regional project and Weyerhaeuser Installations cover the range of site index from about 65 to 125 feet on a 50-year basis. Within the coastal zone and within the inland zone, no relationship between response and site quality is obvious. Average site quality for the coastal installations slightly exceeds that of the inland installations, but whether or not this small difference in average site quality is related to differences in response between the coastal and inland zones has not been determined.

Relationship of Response to Stand and Individual Tree Conditions

The relationship of response to various stand and individual tree conditions has also been examined. Stand age and density of unthinned stands might be expected to affect the magnitude of growth enhancement following fertilization. However, as was the case with soils and site quality, no consistent trends have emerged.

A consistent relationship was observed however, when Crown Zellerbach examined response to nitrogen in stands composed of mixed coniferous species. Near Seaside, Oregon, percent diameter responses were measured 4 to 6 growing seasons after the application of a medium and a high dosage of urea nitrogen (Figure 5). Although the

Figure 5. Comparison of diameter responses for a mixed coastal stand of hemlock and spruce near Seaside, Oregon.

Fertilization/Crown Zellerbach/4 to 6 Growing seasons
MIXED STANDS/Seaside

Diameter response (percent)

hemlock in these stands responded positively to the fertilization, the Sitka spruce exhibited a much larger response. Also near Seaside the effect of 100 and 200 pounds of nitrogen was compared for hemlock and Douglas-fir growing in mixture (Figure 6). When the basal area growths per tree were compared after five growing seasons, the growth of Douglas-fir had increased with both dosages of nitrogen. The growth of hemlock had increased slightly with the 100-pound-per-acre application but had decreased considerably with the 200-pound dosage. Comparisons of basal area growth per tree at Mollala in the western Oregon Cascade Mountains revealed favorable responses of both hemlock and Douglas-fir (Figure 7). The response of hemlock actually exceeded that of Douglas-fir, resulting in nearly equal growth rates of the two species after fertilization.

Figure 6. Comparison of basal area growth per tree for a mixed coastal stand of hemlock and Douglas-fir near Seaside, Oregon.

Fertilization/Crown Zellerbach/5 Growing seasons
MIXED STANDS/Seaside

Basal area growth/tree (sq. ft.)

Figure 7. Comparison of basal area growth per tree for a mixed coastal stand of hemlock and Douglas-fir near Mollala, Oregon.

Fertilization/Crown Zellerbach/6 Growing seasons
MIXED STANDS/Mollala

Basal area growth/tree (sq. ft.)
Crown Zellerbach has also compared the growth and response of upper crown class trees to those of the lower crown class (Figure 8). The findings were not only a greater basal area growth per tree for upper crown class trees but also a greater acceleration of growth due to fertilizer. One interpretation of these findings is that the lower crown class trees are in a poor competitive position to adsorb or utilize the applied nitrogen. The implication is that fertilization may accelerate the rate of tree size differentiation and hasten the mortality of suppressed trees. This effect, however, is yet to be established for hemlock.

Figure 8. Comparison of basal area growth per tree for trees of the upper and lower crown classes.

Fertilization/Crown Zellerbach/2 Growing seasons EFFECT OF CROWN CLASS/Seaside

Basal area growth/tree (sq. ft.)

In contrast to unthinned stands, thinned hemlock has been more responsive to fertilization. After two growing seasons, coastal as well as inland installations of the Regional Forest Nutrition Research Project have responded favorably to nitrogen fertilization (Figure 9). However, the average response of inland installations exceeded those of the coastal zone.

Positive responses have also been recorded for hemlock of about 25 years of age at two Weyerhaeuser installations, one located on Pack Sack Mountain near Aberdeen, Washington, and one located on the Tolt River north of Issaquah. At Pack Sack, 4 years after an initial calibration thinning of all plots, thinning treatments were established which removed growth equivalent to 0, 30, 55, and 80 percent of the growth accrued during the previous calibration period. The growth displayed in Figure 10 is that which occurred in the 4-year period following establishment of the four thinning levels. Although thinning reduced the total gross growth per acre on these young trees, the basal area response to fertilizer increased with thinning, averaging 13 percent for the 55 and 80 percent thinning regimes. The absolute basal area response was greatest for the thinning regime that removed 55 percent of accrued growth.

At the Tolt River Installation (Figure 11), three thinning levels removed 0, 50, and 75 percent of accrued growth. At the end of five growing seasons, the installation had been thinned and fertilized twice. The greatest total gross growth occurred on the plots receiving the heaviest thinning and heaviest fertilization of 400 pounds of nitrogen per acre. The second greatest growth occurred on plots receiving the second level of thinning plus 400 pounds of nitrogen. The ability of these young hemlock to respond to heavy thinning and utilize applied nitrogen has been quite remarkable.
Fertilization and thinning/Weyerhaeuser/5 Growing seasons
TOLT RIVER RESPONSES/Issaquah

Basal area growth (sq. ft.)

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<tr>
<th>Basal area growth removed (percent)</th>
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<tr>
<td>11</td>
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<tr>
<td>12</td>
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<td>13</td>
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Control
N200
N400

Both fertilizers increased the basal area growth over the unfertilized control but ammonium sulfate had been the more effective (Figure 12). The comparison of ammonium nitrate to urea was inconclusive. Ammonium nitrate was ineffective at the dosage of 150 pounds of nitrogen but effective and superior to urea at the 300-pounds-of-nitrogen application. In a subsequent study (Figure 13) installed at four locations near Seaside, the comparison of urea and ammonium nitrate was again inconclusive. After two growing seasons an assortment of negative and positive responses had been recorded for both fertilizer materials.

Because this important question of the appropriate source of nitrogen remains unresolved, efforts of Weyerhaeuser Company, Crown Zellerbach, RFNRP, and the Forest Service are being focused on the issue, with studies planned for 1976 already underway.

Figure 12. Comparison of gross basal area responses to three nitrogen sources applied to a coastal stand of hemlock near Seaside, Oregon.

Fertilization/Crown Zellerbach/4 Growing seasons
NITROGEN SOURCE/Seaside

Basal area response (percent)

<table>
<thead>
<tr>
<th>Nitrogen applied (lb./acre)</th>
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<tr>
<td>0</td>
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<td>5</td>
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Ammonium nitrate
Ammonium sulfate
Urea

Beginning several years ago near Seaside, Oregon, Crown Zellerbach compared urea with ammonium sulfate and ammonium nitrate fertilizers. Ammonium sulfate was compared to urea only at a dosage of 150 pounds of nitrogen per acre. After four growing seasons...
Dosage of nitrogen has been tested in nearly every study that has been installed in the region and the recorded effects have appeared throughout this presentation. Although the relationship of dosage to response remains unclear, in unthinned stands nitrogen in excess of 150 to 200 pounds per acre has not been beneficial. In thinned stands, however, responses have increased up to the heaviest dosages of 300 to 400 pounds. Attempts to determine the most profitable dosage have not been recorded.

The appropriate timing of urea during the coldest and wettest time of the year, as is current practice for Douglas-fir, probably results in the most favorable distribution as well as minimizes any volatility losses. Timing of the application of nitrogen sources other than urea has not been investigated. Little can be said about the duration of response and appropriate frequency of application. For other species, including Douglas-fir, the effect of a single application usually lasts between 4 and 8 years. Preliminary examination of hemlock responses indicate that where response does occur, the duration of response will be comparable to that of Douglas-fir.

Conclusion

Despite the establishment of a large network of plots, many questions about the fertilization of western hemlock remain unresolved. A constantly recurring feature has been a very wide range of responses, making it difficult to develop confidence in responses recorded at individual installations. However, growth enhancements, even in coastal stands, have been documented with sufficient regularity to create optimism that with the proper fertilizer material, dosage, timing, and frequency of application, fertilization is a potentially valuable cultural practice for increasing growth in hemlock of the Pacific Northwest and Canadian Rocky Mountains.

Even though knowledge about the response of hemlock to fertilization is fragmentary and far from perfect, it is not at ground zero. Using currently accepted practices, fertilization of coastal hemlock is probably not profitable; but for Washington Inland and Vancouver Island hemlock, a reasonably good chance exists to increase growth by 10 to 20 percent. Furthermore, thinned stands have proven more responsive than unthinned stands. Where responses do occur, optimum dosages have not been determined, but they probably do not exceed 200 pounds of nitrogen per acre.

Application of nutrients other than nitrogen has not yet been proven useful. Aside from this information, our knowledge about the relationship of hemlock response to various site and stand conditions and to various fertilizer variables remains poorly quantified. However, a considerable amount of research attention is currently being focused on hemlock nutrition and fertilization in an attempt to improve our understanding of these critical relationships.

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