# REGIONAL FOREST NUTRITION RESEARCH PROJECT

Biennial
Report
1972–74

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UNIVERSITY OF WASHINGTON
COLLEGE OF FOREST RESOURCES

# REGIONAL FOREST NUTRITION
# RESEARCH PROJECT

## BIENNIAL REPORT
## 1972 - 1974

COLLEGE OF FOREST RESOURCES
UNIVERSITY OF WASHINGTON

## PARTICIPATING MEMBERS

## 1972 - 1974

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# FOREWORD

The past several years have seen the development and use of numerous computer models designed to assist forest managers decide where and when to harvest, how and when to thin and fertilize, and whether to plant or seed. As experience with these models grows it is apparent that their most serious limitation is in the underlying relationships upon which they are based. The sciences of model-building and quantitative decision-making as applied to forest management have far out-stripped the available data base. Results from sophisticated models are no better than data inputs.

Given this situation in forestry it is essential that first priority be granted to research that provides fundamental information on tree and stand growth; especially how growth is related to site, age, density, species composition and stand structure. Effects of management treatments such as thinning and fertilization must also be included in growth estimates. The Regional Forest Nutrition Research Project was organized specifically to collect just such information on stand growth and fertilizer response over a broad range of soils, sites, and ages in western Oregon and western Washington. Research plots established under this Project are playing a vital role in providing essential data upon which future young growth forest management will be based. For instance, a major regional effort is currently underway to develop yield tables for managed stands under different treatment prescriptions and the plot data will provide a key element in the ultimate refinement of this endeavor.

The basic Project objective of obtaining regional nitrogen fertilizer response data is now in the exciting stages of fruition. The mass of data from nearly 1200 plots is impressive in its magnitude and scope, and it requires increasing effort by Project staff to summarize and assess results. Preliminary findings and analytical techniques form the essence of this Biennial Report; the final Phase I analyses will be made next year upon the conclusion of all remeasurements.

Prospects appear bright that expansion and refinement of this valuable data base will continue beyond the present Phase I termination date of 1975. The cooperative spirit in which the study was launched 5 years ago has hence proven to be a viable and productive long-term research mechanism.

James S. Bethel, Dean
College of Forest Resources

# INTRODUCTION

The Regional Forest Nutrition Research Project was initiated in 1969 with the primary objective of providing resource managers with more accurate data on the effects of fertilizing and thinning young-growth Douglas-fir and western hemlock forests.

Based on the needs for additional information which previous forest fertilization research in the Pacific Northwest had brought to light, the Northwest Forest Soils Council determined that an intensive field program with regional focus should incorporate the following goals:

1. to establish and maintain a series of fertilizing and thinning field trials on participants' lands in western Washington and western Oregon under various conditions of soils, climate, age, and site;
2. to collect and analyze response data from these plots over a 4-year period and report results to subscribers;
3. to conduct supplemental research in related areas such as diagnosis of elemental deficiencies, analysis of the effects of fertilizer application on total ecosystems, effects on wood quality, economics of fertilization and thinning, and mensurational aspects;
4. to report findings regularly to subscribers and to advise them on fertilization problems and practices;
5. to cooperate with other programs and research designed to intensify forest management and increase wood production.

Because of the scope of this program, a cooperative funding approach was used to enlist a broad base of support from regional timber companies, fertilizer manufacturers, and governmental agencies involved with resource management. The College of Forest Resources of the University of Washington administers the project under the direction of Dr. Stanley P. Gessel.

The original research design called for simultaneous establishment of unthinned and thinned fertilizer plots. However, the funding level in 1969 did not permit the full program to proceed, and the cooperators decided to begin with the unthinned plots only. This became known as Phase I when, in 1971, sufficient funds had been generated to reincorporate the thinning-fertilizer trials. The latter portion of the program is referred to as Phase II. All plots were originally scheduled for final remeasurement after they had undergone four growing seasons. It now appears that the Project will be extended beyond four growing seasons in order to determine duration of response, effect of retreatment, and a variety of other questions pertinent to operational forest fertilization in the Douglas-fir Region.

Project development, design, methodology, preliminary 2-year results, and associated basic research studies have been discussed in the 1969-1970, 1970-1971, and 1971-1972 Annual Reports. Time required for the development of sophisticated data-handling techniques and for the availability of the first 4-year growth results postponed preparation of the present Biennial Report, 1972-74. This document concentrates on the work and results of the past 2 years.

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## FIELD PROGRESS REPORT

The Regional Forest Nutrition Research Project (RFNRP) is now beginning its sixth and final year of Phase I and its fourth year of Phase II. Almost twelve hundred research plots have been established during this time. A summary of surviving plots by treatment and number of growing seasons following treatment is presented in Table I. Each year that passes adds enormously to the fund of information on stand and tree growth obtained from these plots.

### Phase I (Fertilization only)

Four-year diameter breast height (DBH) and height measurements on the first half of Phase I plots were completed early in 1974. These data are summarized in this Report. In anticipation of an extension of the Project, maintenance work was also performed on these plots. This included pulling nails so the tags were not overgrown, repainting plot boundaries and updating maps. It is planned to complete measurements of all second-year Phase I plots by December 31, 1974, so that results can be analysed and made available to cooperators close to the scheduled Phase I completion date: June 30, 1975.

TABLE I. RFNRP Surviving Research Plots (September 1974)

| Treatment | Number of Growing Seasons (including 1974) | Number of Surviving Research Plots |
|---|---|---|
| Phase I: | | |
| fertilized | 5 | 216 |
| control | 5 | 109 |
| fertilized | 4 | 233 |
| control | 4 | 118 |
| | Subtotal, Phase I | 676 |
| Phase II: | | |
| thinned only | 3 | 32 |
| thinned & fertilized | 3 | 64 |
| control | 3 | 32 |
| "complete" fertilizer | 3 | 32 |
| fertilized | 3 | 8 |
| thinned only | 2 | 54 |
| thinned & fertilized | 2 | 108 |
| control | 2 | 54 |
| "complete" fertilizer | 2 | 54 |
| fertilized | 2 | 14 |
| thinned only | 1 | 12 |
| thinned & fertilized | 1 | 24 |
| control | 1 | 12 |
| | Subtotal, Phase II | 500 |
| | TOTAL | 1,176 |

### Phase II (Fertilization and Thinning)

DBH measurements were taken during the 1973-74 winter on all Phase II installations which had undergone two growing seasons following treatment. Trees were found to be in excellent condition, virtually escaping serious windthrow and other damage Remaining Phase II plots will be remeasured during the 1974-75 winter.

## Other Field Work

Forest Stand growth is the aggregate of individual tree growth, which depends upon a complex interaction between the tree's age, size, genetic makeup, microsite conditions, vigor, position in the stand, and on the amount of competitive stress that the tree is under. An understanding of how these factors interact to affect tree growth and how they can be manipulated are fundamental goals of growth and yield research. It is apparent that before research plot data can be fully understood, it is necessary to look carefully at individual trees within the plots. With this thought in mind the field crew turned to three new tasks after the completion of 1973-74 remeasurements: 1) stem mapping on selected installations; 2) increment core sampling; and 3) stem analysis.

### Stem mapping

Stem mapping consists of locating each tree in the plot on a coordinate matrix. Using a competitive stress system it is possible to quantify the degree of competition on each tree.[1] The goal of this procedure is to examine treated versus untreated tree growth, using the amount of competition each tree is growing under in addition to such traditional classifications as age, site, and per acre stocking. Stem maps which show the stand before and after treatment are particularly important when determining the degree of release in thinning experiments. This information is also helpful in analyzing fertilizer-thinning interactions and in extending growth and response data to less-than-fully stocked stands. The latter point is important because stands sampled under RFNRP were selected as having from 80-110 percent of "normal basal area stocking,[2] and hence are not representative of lower stocking conditions which are extremely widespread in western Washington and western Oregon.

### Increment core sampling

The growth rate in research plots for the years immediately prior to treatment has been indicated in Scandinavian literature as a useful tool in assessing post-treatment growth. Can a stand's current growth-rate provide an indication of response to fertilizer? The answer to this question is the goal of increment core sampling of selected research plots. Singled out for such sampling over the next several years are two groups of plots:

1) Those plots exhibiting average or normal response over a range of high, medium, and low sites, and covering the ages 15-60. The idea is to relate stand growth as well as response to fertilizer and/or thinning to pre-treatment growth rate. Perhaps the addition of the single variable, current annual increment, (c.a.i.) will strengthen growth prediction equations, thus demonstrating that a good predictor of future growth is current growth. Current annual increment would be valuable for this purpose since it is commonly determined in forest inventories.

2) Plots on which growth is different than expected. Why is it, for example, that a control plot outgrows a fertilized plot? Perhaps it was growing faster to begin with. Abnormal growth plots, both treated and untreated are being examined to see if the cause is apparent.

### Stem analysis

The purpose of stem analysis is to quantify growth along the entire tree bole in order to determine whether or not measurements of DBH and height adequately describe changes affecting tree volume. The field crew is measuring diameter growth at frequent intervals along the bole of trees previously felled in buffer strips for foliage-sampling. Both fertilized and non-fertilized trees are included in the sample. Thinned trees and fertilized-thinned trees will be added when Phase II plots accumulate four growing seasons after treatment.

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[1] Arney, James D. "Tables for Quantifying Stress on Individual Trees." Information Report B.C.-X-78, Canadian Forestry Service, February, 1973.

[2] McArdle, R.E., Meyer, W.H., and Bruce, D., "The Yield of Douglas-fir in the Pacific Northwest." U.S.D.A. Technical Bulletin No. 201., May 1961. Barnes, G.H., "Yield of Even-aged Stands of Western Hemlock." U.S.D.A. Technical Bulletin No. 1273., Sept. 1962.

## PRELIMINARY RESPONSE SUMMARIES

The following summaries of response to nitrogen fertilization are presented in this report:

1. Phase I (unthinned), 4-year data for:
   a) Douglas-fir, 40 installations
   b) Western hemlock, 15 installations

Tables are presented for total basal area, total cubic foot volume and merchantable cubic foot volume.

2. Phase I (unthinned), 2-year data for:
   a) Douglas-fir, 87 installations
   b) Western hemlock, 28 installations

Tables are for total basal area only.

3. Phase II (thinned), 2-year data for:
   a) Douglas-fir, 9 installations
   b) Western hemlock, 7 installations

Tables are for total basal area only.

### Comments on Response Results

Douglas-fir, unthinned, 4-year data

The 4-year data represent approximately one-half of the Phase I installations. Two methods were employed in summarizing these data, representing different levels of complexity. In the first instance, the data were considered on an installation-average basis (i.e., average of plots treated alike within the installation). Installations were then sorted into age and site classes (see Table 2) and average results derived for each cell (see Tables 3a, 7a, 8, 10).

Multiple regression techniques were used as the second method. Results here are based on individual plot data. For further discussion see footnote 22.

Some of the more notable features of the data are listed below:

1. Douglas-fir continues to exhibit impressive response to nitrogen. Generally, response increases as site decreases (Tables 3, 3a, 5, 6, 7, 7a, 8, 9, 10).

2. Low sites appear to be producing more response than high sites, and to do so more consistently (Table 4).

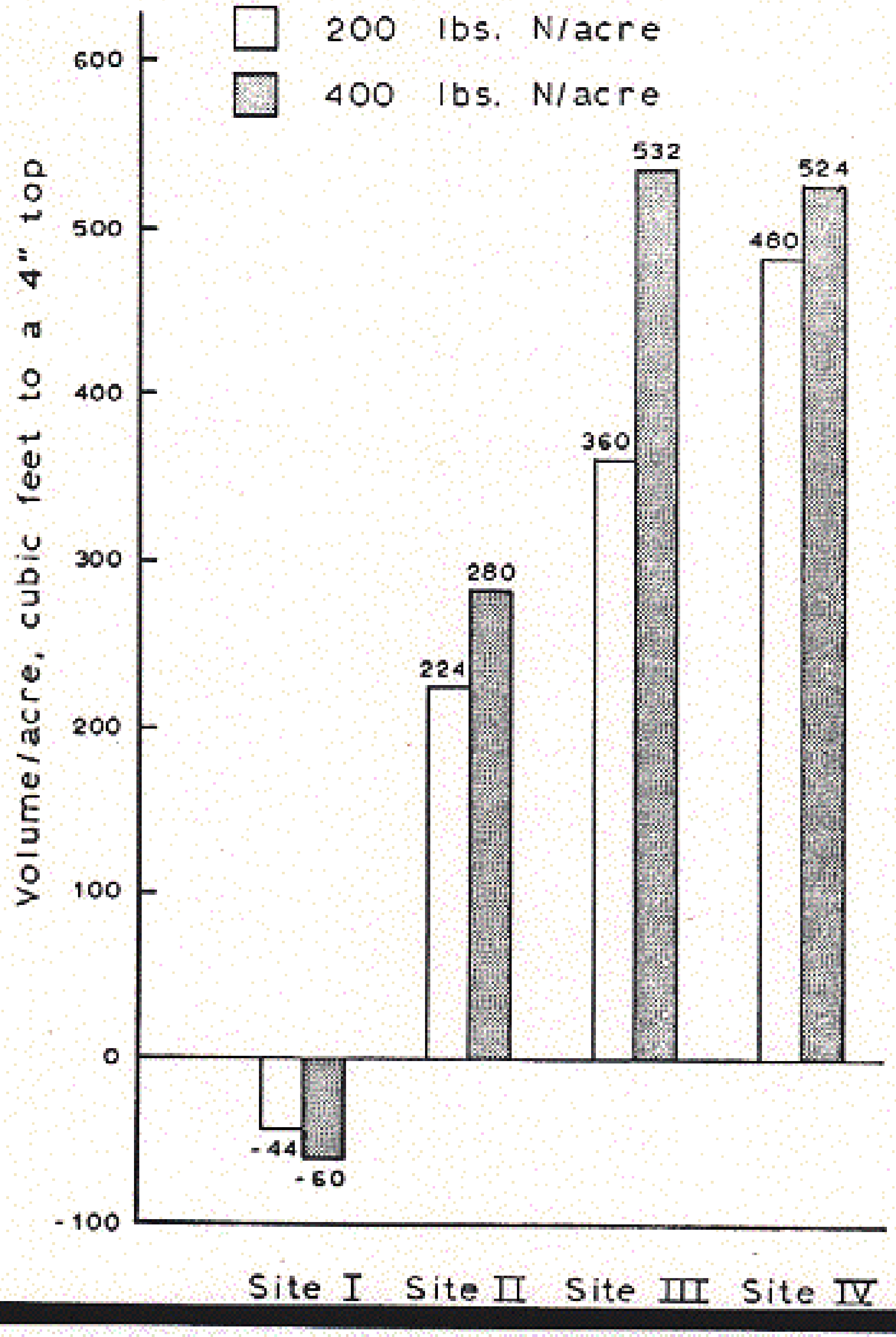
3. Overall, 32 of the 40 Douglas-fir installations responded by at least a ten percent basal area growth increase when treated with 200 lbs of nitrogen per acre, while 31 of the 40 showed similar response to 400 lbs nitrogen per acre (Table 4).

4. Total 4-year merchantable volume gain from nitrogen exhibits a strong increase with decreasing site (Figure 1). The magnitude of this volume gain presents a persuasive economic argument for forest fertilization (Table 9. Also see the economic model on Page 28).

5. Although final judgement as to stand priority for treatment awaits next year's doubling of the data base and statistical analysis, it appears that those organizations contemplating operational fertilization in 1974-75 would do well to concentrate on well-stocked 30 to 45 year-old Douglas-fir stands on sites III and IV. If recently thinned stands are available within these site and age classes, they should be given highest priority for treatment (Tables 19, 20, 21). Undoubtedly other site-age categories also present profitable fertilization opportunities and these will be evaluated when 4-year data over their total range are analyzed.

6. Given the general scarcity and increasing cost of urea, as well as the relative magnitudes of response between treatment rates (Tables 7a and 8), it is also suggested that fertilization be at a rate not exceeding 200 lbs of nitrogen per acre (435 lbs of urea). This too should be regarded as a preliminary recommendation, subject to next year's intensive analysis and future determinations of the duration of response.

FIGURE I   Four-year gross merchantable gain from fertilization, by site class, Douglas-fir, ages 31-45. Source: Table 9.



## Douglas-fir, unthinned, 2-year data

Tables 5, 6, and 6a deal with 2-year data available on all 87 installations in Phase I. All site-age classes are represented, with the exception of site IV, age class 15-30, for which no suitable areas were found. In general, these data also exhibit the same trends as those shown by the available 4-year data, i.e., an increase in total basal area response with decreasing site. Table 6a also suggests that the 200 lb nitrogen treatment is giving better results than is the 400 lb treatment, on an overall basis. Cells in which only one or two installations are contained (Table 5) should be treated with caution, as these may not provide sufficiently large samples from which to make interpretations without more comprehensive analysis.

## Western hemlock unthinned, 4-year data

The 4-year data represent about one-half of the Phase I installations. Their distribution is shown in Table 11. When all the Phase I installations are considered (Table 14) a better distribution occurs.

In general, response to nitrogen in western hemlock does not appear to be good (Tables 12,13,16). As in Douglas-fir, response appears to be greatest on the lower sites, although this response is in no way comparable to that obtained for Douglas-fir. However, caution should again be employed, as the sample sizes are small. Of the 15 installations considered, only 3 responded by ten percent or more to 200 lbs nitrogen per acre, while 4 responded in a similar manner to the 400 lbs nitrogen per acre treatment.

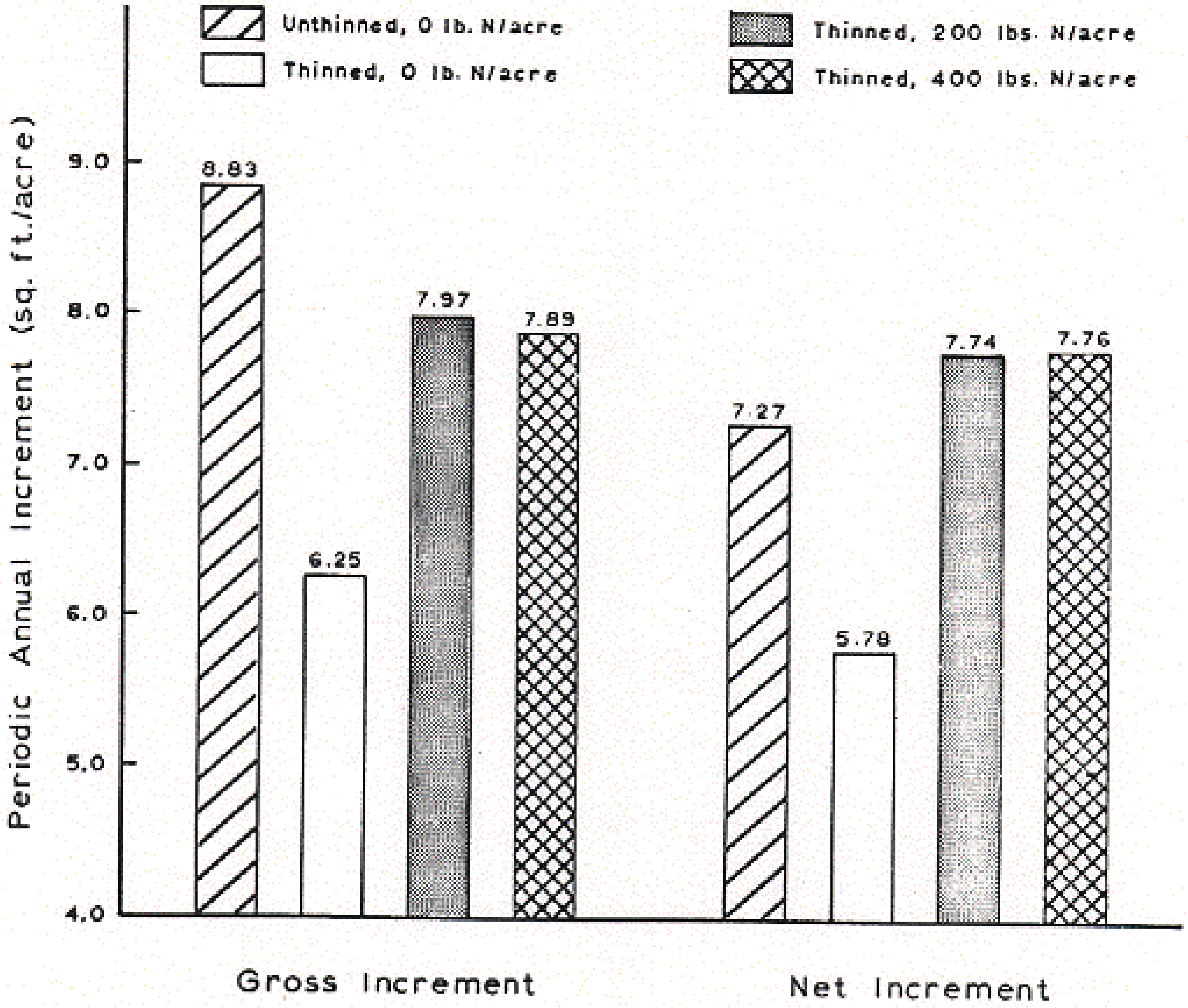
## Western hemlock unthinned, 2-year data

Table 51 incorporated 28 of the 29 western hemlock installations. One, installation 40, was partly destroyed, and has been dropped from this analysis. Response is again not pronounced, with slightly better response as site decreases.

## Douglas-fir, thinned, 2-year data

The Phase II thinning treatment for both Douglas-fir and western hemlock retained 60 percent of initial basal area stocking in well-spaced primarily dominant and codominant trees. All thinned plots were reduced to a common level of basal area. Nitrogen as urea was applied to some plots at the rates of 200 and 400 pounds per acre in late winter, following fall thinning.

FIGURE 2 Two-year gross and net basal area growth after thinning and fertilization, Douglas-fir
Source: Table 19.



The following points can be made:

1. For Douglas-fir, response data for the two growing seasons following treatment strongly suggest that, although growth is reduced by thinning, as expected, this decrease can be strongly ameliorated through fertilization (Table 19). Thus, so-called "thinning shock" can be minimized by fertilization.

2. Net growth on thinned-fertilized stands tends to approximate unthinned levels, and, since this growth takes place on desirable stems, fertilization should result in substantial merchantable volume gains.

3. Every one of the 9 Douglas-fir installations responded by 10 percent or more of the thinned control (Tables 20, 21) when fertilized with 200 pounds of nitrogen per acre.

4. The combination of thinning and fertilizing offers exciting new opportunities in Douglas-fir management. Data from the second year of Phase II (another 26 Douglas-fir installations) are anxiously awaited to substantiate these findings.

5. Figure 2 offers a graphical interpretation of the data presented in Table 19.

<u>Western hemlock, thinned, 2-year data</u>

Average results from the seven thinned western hemlock installations (Table 22) approximate those for Douglas-fir. However, one striking difference is apparent. Whereas thinned Douglas-fir stands responded in all site-age classes (Tables 20 and 21), only the three youngest hemlock installations exhibited response (Table 24). The data base is not yet large enough to warrant any definite conclusions from this observation, but once again hemlock seems to differ from Douglas-fir in its behavior following nitrogen fertilization.

## INDEX TO RESPONSE TABLES

### PHASE I: Douglas-fir

Table 2 Four-year response data for Douglas-fir, number of installations by site and age, 40 installations.

Table 2a Four-year response data for Douglas-fir, number of plots by site and breast height age, 240 plots.

Table 3 Estimated 4-year gross basal area growth response by age, site and treatment. Figures were obtained using regression analysis and are on a plot by plot rather than an installation basis, 240 plots.

Table 3a Four-year gross basal area growth response by age, site and treatment, on an installation basis.

Table 4 Proportion of installations responding by 10 percent or more in basal area, four growing seasons following fertilization. (Based on Table 3a)

Table 5 Two-year response data for Douglas-fir, number of installations by site and age, 87 installations.

Table 6 Two-year gross basal area growth response by age, site and treatment.

Table 6a Proportion of installations responding by 10 percent or more in basal area, two growing seasons following fertilization.

Table 7 Estimated 4-year gross total volume growth response by age, site and treatment. Figures were obtained using regression analysis and are on a plot by plot basis, 240 plots.

Table 7a Four-year gross total volume growth response by age, site and treatment, on an installation basis.

Table 8 Four-year gross merchantable volume growth response by age, site and treatment.

Table 9 Four-year gross merchantable gain from fertilization by age, site and treatment

Table 10 Four-year net merchantable volume growth response by age, site and treatment.

### PHASE I: Western Hemlock

Table 11 Four-year response data for western hemlock, number of installations by site and age, 15 installations.

Table 12 Four-year gross basal area growth response by age, site and treatment.

Table 13 Proportion of installations responding by 10 percent or more in basal area, four growing seasons following fertilization.

Table 14 Two-year response data for western hemlock, number of installations by site and age, 28 installations.

Table 15 Two-year gross basal area growth response by age, site and treatment.

Table 16 Four-year gross total volume growth response by age, site, and treatment.

Table 17 Four-year gross merchantable volume growth response by age, site and treatment.

Table 18 Four-year net merchantable volume growth response by age, site and treatment.

### PHASE II: Douglas-fir

Table 19 Two-year total gross and net basal area growth response to thinning and fertilization.

Table 20 Two-year total gross basal area growth response to thinning and fertilization, by site class.

Table 21 Two-year gross basal area growth response to thinning and fertilization, by age class.

### PHASE II: Western Hemlock

Table 22 Two-year total gross and net basal area growth response to thinning and fertilization.

Table 23 Two-year total gross basal area growth response to thinning and fertilization, by site class.

Table 24 Two-year total gross basal area growth response to thinning and fertilization, by age class.

## PHASE I: DOUGLAS-FIR

TABLE 2 Four-year response data for Douglas-fir, number of installations by site and age [1/]
40 installations

| AGE CLASS | 50-Year Site Class |  |  |  | Total by Age Class |
|---|---|---|---|---|---|
|  | I | II | III | IV |  |
| 15 - 30 | 1 | 6 | 0 | 0 | 7 |
| 31 - 45 | 7 | 6 | 6 | 3 | 22 |
| 46 - 60 | 0 | 7 | 2 | 2 | 11 |
| Total by Site Class | 8 | 19 | 8 | 5 | 40 |

TABLE 2a Four-year response data for Douglas-fir, number of plots by site and breast height age, 240 plots

| BH Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | I |  | II |  | III |  | IV |  |
|  |  | P.A.I.[2/] | %[3/] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 9 |  | 19 |  | 11 |  | 2 |  |
|  | 200 | 11 |  | 19 |  | 5 |  | 2 |  |
|  | 400 | 14 |  | 14 |  | 5 |  | 3 |  |
| 31-45 | 0 | 6 |  | 12 |  | 13 |  | 9 |  |
|  | 200 | 4 |  | 17 |  | 9 |  | 6 |  |
|  | 400 | 3 |  | 20 |  | 10 |  | 7 |  |
| 46-60 | 0 | 0 |  | 4 |  | 0 |  | 0 |  |
|  | 200 | 0 |  | 3 |  | 1 |  | 1 |  |
|  | 400 | 0 |  | 2 |  | 0 |  | 0 |  |

TABLE 3 Estimated Four-year gross total basal area growth response by age, site and treatment. Douglas-fir, using multiple regression on a plot by plot basis. (sq ft/acre/year)[22/]

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | I |  | II |  | III |  | IV |  |
|  |  | P.A.I.[4/] | %[5/] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 6.89 |  | 8.12 |  | 10.30 |  |  |  |
|  | 200 | 10.22 | 48 | 11.01 | 36 | 12.55 | 22 |  |  |
|  | 400 | 11.65 | 69 | 12.63 | 55 | 14.54 | 41 |  |  |
| 31-45 | 0 | 6.15 |  | 6.12 |  | 6.52 |  | 7.26 |  |
|  | 200 | 6.82 | 11 | 7.35 | 20 | 8.23 | 26 | 9.38 | 29 |
|  | 400 | 6.57 | 7 | 7.24 | 18 | 8.32 | 27 | 9.69 | 33 |
| 46-60 | 0 |  |  | 5.20 |  | 4.81 |  | 4.55 |  |
|  | 200 |  |  | 5.85 | 13 | 6.26 | 46 | 6.77 | 48 |
|  | 400 |  |  | 6.21 | 19 | 6.52 | 56 | 6.89 | 51 |

TABLE 3a Four-year gross basal area growth response by age, site and treatment, Douglas-fir. 3/ (square feet/acre/year, minimum D.B.H. - 1.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I. 4/ | % 5/ | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 7.53 | | 8.83 | | | | | |
| | 200 | 8.70 | 16 | 11.27 | 28 | | | | |
| | 400 | 8.12 | 8 | 11.72 | 33 | | | | |
| 31-45 | 0 | 5.80 | | 6.22 | | 5.19 | | 6.79 | |
| | 200 | 7.04 | 21 | 7.47 | 20 | 6.87 | 32 | 8.95 | 32 |
| | 400 | 6.58 | 13 | 8.16 | 31 | 7.13 | 37 | 9.05 | 33 |
| 46-60 | 0 | | | 5.77 | | 4.76 | | 5.40 | |
| | 200 | | | 6.44 | 12 | 5.61 | 18 | 7.20 | 33 |
| | 400 | | | 6.60 | 14 | 6.14 | 29 | 8.10 | 50 |

TABLE 4 Proportion of installations responding by ten percent or more in basal area, four growing seasons following fertilization, Douglas-fir.

| Total Age Class (Years) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | Total by Age Class |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | |
| 15 - 30 | 200 | 1/1 | 5/6 | | | 6/7 |
| | 400 | 0/1 | 5/6 | | | 5/7 |
| 31 - 45 | 200 | 5/7 | 4/6 | 6/6 | 3/3 | 18/22 |
| | 400 | 4/7 | 5/6 | 6/6 | 3/3 | 18/22 |
| 46 - 60 | 200 | | 5/7 | 1/2 | 2/2 | 8/11 |
| | 400 | | 4/7 | 2/2 | 2/2 | 8/11 |
| Total by Site Class | 200 | 6/8 | 14/19 | 7/8 | 5/5 | 32/40 |
| | 400 | 4/8 | 14/19 | 8/8 | 5/5 | 31/40 |

Key: 5/7 = $\frac{\text{number of installations responding by 10\% or more}}{\text{Total number of installations in class}}$

TABLE 5 Two-year response data for Douglas-fir, number of installations by site and age. 6/

| Age Class | 50-Year Site Class | | | | | Total by Age Class |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | |
| 15 - 30 | 2 | 14 | 3 | 0 | 1 | 20 |
| 31 - 45 | 8 | 15 | 14 | 7 | 1 | 45 |
| 46 - 60 | 1 | 9 | 8 | 3 | 1 | 22 |
| Total by Site Class | 11 | 38 | 25 | 10 | 3 | 87 |

TABLE 6 Two-year gross basal area growth response by age, site and treatment, Douglas-fir

(square feet/acre/year, minimum DBH = 1.55")

| Total Age Class (Years) | Treatment (lbs of N per acre) | 50-Year Site Index | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | | V | |
| | | P.A.I.[19] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15 - 30 | 0 | 11.05 | | 10.24 | | 9.98 | | | | 4.95 | |
| | 200 | 12.21 | 11 | 12.17 | 19 | 11.42 | 14 | | | 6.91 | 40 |
| | 400 | 11.85 | 7 | 12.28 | 20 | 12.17 | 22 | | | 5.54 | 12 |
| 31 - 45 | 0 | 5.91 | | 6.54 | | 6.20 | | 6.85 | | 9.28 | |
| | 200 | 7.44 | 26 | 7.49 | 15 | 7.92 | 28 | 9.12 | 33 | 8.68 | - 6 |
| | 400 | 6.88 | 16 | 7.92 | 21 | 8.09 | 30 | 9.26 | 35 | 9.04 | - 3 |
| 46 - 60 | 0 | 5.80 | | 5.89 | | 4.38 | | 6.16 | | 4.53 | |
| | 200 | 5.52 | - 5 | 6.47 | 10 | 5.24 | 20 | 6.78 | 10 | 6.06 | 34 |
| | 400 | 5.28 | - 9 | 6.24 | 6 | 5.47 | 25 | 8.12 | 32 | 5.01 | 11 |

TABLE 6a Proportion of installations responding by 10 percent or more in basal area, 2 growing seasons following fertilization, Douglas-fir.

| Total Age Class | Treatment (lbs of N per acre) | 50-Year Site Class | | | | | Total by Age Class |
|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | |
| 15 - 30 | 200 | 1/2 | 10/14 | 2/3 | | 1/1 | 14/20 |
| | 400 | 0/2 | 9/14 | 2/3 | | 0/1 | 11/20 |
| 31 - 45 | 200 | 6/8 | 10/15 | 13/14 | 6/7 | 0/1 | 35/45 |
| | 400 | 5/8 | 11/15 | 12/14 | 5/7 | 0/1 | 33/45 |
| 46 - 60 | 200 | 0/1 | 5/9 | 6/8 | 2/3 | 1/1 | 14/22 |
| | 400 | 0/1 | 5/9 | 7/8 | 2/3 | 1/1 | 15/22 |
| Total by Site Class | 200 | 7/11 | 25/38 | 21/25 | 8/10 | 2/3 | 63/87 |
| | 400 | 5/11 | 25/38 | 21/25 | 7/10 | 1/3 | 59/87 |

TABLE 7 Estimated Four-year gross total volume growth response by age, site and treatment, Douglas-fir using multiple regression on a plot by plot basis. (cu ft/acre/year)[22]

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 412 | | 397 | | 336 | | | |
| | 200 | 392 | - 5 | 416 | 5 | 431 | 28 | | |
| | 400 | 466 | 13 | 447 | 13 | 400 | 19 | | |
| 31-45 | 0 | 449 | | 392 | | 337 | | 281 | |
| | 200 | 461 | 3 | 447 | 14 | 435 | 29 | 420 | 49 |
| | 400 | 429 | - 4 | 447 | 14 | 432 | 28 | 383 | 36 |
| 46-60 | 0 | | | 417 | | 331 | | 252 | |
| | 200 | | | 446 | 7 | 405 | 22 | 372 | 47 |
| | 400 | | | 449 | 8 | 438 | 32 | 393 | 56 |

TABLE 7a Four-year gross total volume growth response by age, site and treatment, Douglas-fir 3/

(cubic feet total stem/acre/year, minimum D.B.H.=1.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I. 4/ | % 5/ | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 373 | | 360 | | | | | |
| | 200 | 419 | 12 | 418 | 16 | | | | |
| | 400 | 379 | 2 | 436 | 21 | | | | |
| 31-45 | 0 | 399 | | 419 | | 280 | | 300 | |
| | 200 | 442 | 11 | 476 | 14 | 387 | 38 | 433 | 44 |
| | 400 | 431 | 8 | 501 | 20 | 409 | 46 | 421 | 40 |
| 46-60 | 0 | | | 452 | | 281 | | 332 | |
| | 200 | | | 453 | 0 | 345 | 23 | 380 | 14 |
| | 400 | | | 455 | 1 | 366 | 30 | 403 | 21 |

TABLE 8 Four-year gross merchantable volume growth response by age, site and treatment, Douglas-fir 3/

(cubic feet to a 4" top/acre/year, minimum D.B.H.=6.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I. 4/ | % 5/ | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 345 | | 368 7/ | | | | | |
| | 200 | 389 | 13 | 430 7/ | 17 | | | | |
| | 400 | 364 | 6 | 448 7/ | 22 | | | | |
| 31-45 | 0 | 416 8/ | | 400 | | 241 | | 237 | |
| | 200 | 405 | - 3 | 456 | 14 | 331 | 37 | 357 | 51 |
| | 400 | 401 | - 4 | 470 | 18 | 374 | 55 | 368 | 55 |
| 46-60 | 0 | | | 411 | | 271 | | 247 | |
| | 200 | | | 412 | 0 | 330 | 22 | 341 | 38 |
| | 400 | | | 433 | 5 | 343 | 27 | 396 | 60 |

TABLE 9 Total four-year gross merchantable gain from fertilization by age, site and treatment, Douglas-fir 9/

(cubic feet to a 4" top/acre, minimum D.B.H. - 6.55")

| Total Age Class (years) | Treatment (lbs of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | Gain 10/ | % 5/ | Gain | % | Gain | % | Gain | % |
| 15 - 30 | 200 | 176 | 13 | 248 | 17 | | | | |
| | 400 | 76 | 6 | 320 | 22 | | | | |
| 31 - 45 | 200 | -44 | - 3 | 224 | 14 | 360 | 37 | 480 | 51 |
| | 400 | -60 | - 4 | 280 | 18 | 532 | 55 | 524 | 55 |
| 46 - 60 | 200 | | | 4 | 0 | 236 | 22 | 376 | 38 |
| | 400 | | | 88 | 5 | 208 | 27 | 596 | 60 |

TABLE 10 Four-year net merchantable volume growth response by age, site and treatment, Douglas-fir [3]

(cubic feet to a 4" top/acre/year, minimum D.B.H.=6.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | 350[11] | | 366[7] | | | | | |
| | 200 | 373 | 7 | 426[7] | 16 | | | | |
| | 400 | 359 | 2 | 430[7] | 17 | | | | |
| 31-45 | 0 | 391 | | 372 | | 235 | | 235 | |
| | 200 | 345 | -12 | 442 | 19 | 316 | 34 | 344 | 46 |
| | 400 | 305 | -22 | 448 | 20 | 369 | 57 | 353 | 50 |
| 46-60 | 0 | | | 367 | | 263 | | 248[11] | |
| | 200 | | | 377 | 3 | 311 | 18 | 341 | 38 |
| | 400 | | | 377 | 3 | 329 | 25 | 387 | 56 |

## PHASE I: WESTERN HEMLOCK

TABLE 11 Four-year response data for western hemlock, number of installations by site and age. [12]

| Age Class | 100-Year Site Class | | | | Total by Age Class |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| 15 - 30 | 0 | 2 | 0 | 1 | 3 |
| 31 - 45 | 2 | 8 | 0 | 0 | 10 |
| 46 - 60 | 0 | 0 | 2 | 0 | 2 |
| Total by Site Class | 2 | 10 | 2 | 1 | 15 |

TABLE 12 Four-year gross basal area growth response by age, site and treatment, western hemlock [13]

(square feet/acre/year, minimum D.B.H. = 1.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 100-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | | | 14.92 | | | | 12.20 | |
| | 200 | | | 14.73 | - 1 | | | 16.81 | 38 |
| | 400 | | | 13.92 | - 7 | | | 17.69 | 45 |
| 31-45 | 0 | 7.42 | | 6.32 | | | | | |
| | 200 | 6.91 | - 7 | 6.71 | 6 | | | | |
| | 400 | 7.11 | - 4 | 6.55 | 4 | | | | |
| 46-60 | 0 | | | | | 5.39 | | | |
| | 200 | | | | | 5.84 | 8 | | |
| | 400 | | | | | 5.50 | 2 | | |

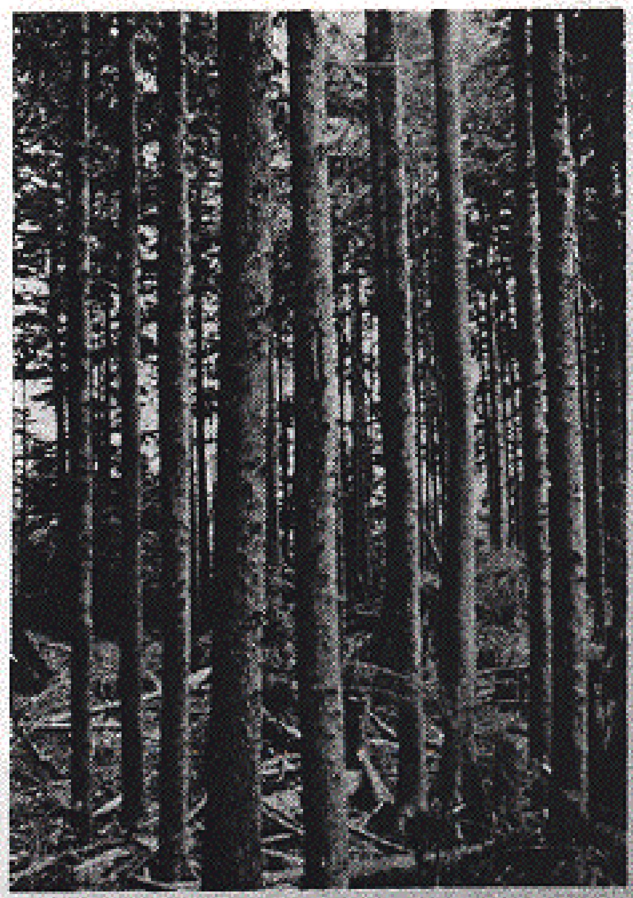


TABLE 13 Proportion of installations responding by ten percent or more in basal area, four growing seasons following fertilization, western hemlock.

| Total Age Class (Years) | Treatment (lbs of N per acre) | 100-Year Site Class | | | | Total by Age Class |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | |
| 15 - 30 | 200 | | 0/2 | | 1/1 | 1/3 |
| | 400 | | 0/2 | | 1/1 | 1/3 |
| 31 - 45 | 200 | 0/2 | 2/8 | | | 2/10 |
| | 400 | 0/2 | 2/8 | | | 2/10 |
| 46 - 60 | 200 | | | 0/2 | | 0/2 |
| | 400 | | | 1/2 | | 1/2 |
| Total by Site Class | 200 | 0/2 | 2/10 | 0/2 | 1/1 | 3/15 |
| | 400 | 0/2 | 2/10 | 1/2 | 1/1 | 4/15 |

Key: 1/2 = $\frac{\text{number of installations responding by 10\% or more}}{\text{total number of installations in class}}$

TABLE 14 Two-year response data for western hemlock, number of installations by site and age.[14]

| Age Class | 100-Year Site Class | | | | Total by Age Class |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| 15 - 30 | 0 | 4 | 3 | 2 | 9 |
| 31 - 45 | 2 | 8 | 5 | 0 | 15 |
| 46 - 60 | 0 | 2 | 2 | 0 | 4 |
| Total by Site Class | 2 | 14 | 10 | 2 | 28 |

TABLE 15 Two-year gross basal area growth response by age, site, and treatment, western hemlock[15]

(square feet/acre/year, minimum D.B.H. = 1.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 100-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[19] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | | | 17.15 | | 12.51 | | 11.42 | |
| | 200 | | | 17.23 | 0 | 13.72 | 10 | 14.04 | 23 |
| | 400 | | | 15.38[16] | -10 | 12.67 | 1 | 14.34 | 26 |
| 31-45 | 0 | 7.64 | | 6.83 | | 8.82 | | | |
| | 200 | 7.50 | - 2 | 8.11 | 19 | 8.04 | -9 | | |
| | 400 | 7.79 | 2 | 7.53 | 10 | 7.95 | -10 | | |
| 46-60 | 0 | | | 4.62 | | 6.44 | | | |
| | 200 | | | 5.91 | 28 | 7.47 | 16 | | |
| | 400 | | | 4.92 | 6 | 7.00 | 9 | | |

TABLE 16 Four-year gross total volume growth response by age, site and treatment, western hemlock[13]

(cubic feet total stem/acre/year, minimum D.B.H.=1.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 100-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | | | 388 | | | | 199 | |
| | 200 | | | 355 | - 9 | | | 370 | 86 |
| | 400 | | | 329 | -15 | | | 377 | 89 |
| 31-45 | 0 | 519 | | 447 | | | | | |
| | 200 | 458 | -12 | 476 | 6 | | | | |
| | 400 | 474 | - 9 | 443 | - 1 | | | | |
| 46-60 | 0 | | | | | 426 | | | |
| | 200 | | | | | 405 | - 5 | | |
| | 400 | | | | | 451 | 6 | | |

TABLE 17 Four-year gross merchantable volume growth response by age, site and treatment, western hemlock[13]

(cubic feet to a 4" top/acre/year, minimum D.B.H. - 6.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 100-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | | | 206 | | | | 87 | |
| | 200 | | | 323 | 57[17] | | | 169 | 94 |
| | 400 | | | 234 | 14 | | | 67 | -23 |
| 31-45 | 0 | 492 | | 422 | | | | | |
| | 200 | 441 | -10 | 434 | 3 | | | | |
| | 400 | 466 | - 5 | 432 | 2 | | | | |
| 46-60 | 0 | | | | | 400 | | | |
| | 200 | | | | | 388 | - 3 | | |
| | 400 | | | | | 439 | 10 | | |

TABLE 18 Four-year net merchantable volume growth response by age, site and treatment, western hemlock[13]

(cubic feet to a 4" top/acre/year, minimum D.B.H.=6.55")

| Total Age Class (yrs) | Treatment (lbs. of N per acre) | 100-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | |
| | | P.A.I.[4] | %[5] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| 15-30 | 0 | | | 205 | | | | 87 | |
| | 200 | | | 320 | 56[17] | | | 169 | 94 |
| | 400 | | | 234 | 14 | | | 67 | -23 |
| 31-45 | 0 | 442 | | 380 | | | | | |
| | 200 | 455[11] | 3 | 390 | 3 | | | | |
| | 400 | 439 | - 1 | 411 | 8 | | | | |
| 46-60 | 0 | | | | | 361 | | | |
| | 200 | | | | | 377 | 4 | | |
| | 400 | | | | | 426 | 18 | | |

## PHASE II: DOUGLAS-FIR

TABLE 19 Two-year total gross and net basal area growth response to thinning and fertilization, Douglas-Fir[18]

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | Gross Basal Area Increment | | | Net Basal Area Increment | | |
|---|---|---|---|---|---|---|
| | P.A.I.[19] | % Growth Increase over Unthinned Control | % Growth Increase over Thinned Control | P.A.I. | % Growth Increase over Unthinned Control | % Growth Increase over Thinned Control |
| Unthinned - 0 | 8.83 | Control | -- | 7.27 | Control | -- |
| Thinned - 0 | 6.25 | - 29 | Control | 5.78 | -20 | Control |
| Thinned - 200 | 7.97 | - 10 | 28 | 7.74 | 6 | 34 |
| Thinned - 400 | 7.89 | - 11 | 26 | 7.76 | 7 | 34 |

TABLE 20 Two-year total gross basal area growth response to thinning and fertilization, by site class, Douglas-fir[18]

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | 50-Year Site Class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I (3 installations) | | II (4 installations) | | III (1 installation) | | IV (1 installation) | |
| | P.A.I.[19] | %[20] | P.A.I. | % | P.A.I. | % | P.A.I. | % |
| Thinned - 0 | 5.08 | | 7.32 | | 4.18 | | 7.57 | |
| Thinned - 200 | 6.26 | 23<br>( 3) | 9.26 | 27<br>( 4) | 5.41 | 29<br>( 1) | 10.50 | 39<br>( 1) |
| Thinned - 400 | 6.02 | 19<br>( 2) | 9.17 | 25<br>( 3) | 5.11 | 22<br>( 1) | 11.17 | 48<br>( 1) |

TABLE 21 Two-year total gross basal area growth response to thinning and fertilization, by age class, Douglas-fir[18]

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | Total Age Class | | | | | |
|---|---|---|---|---|---|---|
| | 15 - 30 (2 installations) | | 31 - 45 (5 installations) | | 46 - 60 (2 installations) | |
| | P.A.I.[19] | %[20] | P.A.I. | % | P.A.I. | % |
| Thinned - 0 | 9.78 | | 5.69 | | 4.13 | |
| Thinned - 200 | 12.28 | 26<br>(2) | 7.14 | 25<br>(5) | 5.75 | 39<br>(2) |
| Thinned - 400 | 12.31 | 26<br>(2) | 7.05 | 24<br>(3) | 5.57 | 35<br>(2) |

## PHASE II: WESTERN HEMLOCK

TABLE 22 Two-year total gross and net basal area growth response to thinning and fertilization, western hemlock21/

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | Gross Basal Area Increment | | | Net Basal Area Increment | | |
|---|---|---|---|---|---|---|
| | P.A.I.19/ | % Growth Increase over Unthinned Control | % Growth Increase over Thinned Control | P.A.I. | % Growth Increase over Unthinned Control | % Growth Increase over Thinned Control |
| Unthinned - 0 | 10.82 | Control | -- | 9.65 | Control | -- |
| Thinned - 0 | 8.60 | -21 | Control | 8.55 | -11 | Control |
| Thinned - 200 | 10.13 | - 6 | 18 | 8.73 | 1 | 14 |
| Thinned - 400 | 10.05 | - 7 | 17 | 9.37 | - 3 | 10 |

TABLE 23 Two-year total gross basal area growth response to thinning and fertilization, by site class, western hemlock21/

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | 100-Year Site Class | | | |
|---|---|---|---|---|
| | I (2 installations) | | II (5 installations) | |
| | P.A.I. 19/ | % 20/ | P.A.I. | % |
| Thinned - 0 | 7.95 | | 8.86 | |
| Thinned - 200 | 9.75 | 23<br>(1) | 10.28 | 16<br>(2) |
| Thinned - 400 | 8.71 | 10<br>(1) | 10.58 | 19<br>(2) |

TABLE 24 Two-year total gross basal area growth response to thinning and fertilization, by age class, western hemlock21/

(square feet/acre/year, minimum D.B.H. = 1.55")

| Treatment (lbs of N per acre) | Total Age Class | | | |
|---|---|---|---|---|
| | 15 - 30 (3 installations) | | 31 - 45 (4 installations) | |
| | P.A.I. 19/ | % 20/ | P.A.I. | % |
| Thinned - 0 | 10.74 | | 6.99 | |
| Thinned - 200 | 13.99 | 30<br>( 3) | 7.23 | 3<br>(0) |
| Thinned - 400 | 14.13 | 32<br>( 3) | 6.98 | 0<br>(0) |

## FOOTNOTES TO RESPONSE TABLES

1. These 40 installations were fertilized in the winter, 1969-70, and represent approximately one-half of the RFNRP data. Missing and lightly represented age-site combinations are generally filled in when all data are available.

2. Average results from 240 Douglas-fir plots, obtained by regression analysis.

3. Average results from 40 Douglas-fir installations, data adjusted for differences in initial basal area/volume stocking. Unfilled cells are not represented by first-year Phase I installations.

4. Periodic annual increment, four growing seasons following fertilization.

5. Percent increase in growth over unfertilized control.

6. These 87 installations were fertilized at two separate times: the first 40 in the winter, 1969-70, the other 47 in the winter, 1970-71. Unfilled cells are not represented by RFNRP Phase I data.

7. Merchantable growth appears larger than total growth because Installation 46 was too young to contain merchantable volume. Table 7a reports the average of 6 installations in this cell, while Tables 8 and 10 report the averages of only five installations.

8. Merchantable growth is larger than total growth because of adjustments for initial stocking.

9. Based on Table 8.

10. Gain measures merchantable volume of fertilizer-induced wood, cubic feet/acre.

11. Net P.A.I. is larger than gross because of adjustments for initial stocking.

12. These 15 installations were fertilized in the winter, 1969-70, and represent approximately one-half of the RFNRP data. Missing and lightly represented age-site combinations are generally filled in when all data are available.

13. Average results from 15 western hemlock installations, data adjusted for differences in initial basal area/volume stocking. Unfilled cells are not represented by first-year Phase I installations.

14. Originally there were 29 Phase I western hemlock installations, but Installation 40 in northwest Oregon was partly destroyed by a storm and has been discarded for this analysis.

15. Average results from 28 western hemlock installations, data adjusted for differences in initial basal area stocking. Unfilled cells are not represented by Phase I installations.

16. Both 400 lb. plots of Installation 86 were destroyed. This figure averages the remaining three installations in this cell only.

17. Large apparent response due to ingrowth into merchantable size class.

18. Average results from 9 Douglas-fir installations (72 plots where unthinned plots are included, 54 plots where only thinned plots are considered).

19. Periodic annual increment, two growing seasons following thinning and fertilization.

20. Percent increase in growth over thinned but unfertilized control. Brackets indicate number of installations responding by 10 percent or more.

21. Average results from seven western hemlock installations (56 plots where unthinned plots are included, 42 plots where only thinned plots are considered).

22. Regression analysis on 4-year data

Four-year Douglas-fir data were subjected to stepwise multiple regression analysis on a plot by plot basis, classified by site index and breast height age. A transformation was later made to total age. Functions of the form:

$$\Delta B = f(A, S, B)$$

$$\Delta V = f(A, S, V)$$

were used to derive both gross basal area and gross volume periodic annual increment, where:

$\Delta B$ = Periodic annual gross basal area increment, sq.ft./acre/yr,
$\Delta V$ = Periodic annual gross volume increment, cu.ft./acre/yr,
$B$ = Initial gross basal area, sq.ft./acre,
$V$ = Initial gross volume, cu.ft./acre,
$A$ = Breast height age,
$S$ = 50-year site index.

Basal area and volume stocking at the time of treatment were determined using all 240 plots, irrespective of treatment. The following equations were derived:

Initial Volume

$$\log V = 2.52159 - .44755 \log A + 1.32759 \log S - 10.42404 (\log S)/A \tag{1}$$

$R^2$ = .9244, S.E. = 0.1206 cu.ft.

Initial Basal Area

$$\log B = 2.26383 - .52763 \log A + .63916 \log S - 6.83882 (\log S)/A \tag{2}$$

$R^2$ = .8475, S.E. = 0.1166 sq.ft.

where

$R^2$ = multiple correlation coefficient,
S.E.= standard error of estimate.

Base 10 logarithms were used in the above analysis.

(Footnote 22 continued)

## Volume and Basal Area Increment

Equations (3) to (8) were next derived for basal area and volume increment on a plot by plot basis, by treatment. These same equations were then used to calculate P.A.I. values for each cell. In order to calculate initial stocking conditions for each site/age class, equations (1) and (2) were used, with:

S = midpoint value of the site class, and
A = midpoint value of the age class

### Basal Area Increment

#### Control Plots

$$\Delta B = -5.36905 + 92.7379(B/A^2) + .00017(B/A)^2(S) - .97593(B/A^2)(S) + .00253(B/A^2)(S^2) + .06198(A) - .00567(B) + .05793(S) \qquad (3)$$

$R^2 = .6311$, S.E. = .91 sq.ft.

#### 200 lb N/acre

$$\Delta B = 3.56613 + 65.53466(B/A^2) - .00026(B/A)^2(S) - .6569(B/A^2)(S) + .00234(B/A^2)(S^2) - .0175(A) + .01058(B) - .00894(S) \qquad (4)$$

$R^2 = .7285$, S.E. = .93 sq.ft.

#### 400 lb N/acre

$$\Delta B = -1.94891 + 91.55275(B/A^2) - .00069(B/A)^2(S) - .85716(B/A^2)(S) + .00317(B/A^2)(S^2) + .02603(A) + .01827(B) + .00626(S) \qquad (5)$$

$R^2 = .6061$, S.E. = 1.28 sq.ft.

### Volume Increment

#### Control Plots

$$\Delta V = -27.05065 - .16784(A) + .34373(S) + .00383(V) + 36.72355(S/A) + .00016(S)(V) + 31.67529(V/A^2) - .22567(V/A^2)(S) \qquad (6)$$

$R^2 = .5139$, S.E. = 64.83

#### 200 lb N/acre

$$\Delta V = 237.89437 + 1.0624(A) - 1.7919(S) - .00417(V) + 21.91318(S/A) + .00018(S)(V) + 48.83119(V/A^2) - .25107(V/A^2)(S) \qquad (7)$$

$R^2 = .4487$, S.E. = 61.99 cu.ft.

#### 400 lb N/acre

$$\Delta V = -403.07985 + 6.71531(A) + 1.92108(S) + .03622(V) + 31.44114(S/A) - .00024(S)(V) + 67.978575(V/A^2) - .34489(V/A^2)(S) \qquad (8)$$

$R^2 = .4147$, S.E. = 61.75 cu.ft.

Yield tables for total basal area and total cubic volume have been prepared from the foregoing analysis and are available to cooperators on request.

# ANALYSIS OF TWO-YEAR DOUGLAS-FIR BASAL AREA GROWTH RESPONSE TO NITROGEN FERTILIZER[1]

Analytical models are important for determining responses to fertilizer treatment. Although empirical and semi-empirical methematical models have traditionally been used in fertilization research, they often have not provided clear interpretation of results. Purely mathematical models are generally over-simplifications of biological processes and do not necessarily provide biological soundness to the estimators.

Previous knowledge of the functional relationships between the model variables is essential. When relationships are based on logical propositions about the theory of growth, the model represents the mathematical expression of the hypotheses according to which observed data will be examined. The model is tested and modified as necessary until a satisfactory expression is found. This is the basis of a biomathematical model.

Strictly speaking, biomathematical models have not yet been applied to the analysis of forest fertilizer growth response, although several models look promising. Because at the time this study was initiated only two-year growth data were available, the approach taken was to develop a mathematically less complex model having geometric characteristics similar to established biomathematical functions.

The analysis was primarily concerned with gross basal area increment response as a function of initial age, initial basal area, site index, and fertilizer treatment. A total of 518 Phase I Douglas-fir plots were considered in this study, as summarized in the following table. The small quantity of data available for Site V made it necessary to eliminate this site class from analysis.

TABLE 25 Phase I Douglas-fir plots, classification by site and treatment.

| 50-year site class | Control | 200#N | 400#N | TOTAL |
|---|---|---|---|---|
| I | 25 | 26 | 28 | 79 |
| II | 67 | 66 | 69 | 202 |
| III | 48 | 53 | 51 | 152 |
| IV | 26 | 23 | 22 | 71 |
| V | 5 | 6 | 3 | 14 |

Before shaping the initial model, available data were plotted and carefully examined to detect abnormalities such as a large departure from the general distribution pattern. The early discovery of these abnormalities provided an opportunity to check and see if they had resulted from errors of measurement, recording or transcribing. The graphical analysis was also useful to study the shapes of the relationships between variables, and clearly showed that basal area increment over age had a well defined distribution pattern per site and treatment. This observation was substantiated in subsequent analyses. A general trend towards higher basal area growth increment for a given age class was observed as fertilizer dose was increased. This was especially noticeable between the control plots and 200 pound N plots.

## The First Model

An initial model to estimate basal area growth increment on the basis of initial basal area provided significant relationships in the middle age classes and on sites II and III only, indicating the mathematical effects of insufficient data in the extreme site and age classes. The correlation coefficients were generally small, indicating the model would have to be expanded to include other variables.

## The Second Model

Graphical analysis and previous work indicated a clear relationship between age and basal area periodic annual increment. The first model was thus expanded to introduce breast height age as a variable. This resulted in a much higher degree of correlation. Only the equations of Site Class IV remained nonsignificant.

When these equations were plotted against the field data, it became apparent that some observations were far from the normal tendency of the data. On close examination of these outliers a common pattern was found: almost all were plots containing over 20 percent of species other than Douglas-fir, especially western hemlock. Assuming that these outliers were primerily due to a different growth rate of hemlock that could distort the Douglas-fir forest type information, it was decided to eliminate from this part of the analysis all those plots in excess of 20 percent hemlock stocking. A total of 102 plots were removed and the analysis was continued with the remaining 416 Douglas-fir plots.

The multiple regression with the second model was run again using these data and over half of the equations were significantly improved in their $R^2$

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[1] This is a summary of Lorenzo Garay's doctoral thesis entitled: "Analysis of Douglas-fir Fertilizer Response in Terms of Basal Area Increment".

and standard error values. In addition, two of the three equations for Site IV were now significant at the 95 percent level.

The new set of equations was plotted against the original data, and the curves still did not reflect a common pattern. This suggested that there was still another source of variation not yet accounted for, possibly related to site index. This was introduced as a variable, expanding the model again.

### The Third Model

The regression coefficients of the second model were plotted against site class, indicating different patterns for each. Substituting the regression coefficients of the model by the equations representing their variation on site, the following expanded model was obtained:

$$\Delta B = d_0 + d_1 S + d_2 A + d_3 AS + d_4 B + d_5 B/A + d_6 (B/A)S + d_7 B/A^2 + d_8 (B/A^2)S + d_9 (B/A)S^2 + d_{10} (B/A)^2 + d_{11} (B/A)^2 S$$

where $\Delta B$ = basal area gross periodic annual increment (sq.ft./acre/year)
$S$ = 50-year site index
$A$ = Breast height age (years)
$B$ = Initial basal area (sq.ft./acre)
$d_0 - d_{11}$ = coefficients associated with regression.

This third model was applied to the data and two sets of equations were obtained: one set included an equation for each particular site class and treatment, and the other set included only one equation per treatment irrespective of the site class. When both sets of equations were plotted on the original data to see which was more representative of the field information, the former behaved erratically. The latter set of equations however did provide a uniform pattern of behavior. Statistical values for this set of equations are presented in Table 26.

TABLE 26 Statistical Values obtained for the Third Model

| Treatments | Control | | 200 | | 400 | |
|---|---|---|---|---|---|---|
| | Full | Reduced | Full | Reduced | Full | Reduced |
| $R^2$ | .73 | .71 | .71 | .70 | .70 | .69 |
| SE | 1.15 | 1.17 | 1.49 | 1.50 | 1.52 | 1.52 |

Comparing the amount of variance explained with the total variance, a substantial amount remained unexplained. There were still sources of variance not accounted for. The treatment effect is obviously one of them, but to introduce treatment as a variable in the model would be premature until the 4-year remeasurements are complete.

### Selecting a reduced form of the Third Model

A stepwise multiple regression analysis was used to determine the relative efficiency of each of the 11 variables in the third model. The variable $B/A^2$ was selected first in all the equations, which means that it was the best estimator of the eleven. The variables were also checked by reducing the model to eliminate those which made nonsignificant contributions. The best reduced form of the equation was found to be :

$$\Delta B = e_0 + e_1 A + e_2 B + e_3 (B/A^2) + e_4 (B/A^2)S + e_5 (B/A^2)S^2 + e_6 (B/A)^2 S$$

If any one of the variables composing this reduced model is eliminated, the resultant model would become significantly different from the full model in one or two treatments. This reduced model explained almost as much variation as did the full model, as indicated in Table 26. The new set of equations was plotted against the field data, indicating a uniform pattern throughout the site and treatment classes.

### Determination of basal area growth response

A set of tables was generated from the reduced model showing basal area increment/acre/year of Douglas-fir as a function of breast height age, initial basal area, and site class for the control plots, 200 lbs N and 400 lbs N. From these tables[1] or the corresponding graphs (example, Figure 3) the following trends were noted:

1) There was a consistent basal area growth response to nitrogen fertilizer application. Increment was increased 15 percent to 25 percent by 200 pounds of N/acre.

2) The growth response tended to be greater towards the lower sites, lower ages and lower initial basal areas.

3) There was no well-defined difference between the response obtained from 200 lb of nitrogen and 400 lb of nitrogen per acre. Sometimes the response lines crossed each other and the 400 lb treatment appeared to produce a smaller response than the 200 lb treatment. It is probable that the slope of treatment response lines is not sufficiently defined by the 2-year increment data.

4) Doubling the amount of nitrogen produced only a slight increase in growth response. But the response to 400 pounds of nitrogen was more uniform over the entire range of age classes than was response to the 200 pound treatment.

5) The most distinct pattern of response was located in the middle age classes and middle site classes where most of the field data were concentrated.

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[1] The tables are available on request; they are based only on 2-year data.

No matter how appropriate the regression model or how well the fitted curves represent a given set of field data, individual plot observations will be scattered, sometimes differing substantially from the estimates represented by the curves. Both high and low departures from the estimates can be important and very useful to the analysis of growth response. Detection of anomalous growth data can lead to a better understanding of the variability of growth response.

All plots determined to be abnormally high or low responders (more or less than 2 sq.ft. of basal area/acre/year) were individually analyzed to determine the factors that could explain a common pattern of behavior, or the specific reasons that could produce such extreme growth values. In the analysis the following tendencies became apparent:

1) The anomalous high responders tended to be associated with high basal area increment/acre/year.

2) Age appeared to have no great influence on the occurrence of anomalous high and low responders.

3) Within treatments, site class appeared to have no influence on the occurrence of extreme values.

4) Treatments appeared to influence the number but not the magnitude of extreme responders. As the amount of nitrogen fertilizer increased, a slight tendency favoring the high responders was observed.

5) For a given age, low initial basal area associated with large basal area increment, produced a high responder more frequently than the converse.

6) Low responders were normally associated with low basal area increment, regardless of initial basal area and site.

7) In general, extreme values were commonly found in lower rather than high site classes.

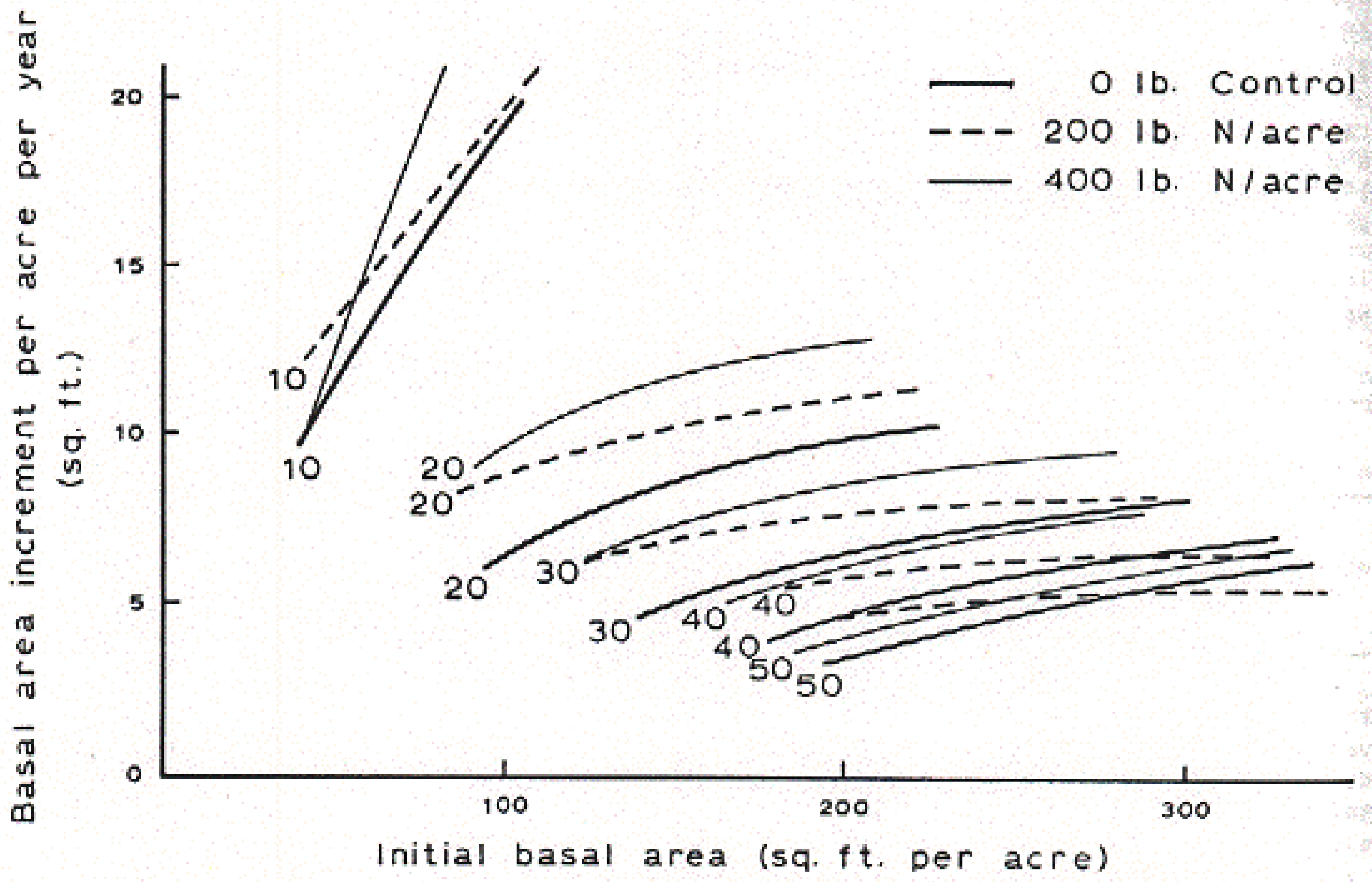
This analysis is considered only as preliminary. In fact, the identity of plots exhibiting high or low response could change when the analysis of four year increment is conducted.

## Conclusion

As stated before, it would be premature to provide firm estimates of basal area increment response based on 2 years of growth data. The purposes of this work were to demonstrate the existence of fertilizer responses and to determine their characteristics. When longer term data become available, the procedure and models now established will be tested and used in the analysis. It is anticipated that the basal area increment figures for 4-year and subsequent remeasurements will provide more consistent and more reliable estimates of response.

The clues provided by mensurational analysis help to orient the investigations and to define areas of needed backup research. Further field investigations are indicated to more completely understand and determine the site and tree characteristics that are producing growth results. A preliminary analysis of some of these factors is presented in the following section.

FIGURE 3 Two-year basal area average annual growth by treatment, age class and initial stocking, Douglas-fir, 50-year site class III



# INVESTIGATIONS OF SOIL, CLIMATE AND PHYSIOGRAPHY

The soils field work under RFNRP was initiated in the summer of 1971. Generally intended to supplement and provide deeper understanding to the statistical growth data, this program was specifically designed to:

1. Classify, characterize and describe the soils at each installation of plots
2. Provide chemical and physical analyses of these soils:
   a. To assist in identifying causes of growth response extremes
   b. To investigate the potential of soils data for predicting forest productivity and growth response to fertilizer application.

Meetings of the Technical Advisory Committee from 1970 to 1972 considered soils and foliar sampling and analysis procedures. It was decided that at each installation a soil pit would be dug in a typical situation and that samples would be taken from each horizon. Composite samples would be made of the surface soils, and forest-floor litter samples would also be taken. A subsampling scheme for foliage was worked out in 1973.

By the end of Summer 1973, soils field work on all 160 Phase I and Phase II installations had been completed. Some difficulty was experienced in classifying soils at certain installations into soil series, but it is expected that these difficulties will be overcome with the aid of chemical analyses.

Regarding the laboratory work, the analyses of major soil horizons will be completed by the end of the current year, 1974. At the time of this report, total nitrogen throughout the profile has been determined for all installations, as has organic matter, pH and bulk density. The cations potassium, calcium, magnesium and sodium have been determined for approximately half the installations as well as cation exchange capacity and base saturation. Some laboratory textural analyses have been carried out to check the field determinations, and analyses for phosphorus will be commenced shortly.

The following work is planned for the future:

1) Field -- The only field work remaining is to classify soils at certain installations into soil series. When growth response data over a 4-year period are available, these data will be grouped by soil series to determine the value of soil series or major characteristics of closely related series in predicting response.

2) Laboratory analyses -- These will be completed for the major horizons at all installations by the end of 1974. This information will be helpful for a wide range of purposes but primarily as an explanation of extremes of low and high response and for regression equations predicting productivity and response.

3) As 4-year growth response data become available, further statistical analyses will be carried out using stand, soil, climatic and physiographic characteristics in an effort to develop predictive tools of use to field foresters.

## Factors Affecting Growth

The investigation of the relationships between soil, other environmental factors, productivity and response was initiated Fall 1973.[1] Although this preliminary work was limited by the availability of only 2-year data and a small number of completed laboratory analyses, it nonetheless achieved a number of significant and potentially useful conclusions. Analytical procedures were established so that refinement will be facilitated in the future as better data are available. A summary of this study report follows.

The primary objective of the study was to examine growth data for the first two years of the Phase I (unthinned) Douglas-fir installations in relation to the soil, climatic and physiographic variables which had been measured in the course of the soils field work.

The study included 86 installations covering the range of latitude from southern Oregon to northern Washington. Each installation included six unthinned plots treated as follows: 2 unfertilized controls, 2 with 200 lbs of nitrogen per acre and 2 with 400 lbs of nitrogen per acre (as urea).

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[1] Cromer, Robin N. "Early Response of Unthinned Douglas-fir to Urea in Western Washington and Oregon," May, 1974. Unpublished report to RFNRP.

Heights, diameters and age were measured initially but only diameters were measured at the end of two years. Basal area increment was therefore the main dependent variable studied.

Soil profile descriptions were available for one pit at each installation and total nitrogen had been determined for each horizon. Elevation, slope, aspect and landform had been recorded during the soils field work and average annual precipitation was determined from state maps.

Analysis of the data was divided into three categories:

a) Estimation of site index based on soil, climatic and physiographic variables using multiple regression. This was done to help determine which environmental variables were most important.

b) Estimation of overall response in basal area increment using analysis of covariance.

c) Estimation of basal area increment for treated and untreated stands using regression equations in order to determine "response" for a given set of stand and environmental parameters.

### a) Estimation of Site Index

Using the single plot closest to the soil pit at each location, the following equation was derived based on soil, climatic and physiographic variables:

$$SI = 100.6 - 1.99E^2 + 0.00107ED^2 + 0.137P$$

where

$SI$ = 50-year site index
$E$ = Elevation (feet ÷ 1000)
$ED$ = Effective depth of soil (cm)
$P$ = Average annual precipitation (in)

The equation explained 43 percent of the variation in site index ($R^2 = 0.43$) and had a standard error of 14.8 feet, which is not of good predictive value but does provide an indication of which variables (other than stand parameters) are important in site index. More accurate and refined expressions of the soil variables are becoming available and it is anticipated that ultimately it will be possible to obtain an equation with considerably better predictive value. Stratification of the data, e.g., into major parent material groups, should assist in this task.

### b) Estimation of Overall Response

Analysis of covariance indicated that the effect of fertilizer treatment on gross basal area increment was statistically significant at the 1 percent level. The effects of initial basal area, site index and number of stems per acre on gross basal area increment were significant when used as covariates in the analysis.

Mean basal area increment for all Phase I Douglas-fir installations is shown in Table 27 for the two year period following fertilization. Since there was no significant difference found between the 200 lb and 400 lb treatments, these groups were combined.

TABLE 27 Mean Basal Area Increment (sq.ft./acre/year) for 86 Douglas-fir Phase I installations; 2 growing seasons following treatment. [1]

| | Treatment | | Difference | Gain |
|---|---|---|---|---|
| | Control | Fertilized (200# & 400#) | | |
| | | (sqft/acre/year) | | (percent) |
| Gross Increment | 6.87 | 8.33 | 1.46 | +21 |
| Net Increment | 5.44 | 6.42 | 0.98 | +18 |
| Mortality | 1.43 | 1.91 | 0.48 | +34 |

[1] Figures are unadjusted, since adjustment by covariance made little difference to mean values.

### c) Estimation of Basal Area Growth

Both stand and environmental parameters were used in this analysis. Stand variables were consistently more highly correlated with gross basal area increment than were environmental variables, on both control and treated plots. However several of the environmental variables did improve the equations slightly.

Separate equations were obtained for control and both treated groups, using all available variables. The southern Oregon plots (Province VII) were omitted as they appear to form a different population, and will be analyzed at a later date.

The following equations were obtained for the different treatments using all available variables. In all cases $B/A^2$ was the most powerful explanatory variable.

For the 149 untreated plots:

$$\Delta B = 3.48 + 11.9B/A^2 + 0.114E^2$$

This explained 71 percent of the variation ($R^2$=0.71) and had a standard error of 1.36 sq.ft.

For the 149 plots treated with 200 lb N/acre:

$$\Delta B = 3.61 + 11.5B/A^2 + 0.002ST$$

This explained 74 percent of the variation ($R^2$=0.74) and had a standard error of 1.49 sq.ft.

For the 150 plots treated with 400 lb N/acre:

$$\Delta B = 4.2 + 10.7B/A^2 + 0.0016ST$$

This explained 65 percent of the variation ($R^2$=0.65) and had a standard error of 1.84 sq.ft. Variables used in these equations are:

$\Delta B$ = Basal area gross periodic annual increment (sq.ft./acre/year)
$B$ = Initial basal area (sq.ft./acre)
$A$ = Breast height age (years)
$E$ = Elevation (feet ÷ 1000)
$ST$ = Number of stems/acre

In order to test for significant differences between treatments, it was necessary to decide upon one model for both treated and untreated groups. The two treated groups were first tested, and as no significant difference was found between them, they were combined into one group. However, a significant difference was found between the controls and the combined treated plots.

It was decided to use a model including the variables $B/A^2$, $E^2$ and ST.

The following equations were obtained:

For the 149 control plots:

$$\Delta B = 3.34 + 11.35B/A^2 + 0.095E^2 + 0.0004ST$$

This equation explained 71 percent of the variation ($R^2 = 0.71$).

For the 299 treated plots:

$$\Delta B = 3.83 + 11.03B/A^2 + 0.126E^2 + 0.0016ST$$

This equation explained 70 percent of the variation ($R^2 = 0.70$).

Elevation was found to be the single most important environmental variable and surprisingly had a positive relationship to gross basal area increment with these data. Soil depth and soil nitrogen content did not appear to be correlated with basal area increment, whereas these variables were correlated with site index.

Several of these relationships are shown in Table 28.

TABLE 28 Effect of several variables on site index and basal area increment

| Variable | Site Index | Basal Area |
|---|---|---|
| Elevation | - | + |
| Precipitation | + | + |
| Soil texture | + | + |
| Soil depth | + | 0 |
| Soil nitrogen | + | 0 |
| Basal area | 0 | - |
| # Stems | 0 | + |

0 = little or no correlation

+ = positive relationship

- = negative relationship

Effects of other environmental variables may have been masked because of variability within installations and the fact that only one soil pit per installation was available.

In both of the above equations, approximately 70 percent of the variation is explained by stand parameters and elevation and it would seem reasonable to assume that soil, climatic and physiographic characteristics may explain a large part of the remaining 30 percent. As data on volume increment over a longer period of time become available, together with the chemical analyses of the soils, it should be possible to produce equations for reliably predicting response in terms of cubic feet per acre based on both stand and soil characteristics.

This study has served a useful purpose in charting a course which can be followed and refined with minimum effort in the future. Preliminary work on foliar analysis was also initiated but because of the small sample size it was decided to leave discussion of these results until a later date when further results become available.

## DEVELOPMENT OF PROCEDURES FOR HANDLING VARIATION IN RESPONSE DATA

A frustrating experience in assessing response to fertilization and thinning is the occasional variation in performance between research plots located in close proximity to each other. Why, for example, may a control plot appear to outgrow an adjacent fertilized plot, even though both were chosen to represent a well-stocked stand of the same age and site?

Even though plots in natural stands may look alike, they seldom are. Important differences are frequently observed when stand data are examined in detail. Observation of Phase I data for Douglas-fir points toward the following explanations for differences in growth between "uniform" research plots:

1. differences in total stocking
2. differences in the tree size distribution
3. differences in the competitive status of trees
4. differences in species composition
5. differences in micro-site and/or soil
6. presence of physical damage, disease (especially root disease) and insects

This paper is concerned with only the first three of these problem areas. Methods for handling the others are also under development.

Differences in total stocking

Higher stocking means higher growth, at least up to very high densities in young natural stands of Douglas-fir. Analysis of covariance is a statistical procedure for handling the effect of differences in initial stocking on post-treatment growth. In essence, this technique removes the effect of stocking on growth and projects growth for all plots in an installation to a level based on the same average stocking. Results of a covariance adjustment for stocking on Installation 29[1] are demonstrated in Table 29. Growth is reduced on the heavier-stocked plots and increased on the lighter plots. As a result, what appeared to be a negative response to 200 pounds of nitrogen per acre is turned into a positive response. Adjustment of growth for initial stocking using analysis of covariance was carried out for all RFNRP growth data presented in this Report.

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[1] Installation 29 is a 33 year-old, site 136 Douglas-fir stand located in the Oregon Cascades east of Lebanon.

TABLE 29 Covariance adjustment of growth to allow for differences in initial volume stocking, Installation 29 1/

(cubic feet total stem/acre, minimum D.B.H.=1.55")

| Treatment (lbs of N per acre) | Initial Volume 2/ | Unadjusted Data | | Adjusted Data | |
|---|---|---|---|---|---|
| | | P.A.I. 3/ | Volume Response 4/ | P.A.I. | Volume Response |
| 0 | 9,128 | 426 | | 403 | |
| 200 | 8,151 | 400 | -26 | 431 | 28 |
| 400 | 8,856 | 446 | 20 | 438 | 35 |

1. Douglas-fir, 33 years old at time of fertilization, 50-year site 136.
2. Mean of two plots for each treatment, cubic feet/acre.
3. Periodic annual increment, 4 growing seasons following fertilization, mean of two plots for each treatment, cubic feet/acre/year.
4. Increase or decrease in 4-year P.A.I., cubic feet/acre/year.

## Differences in tree size distribution

In an even-aged stand, larger trees exhibit the highest growth. Figure 4, which was developed from control plot data for Installation 29, is typical of this relationship. Obviously, a weighting toward the larger tree sizes can affect growth of the stand. Figure 5 exhibits hypothetical but realistic data for two 0.10 acre plots of exactly the same cubic foot volume stocking.[2] Plot A contains a relatively large number of small trees while plot B contains fewer trees but more large trees. If all trees grow at the average 4-year growth rates for their D.B.H. class, as determined from Figure 4, then plot A would be expected to grow at a P.A.I. of 351 cubic feet/acre and plot B at a P.A.I. of 389 cubic feet/acre (Table 30). Hence growth in a plot depends not only on the total level of stocking, but also on the distribution of stocking among the various tree sizes. Plots established in natural stands rarely exhibit uniform tree size distributions, thus distorting evaluation of response to fertilization. High growth recorded on fertilized plots may be partly attributable to the presence of a few large trees. In a similar manner, lack of fertilizer response may possibly be traced to a high growth rate on control plots that is related to stand structure.

One approach to handling the problem of differences in stand structure is to increase the number of experimental replications. Then, differences between plots tend to be spread evenly between treatments, and comparisons are valid. The RFNRP data are extensive enough to allow broad interpretations of results to be made with good reliability. However, accuracy of response predictions can be

FIGURE 5 Number of trees by D.B.H. class, two hypothetical plots of equal cubic volume stocking.

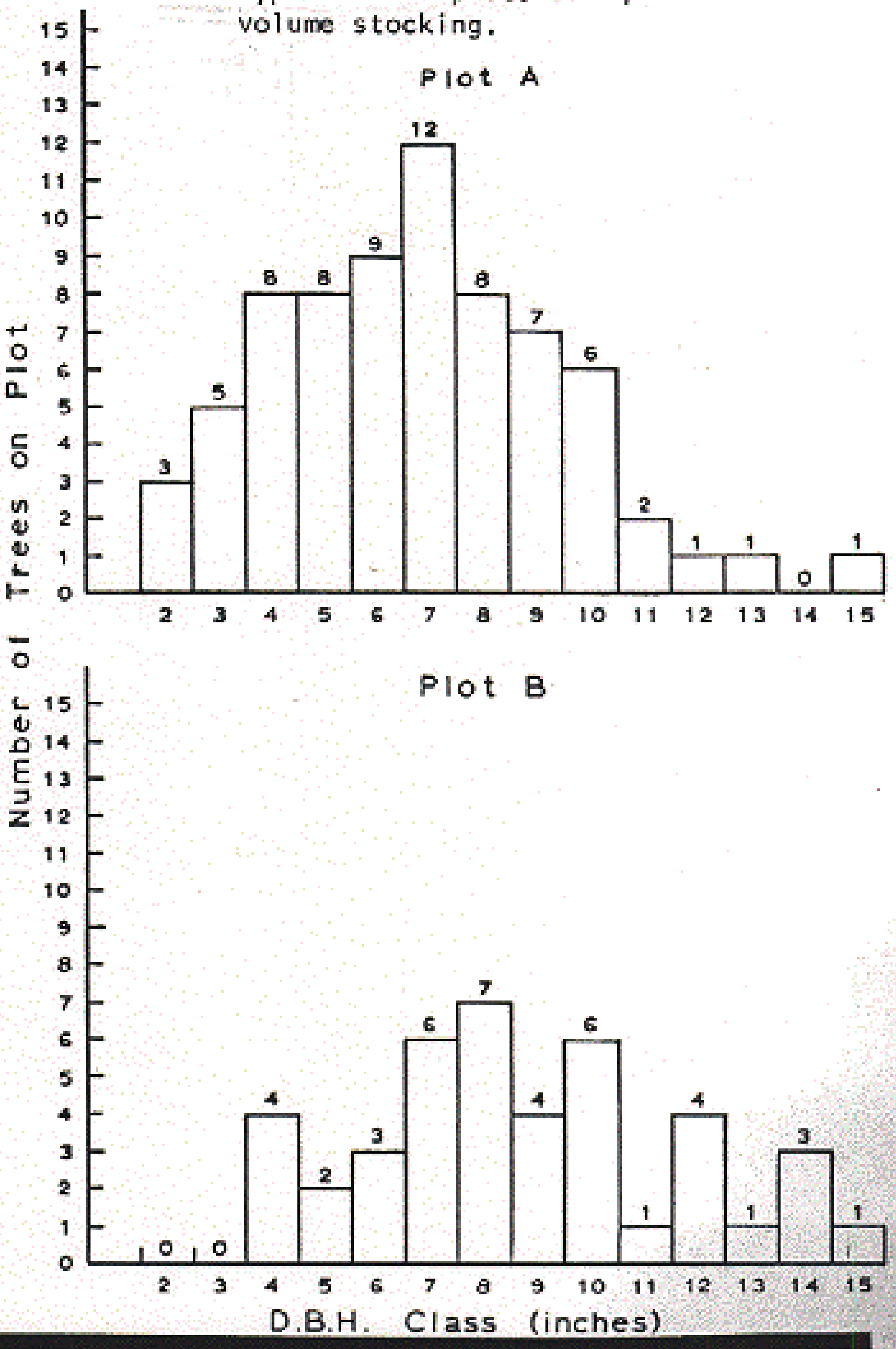
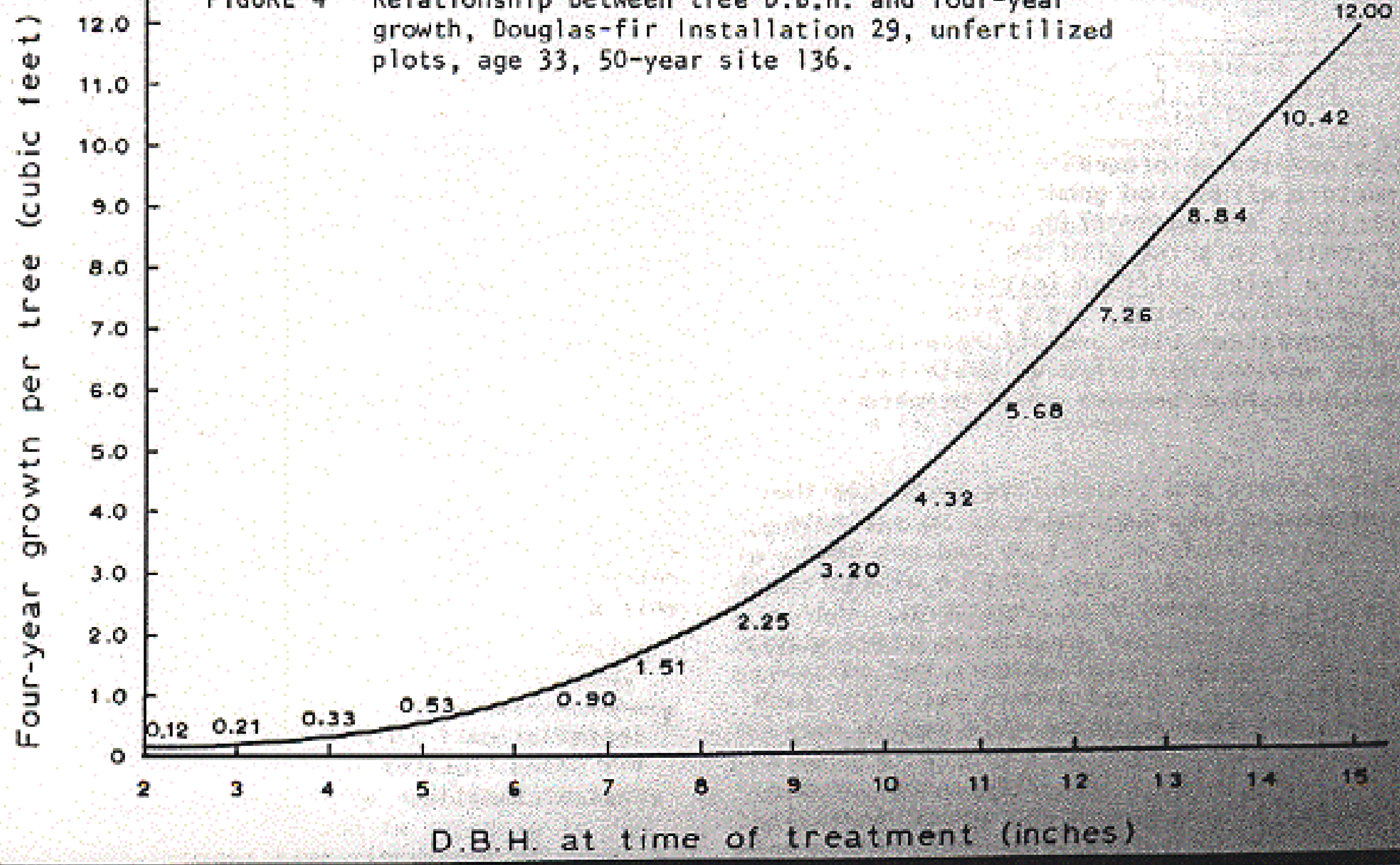


FIGURE 4 Relationship between tree D.B.H. and four-year growth, Douglas-fir Installation 29, unfertilized plots, age 33, 50-year site 136.



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[2] Volume on both of these plots is 673 cubic feet (tarif 35).

TABLE 30 Projected periodic annual increment for two hypothetical 0.1 acre plots of equal cubic volume stocking.

| D.B.H. Class When Treated (inches) | Average four-year growth per tree 1/ (cubic feet) | Plot A 2/ | | Plot B 2/ | |
|---|---|---|---|---|---|
| | | Number of trees on plot 3/ | Projected four-year growth in class (cubic feet) | Number of trees on plot 3/ | Projected four-year growth in class (cubic ft) |
| 2 | 0.12 | 3 | 0.4 | 0 | 0 |
| 3 | 0.21 | 5 | 1.1 | 0 | 0 |
| 4 | 0.33 | 8 | 2.6 | 4 | 1.3 |
| 5 | 0.53 | 8 | 4.2 | 2 | 1.1 |
| 6 | 0.90 | 9 | 8.1 | 3 | 2.7 |
| 7 | 1.51 | 12 | 18.1 | 6 | 9.1 |
| 8 | 2.25 | 8 | 18.0 | 7 | 15.8 |
| 9 | 3.20 | 7 | 22.4 | 4 | 12.8 |
| 10 | 4.32 | 6 | 25.9 | 6 | 25.9 |
| 11 | 5.68 | 2 | 11.4 | 1 | 5.7 |
| 12 | 7.26 | 1 | 7.3 | 4 | 29.0 |
| 13 | 8.84 | 1 | 8.8 | 1 | 8.8 |
| 14 | 10.42 | 0 | 0 | 3 | 31.3 |
| 15 | 12.00 | 1 | 12.0 | 1 | 12.0 |
| Total Projected Four-year Growth | | | 140.3 | | 155.5 |
| Projected P.A.I. 4/ (cu.ft./acre) | | | 351 | | 389 |

1. From Figure 4 (unfertilized plots)
2. Initial stocking of both plots = 673 cubic feet (tarif 35)
3. From Figure 5.
4. Projected P.A.I./acre = $\frac{\text{(4-year projected plot growth)(10)}}{4}$

improved by developing procedures for examining stand structure effects on growth. Several analytical techniques are under study and offer possibilities of coming to grips with the problem. These procedures are being utilized initially to examine so-called "anomalous data", i.e., plot growth data that are inconsistent with overall results. Eventually these methods may prove valuable in studying general relationships between stand structure and growth.

One straightforward and inexpensive technique that is being attempted experimentally is to estimate growth of treated plots as if they had not been treated, and then isolate that portion of increased growth that is attributable to treatment. This approach, which is referred to here as stand structure analysis, uses an installation's two control plots to define unfertilized growth rates for each D.B.H. class, and then projects this growth rate to each treated plot, based on that plot's actual tree D.B.H. distribution. The difference between projected unfertilized growth and actual fertilized growth becomes the measure of response. An example of this procedure applied to Installation 29, an anomalous low responder, is presented in Table 31. In this instance stand structure analysis indicates more response than covariance adjustment for initial stocking (Table 32) and brings this installation into a more consistent situation with regard to the overall response data. Stand structure analysis as applied to an anomolous high responder, Installation 1[3], is summarized in Table 33. In this example response estimates are decreased, again removing this installation from the anomalous category. In the cases studied so far stand structure analysis increased response estimates for very low responders and decreased response estimates for very high responders. As an aid to removing anomalous data this approach looks promising.

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[3] Installation 1 is a 43-year-old, site 113 Douglas-fir stand located in the Washington Cascades, east of Seattle.

TABLE 31 Stand structure analysis for Installation 29, 400 pounds of nitrogen per acre, two 0.1 acre plots.

| D.B.H. Class When Treated (Inches) | Average four-year growth per tree [1] (cu.ft.) | Plot #172 [4] | | Plot #174 [4] | |
|---|---|---|---|---|---|
| | | Number of Surviving Trees on Plot | Projected four-year growth in class (cu.ft.) | Number of Surviving Trees on Plot | Projected four-year growth in class (cu.ft.) |
| 2 | 0.12 | 0 | 0 | 0 | 0 |
| 3 | 0.21 | 0 | 0 | 0 | 0 |
| 4 | 0.33 | 1 | 0.3 | 2 | 0.7 |
| 5 | 0.53 | 4 | 2.1 | 9 | 4.8 |
| 6 | 0.90 | 10 | 9.0 | 17 | 15.3 |
| 7 | 1.51 | 12 | 18.1 | 14 | 21.1 |
| 8 | 2.25 | 2 | 4.5 | 7 | 15.8 |
| 9 | 3.20 | 6 | 19.2 | 8 | 25.6 |
| 10 | 4.32 | 2 | 8.6 | 2 | 8.6 |
| 11 | 5.68 | 3 | 17.0 | 1 | 5.7 |
| 12 | 7.26 | 4 | 29.0 | 1 | 7.3 |
| 13 | 8.84 | 2 | 17.7 | 0 | 0 |
| 14 | 10.42 | 1 | 10.4 | 0 | 0 |
| 15 | 12.00 | 0 | 0 | 0 | 0 |
| Total Projected Growth on Unfertilized Plot (cu.ft.) | | | 135.9 | | 104.9 |
| Total Actual Growth on Fertilized Plot [2] (cu.ft.) | | | 172.2 | | 149.8 |
| Four-year Fertilizer Response on Plot (cu.ft.) | | | 36.3 | | 44.9 |
| Increase in P.A.I.[3] (cu.ft./acre) | | | 90.8 | | 112.2 |

1. From Figure 4. Based on the installation's two unfertilized plots.
2. Growth of surviving trees only.
3. Increase in P.A.I./acre = $\frac{\text{(Four-year plot response)(10)}}{4}$
4. Treated with 400 pounds of nitrogen per acre, 0.1 acre plots.

TABLE 32 Fertilizer response estimated by two methods of analysis, Installation 29

| Treatment (lbs of N per acre) | Volume Response to Treatment - Increase in P.A.I.[1] (cu.ft./acre/year) | | |
|---|---|---|---|
| | Raw Data[2] | Data Adjusted for Differences in Initial Volume Using Analysis of Covariance[2] | Stand Structure Analysis[3] |
| 200 | -26 | 28 | 51 |
| 400 | 20 | 35 | 101 |

1. Mean of two plots for each treatment, 4 growing seasons following treatment.
2. From Table 29.
3. 400 lbs N/acre treatment is mean of two plots, Table 31. 200 lbs N/acre treatment analyzed in a similar manner.

TABLE 33 Fertilizer response estimated by two methods of analysis, Installation 1[1]

| Treatment (lbs of N per acre) | Volume Response to Treatment - Increase in P.A.I.[2] (cu.ft./acre/year) | | |
|---|---|---|---|
| | Raw Data | Data Adjusted for Differences in Initial Volume Using Analysis of Covariance | Stand Structure Analysis |
| 200 | 93 | 103 | 73 |
| 400 | 111 | 119 | 94 |

1. Douglas-fir, age 43 when treated, 50-year site 113.
2. Mean of two plots for each treatment, 4 growing seasons following treatment.

### Differences in the competitive status of trees

It is important to develop analytical techniques that not only consider sources of variation in research data, but also provide reasonable consistency in results. Stand structure analysis needs more development, and among the improvements under study is inclusion of a tree's possition in the stand and competitive situation (as well as its size) in growth projection. The hypothesis here is that a portion of the variation in response is due to differences in competitive situations of (especially the larger) trees on the plots. A simple approach which utilizes data already available is to project growth from control plots to treated plots based on crown class as well as D.B.H. As more accurate measurements of competition, such as competitive stress index, become available they too can be included in the analysis.

The foregoing is presented to stimulate interest in new methods of analyzing data, especially when "conventional" techniques do not seem to give satisfactory results. Stand structure analysis is but one of several promising new ideas being studied under RFNRP.

## HOW MUCH CAN YOU AFFORD TO SPEND ON FOREST FERTILIZATION? AN ECONOMIC MODEL

The RFNRP will publish in 1975, upon completion of the 4-year Phase I response analysis, a set of economic guidelines for fertilization based on numerous combinations of age, site, treatment[1] and species. As a preview, and in order to assist cooperators in making immediate fertilization decisions, the following analysis has been prepared. Note that this study is limited to well-stocked stands of Douglas-fir, ages 31-45 in site III, and ages 31-60 in site IV. The response estimate of 300 cubic feet per acre is conservative (see Table 10) and will be updated next year when more complete data are available. In addition to site and stand parameters, assignment of stand priority for fertilization should consider other factors affecting timber value, particularly accessibility and slope. Length of investment period is also important. Generally, the most profitable investment opportunities are those in which gain from fertilization is captured quickly.

### The Model

Do not fertilize unless

$$\left[\begin{array}{c}\text{Cost of}\\ \text{Fertilization}\end{array}\right] < \left[\begin{array}{c}\text{Discounted}\\ \text{Value of}\\ \text{Gain from}\\ \text{Fertilization}\end{array}\right]$$

where:

$$\left[\begin{array}{c}\text{Discounted}\\ \text{Value of}\\ \text{Gain from}\\ \text{Fertilization}\\ (\$/\text{acre})\end{array}\right] = \frac{\left[\begin{array}{c}\text{Merchantable}\\ \text{Volume of}\\ \text{Fertilizer-}\\ \text{induced wood}\\ (\text{cu.ft./acre})\end{array}\right]\left[\begin{array}{c}\text{Stumpage}\\ \text{Value}\\ (\$/\text{cu.ft.})\end{array}\right]}{(1 + i)^n}$$

i = interest rate used for discounting
n = years until gain from fertilizer is recovered

### Response Assumptions

1. Fertilizer will be applied to well-stocked stands, predominantly Douglas-fir, ages 31-45, site III; and ages 31-60, site IV.
2. Treatment = 200 pounds of nitrogen per acre (435 pounds of urea)
3. Merchantable gain from fertilization = 300 cubic feet/acre, accruing in the five years following treatment.

### Use of the Discounted Value Graphs

1. Decide on the stumpage price assumption (high, medium or low) that best fits your situation. Turn to the proper graph. Stumpage prices should reflect after-tax values.
2. Determine the appropriate interest rate to use for discounting returns.
3. Estimate the investment period, i.e., the number of years until the fertilizer investment is recovered. Generally this will be the period of time until the stand is scheduled for harvest cutting or commercial thinning.
4. On the vertical axis read discounted value of gain attributable to fertilization.
5. Compare expected after tax fertilization cost per acre with discounted value of gain per acre. If the latter exceeds the former, fertilization is economically justified.

### Example

1. Medium stumpage price assumption (use Figure 7).
2. 6% interest rate used for discounting.
3. Thirty-five year-old site III Douglas-fir stand scheduled for harvest at age 60 (hence investment period is 25 years).
4. Discounted gain from fertilization = $93 per acre (from Figure 2).

Conclusions: Fertilization is economically justified in this stand at costs per acre less than $93.

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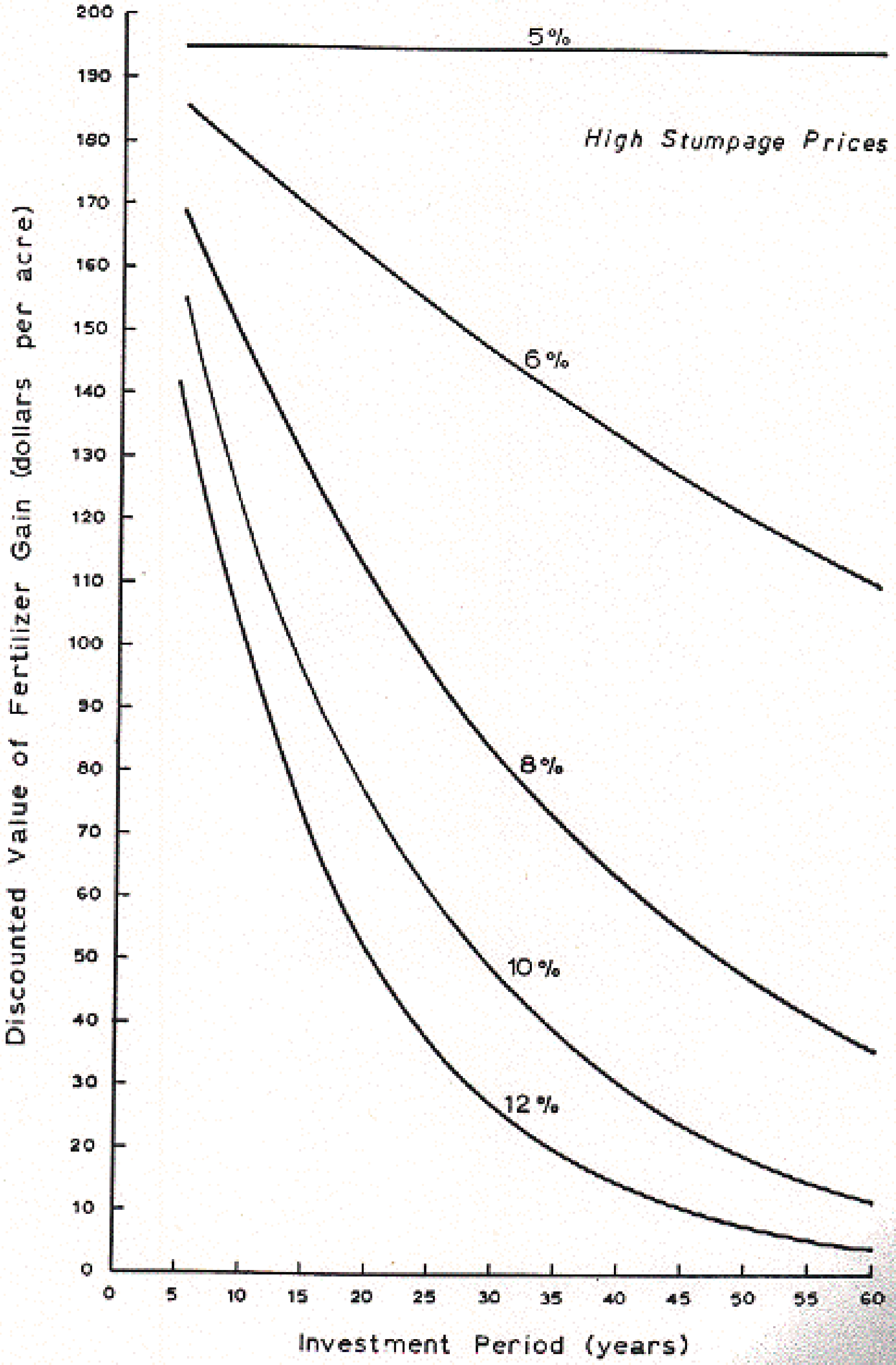
[1] Thinned and fertilized stands will also be included in the analysis.

## Solution of the Model for Three Price Assumptions

Case #1, High Stumpage Prices:

1. current stumpage value = \$0.65/cubic foot[2]
2. long term annual rate of stumpage value increase = 5%

FIGURE 6 Effect of investment period and interest rate on discounted value of gain from fertilizer (high stumpage price assumption).



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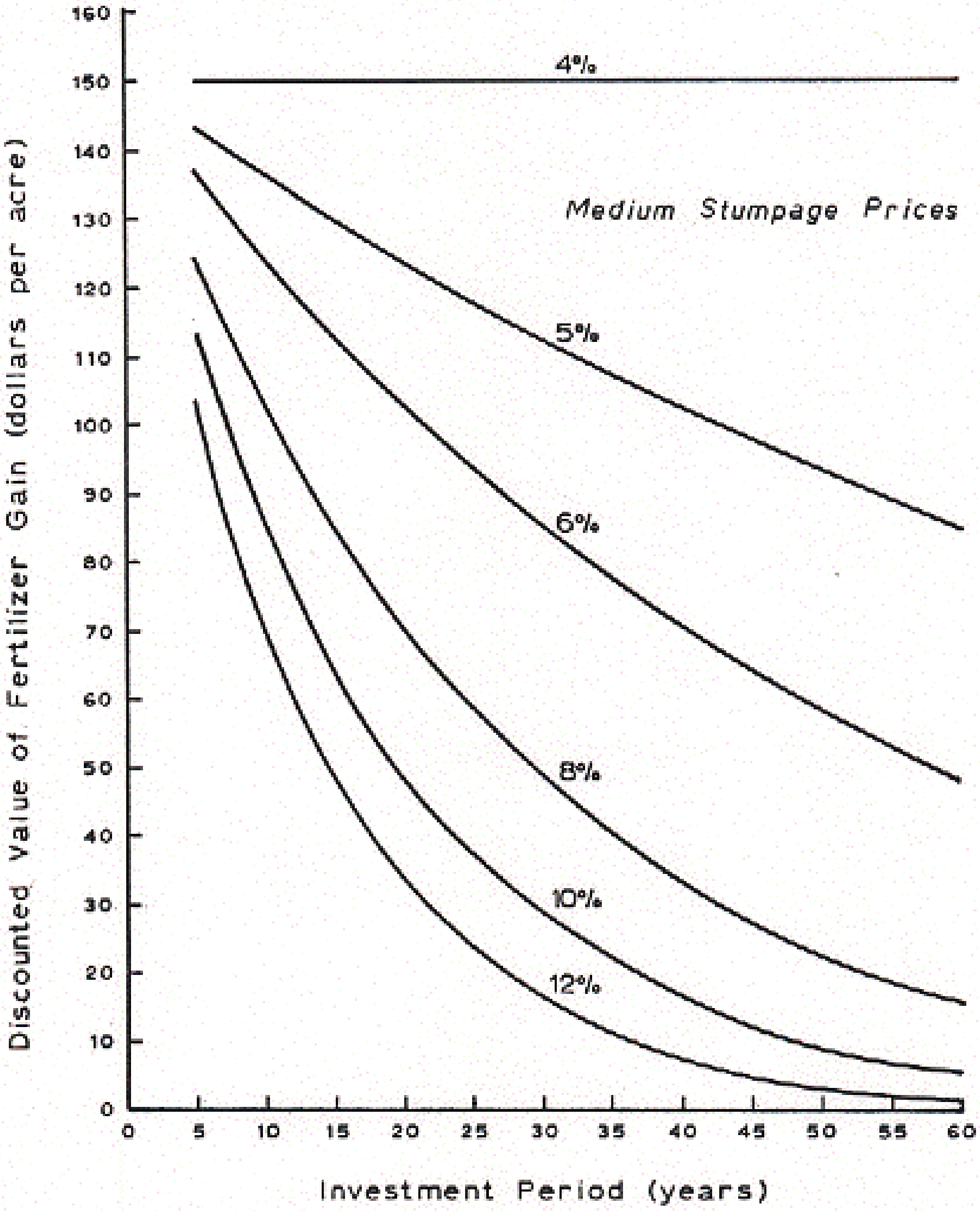
[2] \$0.65 per cubic foot is equivalent to approximately \$110 per thousand board feet.

Case #2, Medium Stumpage Prices

1. current stumpage value = $0.50/cubic foot[3]
2. long term annual rate of stumpage value increase = 4%

FIGURE 7 Effect of investment period and interest rate on discounted value of gain from fertilizer (Medium stumpage price assumption).



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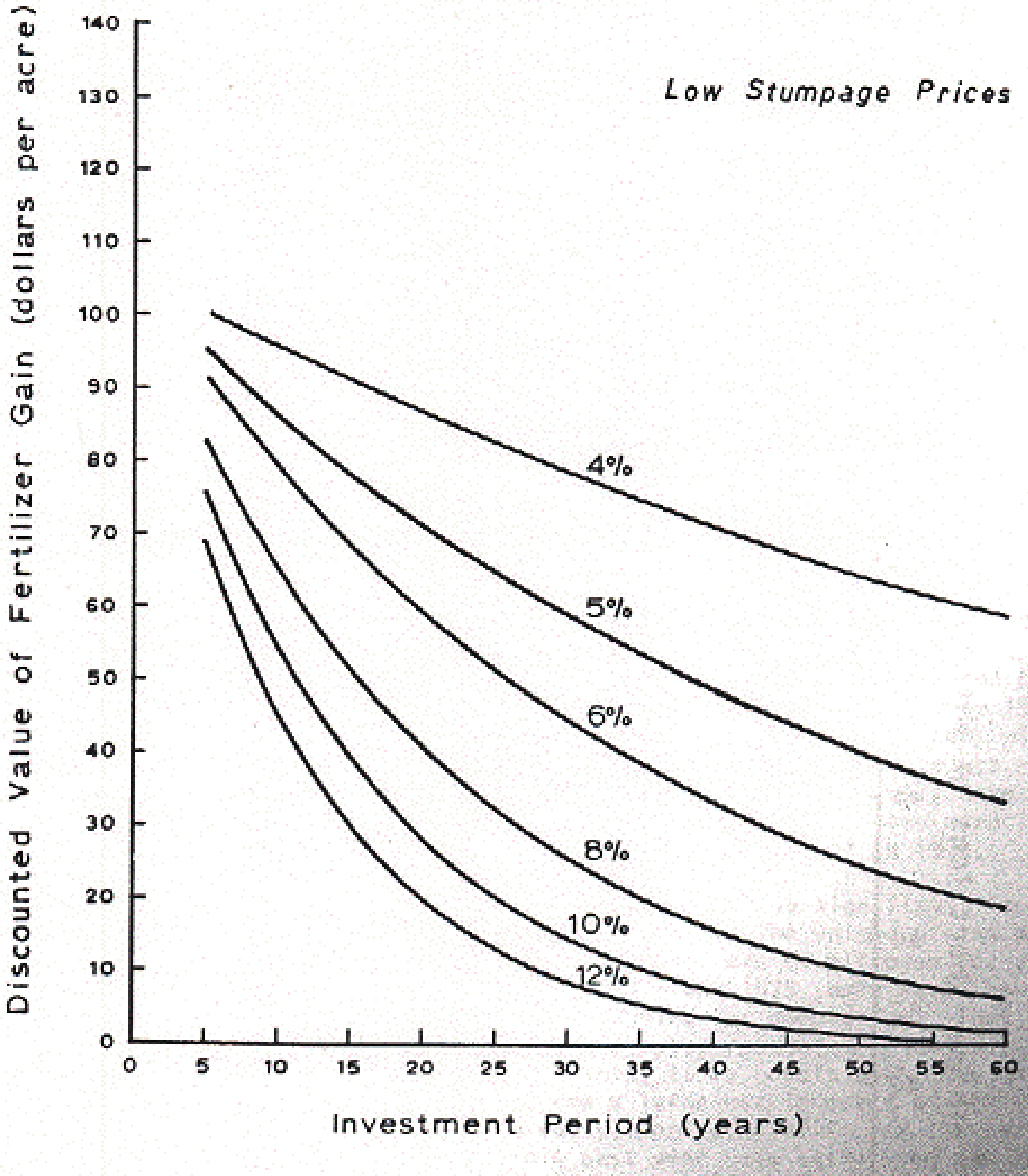
[3] $0.50 per cubic foot is equivalent to approximately $85 per thousand board feet.

Case #3, Low Stumpage prices:

1. current stumpage value = \$0.35/cubic foot[4]
2. long term annual rate of stumpage increase = 3%

FIGURE 8 Effect of investment period and interest rate on discounted value of gain from fertilizer (Low stumpage price assumption).



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[4] \$0.35 per cubic foot is equivalent to approximately \$60 per thousand board feet.

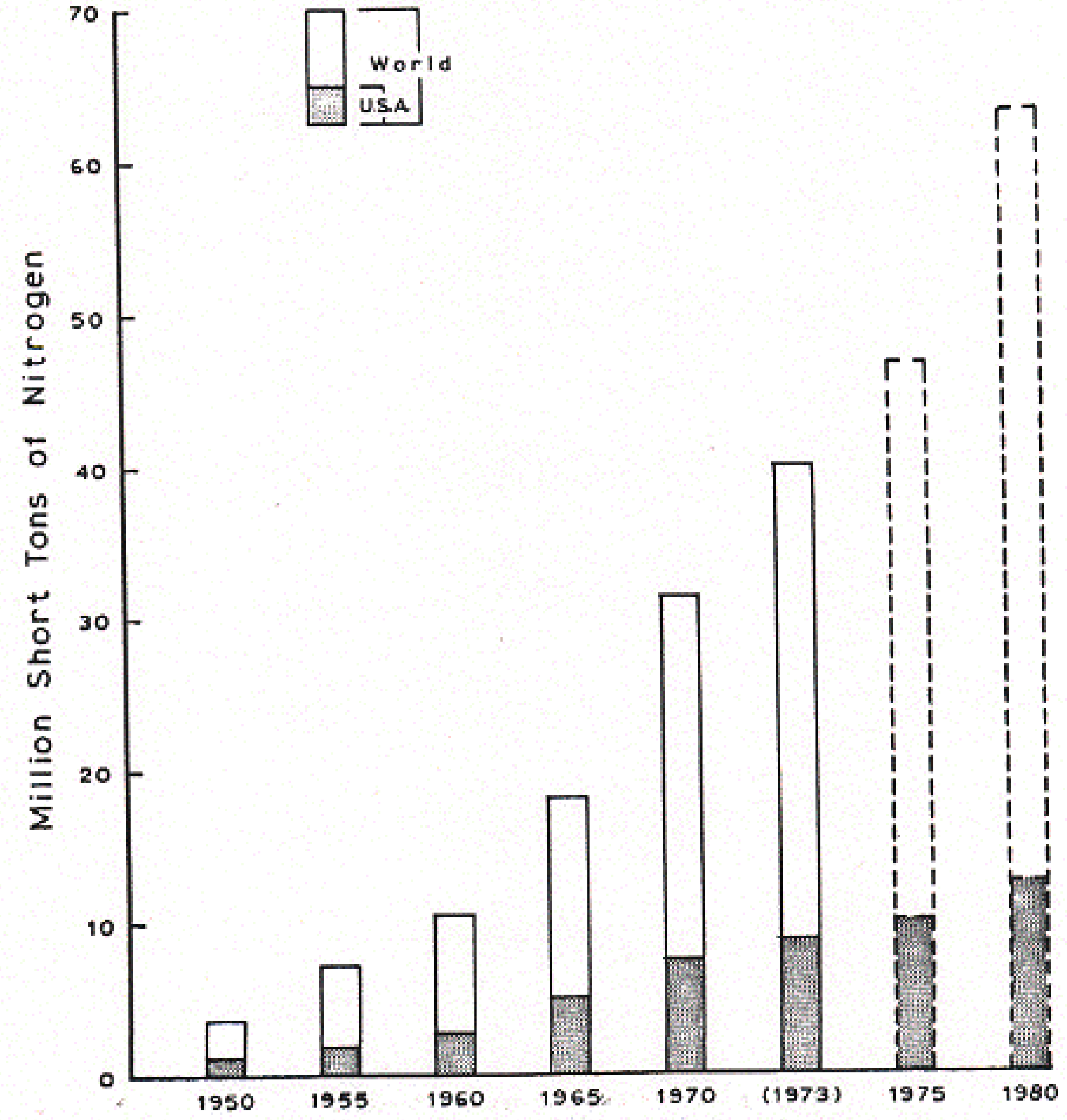
# FORECAST FOR NITROGEN FERTILIZER SUPPLY

Pacific Northwest forest land managers are primarily interested in forest fertilization as an economically attractive means of increasing timber supply. Preliminary response results presented in this Biennial Report indicate good potential for increasing production, but whether or not this is an economically sound proposition depends in part on the cost of fertilizer materials. With the cost of urea having in some instances almost tripled since the lifting of U.S. domestic price controls in October 1973, forest managers must assess their situations carefully. What is the long-range supply outlook? Can forestry compete with agriculture in an increasingly hungry world? Are both forestry and agriculture predicating their futures on materials whose production cannot be sustained, perhaps at any price?

These are complex questions. In order to provide insight into their answers it is necessary to understand how the current market situation evolved. Adjustments within the Pacific Northwest regional market may in the long run stabilize supply in this area, but cost will in large part be dependent upon overall world market conditions. This paper deals primarily with the general trends of nitrogen fertilizer supply in the international market, and some of the factors which influence it.

Figure 9 indicates that both world and United States consumption of nitrogen have more than tripled in the 13 years since 1960. The rate of increase on a worldwide basis surpassed that for the United States, as the "green revolution" promised large crop yields to a vast segment of the world's population in areas where the use of fertilizers literally means the difference between life and death.

FIGURE 9



The world fertilizer market was relatively stable during the early to mid-1960's. Crop failures in various parts of the world produced large food exports from countries such as the United States. Fertilization, particularly with nitrogen, was an obvious way to maximize yields. On a much smaller scale forest fertilization was proving to be a useful silvicultural technique and was beginning to be conducted operationally in many areas. Coincident with increased fertilizer demand were technological advances in the manufacture and application of nitrogen fertilizers, and hence it is small wonder that large amounts of capital were invested in what appeared to be an opportunity for sustained profits.

Many new fertilizer plants were built in the United States and foreign countries, their opening coinciding with a period of worldwide economic recession in the late 1960's. The result was an oversupply of nitrogenous fertilizers and the beginning of a 5-year period of overcapacity, excess production, minimal growth in demand, large inventories, tight competition, low profits, and a subsequent chain reaction of plant closure and lack of new investment. The bad situation in the U.S. fertilizer industry was made worse with the advent of domestic price controls in the summer of 1971. Prices of farm commodities, themselves increasingly dependent on fertilizer, were not frozen. Farmers were demanding more and more fertilizer materials, at prices frozen at the depressed levels of the late 1960's. This rather bleak picture made it more attractive for producers to export fertilizer than to sell on the U.S. market, and a large upturn in exports did indeed occur. Little domestic nitrogen capacity was added during this period.

When price controls were lifted in October 1973, domestic and world demand were at an alltime high. Millions of acres of U.S. farmland, long off the roles, had returned to production, in part because of the agreement to export large quantities of wheat to the Soviet Union. Prices of farm commodities were putting farmers in the black for the first time in decades. American fermers planted 9 percent more corn and 44 percent more wheat in 1973-74 than in the 1972-73 crop year. But the nitrogen fertilizer industry had been so severely stifled that it was now faced with shortages everywhere. The result was inevitable: high demand, small supply -- the price soared. If that was not dismal enough, shortages of feedstock for ammonia production, such as natural gas, naphtha, and other petroleum derivatives, in addition to tight pollution standards, reduced levels of operation at many plants during the 1973-74 period. And industrial demand for ammonia and its derivatives was also strong, e.g., in the explosives, nylon, and acrylic industries.

That, briefly, is how the present situation occurred. What is in store for the future? Will the supply-demand situation come into balance, and at what price to the consumer? Will the industry resume an expansion program? Will it benefit from the lessons of the last decade? Only time will answer these questions, but a number of encouraging facts are known.

Plant nutrient forecasts for 1980 by the Agency for International Development predict a continuation of the current strong fertilizer demand. Nitrogen consumption is expected to approach 63 million short tons, a sixfold increase since 1960. Over three quarters of this total demand for nitrogen will be in the developed nations, particularly the U.S.S.R., Eastern Europe, North America, and Western Europe, although many developing nations are expected to increase use at a rate approaching 10 percent.

Some of the important agricultural factors which affect this total demand picture for nitrogen are:

1. The expanding worldwide demand for meat:
Beef producers increasingly rely on grain crops for feed, fertilization of pastures, and use of urea as a direct diet supplement to cattle.

2. The wheat situation: Unprecedented demand has caused a sharp upswing in production from wheat-producing areas, and concomitantly an increase in demand for nitrogen fertilizers. The use of high-yield hybrid strains is now being tested on a large scale, and wheat may eventually follow the lead of hybrid corn as a huge consumer of fertilizer nitrogen. Wheat strains in general have been shown to be highly different in their efficiencies of nitrogen metabolism, and in the future hybrids will probably be used that produce the most protein with the least fertilizer application.

3. The extent to which soybeans are used as feed for domestic cattle and to humans directly: Since soybeans fix nitrogen from the atmosphere, they do not require as large quantities of nitrogen fertilizer as many crops do.

The developing nations are in many cases planning their own ammonia-production facilities, particularly on the Pacific rim and in the Mideast where natural gas reserves are plentiful. In 1972, approximately 83 percent of the nitrogen capacity was in the world's developed regions; by 1980, it is anticipated that less than 75 percent will be. The traditional world nitrogen traders -- North America, Western Europe, and Japan will have less than 50 percent of the world nitrogen capacity by 1980, compared with 60 percent in 1972.

This shift will have significant impacts on future trade patterns. The United States and Canada have been net exporters of nitrogen for a number of years, but in 1974 and 1975, only seven new ammonia plants are scheduled for completion. That is not enough to meet projected increases in demand. Without additional plants, it is possible that North America could become a large net importer of nitrogen. However, greatly improved profits for the fertilizer industry this past year have stimulated new investment. There has been a number of announcements of new ammonia production facilities, and it appears that if a major portion of these were to be completed by 1980, the U.S. would at least be able to supply its estimated internal consumption of 12.5 million tons of nitrogen fertilizers.

Of particular significance to the Pacific Northwest is the fact that Canada is among the world's leading producers of fertilizer materials. Its recent production of nitrogen has been around 1 million tons annually, but its large natural gas reserves together with improved market conditions have provided an impetus for the consideration of at least four major new plants. By 1980, Canadian nitrogen capacity could be over 5 million tons, and a large portion of this would be exported. Since most of the U.S. production of nitrogen occurs in the southeastern part of the country, transportational costs have long resulted in a competitive advantage for Canadian fertilizer imports into portions of the northern United States, and as long as trade between the two countries remains relatively unrestricted, this trend is likely to continue.

It is impossible to predict at this point exactly what future supply in North America is likely to be. Some experts predict, for instance, that by 1980, the United States will have a surplus of 5 million tons of fertilizer nitrogen annually; others advise that the United Stated will become a net importer of nitrogen in the near future and remain so. The industry is understandably moving cautiously, anxious to avoid the pitfalls which overcapacity created for it during the 1960's.

Although expansion plans have been announced, many are in the earliest stages of formulation. The cost of new plants has jumped tremendously since the mid-1960's, as has the cost of money to construct them. Notable changes in market conditions can occur before 1980, as the traumatic events of the past year too clearly emphasize. If the bottom were to fall out of the wheat market, for instance, it would profoundly affect the prospects of the nitrogen fertilizer market. On the other hand, to the extent that new uses such as forest fertilization can be developed, the market will tend to be stabilized.

While the long term supply outlook is generally encouraging, predictions are generally in agreement that shortages will continue during the 1974-77 period, and may even become more severe unless major difficulties can be corrected. Besides the need for expansion of production, serious shortfalls exist in attaining maximum capacity of existing plants, due to such factors as obsolescence of machinery, spare part shortages, feedstock limitations, and scarcity of rolling stock to transport materials. Failure to operate efficiently is particularly severe in the developing countries, where the previously mentioned problems are further aggravated by lack of trained manpower, power outages, lack of preventive maintenance, and protective government policies. It is obvious that much could be done to improve current supply-demand stability if the impact of these problems was lessened.

Nitrogen fertilizers are now at alltime price highs on the international market. Worldwide nitrogen prices apparently have not yet peaked. The lagtime necessary to significantly increase production means that it may be 3 to 4 years before appreciable price decreases take place. It is certain that prices never again will achieve the low levels of the 1969-71 period, when many nitrogen products actually sold for less than the cost of their production. This general picture is confounded by rampant worldwide inflation rates, further weakening any cost predictions that could be made at this time.

A key factor in the future market for nitrogen fertilizer is the availability and cost of feedstock used in its manufacture. While a variety of hydrocarbon fuels can be transformed into hydrogen for ammonia production, natural gas is by far the most widely used. In spite of some predictions that the cost of natural gas will triple in the next decade, it is likely to remain the favored feed until at least the mid-1980's. This is because the cost of alternate fuels is also increasing, and plant construction costs raise markedly as feedstock complexity is increased.

In the United States, only about 2 to 3 percent of total natural gas output is used annually in the production of ammonia. Each ton of ammonia (86 percent nitrogen) requires over 38,000 cubic feet of gas in a modern plant, approximately 22,000 cubic feet as feedstock and 16,000 cubic feet as fuel. Costs involved with transporting large amounts of natural gas usually mean that the ammonia plant is located at the gas field. Hence, in the United States production is centered in such southern states as Texas, Oklahoma, and Louisiana. This is also in part due to government regulations affecting transportion, pricing, and exploration for gas. Many argue that current regulatory policies have hurt the natural gas industry, and that free pricing of natural gas is required to adequately resume an expansion program. It is likely that cutbacks in gas supply will be greater during 1974-75 than they were this past winter. Because of the essential nature of the fertilizer industry in agriculture, it must have priority for feedstock if production schedules are to be met. Interruptible, reduced and uncertain supplies do not allow plants to operate efficiently.

Urea has been the most favored form of nitrogenous fertilizer used in forests of the Pacific Northwest. Generally containing 46 percent nitrogen, the production of a ton of urea requires 0.6 ton of ammonia and 0.8 ton of carbon dioxide. Because large quantities of $CO_2$ are generated by the combination of gas and air in the production of ammonia, urea plants are normally situated adjacent to ammonia plants.

Because of production advantages, desirable handling characteristics and high analysis, urea is rapidly becoming the world's leading nitrogen fertilizer. By 1980, it is expected that urea will account for 40 percent of the world's nitrogen capacity.

## Nitrogen Supply in the Pacific Northwest

Approximately 220,000 acres of forest land were fertilized in western Washington and western Oregon in 1973, requiring some 16,500 tons of nitrogen. It has been estimated that ultimately three to ten times this acreage will be fertilized each year. Most locally produced nitrogen is used in agriculture and general industry, such as the production of glues for plywood and particle board from urea. Consequently, the supply situation for 1974 is quite limited, especially with respect to urea. It will remain so for at least several more years. The present availability of ammonium nitrate appears to be better in the local market, and this material could be considered for some fertilization programs.

In the long run, the urea supply in the Pacific Northwest should receive considerable relief with the announced doubling in capacity of a large plant in Kenai, Alaska and the influx of fertilizers from new plants in southern Alberta. Because of the presence of major ports, the region might also receive materials from Mexico, Venezuela, and the Soviet Union where large plants are also being constructed. The economics of shipping large quantities of fertilizer materials from such remote places is questionable, however, and will of course depend on prevailing market prices. Minimally these are expected to be in the range of $150 to $200 per ton for urea.

## CONCLUSIONS

In the short run, emphasis must be placed on assuring adequate feedstock for existing fertilizer manufacturing plants. Efficiencies must be improved in all aspects of fertilizer maufacturing and transportation. The industry should not be discouraged from making new investment by misguided domestic "relief" measures such as a fertilizer export embargo.

Confidence in the future and availability of feedstock reserves are the most important factors in the long term supply outlook. Many of the problems discussed in this report will be short term cyclical ones if government and industry planning can adequately balance the myriad circumstances currently affecting these supply-demand relationships.

Prices of nitrogenous fertilizers for use in forestry will depend on the strength of the farm market and of other industricl users. The source of materials will also play a key role in cost; dependence on imported supplies (other than perhaps Canada) would substantially increase prices.

In light of this overall situation, forest land managers in the Pacific Northwest should carefully select areas for fertilization that are likely to produce maximum response. Cooperators in the RFNRP will be assisted in these determinations by Project staff.

## REFERENCES

*Fertilizer Trends 1973* - Bulletin y-77, National Fertilizer Development Center, Tennessee Valley Authority (June 1974).

*World Fertilizer Market Review and Outlook* - National Fertilizer Development Center, Tennessee Valley Authority (March 1974).

*World Nitrogen Fertilizer Market Outlook* - Circular 2-50, Tennessee Valley Authority (August 1974).

*Soaring Farm Demand Spurs New Ammonia Buildup*, Chemical Week, (July 17, 1974).

*World Nitrogen Fertilizer Market Outlook*, Tennessee Valley Authority Circular 2-50, (August 1974).

*World Appetite for Fertilizer Hits New High*, Chemical Week, (September 4, 1974).

## BUDGET SUMMARY

Since the initiation of RFNRP in April 1969, a total of $473,352.43 was expended up to the end of year 05: June 30, 1974. The account and category breakdown is:

| | Phase I | Phase II | Total |
|---|---|---|---|
| Salaries and Wages | $241,937.95 | $34,194.53 | $276,132.48 |
| Employee Benefits | 19,227.67 | 2,515.35 | 21,743.02 |
| Indirect Costs | 43,044.35 | 5,657.01 | 48,701.36 |
| Supplies and Equipment | 33,078.07 | 8,268.08 | 41,346.15 |
| Travel | 49,575.27 | 35,854.15 | 85,429.42 |
| TOTAL | $386,863.31 | $86,489.12 | $473,352.43 |

Approximately 25 percent of these amounts has supported basic research projects which were supplemental to the field trials.

The cost of many items has increased since 1969 far faster than the originally-calculated 5 percent per year. This is particularly true of travel-related items such as lodging and vehicle expenses. However, significant savings have also occurred. Largely due to direct assistance by Project cooperators in supplying fertilizer materials, thinning, and in assisting the remeasurement crew, manpower has been kept to a minimum. The policy has been to enlarge the 2-man permanent field crew only as required by periods of heavy work load. Also, the initiation of RFNRP coincided with the beginning of a period of tremendous expansion in the facilities and programs of the College of Forest Resources. The Project has hence been both contributor to and beneficiary of the consequent synergistic interchange.

In the 5-year period ending June 30, 1974, a total of $541,052 had been invested by the cooperators in the Project. Of this amount $425,138 was for Phase I and $115,914 for Phase II. The residual together with new funds for 1974-75 will be earmarked primarily for data analysis and research studies related to major problem areas.

# FUTURE OF THE RFNRP

The large investment and resulting long term value of the research plots established under this Project warrant continuing effort beyond the 4-year remeasurement schedule for Phases I and II. Discussions with the Technical Advisory Committee and the Cooperators' Liaison Committee led to the development of a Proposal for Five-Year Extension of Research, distributed in Spring 1975. The extension period would be from July 1, 1975 (the termination of Phase I) to June 30, 1980. Major emphases of research include:

1. Continued monitoring and retreatment of Phase I and Phase II installations in order to:
   a. Study duration of response
   b. Study effect of retreatment

2. Additional installations treated with rates of urea nitrogen other than 200 lb and 400 lb, in order to determine optimum treatment level.

3. Additional installations on low sites in order to augment the data base and improve regression relationships.

4. Extension of work to stands less than 20 years total age in order to:
   a. Study effects of fertilization, thinning, and interactions between fertilization and thinning.
   b. Study the timing of fertilization in relation to thinning.
   c. Study techniques for maximizing height growth of new plantations using fertilizer, thinning and herbicides.

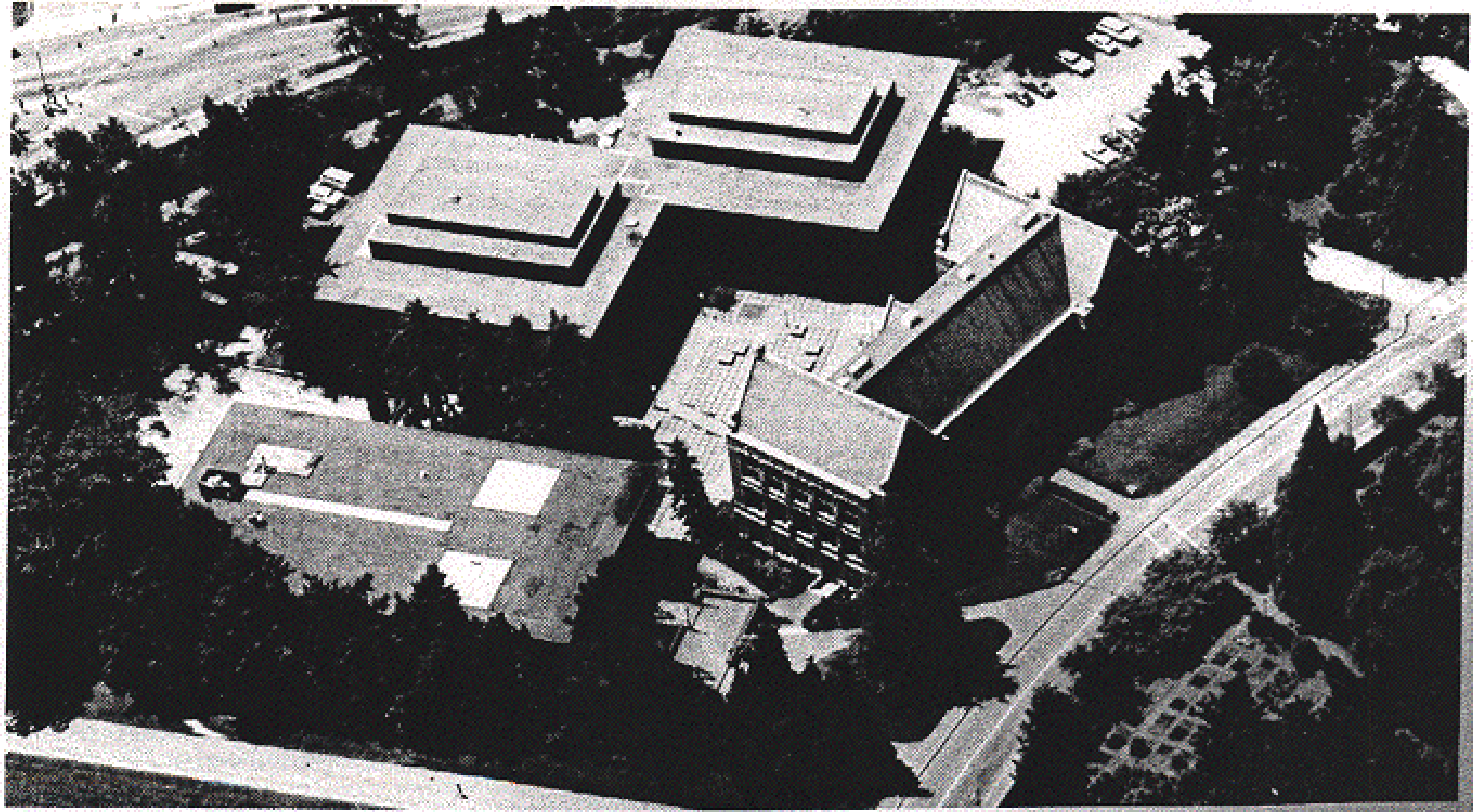
5. Establishment of additional plots in stands of western hemlock in order to:
   a. Study response to forms of nitrogen fertilizer other than urea.
   b. Study response when fertilizer is applied in seasons other than winter.

6. Basic research in tree nutrition, soil fertilizer chemistry, mensuration and economics.

The RFNRP has concentrated during the past 5 years on building and maintaining a system for monitoring response to treatment. The job now is to derive as much information as possible from the experiments. The complexity of the natural systems involved continually opens new avenues of investigation, requiring new approaches to the analysis.

It is hoped that in addition to the present cooperators additional support will be forthcoming for the proposed extension. Besides assuring adequate funding and potential installation sites, this will broaden the base of involvement by organizations, scientists and management foresters, all who share a mutual interest in the overall objectives of this cooperative research.

Copies of the extension proposal are available from Project Supervisor William Atkinson.



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