REGIONAL FOREST NUTRITION

RESEARCH PROJECT

BIENNIAL REPORT
1976-1978

COLLEGE OF FOREST RESOURCES
UNIVERSITY OF WASHINGTON

August 1979

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1976-1978

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FOREWORD

This report will reach you near the end of the tenth year of the Regional Forest Nutrition Research Project. In that time the complexity of forest management has increased, and inflation has impacted operating costs, wood values, and forest land values. The crucial national need for more raw materials requires greater production from each forest acre. Information contained in the RFNRP data bank becomes more valuable each year in helping the forest land manager direct activities to increase wood production. This project is emerging as one of the major contributors to forest growth information in North America. Numerous national and international forest research workers visit the College each year to review progress and discuss results. This communication improves our ability to respond to local needs.

We believe this report, which summarizes growth information for six years of treatment, will be of interest to all foresters, but especially to those who must make management and investment decisions. The economic analysis indicates that fertilization is a profitable alternative on many acres of forest land. Not only is fertilization an economic alternative, but also a good energy investment. If we make the reasonable assumption, supported by our data, that a pound of nitrogen that requires an energy investment of about 30,000 BTU's will produce an added cubic foot of wood containing about 300,000 BTU's, the energy gain is quite obvious.

Because of statistical necessity, our data analysis is based on regional averages. We realize that each landowner is faced with a variety of soil, site, stocking, and forest age conditions, and that decisions have to be made on a stand basis. Our recommendations take as many of those variables into account as possible. However, we still must deal with the problem of variations in fertilizer response within local areas. We are making every attempt to deal with this refinement problem and improve our response predictability. To this end, soil analysis has now been completed on most of the installations, along with studies of foliage elemental content. We are relating this information, together with parent material of the soils, to specific response of each installation. Indications that sulphur may be a factor in reduced response to nitrogen is being studied in conjunction with the Research Division of the New South Wales Forest Service in Sydney, Australia. We are also cooperating with the Washington Department of Natural Resources in nitrogen availability studies and the relationship of available nitrogen and response.

We hope the information presented in this report will be of value in your immediate programs. We also stress that what you have helped to set up in this cooperative project stretches far beyond initial regional considerations and is now providing a storehouse of information which finds interest and use throughout the world.

S. P. Gessel

INTRODUCTION

The Regional Forest Nutrition Research Project (RFNRP) 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 in the Pacific Northwest.

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

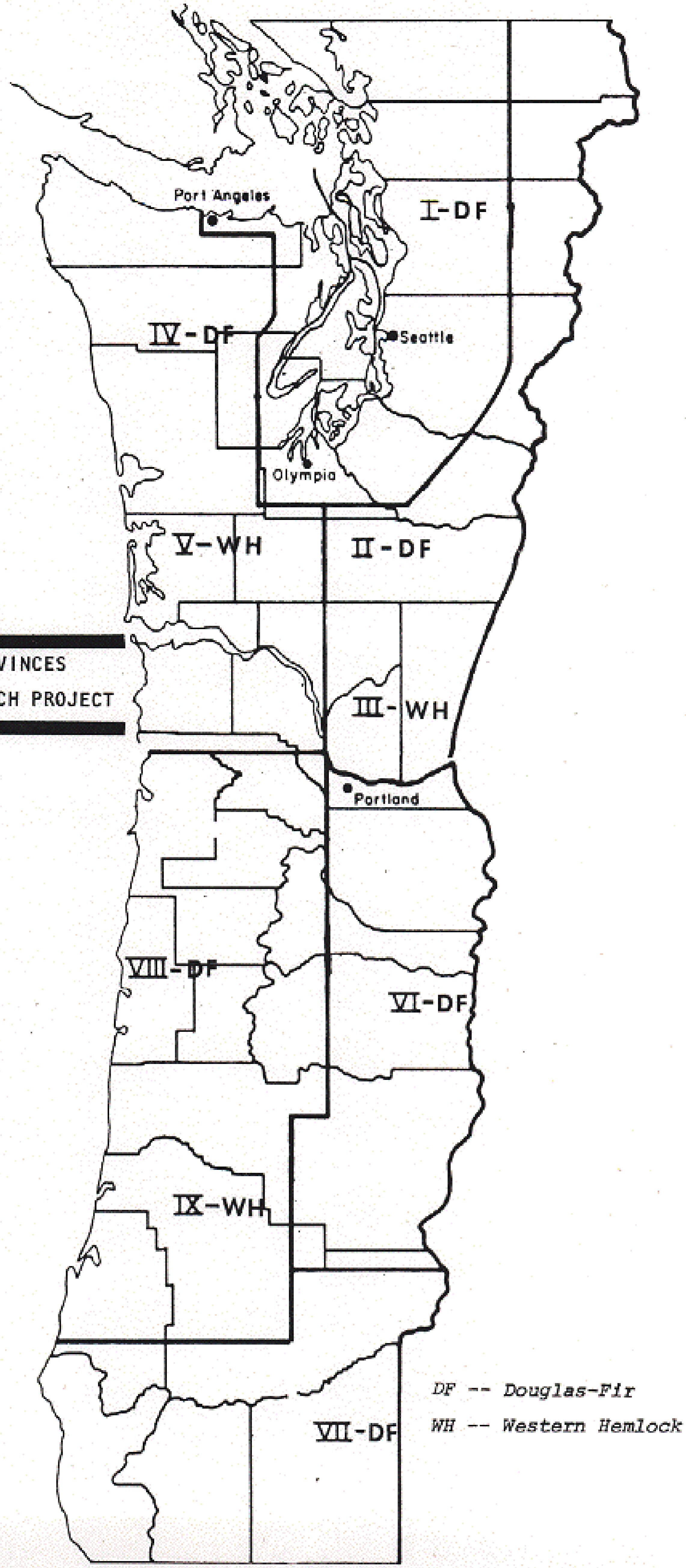
1. To establish and maintain a series of fertilizing and thinning field trials on participants' lands in western Washington and western Oregon under various conditions of soils, climate, age, and site;
2. to collect and analyze response data from these plots and report results to subscribers;
3. to conduct 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 techniques to detect response;
4. to report findings regularly to subscribers and to advise them on fertilization problems and practices;
5. and 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 and executes the project under the direction of Dr. Stanley P. Gessel.

A total of six Douglas-fir and three western hemlock provinces are employed for design purposes. The original research design called for simultaneous establishment of unthinned and thinned fertilizer plots. However, funding levels 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 incorporate 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 four growing seasons.

The years 1975 and 1976 saw another extension of the RFNRP data base with the initiation of Phase III (July 1, 1975-June 30, 1980). Measurement of existing plots is continuing to determine duration of response and effects of retreatment, and a number of new research plots have been established in 10-20 year-old stands and in areas of low natural forest productivity. Since 1969, approximately 1,450 permanent growth plots have been established in western Washington and western Oregon under RFNRP. Over 90% of all plots established are essentially undamaged and are still providing valuable data.

DOUGLAS-FIR AND WESTERN HEMLOCK PROVINCES
OF REGIONAL FOREST NUTRITION RESEARCH PROJECT



Surviving installations at the time of publication of this report, together with the number of growing seasons after-treatment which they will have accumulated by June 30, 1980 are as follows:

Date of establishment	Type of installation	Number of installations	Growth Seasons after treatment, June 30, 1980
1969	Phase I	40DF, 14WH	10
1970	Phase I	46DF, 13WH	9
1971	Phase II	9DF, 7WH	8
1972	Phase II	26DF, 1WH	7
1973	B. L. M.	6DF	6
1975	Phase III	23DF, 6WH	4
1975	Willamette National Forest	4DF	4
1976	Mt. Hood National Forest	1DF	3
1977	Siskiyou National Forest	8DF	2
1977	B. L. M.	6DF	2
1977	Phase III Regen.	2DF	2
1977	Phase III Intensive hemlock	1WH	2
1978	Colville National Forest	4DF	1

Total = 217 installations

The coming of maturity of major components of this data base permits increasingly sophisticated analyses to be performed. Basic summary and analysis work is supplemented by research studies on specific mensurational questions, silvicultural and economic recommendations, and soil-nutritional aspects. Depending on topical priorities of supporting basic research studies, an average of three graduate students each year since 1969 have been employed to assist the Project faculty and staff in developing information for the cooperators.

Current funding for these long-term studies terminates June 30, 1980. A Phase IV proposal is being developed in consultation with cooperators and the Technical Advisory Committee. Continued research is planned in a number of areas, including remeasurement and retreatment of existing plots, refinement of specific-area response estimates by intensive analysis techniques, fertilization and thinning in young spaced plantations, new plots to incorporate lower stocking levels, assessment of operational fertilization, and new plots in older stands. A more detailed summary of future proposed work is presented in a later section of this report.

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I. REGIONAL GROWTH AND RESPONSE ANALYSIS OF THE TOTAL STAND FOR UNTHINNED DOUGLAS-FIR, SIX YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

The primary objective of this study is to attain a regional estimate of mean response according to relevant stand variables such as age, site, etc. Response, measured as an increase in growth rate due to fertilizer application, can be thought of as:

$$\text{Response} = \begin{bmatrix} \text{Unthinned} \\ \text{Fertilized} \\ \text{Total Stand} \\ \text{Growth Rate} \end{bmatrix} \text{ minus } \begin{bmatrix} \text{Growth Rate} \\ \text{as in} \\ \text{Unthinned} \\ \text{Unfertilized} \\ \text{Total Stand} \end{bmatrix}$$

Analysis of response is based on 401 plots of 1/10-acre or larger size, comprised of at least 80% Douglas-fir type stands. This data base covers breast-height age classes 10 through 50, and 50-year site index classes 1 through 4. All increment figures are gross p.a.i. (periodic annual increment). The distribution of plots along with tables of initial volume and initial basal area are located in Appendix A. This portion of the mensurational results is based on 6 years of growth data. Growth data for 8 years have been processed from half of the Phase I installations and results will become available after data from all installations have been analyzed.

Results of Analysis

1. Gross P.A.I. of Total Basal Area: The average response across the data ranges of age, site, and basal area was about 23% to 200 pounds of nitrogen and about 26% to 400 pounds of nitrogen. Response was significantly related to site index, initial basal area, and the logarithm of the level of N-application. The smoothed estimates of growth rate are presented in Table 1, with smoothed response estimates given in Table 2. The response to fertilizer is greatest in the lower site classes and in the lower range of the basal area, the latter which accounts for the trend across age in Table 2 (age was not significantly related to response).

2. Gross P.A.I. of Total Volume: The results of the volume increment analysis show a mean response of 53 cubic feet per acre per year to 200 pounds of nitrogen across the range of data. This response represents a 16% increase over the estimated increment of the unfertilized stands.

Table 1.

Estimated mean 6-year gross total basal area growth
for unthinned Douglas-fir.
(square feet/acre/year, minimum d.b.h. = 1.55 inches)

B.H. AGE CLASS (Yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I	II	III	IV
		P.A.I.	P.A.I.	P.A.I.	P.A.I.
10	0	12.3	12.1	11.5	-
	200	13.9	14.5	15.0	-
	400	14.1	14.8	15.5	-
20	0	8.3	8.1	7.8	7.5
	200	8.7	9.2	9.7	10.2
	400	8.8	9.4	10.0	10.6
30	0	6.5	6.2	5.9	5.5
	200	6.8	7.3	7.7	8.1
	400	6.9	7.4	7.9	8.4
40	0	5.6	5.2	4.7	4.2
	200	5.9	6.2	6.5	6.7
	400	5.9	6.3	6.7	7.1
50	0	4.7	4.2	3.6	2.9
	200	5.0	5.1	5.3	5.4
	400	5.0	5.3	5.5	5.7

Table 2.

Estimated mean response of 6-year gross total basal area
growth for unthinned Douglas-fir.
(square feet/acre/year, minimum d.b.h. = 1.55 inches)

B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I	II	III	IV
		P.A.I.	P.A.I.	P.A.I.	P.A.I.
10	200	1.2	2.0	2.8	-
	400	1.4	2.3	3.1	-
20	200	.4	1.2	1.9	2.7
	400	.5	1.3	2.2	3.0
30	200	.3	1.0	1.8	2.5
	400	.4	1.2	2.0	2.9
40	200	.3	1.0	1.7	2.5
	400	.3	1.1	2.0	2.8
50	200	.3	1.0	1.7	2.5
	400	.3	1.1	1.9	2.8

The average response to 400 pounds of nitrogen is 59 cubic feet per acre per year across the range of data, an increase of approximately 18% over the estimated increment of the unfertilized stands.

The standard error associated with the response estimates is 13-14% of response for both levels of fertilizer application. This is to say the actual mean response to fertilizer may differ from 53 cu.ft./ac./yr. (200 lb-N) or from 59 cu.ft./ac./yr. (400 lb-N) by $\pm$ 8 cu.ft./ac./yr.

There was no statistically significant effect (95% confidence level) of age, initial basal area, or number of stems on the response to fertilizer. However, the logarithm of nitrogen application level and site index were significant in estimating response. These two variables account for the trend in smoothed response estimates (cu.ft./ac./yr) as seen in Table 3.

The smoothed increment estimates of both untreated stands and stands receiving fertilizer applications are summarized in Table 4. An example of the smoothed growth trends for untreated and treated stands is given in Figure 1.

Table 3.

Estimated mean response of 6-year gross total volume growth for unthinned Douglas-fir.
(cubic feet/acre/year, minimum d.b.h. = 1.55 inches)

B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	200	30.2	45.4	60.7	75.9
	400	34.2	51.4	68.6	85.8
20	200	30.2	45.4	60.7	75.9
	400	34.2	51.4	68.6	85.8
30	200	30.2	45.4	60.7	75.9
	400	34.2	51.4	68.6	85.8
40	200	30.2	45.4	60.7	75.9
	400	34.2	51.4	68.6	85.8
50	200	30.2	45.4	60.7	75.9
	400	34.2	51.4	68.6	85.8

Table 4.

Estimated mean 6-year gross total volume growth for unthinned Douglas-fir.
(cubic feet/acre/year, minimum d.b.h. = 1.55 inches)

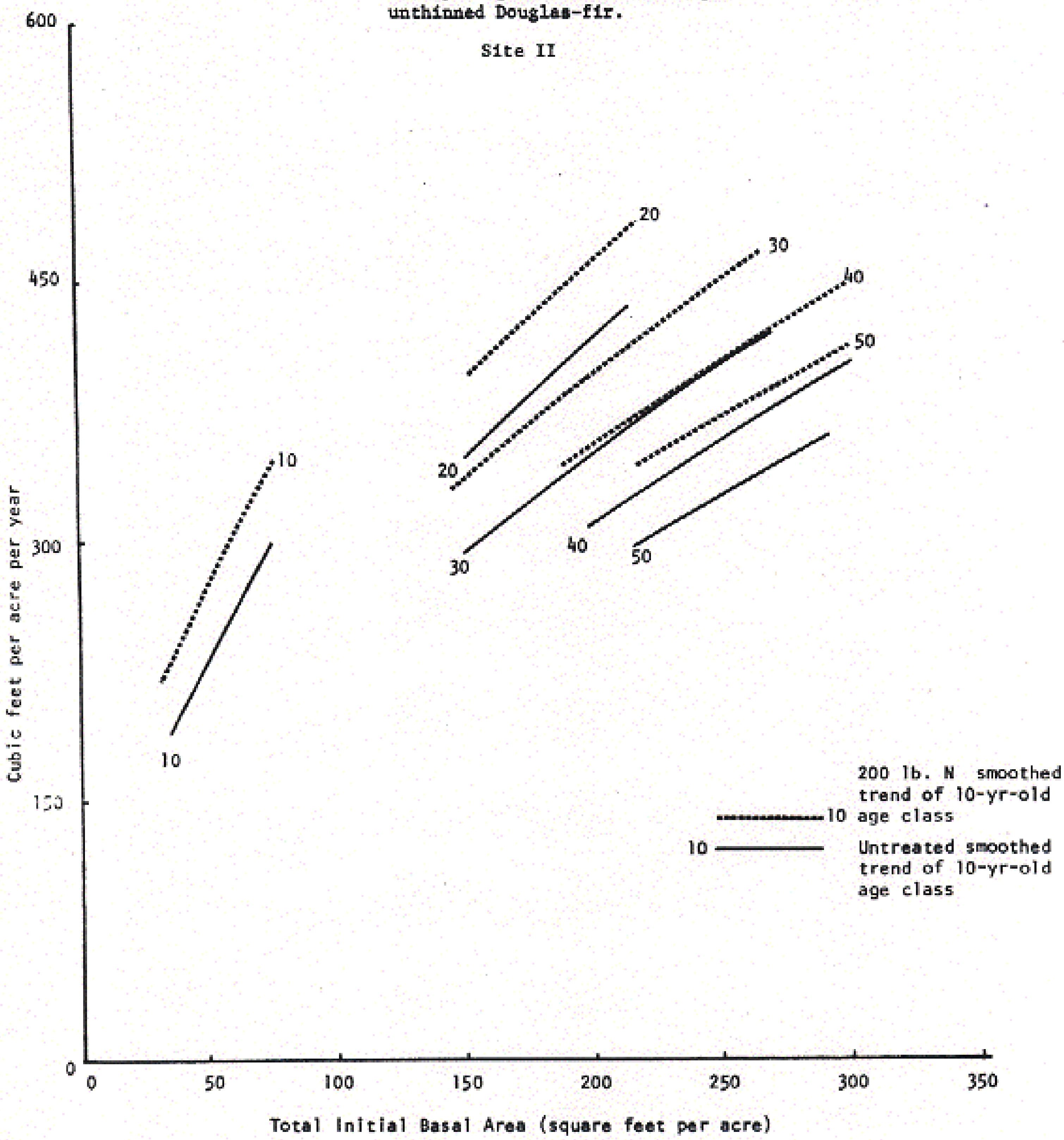
B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	0	255.7	221.9	187.9	-
	200	286.5	267.9	249.1	-
	400	290.5	273.9	257.1	-
20	0	423.4	357.0	292.2	229.2
	200	454.2	403.1	353.5	305.7
	400	458.2	409.1	361.5	315.6
30	0	445.8	372.3	301.3	233.1
	200	476.6	418.3	362.6	309.6
	400	480.6	424.3	370.5	319.6
40	0	432.1	359.2	289.1	222.1
	200	463.0	405.2	350.3	298.6
	400	467.0	411.2	358.3	308.5
50	0	410.1	339.9	272.6	208.6
	200	440.9	385.9	333.8	285.1
	400	444.9	391.9	341.8	295.0

Figure 1.

TREATMENT: 0 and 200 lbs. N per acre

Estimated trends of 6-year gross total volume growth for unthinned Douglas-fir.

Site II



II. REGIONAL GROWTH AND RESPONSE ANALYSIS OF THE MERCHANTABLE STAND FOR UNTHINNED DOUGLAS-FIR, SIX YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

The 6-year merchantable gross growth rate was analyzed much the same as the 4-year merchantable growth analysis reported in the last (1974-1976) Biennial Report from the project; the gross increment (cu.ft./ac./yr.) in merchantable volume was calculated for trees of d.b.h. greater than 6.55 inches and measured to a 4-inch top.

The primary objective was to provide a regional estimate of mean response in merchantable units according to relevant stand variables (e.g. site index, d.b.h. age, etc.). Response is measured as an increase in growth rate due to application of fertilizer and can be thought of as:

$$\text{Response} = \begin{bmatrix}\text{Unthinned} \\ \text{Fertilized} \\ \text{Merchantable} \\ \text{Stand Growth} \\ \text{Rate}\end{bmatrix} \text{ minus } \begin{bmatrix}\text{Growth Rate} \\ \text{as in the} \\ \text{Unthinned} \\ \text{Unfertilized} \\ \text{Merchantable} \\ \text{Stand}\end{bmatrix}$$

The merchantable stand growth results of Phase I are also based on 6 years of growth data, analysed from 386 plots of 1/10-acre and larger size, and comprised of at least 80% Douglas-fir type stands. The data base covers breast-height age classes 15 through 45, and 50-year site classes 1 through 4. All increment figures are gross p.a.i.

A summary of 6-year unthinned Douglas-fir, comparing the total stand p.a.i. and merchantable stand p.a.i., is presented in Figure 2. Tables of plot distribution, initial basal area, and initial volume are located in Appendix A.

Results of Analysis

Gross volume p.a.i. of the merchantable stand without ingrowth was analysed. Results of the volume increment analysis indicate a mean response of 41 cu.ft./ac/yr. to 200 pounds of nitrogen application and 55 cu.ft./ac./yr. to 400 pounds of nitrogen application. These figures represent relative increases of 15% and 20% for the respective levels of fertilizer application over the merchantable growth rate of the untreated stands. Response was significantly related to the logarithm (base 10) of the level of N-application but did not change significantly with age, site index, or basal area. Smoothed estimates of the growth rate are presented in Table 5. An example of the smoothed trends of growth rate for untreated and treated stands is presented in Figure 3.

Figure 2.

Summary of expected mean 6-year gross volume p.a.i. and percent response of unthinned Douglas-fir for both the total stand (cu.ft./ac./yr.; min. d.b.h. = 1.55 inches) and the merchantable stand (cu. ft./ac./yr.; min. d.b.h. = 6.55 inches, to a 4-inch top).

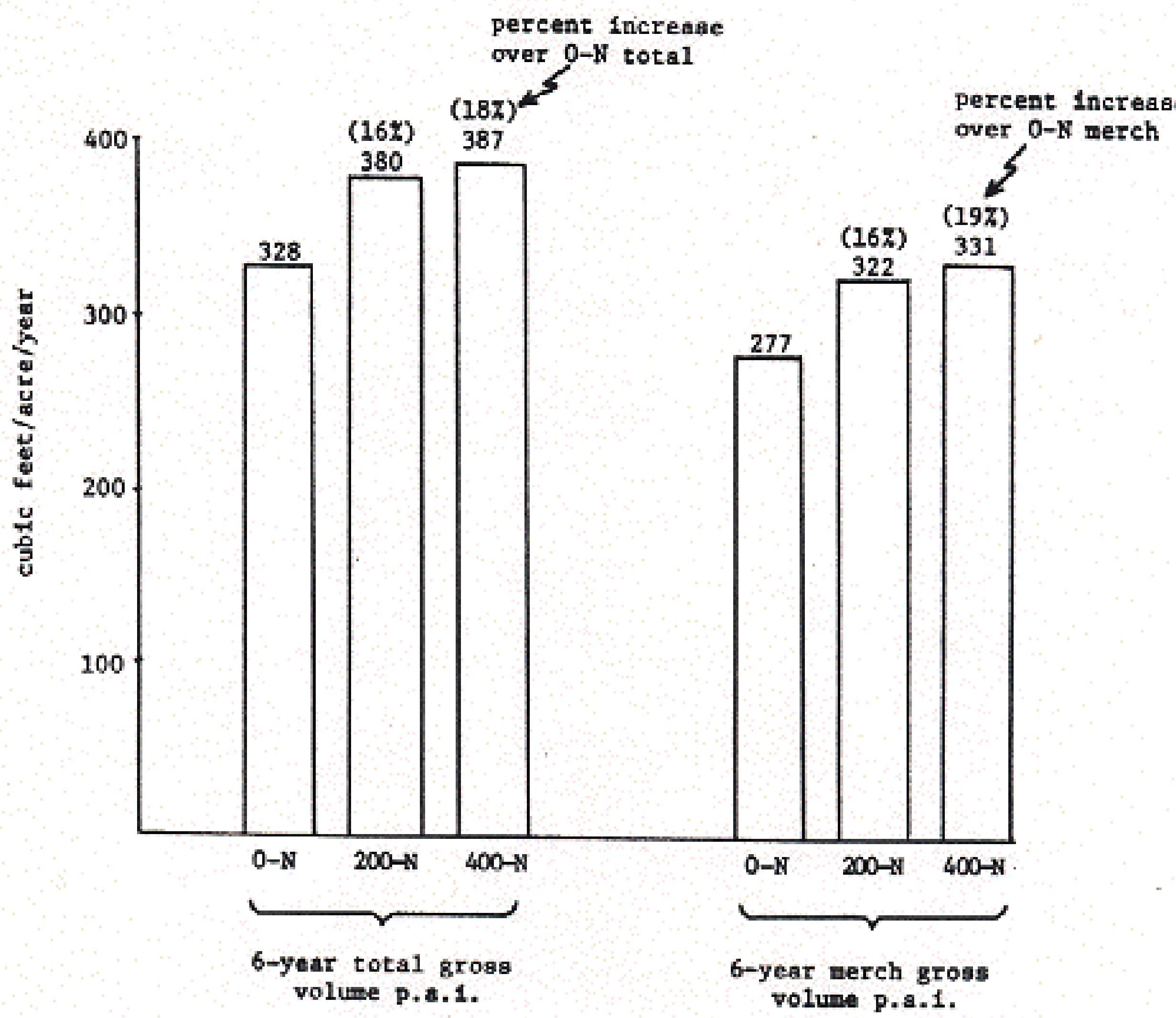


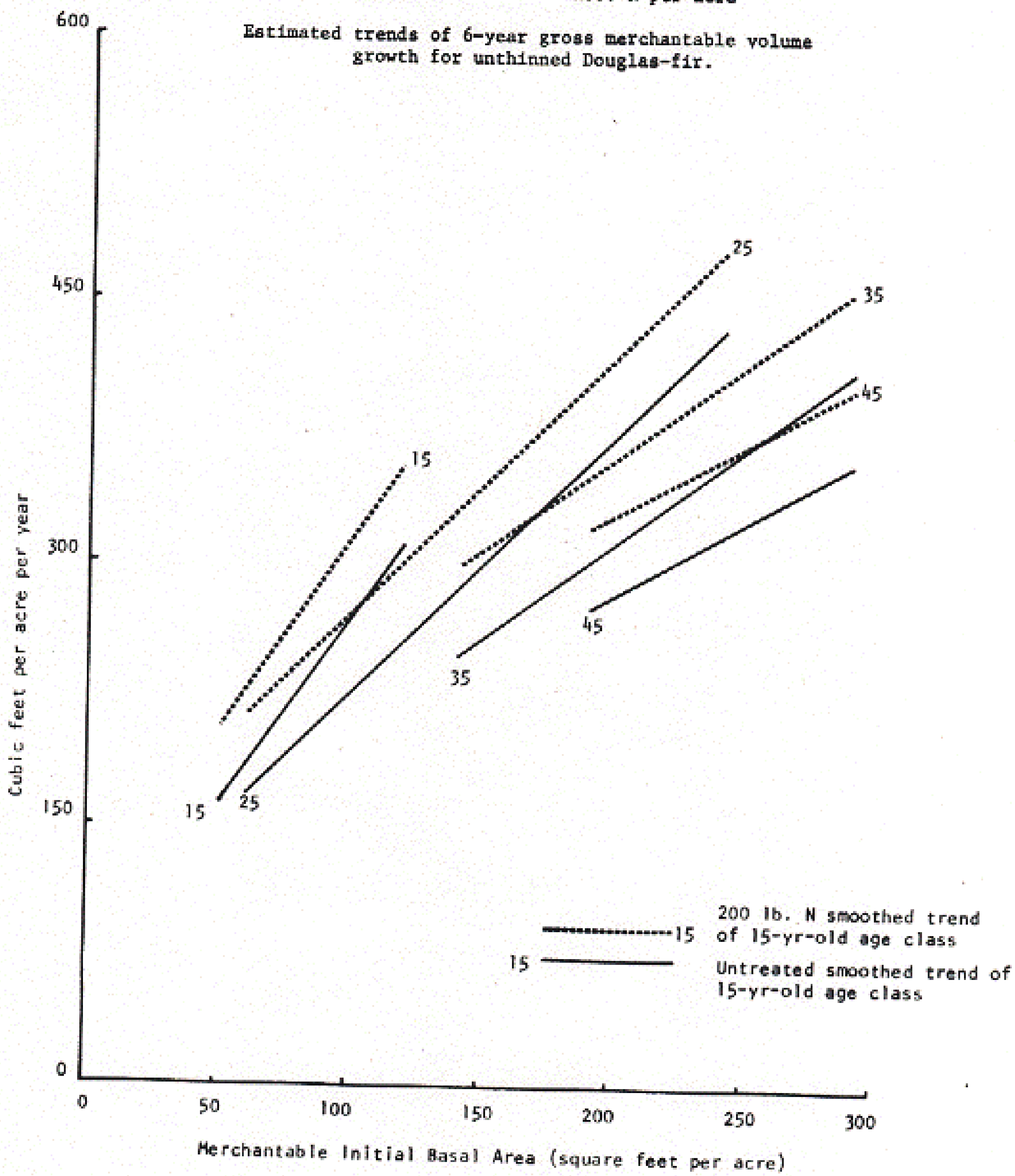
Table 5.

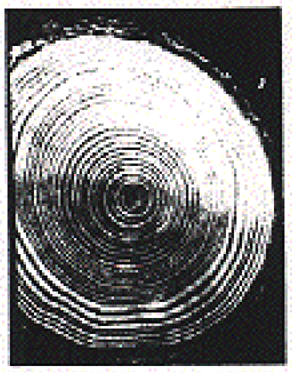
Estimated mean 6-year gross merchantable volume growth for unthinned Douglas-fir. (cubic feet/acre/year, minimum d.g.h. = 6.55 inches to a 4 inch top)

B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I P.A.I.	SITE CLASS II P.A.I.	SITE CLASS III P.A.I.	SITE CLASS IV P.A.I.
15	0	267.7	150.0	32.4	-
	200	312.9	195.2	77.5	-
	400	318.8	201.1	83.4	-
25	0	374.0	282.8	191.6	100.5
	200	419.1	328.0	236.8	145.7
	400	425.0	333.9	242.7	151.6
35	0	393.8	319.8	245.7	171.6
	200	439.0	365.0	290.9	216.8
	400	444.9	370.8	296.8	222.7
45	0	383.6	320.5	257.4	194.3
	200	428.8	365.7	302.6	239.5
	400	434.7	371.6	308.5	245.4

Figure 3.

TREATMENT: 0 and 200 lbs. N per acre





III. DURATION OF REGIONAL GROWTH RESPONSE OF THE TOTAL STAND FOR UNTHINNED DOUGLAS-FIR, SIX YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

The present analysis of the 6-year p.a.i. shows a substantial response to fertilizer application. The next questions are whether or not this response is sustained through the entire 6-year period, and, secondly, does response behave the same for both levels of fertilizer application. Both of these questions can be resolved to a large extent by examining each of the three 2-year growth periods following fertilizer application, in the same manner that the 6-year growth data was analyzed. Duration of response has been examined in essentially three steps of data classification, each of which is a comparison of the three 2-year growth period:

(i) Average estimated response over all ages and sites..
(ii) Average estimated response by site class.
(iii) Average estimated response by age and site.

It is important to remember that the three response figures are each 2-year averages. Thus a peak in response in the second 2-year period for example, would imply a peak in either the third or fourth year following treatment. Likewise, if response disappeared in the second 2-year period, the falloff could pertain to either the third or fourth year after treatment. All figures were tested at the α=.05 level and are statistically significant unless indicated by "NS" (=nonsignificant).

Results of Analysis

1. Response across all age and site classes: The data in Table 6 show growth rate is declining for both the untreated stands and the treated stands. The results of the analysis with estimates of mean response for each 2-year period are summarized in Figure 4. Although the response has declined from the second to the third period, it is nontheless substantial in the third 2-year period. In addition, the response to 400 pounds of nitrogen appears to be better sustained than the response to 200 pounds of nitrogen, in the third 2-year period.

Table 6.

Average gross total basal area growth of unthinned Douglas-fir for each 2-year period (square feet/acre/year; minimum d.b.h. = 1.55 inches)

TREATMENT (Pounds of N per acre)	TWO-YEAR GROWTH PERIODS 1	2	3
	P.A.I.	P.A.I.	P.A.I.
0	6.73	6.10	5.81
200	8.26	7.73	6.82
400	8.35	7.95	7.29

2. Response within site class (Figures 5-8): This stratification was logical since it has been demonstrated that the trend of response across site index is statistically significant.

As was expected, response on site I stands (Figure 5) is less than the response on the other sites, while at the other end of the range, response on site IV (Figure 8) stands is much higher than on the other sites. In all four site classes, the third 2-year period clearly shows that continuing response is higher for the 400 pound nitrogen application than for the 200 pound application. The trends of response in both site classes II and III are very similar to the regional trends of step 1. This also would be expected since the mean site index for the region is located very nearly between site classes II and III.

3. Response by Age Class and Site Class (Appendix B): The response data were further stratified by age and site for the fertilizer levels of each 2-year growth period. It is unavoidable that with each subsequent stratification of data some age and site categories are poorly represented and in a few cases totally absent. This is particularly evident in the age class extremes (10-year and 50-year) and in the site class extremes (I and IV). Therefore only those "cells" of classification containing four or more observations (in all three treatments) were analyzed so that some statistical significance could be attached to the means of response.

With few exceptions, the response to 400 pounds of nitrogen is greater than the response to 200 poound of nitrogen in both the first and second 2-year growth period.

Figure 4.

Estimated mean response of gross total basal area growth by 2-year periods for Douglas-fir (square feet/acre/year; minimum d.b.h. - 1.55 inches)

All Sites; All Ages

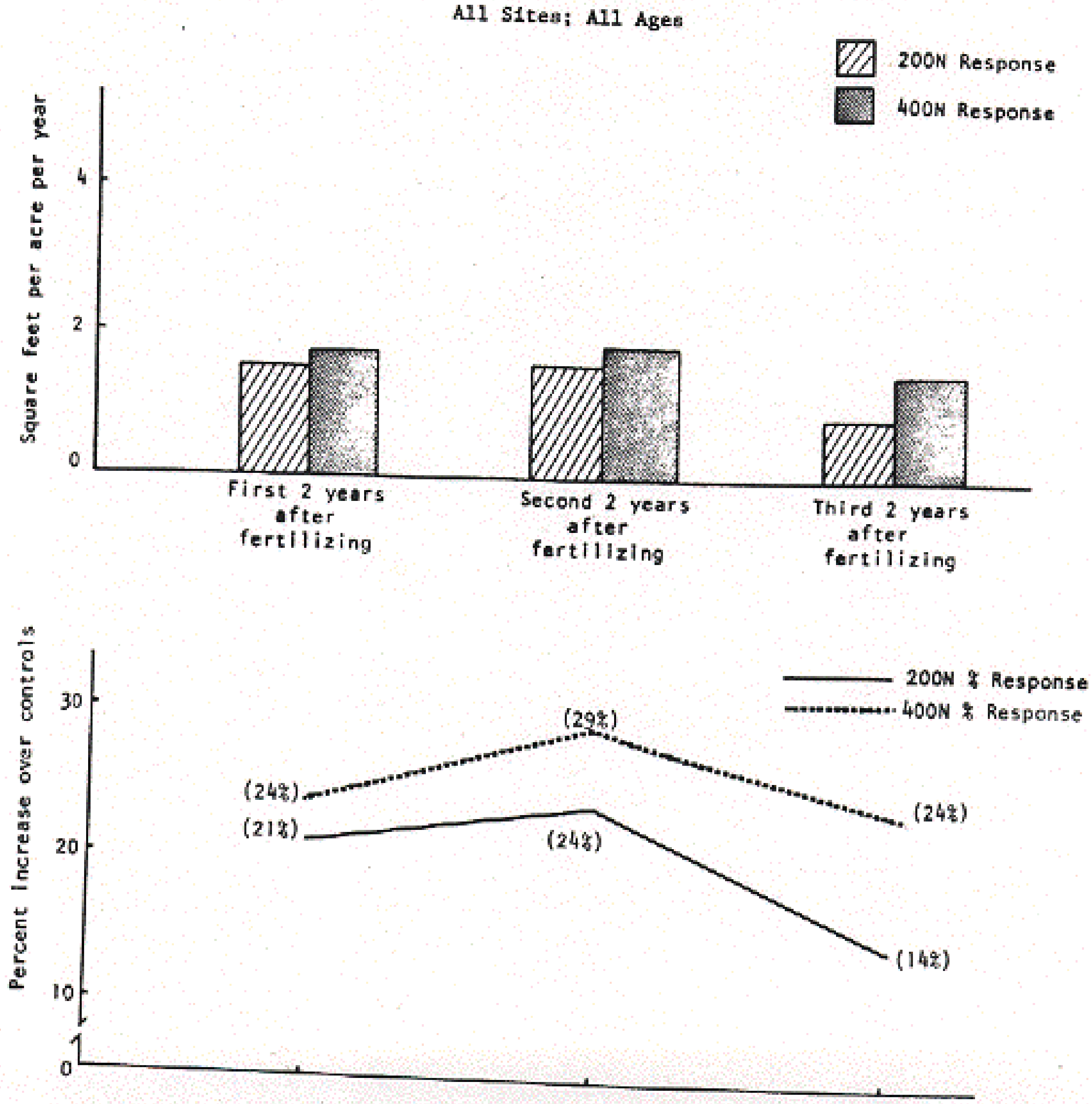


Figure 5.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

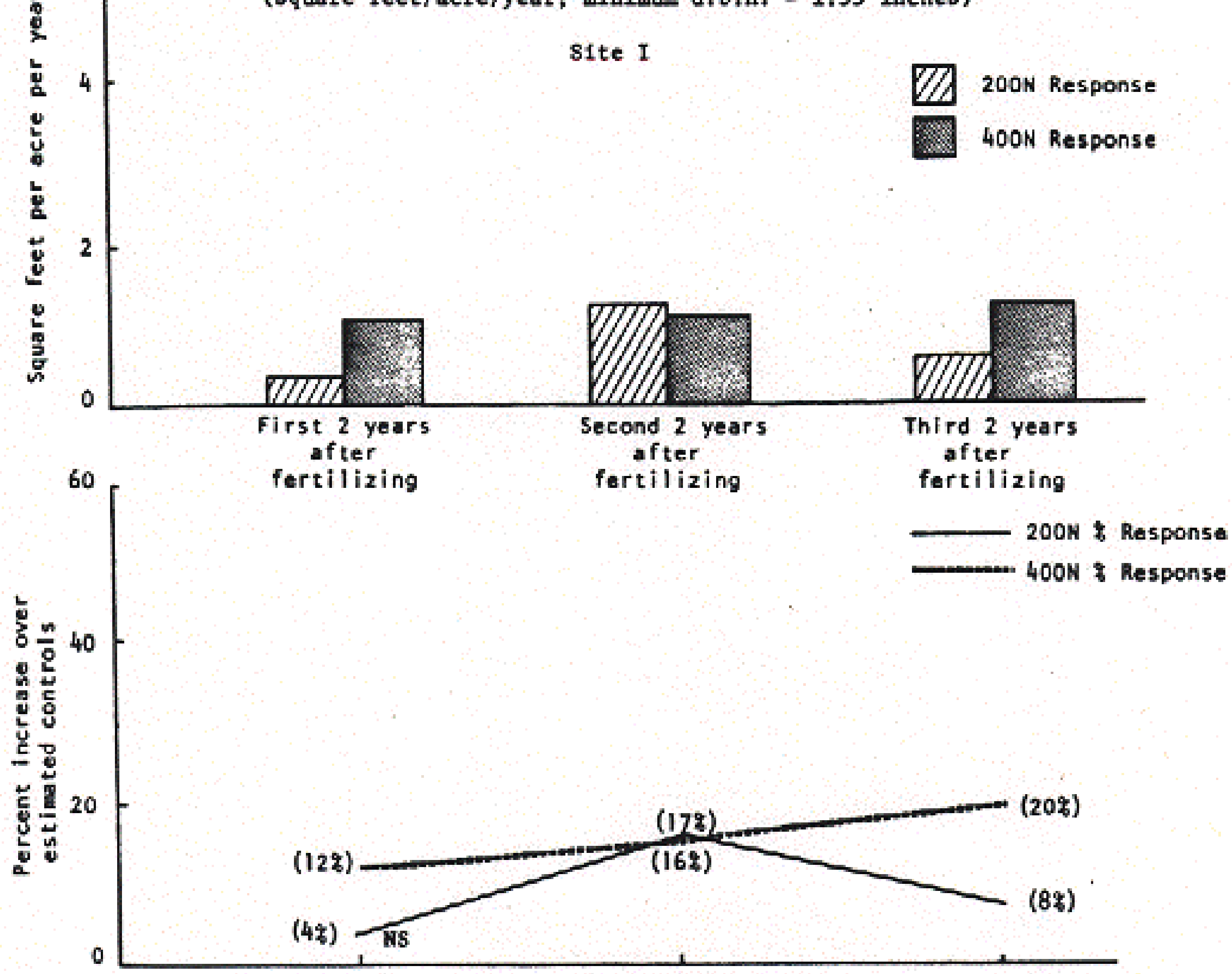


Figure 6.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

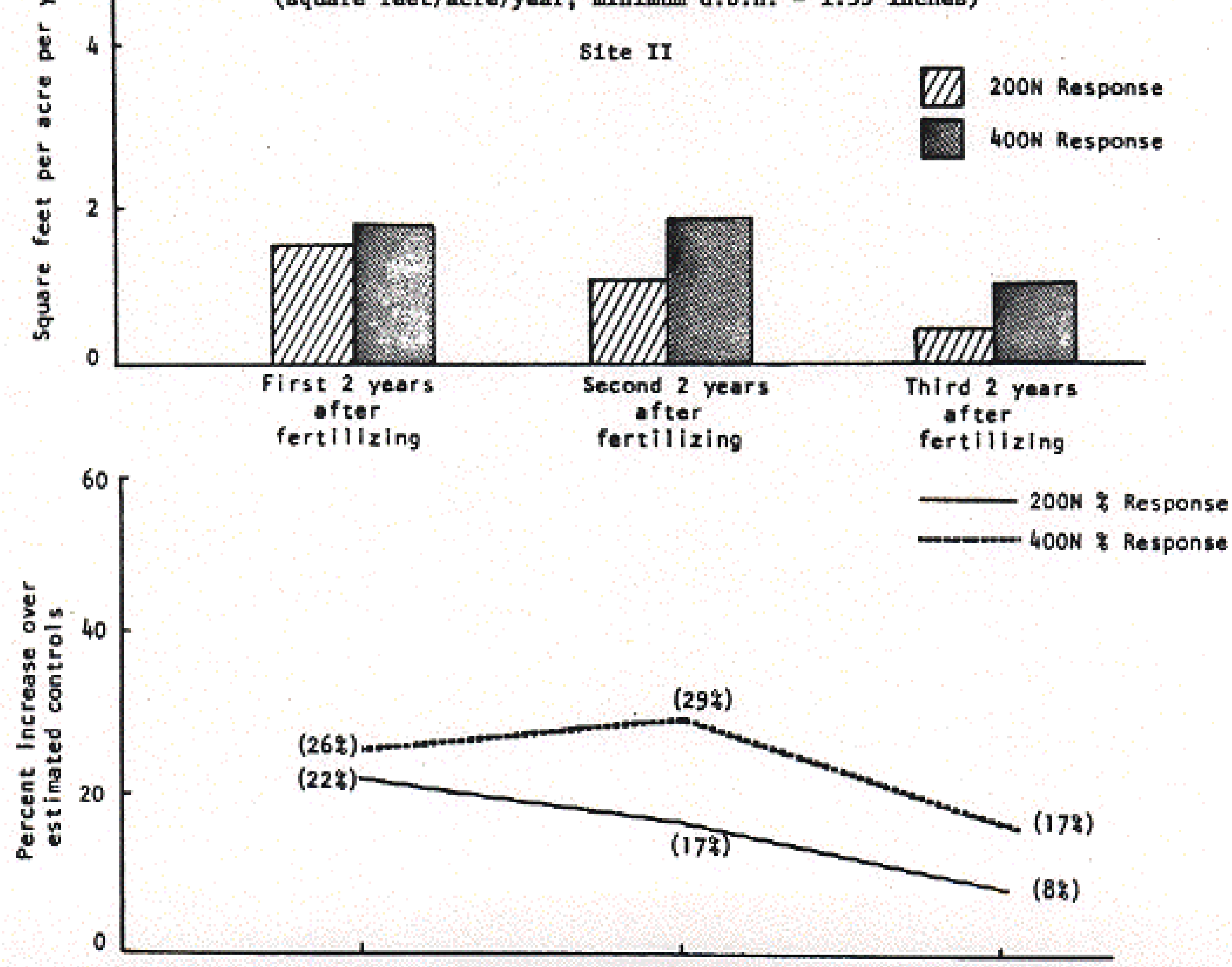


Figure 7.

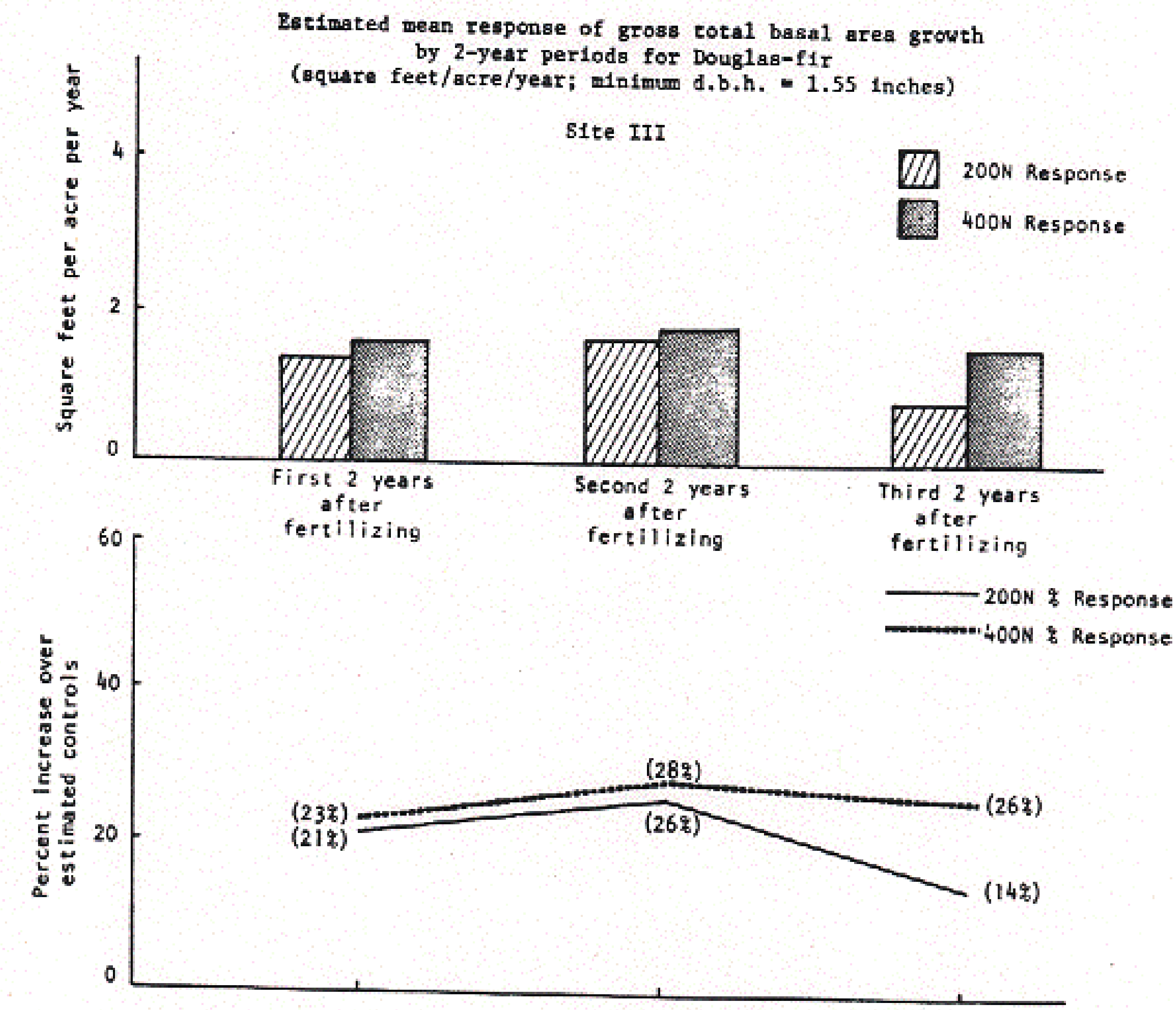
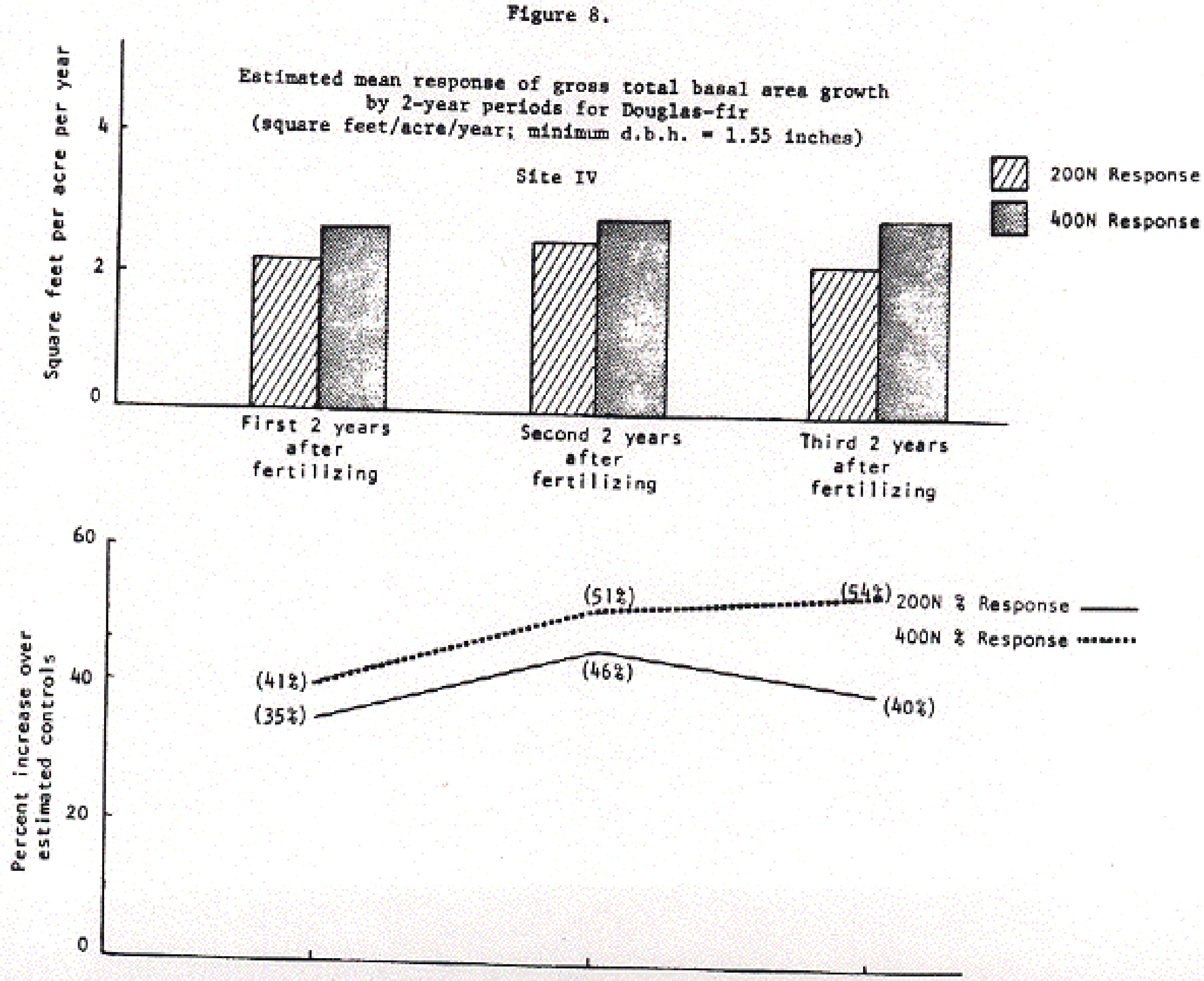


Figure 8.



Upon completion of the third 2-year growth period, the response to 400 pounds of nitrogen is maintained better in every case. The "peak" response to both levels of fertilizer appears to be in the second 2-year growth period in the majority of cases.

It is interesting to note that under the 200 pound nitrogen application, response in the third 2-year growth period was statistically significant in six out of nine cases. And under the 400 pound nitrogen application, response at the end of the third 2-year growth period was still statistically significant for <u>all</u> nine age and site categories.

Conclusions

The analysis by 2-year growth periods not only substantiates the 6-year results of growth response but also indicates that the greater gain from 400 pounds of nitrogen is enhanced by its longevity in response duration. Also the response "peak" occurs in the third or fourth year (second 2-year growth period) after fertilizer application. Response is statistically significant, in general, at the end of the fifth or sixth year (third 2-year growth period) after fertilizer application. The outcome of the 8-year Phase I growth analysis may strongly influence decisions regarding amounts of fertilizer for initial application and timing of the reapplication. Thus the importance of this particular aspect of the regional analysis has been strongly emphasized. This latter trend can be better confirmed when the fourth 2-year period is analysed.

IV. REGIONAL GROWTH AND RESPONSE ANALYSIS OF THE TOTAL STAND FOR THINNED DOUGLAS-FIR, FOUR YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

This section of the Biennial Report is concerned with:

i) Response to fertilizer in basal area increment (gross p.a.i.);

ii) response to fertilizer in volume increment (gross p.a.i.); and

iii) contrast of response to fertilizer in both volume and basal area increment (gross p.a.i.) for thinned and unthinned stands. Response, measured as increase in growth rate due to application of fertilizer to a thinned stand, can be thought of as:

Response = [Thinned Fertilized Total Stand Growth Rate] minus [Growth Rate as in the Thinned Unfertilized Total Stand]

Analysis of response is based on 191 plots of 1/10 acre or larger, containing growing stock of at least 80% Douglas-fir. This data base covers breast-height age classes 15 through 45, and 50-year site classes 1 through 4. All increment figures are 4-year gross p.a.i. (periodic annual increment). The distribution of plots along with tables of initial basal area (post-thin) and initial volume (post-thin) are given in Appendix A.

Results of Analysis

1. Gross P.A.I. of Total Basal Area: Although the main topic of interest is response in cubic feet per acre, basal area p.a.i. response was analysed as a preliminary step. The average response across the data ranges of age, site, and basal area was about 35% to 200 pounds of nitrogen and about 39% to 400 pounds of nitrogen. Response was significantly related to both initial basal area (after thinning) and the logarithm (base 10) of the level of N-applications, the response being the greatest in the lower range of basal area. The smoothed estimates of total growth rate are presented in Table 7.

2. Gross P.A.I. of Total Volume: Results of the volume increment analysis show a mean estimated response of 64 cubic feet per acre per year to 200 pounds of nitrogen. This response represents a 25% increase over the mean estimated growth rate of the unfertilized thinned stands.

The average estimated response to 400 pounds of nitrogen is 72 cubic feet per acre per year, an increase of 28% over the mean estimated growth rate of the unfertilized thinned stands. The standard error associated with the response estimates is about 12% of

Table 7.

Estimated mean 4-year gross total basal area growth for thinned Douglas-fir.
(square feet/acre/year, minimum d.b.h. = 1.55 inches)

B. H. AGE CLASS (Yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS			
		I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
15	0	10.1	9.9	9.7	9.4
	200	11.4	11.7	12.0	12.3
	400	11.6	12.0	12.3	12.6
25	0	6.7	6.8	6.8	6.8
	200	8.0	8.6	9.1	9.7
	400	8.2	8.8	9.4	10.0
35	0	4.7	5.0	5.2	5.4
	200	6.0	6.8	7.6	8.3
	400	6.2	7.1	7.9	8.7
45	0	3.5	3.9	4.3	4.6
	200	4.9	5.8	6.6	7.5
	400	5.0	6.0	6.9	7.9

response for both levels of N-application. That is, the actual mean response to fertilizer may differ from the estimated 64 cu.ft./ac./yr. (200 lb-N) or the estimated 72 cu.ft./ac./yr. (400 lb-N) by ± 8 cubic feet per acre per year.

There was no statistically significant effect of age, site index, or basal area on the response to fertilizer. However, the logarithm (base 10) of the nitrogen application level was statistically significant in explaining response. The smoothed growth estimates of the fertilized thinned stands are summarized in Table 8. Smoothed trends of growth rate are exhibited in Figure 9.

3. Fertilizer Response for Thinned and Unthinned Stands: The mean response to fertilizer applications in Phase I unthinned stands compared to Phase II thinned stands is exhibited in Figure 10 for volume p.a.i. and Figure 11 for basal area p.a.i. Direct comparison of the Phase I and Phase II smoothed estimates would be helpful in estimating a thinning effect and the possibility of a thinning-fertilizer interaction. However, the respective ranges of basal area stocking from the two data sets do not overlap sufficiently due to a lack of low-stocked unthinned stands in Phase I. In order to test the important null hypothesis that growth in thinned stands is not different from growth in understocked unthinned stands, below-normal natural stocking conditions are needed. Thus any extrapolation of Phase I estimates for comparison with Phase II data would be hazardous.

Table 8.

Estimated mean 4-year gross total volume growth for thinned Douglas-fir.
(cubic feet/acre/year, minimum d.b.h. = 1.55 inches)

B.H. AGE CLASS (Yrs.)	TREATMENT (Pounds of N per acre)	DOUGLAS-FIR BASAL AREA				
		55 P.A.I.	85 P.A.I.	115 P.A.I.	145 P.A.I.	175 P.A.I.
15	0	208.0	299.7	391.4	-	-
	200	272.0	363.7	455.5	-	-
	400	280.4	372.1	463.8	-	-
25	0	156.3	219.8	283.3	346.9	410.4
	200	220.4	283.9	347.4	410.9	474.5
	400	228.7	292.2	355.8	419.3	482.8
35	0	-	-	223.7	271.7	319.7
	200	-	-	287.8	335.8	383.8
	400	-	-	296.1	344.1	392.1
45	0	-	-	187.2	225.6	264.0
	200	-	-	251.2	289.7	328.1
	400	-	-	259.6	298.0	336.5

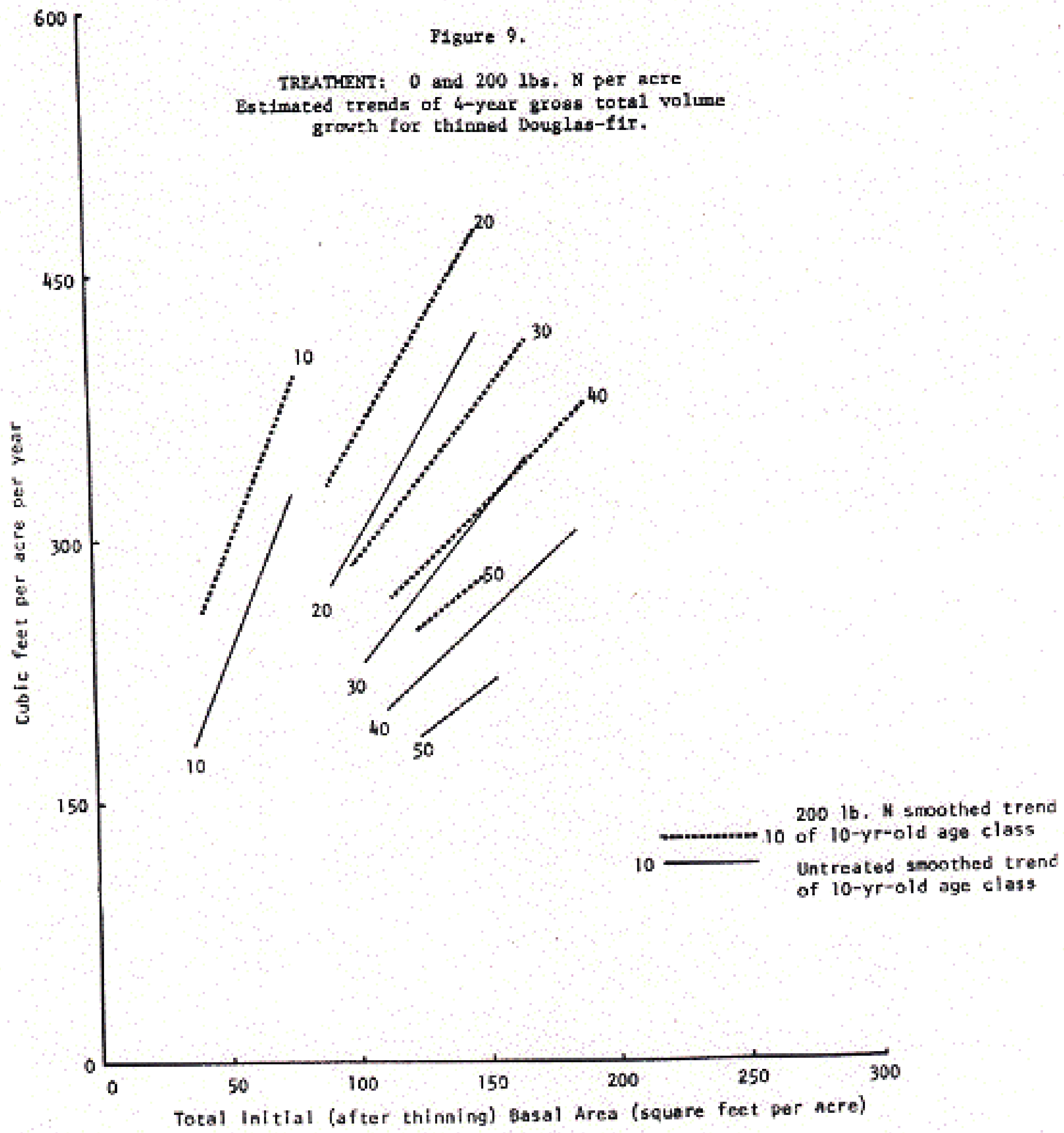


Figure 10.

Summary of Phase I and Phase II mean estimated 4-year gross total volume growth for Douglas-fir. (cubic feet/acre/year, minimum d.b.h. = 1.55 inches)

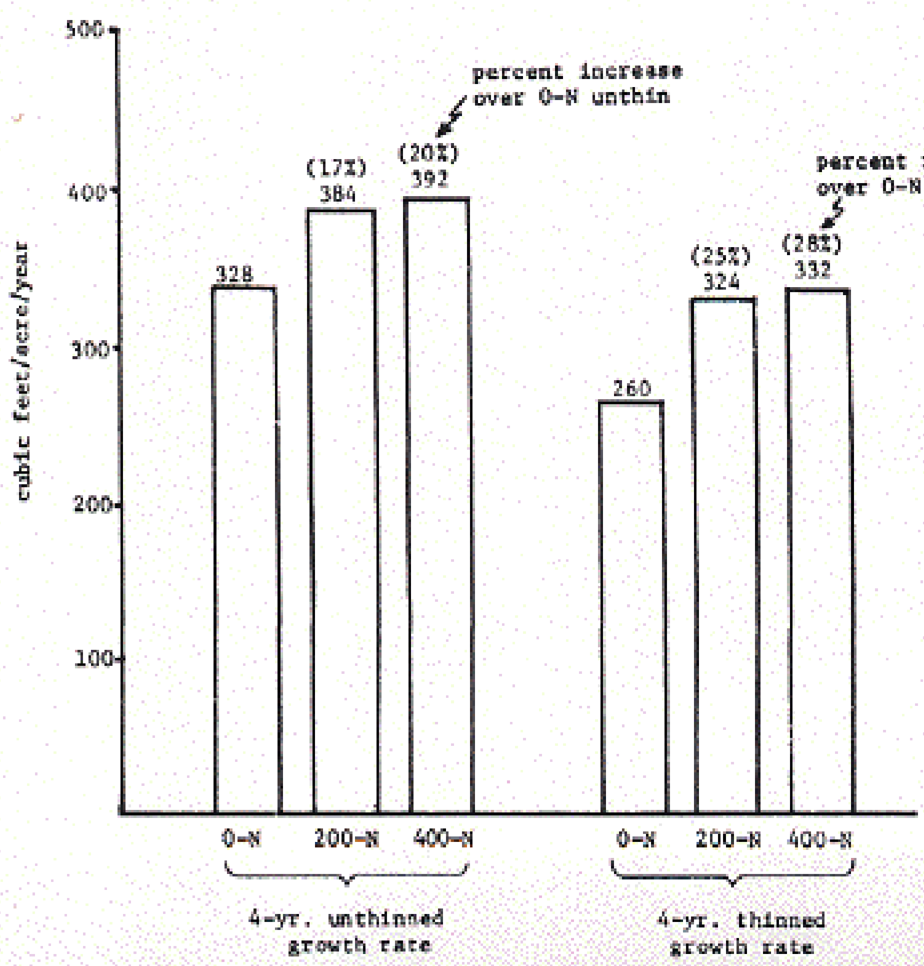


Figure 11.

Summary of Phase I and Phase II mean estimated 4-year gross total basal area growth for Douglas-fir. (square feet/acre/year, minimum d.b.h. = 1.55 inches)

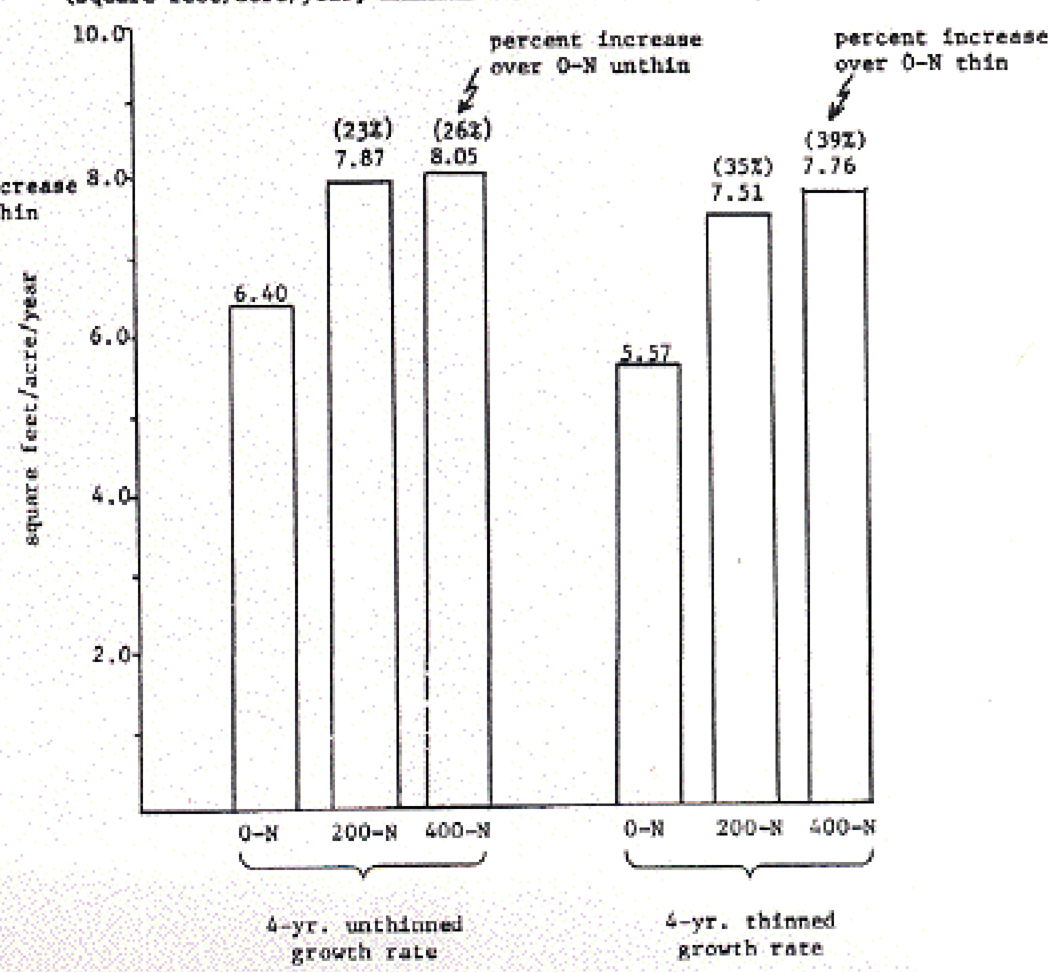


Table 9.

Average stand conditions and estimated mean response for 4-year gross total growth rate of Phase I and Phase II (Douglas-fir).

Treatment: 200 lbs. N/ac

	cu.ft./ac./yr.	sq.ft./ac./yr.
Phase I (unthinned)	56 (17%)	1.47 (20%)
Phase II (thinned)	64 (25%)	1.94 (35%)

Treatment: 400 lbs. N/ac

	cu.ft./ac./yr.	sq.ft./ac./yr
Phase I (unthinned)	64 (20%)	1.65 (22%)
Phase II (thinned)	72 (28%)	2.19 (39%)

Average Initial Stand Conditions

	Age	Site Index	Basal Area
Phase I (unthinned)	32 years	117 ft.	202 sq.ft./ac.
Phase II (thinned)	30 years	115 ft.	121 sq.ft./ac.

In Table 9 are summarized the Phase I (unthinned) and II (thinned) responses to fertilizer four years following application, along with average initial stand conditions. There is very little difference in initial stand age or in initial site index between Phases I and II. The lower initial stocking of Phase II is due to the reduction from thinning. Clearly both the absolute and the relative responses are greater from the thinning and fertilizer combination (Phase II) than from fertilizer alone (Phase I).

V. FERTILIZATION OF THINNED DOUGLAS-FIR STANDS -AN ECONOMIC ASSESSMENT-

Should fertilizer be applied to thinned stands of Douglas-fir in preference to unthinned stands? What priorities, if any, should be given to thinned stands? Questions of this sort are becoming common today as thinning and fertilizer programs expand. This study is an initial attempt to place the fertilization of thinned stands in its proper economic perspective.

Previous economic analyses under RFNRP have concluded that, in general, the most profitable Douglas-fir stands to fertilize are those close to final harvest and on medium to low sites. Table 10 summarizes previously published priorities for fertilization of well-stocked, unthinned stands of Douglas-fir. Suppose one has available a site II, 45 year-old stand that has already been thinned. Where would this stand fit in the priority list? Should it be fertilized before an unthinned site III stand of the same age?

Since 4-year results of the Phase II thinning-fertilizer study are now available, it is possible to re-examine the profitability of fertilizer investments in stands of various age/site combinations, both thinned and unthinned. This study assumes that 200 pounds of nitrogen are applied as urea fertilizer, and that the extra wood attributable to fertilizer is harvested and sold ten years later, either as a clearcut or as a thinning. Major differences from previous analyses are: (1) use of 6-year unthinned fertilizer response data, rather than 4-year data; (2) use of a 3% "real" price increase (over inflation) for estimating future stumpage values rather than the 5% increase used previously; and (3) use of 4-year thinning-fertilizer response data.

Table 10 Stand Priorities for Fertilization-Unthinned Stands Only

Douglas-fir Stand Age When Fertilized	50-Year Site Class			
	IV	III	II	I
25	15	13	14	16
35	9	8	10	12
45	6	4	5	11
55	2*	1	2*	7

Notes:
(1) Source, RFNRP Biennial Report 1974-76
(2) * = tie
(3) Ranking based on rate of return

Table 11. Assumed 10 Year Volume Response from One Fertilization Douglas-fir (Bd. Ft./Acre, Scribner, 6" Top)

Stand Age when Treated	Unthinned, well-stocked: 50-year Site Class IV	III	II	I	Thinned: 50-year Site Class IV	III	II	I
25	990	910	790	610	1,140	1,060	930	710
35	1,180	1,090	880	700	1,320	1,230	1,010	800
45	1,290	1,180	950	740	1,430	1,320	1,080	850
55	1,360	1,230	990	770	1,500	1,380	1,130	870

Notes:
(1) 200 pounds nitrogen per acre
(2) Derived by applying Bd. Ft./cubic foot ratios to cubic volume response
(3) Table volumes have been reduced 20% from RFNRP estimates to allow for "operational falldown"

Volume response assumptions by site, age, and thinning treatment are given in Table 11. Conversions from cubic feet to board feet were based on board foot/ cubic foot ratios. These response estimates are somewhat higher than those used previously, which reflects the fact that response continued at a higher-than-anticipated rate through the fifth and sixth years following treatment. Thinned stand response is somewhat higher than unthinned stand response. Although cubic foot response is assumed to be the same in thinned and unthinned stands, the former have a higher board foot/cubic foot ratio and hence a higher board foot response.

Assumptions regarding current stumpage prices are presented in Table 12. Prices for the thinned stands assume thinning was carried out ten years previously, hence trees are larger and values higher. These prices carried forward ten years at a 3% interest rate are given in Table 13. The 3% rate represents a "real" increase in stumpage price over and above inflation.

Values in Table 13, thus, are estimates of stumpage price for which harvested trees are sold ten years hence, in 1989. Since no inflation factor was included in the estimation of future stumpage prices, they are in terms of 1979 dollars. Differences between sites, ages, and thinning treatment are based on average tree size associated with each, and primarily reflect harvest cost differences. However, it should also be noted that wood from larger trees is also more valuable because of higher lumber recovery and higher log grades.

Value gain from fertilization is estimated in Table 14, which was derived by applying stumpage prices on Table 13 to volume gains of Table 11. For example a thinned 45 year-old, site II stand is expected to provide 1,080 board feet per acre of response, which will be valued at \$149 per M board feet in 1989 when sold. Thus value gain is 1.080 (149) ≅ \$161 per acre, as shown in Table 14.

Assuming a \$50 per acre fertilization cost in 1979, the rates of return are listed in Table 15. They are called

Table 12. Assumed Stumpage Prices 1979

Douglas-fir (Dollars/M Bd. Ft.)

Stand Age in 1979	Unthinned: 50-year Site Class IV	III	II	I	Thinned Ten-Years previously: 50-year Site Class IV	III	II	I
25	29	35	40	48	36	42	47	55
35	44	56	67	79	51	63	74	86
45	58	74	90	101	65	81	97	108
55	70	89	104	117	77	96	111	124
65	80	99	112	126	87	106	119	133

Table 13. Estimates Stumpage Prices in 1989 (1979 Dollars)

Douglas-fir (Dollars/M Bd. Ft)

Stand Age	Unthinned				Thinned Ten Years Previously			
	50-Year Site Class				50-year Site Class			
In 1989	IV	III	II	I	IV	III	II	I
35	59	75	90	106	69	85	99	116
45	78	99	121	136	87	109	130	145
55	94	120	140	157	103	129	149	167
65	108	133	151	169	117	142	160	179

Notes:

(1) Derived by applying a 3% "real" increase to the prices of Table 12.

(2) Values in Table 13 are in 1979 dollars.

"real" rates of return because they are in terms of constant 1979 dollars. Effects of inflation have been removed. An investment earning a 6% "real" rate over a period of time during which the inflation rate averaged 8% would show a return of 14% if inflated prices were used in the analysis.

In order to be consistent, interest earned in Table 15 should be compared with an alternative rate of return (or minimum rate which must be earned in order for the investment to be profitable) that is itself "real" or free of inflated earnings.

Over many years, and in spite of the ups and downs of inflation, the "real" rate of return on conservative low-risk investments has run around 3 to 4%. Since forestry investments involve greater risks it is reasonable to require that they earn a higher rate, which will vary with individual organizations. If, for example, a 6% rate is required on forestry investments, the data in Table 15 would suggest that no unthinned 25-year-old stands should be fertilized, but fertilization of sites II and III thinned stands of this age would be marginally profitable.

Table 14. Estimated 10 Year Value Gain from One Fertilization-1979 Dollars

Douglas-fir (Dollars/Acre)

Stand Age	Unthinned				Thinned Ten Years Previously			
	50-Year Site Class				50-Year Site Class			
In 1979	IV	III	II	I	IV	III	II	I
25	58	68	71	65	79	90	92	82
35	92	108	106	95	115	134	131	116
45	121	142	133	116	147	170	161	142
55	147	164	149	130	175	196	181	156

Notes:

(1) 200 pounds nitrogen per acre

(2) Values in Table 14 are in 1979 dollars

Table 15. Estimated "Real" Rate of Interest Earned on Fertilizer Investment, 1979-1989

Douglas-fir (Percent)

Stand Age when Fertilized	Fertilizer Applied to Unthinned Stands: 50-Year Site Class IV	III	II	I	Fertilizer Applied to Previously Thinned Stands: 50-Year Site Class IV	III	II	I
25	1.5	3.1	3.6	2.7	4.7	6.1	6.3	5.1
35	6.3	8.0	7.8	6.6	8.7	10.4	10.1	8.8
45	9.2	11.0	10.3	8.8	11.4	13.0	12.4	11.0
55	11.4	12.6	11.5	10.0	13.3	14.6	13.7	12.1

Notes:

(1) 1979 fertilizer cost is assumed to be $50/acre for 200 pounds nitrogen per acre

(2) Thinning cost is not included in the above results. Thinning is presumed to have been carried out prior to fertilization.

Rates of return in Table 15 can be used as an index of relative profitability, and stands may be ranked accordingly. The result is Table 16, which allows an assessment of the importance of choosing previously thinned stands for fertilization. Since the top four priorities are all thinned stands, and eight out of the top twelve are thinned stands, we conclude that thinned stands, if available, offer attractive opportunities for fertilization. This advice must be tempered with the caution not to ignore site and age in picking stands to fertilize, as is also apparent in Table 16. And of course, do not ignore other determinants of wood value such as difficulty of logging and accessibility.

Note that this analysis does not include the cost of thinning, but merely has been made independently, or that previously thinned stands are already available as candidates for fertilizer.

Table 16. Stand Priorities for Fertilization

Douglas-fir

Stand Age when Fertilized	Fertilizer Applied to Unthinned Stands: 50-Year Site Class IV	III	II	I	Fertilizer Applied to Previously Thinned Stands: 50-Year Site Class IV	III	II	I
25	32	30	29	31	28	26	24*	27
35	24*	21	22	23	20	13	15	18*
45	17	11*	14	18*	9*	4	6	11*
55	9*	5	8	16	3	1	2	7

Notes:

(1) * = tie

(2) Ranking based on rate of return

(3) Thinning cost is not included

VI. FOREST FERTILIZATION AND THE AGE GAP PROBLEM

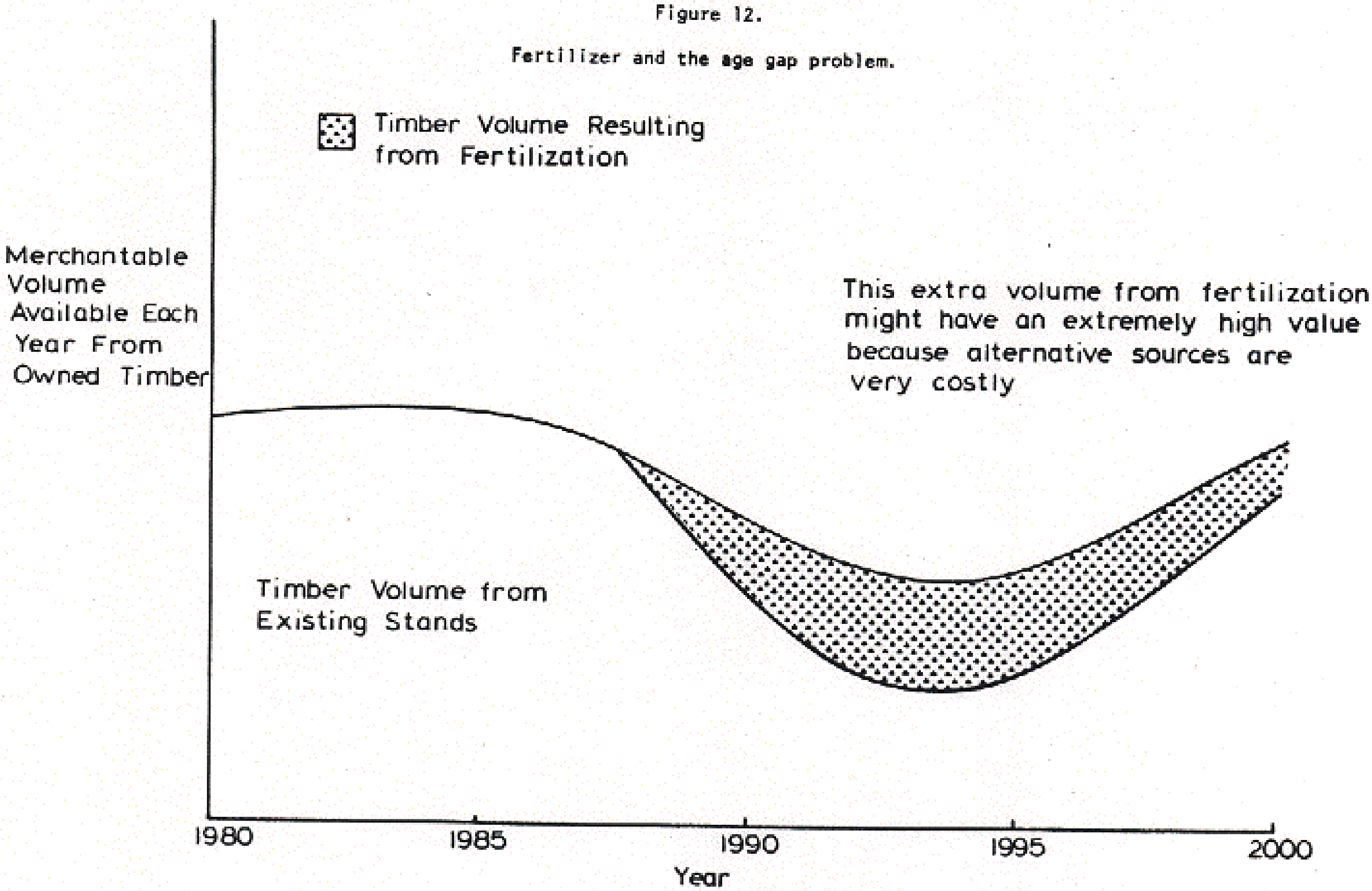
The situation in which one or more age classes of timber are not adequately represented in a forest is known as the age-gap problem. When cutting reaches a timber-deficient age class, it is necessary to adjust harvest level, log source, or both. In western Oregon and western Washington the age-gap problem is one of the major factors affecting timber supply. For a number of forest owners a large adjustment of cut is unavoidable. Such an adjustment is, in fact, currently underway.

What can a forest manager do when faced with an age-gap problem? Several alternatives exist. For example, merchantable timber can be cut out, production facilities closed, and a holding operation mounted until young timber matures. Such a solution has drastic consequences, not only for the organization involved but for the forest community in which it operates. Another alternative for dealing with the age-gap problem is to attempt to keep the operation running by an increasing reliance on log purchases from public agencies or on the open market. This solution is, in fact, being pursued by an increasing number of timber companies. Wood supply costs in the form of purchased stumpage or logs can be expected to increase dramatically in the Northwest as demands increase and public agency allowable cuts decrease from a shrinking forest base and environmental constraints.

A third way of facing a decline of self-owned merchantable timber is by combining the first two alternatives, and adding a program of intensive forestry. This approach involves some retrenchment of production, investment in facilities for processing small logs, open market wood purchases, and management of existing young stands to bring them to merchantable size as soon as possible. Such a management program includes thinning to concentrate growth on fewer stems, and

Figure 12.

Fertilizer and the age gap problem.



fertilization to increase growth of these stems. When used in this manner, forest fertilization may provide a value return that is extremely high. This might be termed the "strategic value" of forest fertilization. Such high values are imputed to forest fertilization because of the substitution of fertilizer-produced wood for high-priced purchases logs and stumpage. Figure 12 depicts this phenomenon. Thus the value of a thinning fertilizer program might be higher than expected if it reduces dependence on open-market wood purchases. Fertilizer, in fact, may well offer the only way of increasing growth of existing young stands. Certainly, forest fertilization can play an important role in coping with the age-gap problem.

VII. REGIONAL GROWTH AND RESPONSE ANALYSIS OF THE TOTAL STAND FOR THINNED WESTERN HEMLOCK, FOUR YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

A total of eight western hemlock installations, each with six plots 1/10-acre or larger, received the following treatments in Phase II:

16 Plots-thinned and unfertilized.
16 Plots-thinned and 200 lbs. N
16 Plots-thinned and 400 lbs. N

Analysis of the data in its entirety revealed no significant differences in average growth rate among these three treatments. The data were then stratified into two geographical areas and into two age groups within the areas and tested for differences. Finally the results were compared with a similar analysis completed for the Western Hemlock installations of Phase I (four years after fertilizer application).

A statistically significant difference (at 95% confidence level) in mean growth rates between fertilized and unfertilized stands was considered a significant response. This section is concerned with:

1). Response to 200 lb.-N application on younger (12-23 years) and older (24-35 years) thinned hemlock stands within the Coastal area.
2). Response to 200 lb.-N application on younger (12-23 years) and older (24-35 years) thinned hemlock stands within the Cascade area.
3). Contrast of response to fertilizer between Phase I (unthinned) stands and Phase II (thinned) stands.

Results of Analysis

1. Basal area gross p.a.i.
    i) The younger stands in the Coastal area had a statistically significant response of 22% (Table 17).
    ii) The younger stands and older stands showed a 32% and 10% respective response (Table 17) in the Cascade area.
    iii) The only statistically significant response to fertilizer on the unthinned stands of Phase I was 17% in the Cascade younger stands (Table 18).

2. Volume gross p.a.i.
   i) There was no significant response for either age group in the Coastal area.
   ii) The younger stands of the Cascade area exhibit a statistically significant response of 25% (Table 17).
   iii) For the unthinned stands of Phase I, the strata showed no significant response to fertilizer.

Conclusions

For unthinned stands (Phase I) the only significant response to fertilizer appears in the younger (12-23 years) stands of the Cascades. The Phase II plots also exhibited the best response to fertilizer in combination with thinning in this stratum.

Table 17.

Results of tests for significant (95% confidence level) differences between mean total growth rate of thinned unfertilized stands and mean total growth rate of thinned fertilized (200 lbs.-N/ac.) stands for Western Hemlock.

Phase II

Four-year Response of Basal Area p.a.i.
(sq.ft./ac./yr.; min. d.b.h. = 1.55 in.)

	Younger (12-23 yrs.)	Older (24-35 yrs.)
CASCADE	diff = 3.575 (32%) s.e. = 1.78436 n = 8 significant	diff = 0.65 (10%) s.e. = .24664 n = 8 significant
COASTAL	diff = 2.375 (22%) s.e. = 1.06605 n = 8 significant	diff = 0.65 s.e. = .65796 n = 8 nonsignificant

Four-year Response of Volume p.a.i.
(cu.ft./ac./yr.; min. d.b.h. = 1.55 in.)

	Younger (21-23 yrs.)	Older (24-35 yrs.)
CASCADE	diff = 70.75 (25%) s.e. = 23.9 n = 8 significant	diff = -9.0 s.e. = 24.0 n = 8 nonsignificant
COASTAL	diff = 45.0 s.e. = 41.9 n = 8 nonsignificant	diff = 8.5 s.e. = 52.8 n = 8 nonsignificant

Table 18.

Results of tests for significant (95% confidence level) differences between mean total growth rate of unthinned unfertilized stands and mean total growth rate of unthinned fertilized (200 lbs.-N/ac.) stands for Western Hemlock.

Phase I

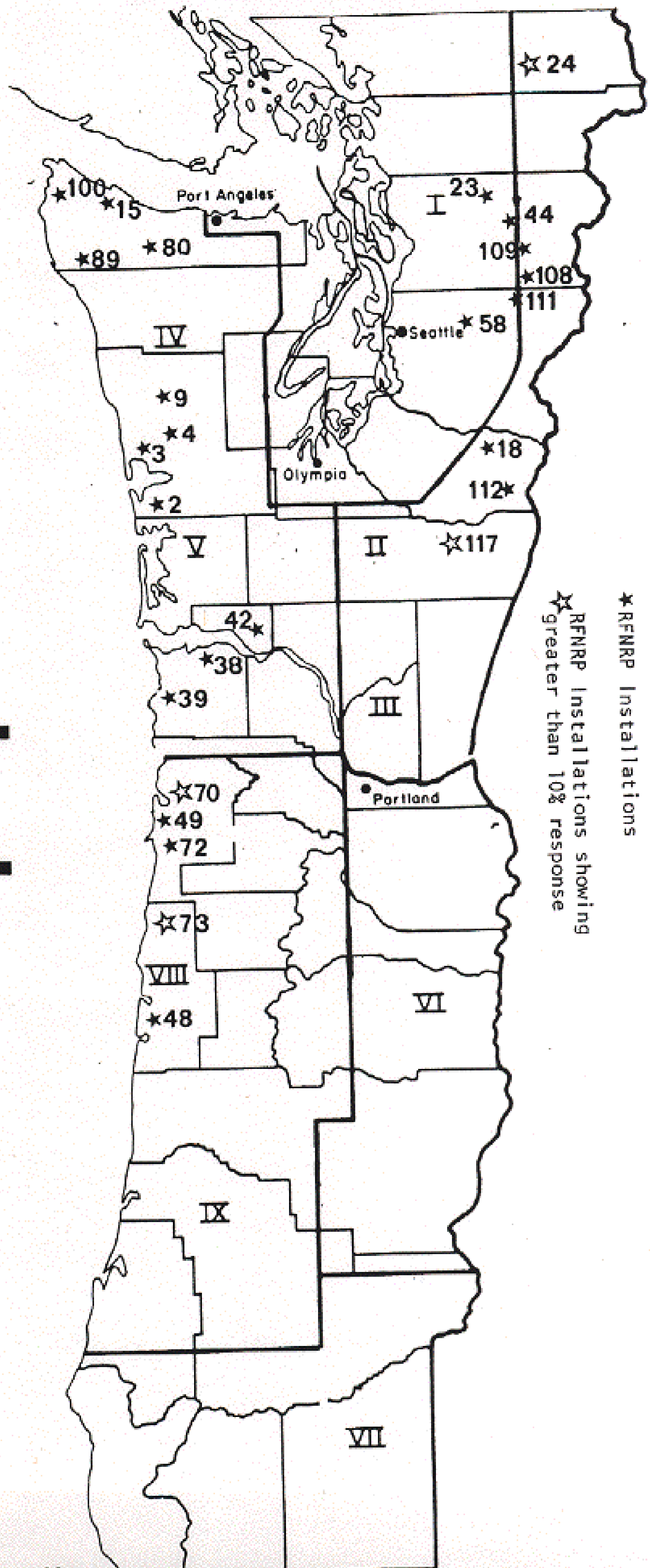
Four-year Response of Basal Area p.a.i.
(sq.ft./ac./yr.; min. d.b.h. = 1.55 in.)

	Younger (12-23 yrs.)	Older (24-35 yrs.)
CASCADE	diff = 2.288 (17%) s.e. = .73774 n = 16 significant	diff = .686 s.e. = .84118 n = 15 nonsignificant
COASTAL	diff = -.496 s.e. = 1.1002 n = 17 nonsignificant	diff = -.618 s.e. = .5724 n = 26 nonsignificant

Four-year Response of Volume p.a.i.
(cu.ft./ac./yr.; min. d.b.h. = 1.55 in.)

	Younger (12-23 yrs.)	Older (24-35 yrs.)
CASCADE	diff = 37.2 s.e. = 25.8 n = 16 nonsignificant	diff = 12.7 s.e. = 42.2 n = 15 nonsignificant
COASTAL	diff = -14.5 s.e. = 46.8 n = 17 nonsignificant	diff = -18.6 s.e. = 26.6 n = 26 nonsignificant

WESTERN HEMLOCK PLOT LOCATIONS



VIII RADIAL INCREMENT RESPONSE ANALYSIS OF UNTHINNED WESTERN HEMLOCK, UP TO NINE YEARS FOLLOWING FERTILIZER APPLICATION.

Introduction

All undamaged Phase I western hemlock installations (26) were analyzed using a "paired tree" approach. This study was undertaken to verify patterns of treatment response arising from the use of standard plot-comparison analytical techniques.

The specific goal of this study was to determine if there had been a change in the radial growth trend of upper crown class individuals as a result of fertilization 8 to 9 years previously. It is not possible by this abbreviated type of analysis to provide per-acre volume or basal area growth response figures.

Tree pairs were selected using current tree attributes such as d.b.h., crown class, and species, along with pretreatment radial growth trends. The latter greatly increased the sensitivity of the tree pairing process, as it provided a means of comparing an individual's radial growth pattern as well as its size and competitive relationship at a specific point in time.

Tree pairing or grouping is based on the premise that if two or more individuals are currently the same size, crown class, and species, and during the past years have grown radially at approximately the same rate, they will continue to grow at the same rate in the near future. Thus, once suitable pairs or groupings are made using these criteria, differences in future radial growth between control and treated individuals could be considered due to treatment.

Using plot records prior to field visits, each Phase I western hemlock installation was screened for potential sample trees to be used in the paired tree analysis. On each installation, sample tree selection was confined to dominant and codominant crown classes. An installation sample consisted of 15 trees per plot (30 trees/treatment) with a target ratio of dominant and codominant trees of 2:1. Caliper measurement points were marked and used to locate increment coring points. Due to the common oval-shape exhibited by hemlock trunks, each tree was cored at the most northerly point along the long axis and at the caliper measurement point 90° clockwise.

In the laboratory, each increment core was sanded and prepared for measurement with a binocular telescope and electronic core measuring instrument. Annual radial increment was measured and recorded for a 20-year period of each core. Average annual radial increment was computed for each sample tree. These data were then compiled and placed into a computer analysis routine that grouped sample trees within an installation, based on the following criteria: a) d.b.h. within 1.0 inches, b) same crown class, c) mean 7-year pretreatment radial growth within 0.005 inches.

Based on these groupings, comparisons between treatments were made to evaluate response or lack of response. Deviations between treated and control sample trees were considered related to treatment. A table of results is shown in Appendix A (A-11).

Results

In general, results substantiate previous indications of a prevalent lack of hemlock fertilizer response, especially on coastal sites. As with previous work, there is wide variability. Percent radial growth response for all 26 installations was a positive 4% for both 200 and 400 pound treatments (± 15% and ± 17% respectively). The 15-24 year age class (breast height age at time of treatment in 1969 or 1970) showed the highest and most consistent response (Figure 13), whereas no significant site relationship was detected (Figure 14). Generally, the Washington Cascade province showed more consistent results than the Washington and Oregon coastal provinces, although it did not stand out as an average high-responding area.

Only four installations (numbers 24, 70, 73, and 117) in all provinces registered a 10% or greater response in both 200 pound and 400 pound treatments. Of these, only the two installations (24 and 117) in the Washington Cascades responded significantly above .90 probability level of

Figure 13.

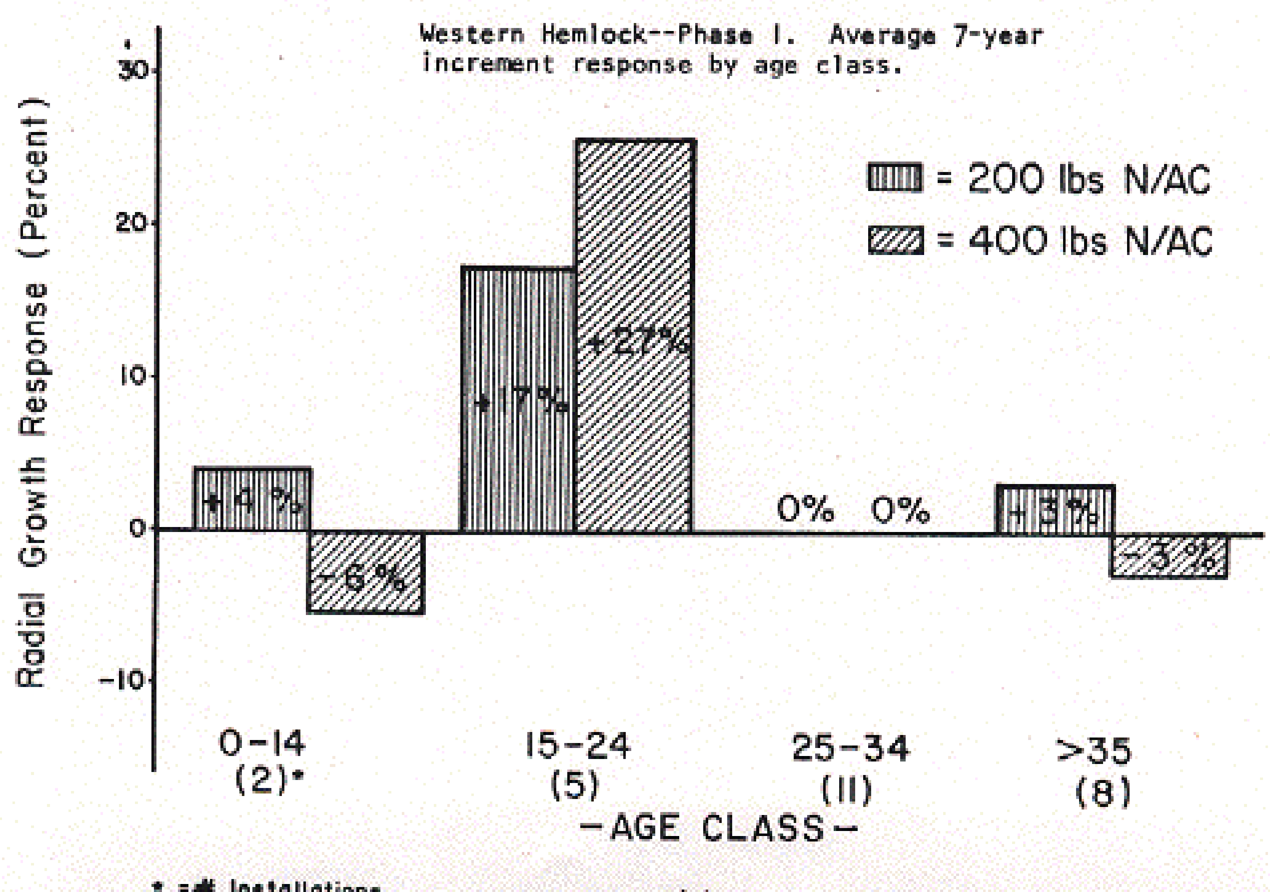
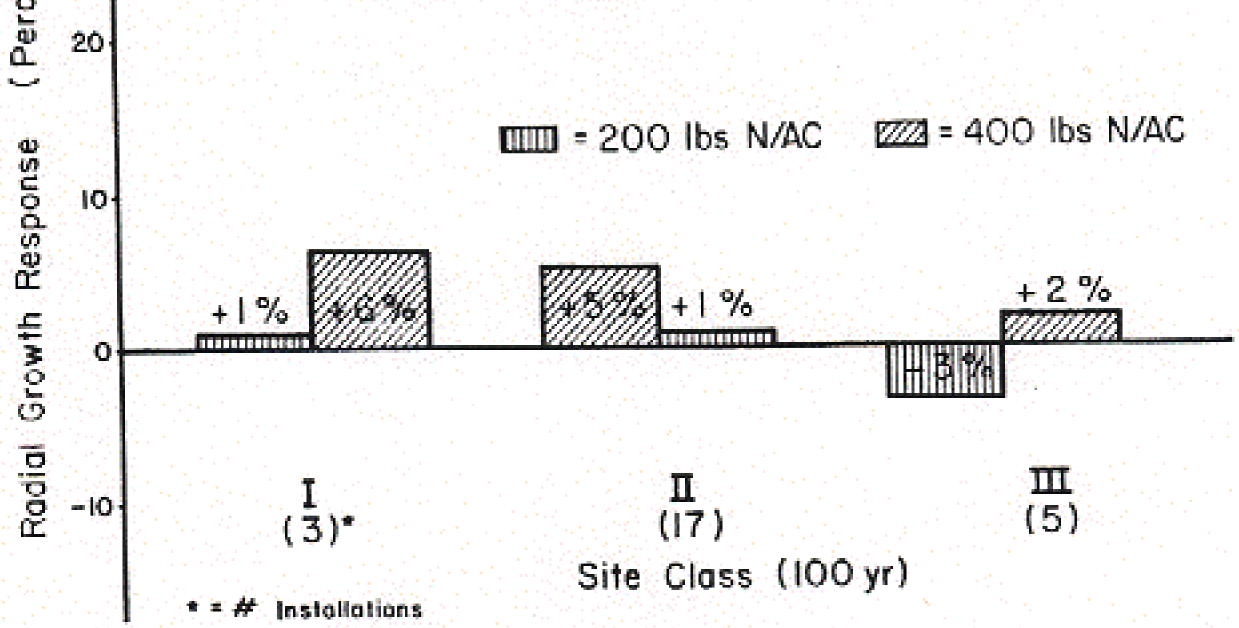


Figure 14.

Western Hemlock--Phase I. Average 7-year increment response by site class.



the calculated paired-t value. Installations with this level of significance are underlined in the following paragraphs.

An additional four installations (all in the Washington Coastal Province) produced a 10% or greater response in the 200 pound treatment only (numbers 15, 38, 42 and 80). Finally, three other installations had a ten percent or greater response in the 400 pound treatment only (numbers 72-Ore. Coast, 109, and 112-both Wash. Cascades). Hence, a total of 11 out of 26 installations showed 10% greater response to one or both fertilizer levels.

As was the case in previous hemlock plot-comparison studies, nonresponse to fertilization was also exhibited in all provinces. Two Washington coastal installations (numbers 2 and 3) exhibited lesser post-treatment growth by 10% or more in both the 200 and 400 pound plots when compared to the growth of their control plots. In all but the 400 pound treatment of installation 2, this was significant above a .90 probability level. Two Washington Cascades' installations (numbers 58 and 109), and two Oregon Coastal installations (numbers 48 and 49) exhibited lesser growth by 10% or more in the 200 pound treatment than in the control. Three additional installations (number 111-Wash. Cascades, 42, and 100-both Wash. Coast) exhibited lesser growth by 10% or more in the 400 pound treatment than in the control. Hence, a total of 9 out of 26 installations showed a lesser growth by 10% or more in one or both fertilizer levels when compared to controls. Two of these installations (numbers 42 and 109) had registered a positive response in one treatment (see previous paragraph).

Based on site observations made at time of core sampling, several nonresponding areas were noted as having been significantly damaged by disease, weather, or man. In most cases, this damage was not uniformly distributed throughout the installation, creating a differential impact on growth. Further assessment of damage and structure differences between plots within an installation is needed to clarify the lack of response phenomenon.

Possible reasons for variability in hemlock response estimates, apart from the obvious explanation that actual growth and response patterns are indeed highly variable, include installations being partially damaged, the low numerical magnitude of growth and response, particularly in older installations (and hence the difficulty of employing sufficiently sensitive measurements), and the use in this analysis of a simple mean pretreatment growth figure based on 7 years, whereas trends might have been in effect within that 7-year increment to alter subsequent growth predictions one way or another.

Conclusions

The only significant response to both fertilizer levels was found in the "young" installations of the Cascade province, which substantiates results of other hemlock studies by RFNRP. But the overall lack of response exhibited by unthinned hemlock raises many questions. Is it related to available growing space at time of treatment, response being registered at higher levels on the stem, adequate natural levels of available nitrogen, growth limitations resulting from shortages of other nutrients, suitability of nitrogen forms other than urea, or widespread presence of root-rot disease? These questions are unanswered, but are the subject of current and future investigations under RFNRP.

IX RECENT FINDINGS AND PROPOSED NEW WORK

The findings from each phase of the study are reported in the preceding sections. Summarized below are some specific points of importance in planning the future program. In part these are results that reveal some deficiencies of the past studies which should now be given special consideration in plans for future work, as follows:

1) In the Phase I unthinned fertilized stands, the range of basal area per acre in the study plots is generally high, because the plots were chosen to represent "well-stocked" stands. Some stands now being fertilized by cooperators have lower stocking, but since our data do not cover that lower range of basal area we cannot predict response effectively for those stands. Also, there is no opportunity at present to compare response in stands with low stocking due to thinning, with that in stands with equally low stocking due to natural causes.

2) Similarly, the project plots represent stands of age class 10-60 years, and some cooperators have large areas of older stands for which they need estimates of potential response to fertilizer.

3) The unthinned hemlock stands, in general, show little or no response to fertilizer, and it appears this may be associated with very high density in these stands. Therefore, it may be best to concentrate more on fertilizer response in thinned stands of hemlock.

4) All the response figures originate from plots carefully treated to exact dosage levels, uniformly applied by hand. But the estimates from these are being used to predict the outcome of operational applications over large areas with much less control over uniformity of dosage, and very little control over the diversity of stand composition and density. There is some concern that there may be "operational falldown," a lesser amount of response than under experimental conditions. Hence, a study is warranted to estimate the likely magnitude of this falldown.

It is partly on the basis of these findings that the proposals for future work have been drafted.

X OUTLINE OF PHASE IV PROPOSAL

The following is an outline of the proposal for a 5-year extension of the Regional Forest Nutrition Research Project, from July 1, 1980 through June 30, 1985. Much of the planned work revolves around data from permanent plots already established, which become more valuable with age, both with respect to fertilizer recommendations and to forest productivity information. It is also proposed to extend work into new areas thought to represent the most important unanswered current questions in forest fertilization and thinning which have direct application to field practice.

Continuation of Existing Work

The organizational structure of the project has provided a harmonious marriage between operational questions of the cooperators and applied research interests of the College. Future research activities will continue to be practically-oriented and will seek to clarify operational fertilization problems. As promising techniques are developed, they will be applied and tested in the overall context of the pProject's design.

1. Remeasurement and retreatment of existing plots.

The approximately 1450 Phase I, II, and III plots form the basic strength of RFNRP. By July, 1980, measurements will have been carried out for as long as ten years after the first treatment. At eight years half of the unthinned Douglas-fir plots were refertilized, and the other half left to grow under the effects of the first treatment. This scheme will provide data on duration of response from one treatment as well as on response to a second treatment. Retreatments are also recommended for Phase I hemlock plots and for Phase II plots in the future.

2. Continuation of work in methods for estimating fertilizer response.

Estimating regional fertilizer response. In order to make recommendations on fertilizer practices is the primary goal of RFNRP, and consequently experimental design and analysis techniques appropriate to that goal are employed. However, there is also a need for close examination of response patterns on a local basis. Pilot studies undertaken to date indicate value in performing additional intensive mensurational work on Phase I and Phase II data, including multiple-element plots established in Phase II. Sufficient time has now elapsed since initial treatment to present a clearer picture of the effects of stand structure and other natural causes of variation on response patterns within specific areas.

3. Continuation of work in predicting fertilizer response.

In addition to development of mensurational techniques to measure response, several approaches turned up by soils and foliage studies conducted to date warrant wide investigation. For instance, trees growing on soils of different parent materials seem to vary in their ability to respond to fertilizer. Further efforts are required to determine the usefulness of these techniques and to refine sampling procedures. The primary goal of such work is to derive relatively inexpensive methods of predicting fertilizer response prior to treatment. Removal of the uncertainty surrounding treatment of specific stands has the potential to vastly increase the profitability of forest fertilization.

4. Continuation of work in the economics of forest fertilization.

With respect to economics, future work includes continued sophistication of techniques for measuring profitability and assigning priorities for treatment, as well as the quantification of response to fertilizer in terms of changes in log size. Large logs are not only cheaper to harvest than small logs, but yield a higher product value per unit of volume. Size increase due to fertilizer is a major contributor to the profitability of forest fertilization.

New Activities in Phase IV

The Regional Forest Nutrition Research Project is approximately ten years old. That relatively short period of time has witnessed remarkable changes in forest practices in the Douglas-fir region. Increasing emphasis on young-stand management has developed in conjunction with greater intensity of management efforts. As the principal intensive-silviculture data base in the region, RFNRP should continue to promote the development of information needed for the transition to the "third forest".

Similarly, knowledge gained since the inception of RFNRP has indicated several important gaps in the data base which are of immediate concern to the management of widespread areas of existing Pacific Northwest stands. This proposal addresses several of these situations which are judged to merit further empirical investigation.

1. Fertilization and thinning in man-made forests.

Forests under management today can be characterized as to whether or not they have undergone early spacing control. Most current young-growth management efforts have been aimed at naturally regenerated, unspaced stands. To date, work under RFNRP has reflected this situation, and has concentrated on fertilization and thinning of natural stands. Managed forests of the future will frequently grow under controlled spacing conditions. It is therefore essential to begin laying groundwork for growth and yield projections in these man-made forests. It is proposed to establish a number of study areas 8-15 year-old plantations representing a range of site and geographic conditions.

2. Fertilizer response in areas of less than full stocking.

Plots established to date under RFNRP have been deliberately selected to represent heavy stocking conditions. Consequently, the effects of lesser stocking levels on response cannot be completely assessed with current data, even though it is recognized that operational fertilization areas are generally less fully stocked (on the average) than are research plots. The effect of fertilizer response on under-stocked stands and "average" forest conditions must be measured if the economic assessment of operational fertilizer programs is to be accurately determined. The fundamental approach will be to study relatively few areas, but study these areas in detail using large plots, more than two replications of treatment, and intensive mensurational techniques. Stands of wide variability in stocking (40-80 percent of normal) will be studied.

3. Assessment of "operational falldown".

Concern has often been expressed over a possible "operational falldown" in response. This might happen because of differences between operational treatments and experimental treatments, or because of differences in average stand conditions and sample plot conditions. To the extent that a reduction in stocking is involved in this response difference it will be investigated under Part 2 above. Variation in application uniformity, however, still remains to be assessed. RFNRP plots have been hand-fertilized under carefully controlled conditions. It is proposed that several stands which were fertilized operationally in the past will be investigated to determine response. It is also proposed that several new operational fertilizations will be investigated to determine fertilizer distribution and its effect on response.

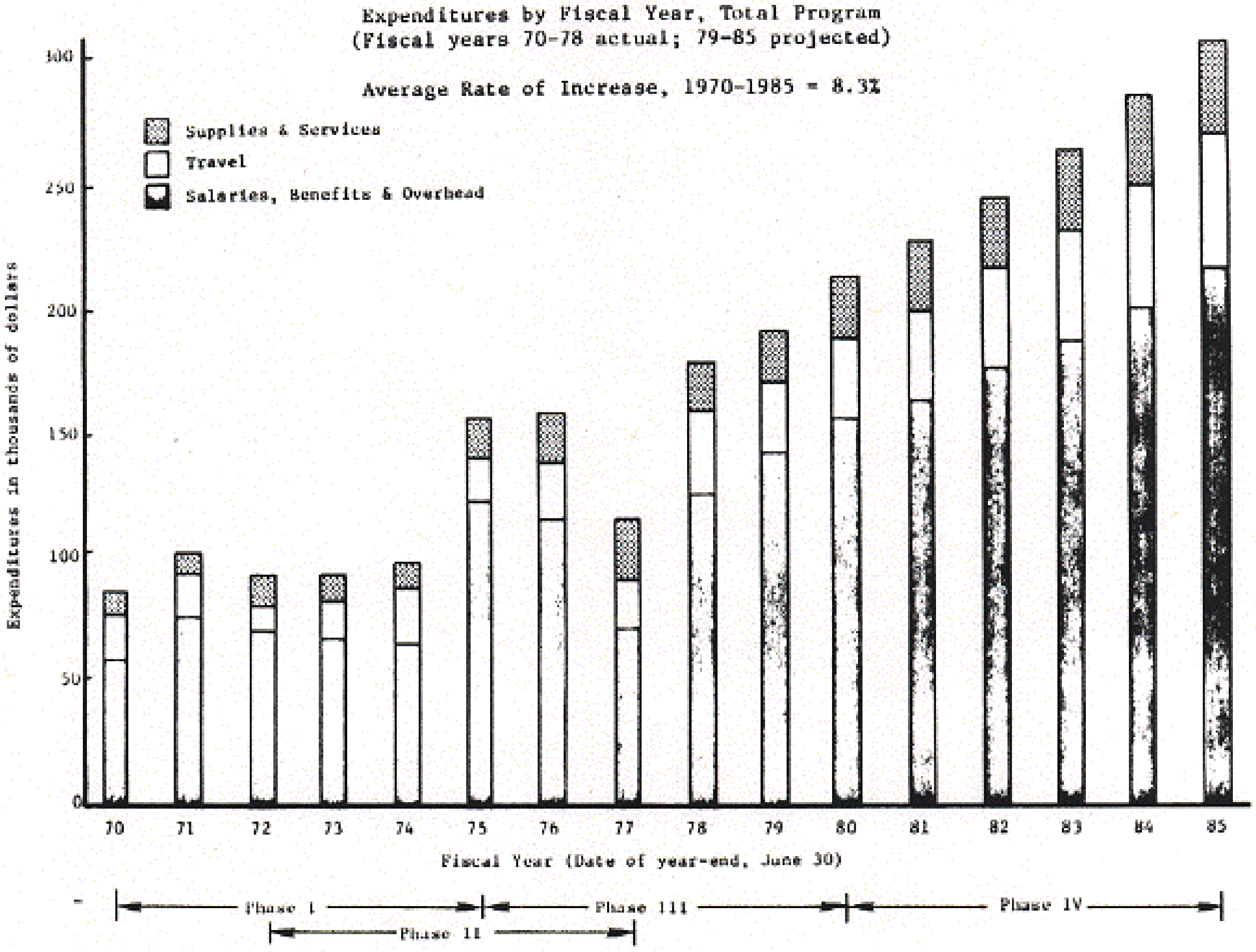
4. Response in older stands.

Economic studies indicate that fertilizer should be applied where stumpage values are high. A vast acreage of Douglas-fir stands 60-100 years old exists in Oregon and Washington and will be a critical part of the timber supply picture for many years. Data are incomplete about fertilizer response in such stands, as RFNRP plots were all less than 60 years old when treated. It is proposed to throughly review existing information and perhaps establish several installations in stands aged 60-100 years.

The budget for Phase IV would essentially continue current funding levels as adjusted for inflation. The proceeding outline is not quantitatively specific as to Phase IV plans, and not all the above items are considered to be of equal weight. However, this summary does emphasize the general directions anticipated for RFNRP as it enters its second decade of involvement in this tremendously exciting period of Pacific Northwest Forestry.

REGIONAL FOREST NUTRITION RESEARCH PROJECT

Expenditures by Fiscal Year, Total Program
(Fiscal years 70-78 actual; 79-85 projected)



BUDGET SUMMARY

Expenditures all phases from Project Initiation to June 30, 1978

Fiscal Year	Salaries, Benefits, Overhead	Travel	Supplies, Equipment, Contractual Services	Annual Total	Cumulative Total
69-70	$ 57,296.52	$17,179.92	$10,580.33	$ 85,056.77	$ 85,056.77
70-71	77,052.25	18,052.08	5,663.31	100,767.64	185,824.41
71-72	69,875.49	12,680.81	10,339.28	92,895.58	278,719.99
72-73	68,945.49	14,581.74	9,016.18	92,543.41	371,263.40
73-74	67,002.83	19,731.71	9,628.02	96,362.56	467,625.96
74-75	122,735.47	16,123.71	15,951.16	154,810.34*	622,436.30
75-76	114,786.86	23,355.79	16,957.83	155,100.48	777,536.78
76-77	69,623.56	19,154.61	22,843.42	111,621.59**	889,158.37
77-78	124,438.34	33,071.33	16,997.31	174,506.98	
			9 year total:		1,063,665.35

* Initiation Phase III

** During F.Y. 76-77 it was possible to shift certain project personnel to other budgets for supplemental studies.

Cooperators Liaison Committee

G. M. Bowe	Barringer and Associates, Inc.
E. C. Scheider	Boise Cascade Corporation
Byron Thomas	Bureau of Land Management
Jeff Madsen	Champion International Corporation
R. D. Johnson	Chevron Chemical Company
W. E. Duggins	Collier Carbon & Chemical Corp.
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Steve Webster	Weyerhaeuser Research Center

RFNRP - PERSONNEL

College of Forest Resources Staff

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Gerard F. Schreuder	Director, Center for Resource Management Studies
William A. Atkinson	Project Supervisor
Ian G. Morison	Soils Program Supervisor
Kenneth J. Turnbull	Mensuration Director
Krishna P. Rustagi	Mensuration Associate
Steven G. Archie	Fiscal Coordinator
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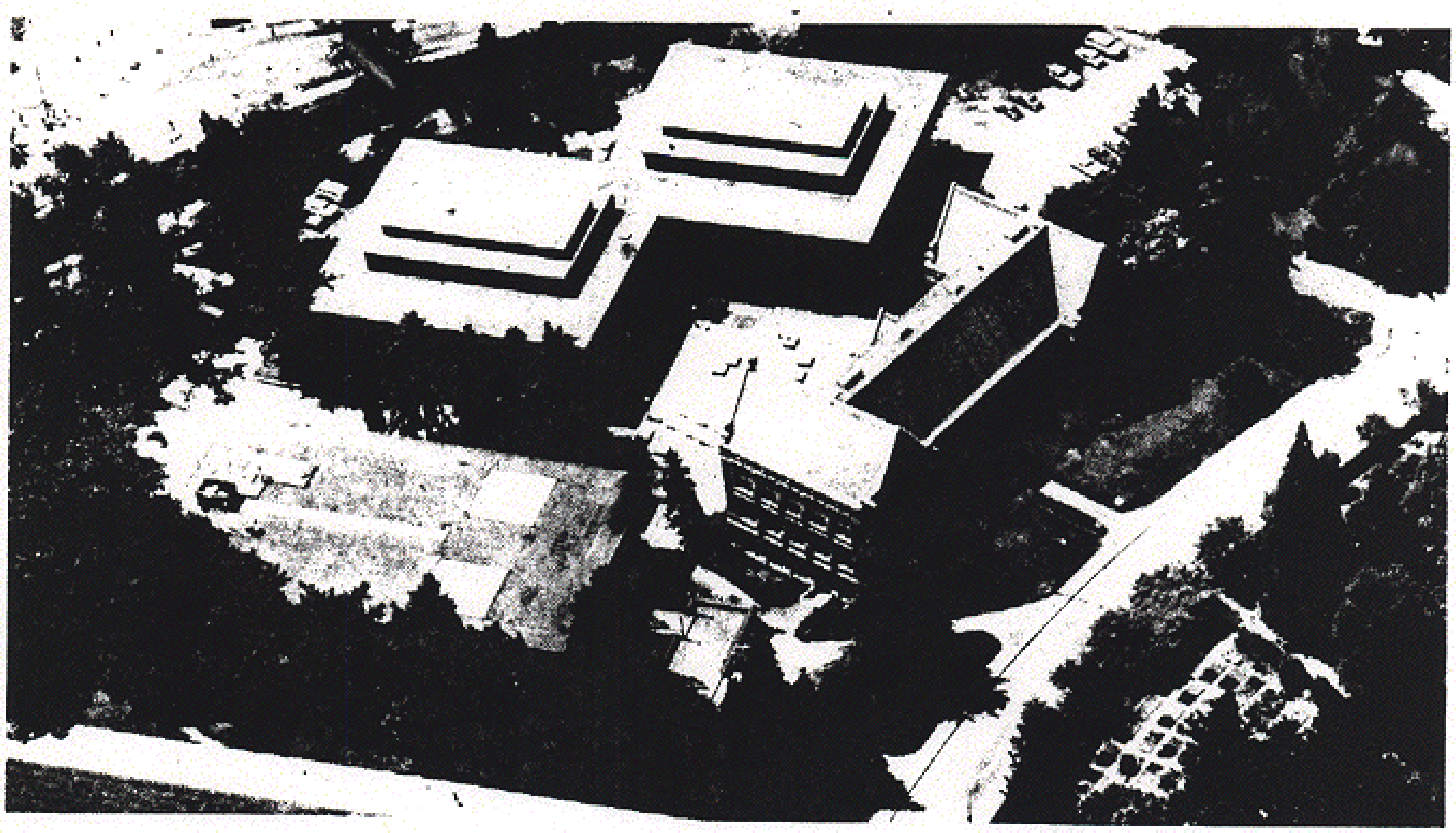
William M. Bizak	Field Technician
Charles E. Peterson	Project Mensurationist
Albert L. Becker	Data Manager



APPENDIX A

(Mensurational Studies)

DOUGLAS-FIR

Tables

A-1	Phase I total stand plot distribution
A-2	Phase I total stand estimates of initial volume
A-3	Phase I total stand estimates of initial basal area
A-4	Phase I merchantable stand plot distribution
A-5	Phase I merchantable stand estimates of initial volume
A-6	Phase I merchantable stand estimates of initial basal area
A-7	Phase II total stand plot distribution (by Age and Site)
A-8	Phase II total stand plot distribution (by Age and Basal Area)
A-9	Phase II total stand estimates of initial volume
A-10	Phase II total stand estimates of initial basal area

WESTERN HEMLOCK

A-11	Phase I radial increment analysis

Table A-1.

Distribution of 1/10-acre plots used in 6-year total gross response analysis of unthinned Douglas-fir. 401 plots

B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	0	2	3	1	-
	200	2	2	-	-
	400	2	2	1	-
20	0	3	11	11	1
	200	3	15	9	2
	400	1	9	13	-
30	0	10	21	11	5
	200	12	14	14	9
	400	14	14	15	8
40	0	3	14	13	7
	200	1	19	15	7
	400	1	23	13	5
50	0	2	7	4	2
	200	2	4	5	3
	400	2	3	6	-

Table A-2.

Estimated mean initial total volume for unthinned Douglas-fir. (cubic feet/acre, minimum d.b.h. = 1.55 inches)

Site Index

B.H. Age	80	90	100	110	120	130	140	150
10	264.6	307.7	352.0	397.7	444.4	492.3	541.3	591.2
15	901.4	1082.0	1273.0	1476.7	1689.9	1913.1	2145.9	2388.1
20	1676.5	2044.7	2442.1	2867.7	3320.6	3800.3	4305.9	4836.9
25	2444.0	3009.4	3625.2	4290.1	5003.1	5763.1	6569.4	7421.1
30	3151.7	3905.8	4731.9	5628.9	6595.4	7630.4	8732.9	9902.1
35	3787.8	4715.4	5736.2	6848.8	8051.9	9344.4	10725.4	12193.9
40	4354.8	5439.9	6637.9	7947.3	9367.0	10895.0	12533.2	14277.8
45	4860.0	6087.2	7445.4	8933.3	10549.9	12294.2	14165.3	16162.3
50	5311.4	6666.8	8169.9	9819.5	11614.8	13554.8	15638.5	17865.5

Table A-3.

Estimated mean initial total basal area for unthinned Douglas-fir.
(square feet/acre, minimum d.b.h. = 1.55 inches)

B.H. Age	Site Index 80	90	100	110	120	130	140	150
10	40.8	42.4	43.8	45.1	46.4	47.6	48.7	49.8
15	84.5	89.8	94.8	99.6	104.2	108.6	112.8	116.9
20	118.2	127.1	135.6	143.8	151.6	159.3	166.7	173.9
25	142.0	153.8	165.1	175.0	186.7	197.0	207.1	217.0
30	158.7	172.5	186.1	199.2	212.0	224.4	236.6	248.6
35	170.4	186.0	201.1	215.8	230.2	244.3	258.1	271.6
40	178.6	195.4	211.8	227.8	243.4	258.7	273.8	288.6
45	184.4	202.1	219.4	236.4	253.0	269.3	285.3	301.0
50	188.5	206.9	224.9	242.6	259.9	276.9	293.7	310.2

Table A-4.

Distribution of 1/10-acre plots used in 6-year merchantable gross response analysis of unthinned Douglas-fir. 386 plots

B.H. AGE CLASS (yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
15	0	1	1	2	-
	200	2	1	2	-
	400	-	2	1	-
25	0	14	22	7	3
	200	16	24	12	5
	400	17	25	9	2
35	0	5	17	16	7
	200	4	17	10	11
	400	1	14	20	9
45	0	4	12	9	5
	200	3	13	12	2
	400	2	15	9	1

Table A-5.

Estimated mean initial merchantable volume for unthinned Douglas-fir.
(cubic feet/acre, minimum d.b.h. = 6.55 inches to a 4 inch top)

B.H. Age	Site Index 80	90	100	110	120	130	140	150
20	-	-	439.1	939.7	1487.9	2074.8	2693.6	3338.4
25	367.7	1005.0	1726.2	2515.5	3360.7	4252.4	5184.0	6150.6
30	1215.0	2090.4	3057.5	4099.9	5206.1	6368.2	7581.5	8843.1
35	2038.0	3115.5	4290.8	5548.9	6880.6	8280.3	9745.7	11276.2
40	2789.5	4036.5	5387.8	6831.0	8359.4	9970.2	11663.3	13439.6
45	3458.7	4849.1	6351.2	7955.5	9658.1	11458.7	13358.8	15360.5
50	4049.7	5563.1	7196.4	8943.2	10802.2	12774.8	14864.0	17072.9

Table A-6.

Estimated mean initial merchantable basal area for unthinned Douglas-fir. (square feet/acre, minimum d.b.h. = 6.55 inches)

B.H. Age	Site Index 80	90	100	110	120	130	140	150
20	-	-	11.9	39.9	65.0	87.3	107.3	125.0
25	7.1	43.9	76.4	105.0	130.1	152.3	171.9	189.4
30	55.6	92.3	124.2	151.8	176.0	197.3	216.3	233.4
35	91.7	127.2	157.7	184.1	207.2	227.7	246.3	263.4
40	118.0	152.0	181.0	206.2	228.4	248.5	266.9	284.1
45	137.1	169.5	197.2	221.4	243.1	262.9	281.3	298.7
50	150.9	181.9	208.5	232.1	253.3	273.0	291.4	309.1

Table A-7.

Distribution of 1/10-acre plots used in 4-year total gross response analysis of thinned Douglas-fir. 191 plots

B.H. AGE CLASS (Yrs.)	TREATMENT (Pounds of N per acre)	SITE CLASS I	II	III	IV
15	0	-	3	4	1
	200	-	2	4	-
	400	-	1	5	-
25	0	1	8	-	2
	200	3	5	1	4
	400	1	8	3	2
35	0	5	6	11	3
	200	5	10	7	3
	400	6	8	10	2
45	0	1	9	8	2
	200	1	7	9	1
	400	-	6	10	3

Table A-8.

Distribution of 1/10-acre plots used in the 4-year total gross response analysis of thinned Douglas-fir. 191 plots

B. H. AGE CLASS (Yrs.)	TREATMENT (Pounds of N per acre)	Douglas-fir Basal Area				
		55 P.A.I.	85 P.A.I.	115 P.A.I.	145 P.A.I.	175 P.A.I.
15	0	6	2	2	-	-
	200	8	2	2	-	-
	400	7	2	2	-	-
25	0	2	2	8	5	-
	200	1	2	7	6	1
	400	1	1	11	4	1
35	0	-	-	13	7	3
	200	-	-	13	4	3
	400	-	-	12	7	2
45	0	-	-	2	9	3
	200	-	-	1	9	3
	400	-	-	2	10	3

Table A-9.

Estimated mean initial total volume for thinned Douglas-fir. (cubic feet/acre, minimum d.b.h. = 1.55 inches)

B.H. Age	Site Index 80	90	100	110	120	130	140	150
10	-	360.8	461.9	576.8	705.8	849.1	-	-
20	1071.5	1324.9	1609.2	1924.7	2272.0	2651.7	3064.1	-
30	2116.3	2559.9	3049.8	3586.8	4171.7	4805.3	5488.5	6222.0
40	3082.5	3699.4	4376.3	5114.2	5914.5	6778.2	7706.7	-
50	3759.9	4507.3	5326.3	6218.5	7185.7	-	-	-

Table A-10.

Estimated mean initial total basal area for thinned Douglas-fir.
(square feet/acre, minimum d.b.h. = 1.55 inches)

	Site Index							
B.H. Age	80	90	100	110	120	130	140	150
10	-	31.3	39.9	48.4	57.0	65.6	-	-
20	65.7	74.3	82.8	91.4	100.0	108.5	117.1	-
30	96.8	105.4	113.9	122.5	131.1	139.6	148.2	156.8
40	116.0	124.6	133.2	141.7	150.3	158.8	167.4	-
50	123.4	131.9	140.5	149.0	157.6	-	-	-

Table A-11.

Results of "paired-tree" western hemlock analysis
grouped by province, age class, and site class.

Category	No. of Installations	200 lb. N response (%)		400 lb. N response (%)	
		Avg.	Standard deviation	Avg.	Standard deviation
Total	(26)	+ 4%	(± 15%)	+ 4%	(± 17%)
Province III	(10)	+ 6%	(± 15%)	+11%	(± 20%)
Province V	(11)	+ 3%	(± 14%)	- 4%	(± 13%)
Province IX	(5)	+ 1%	(± 19%)	+ 7%	(± 11%)
Age 0-14	(2)	+ 4%	(± 4%)	- 6%	(± 16%)
Age 15-24	(5)	+17%	(± 14%)	+27%	(± 17%)
Age 25-34	(11)	0%	(± 15%)	0%	(± 12%)
Age > 35	(8)	+ 3%	(± 13%)	- 3%	(± 11%)
Site I	(3)	+ 1%	(± 20%)	+ 6%	(± 2%)
Site II	(17)	+ 5%	(± 14%)	+ 1%	(± 16%)
Site III	(5)	- 3%	(± 15%)	+ 2%	(± 11%)

APPENDIX B

(Unthinned Douglas-fir Duration of Response Studies)

Figure B-1.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site I; Age 30

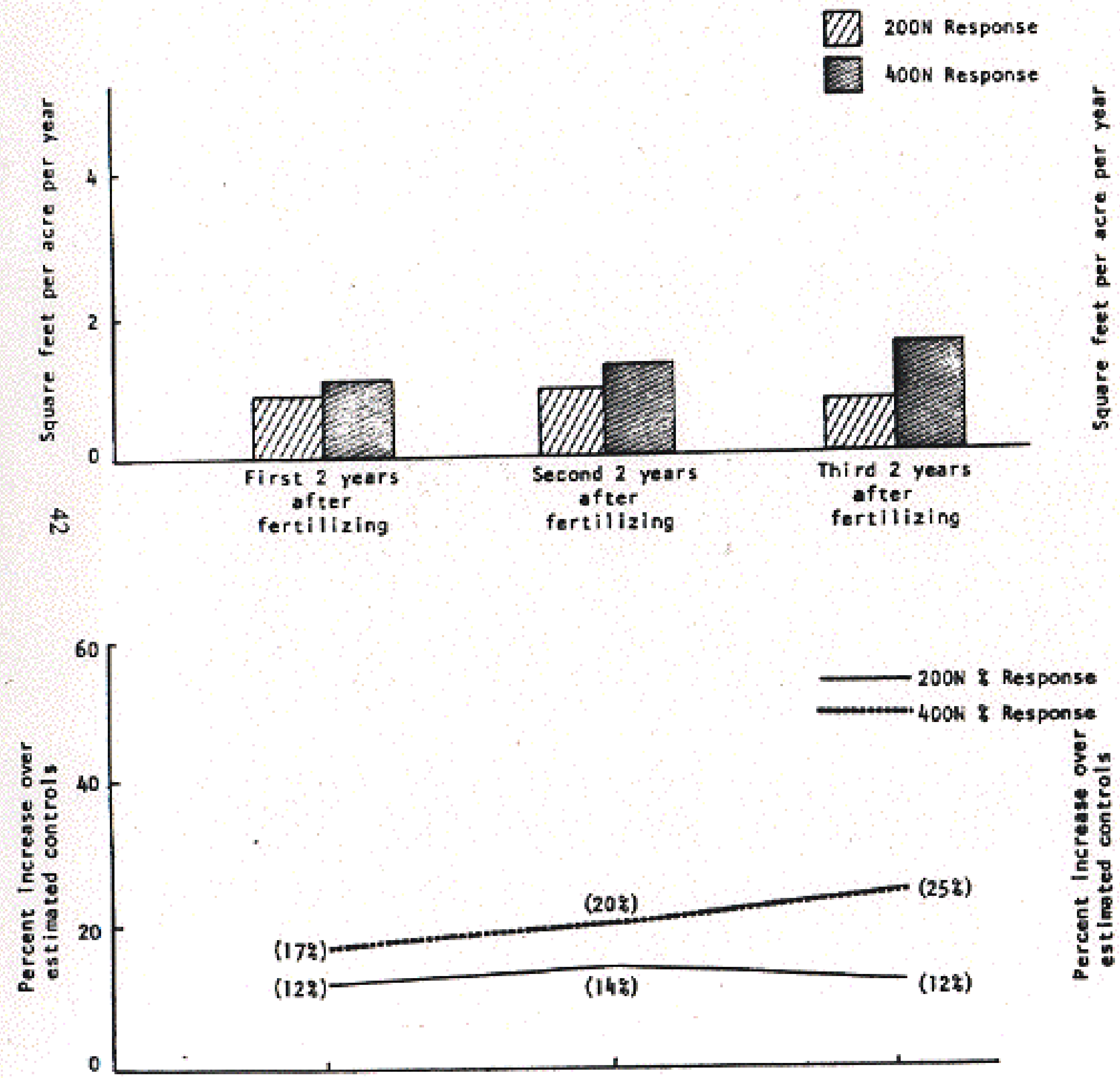


Figure B-2.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site II; Age 20

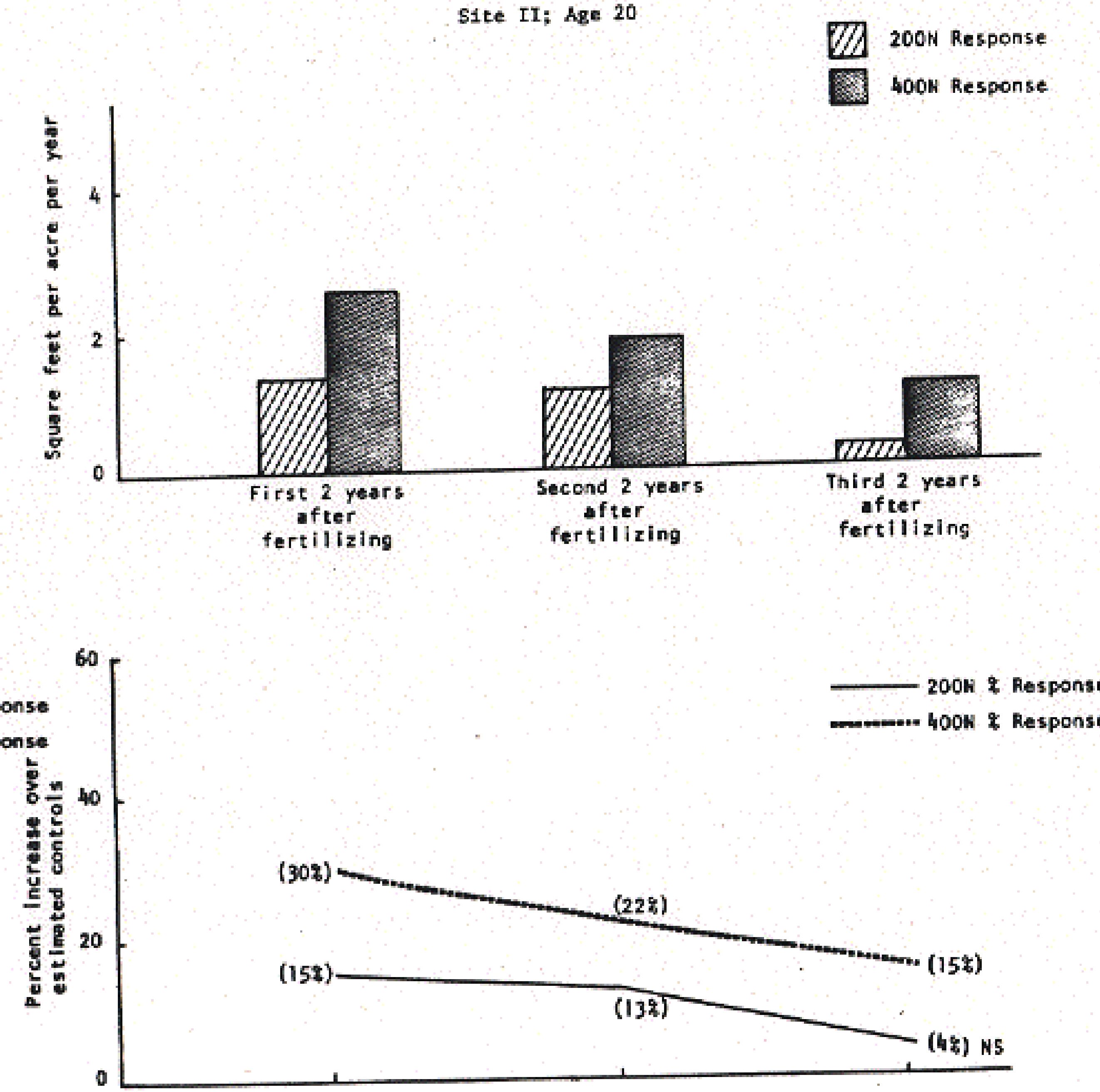


Figure B-7.

Estimated mean response of gross total basal area growth by 2-year periods for Douglas-fir (square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site III; Age 40

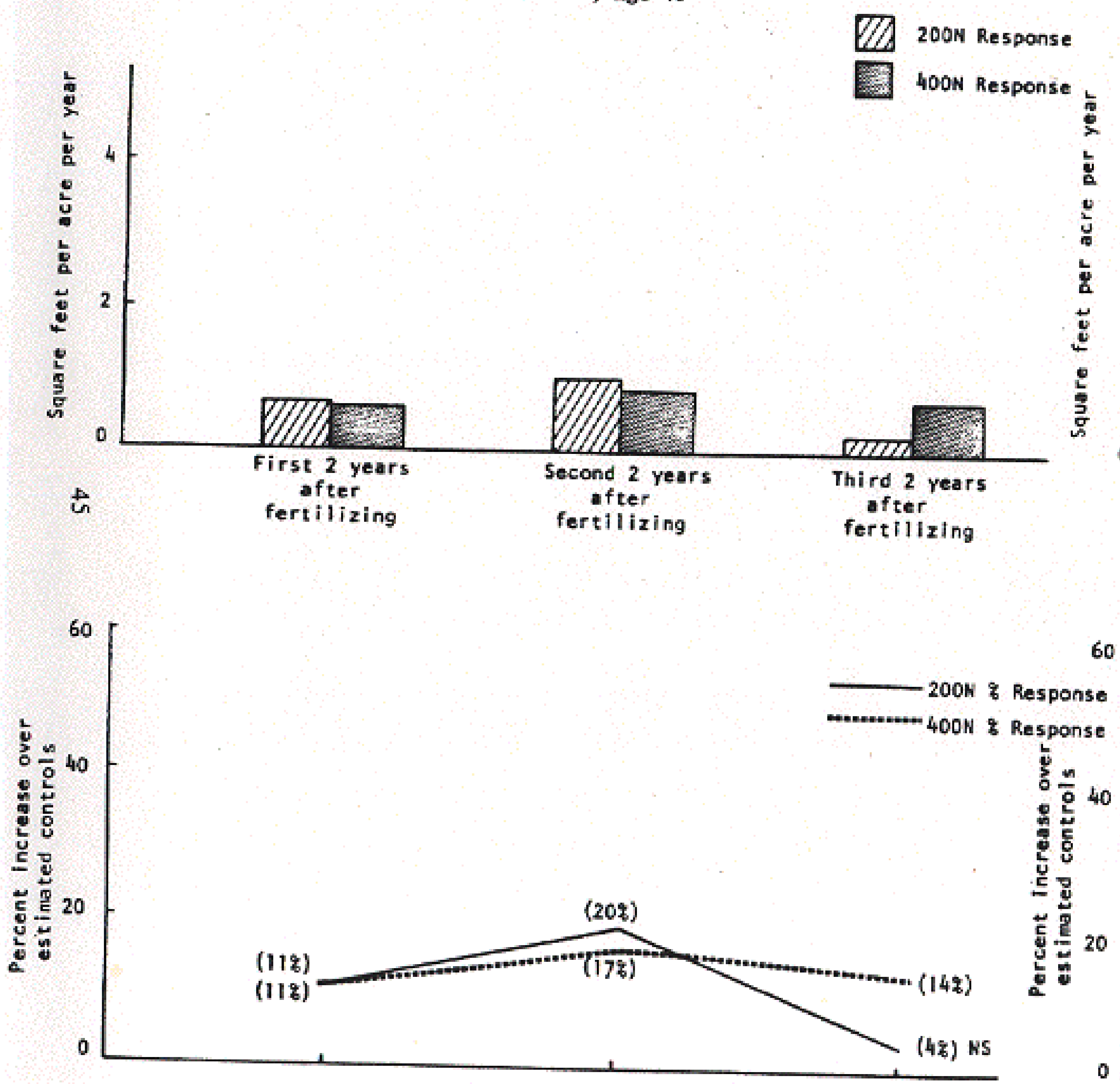


Figure B-8.

Estimated mean response of gross total basal area growth by 2-year periods for Douglas-fir (square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site IV; Age 30

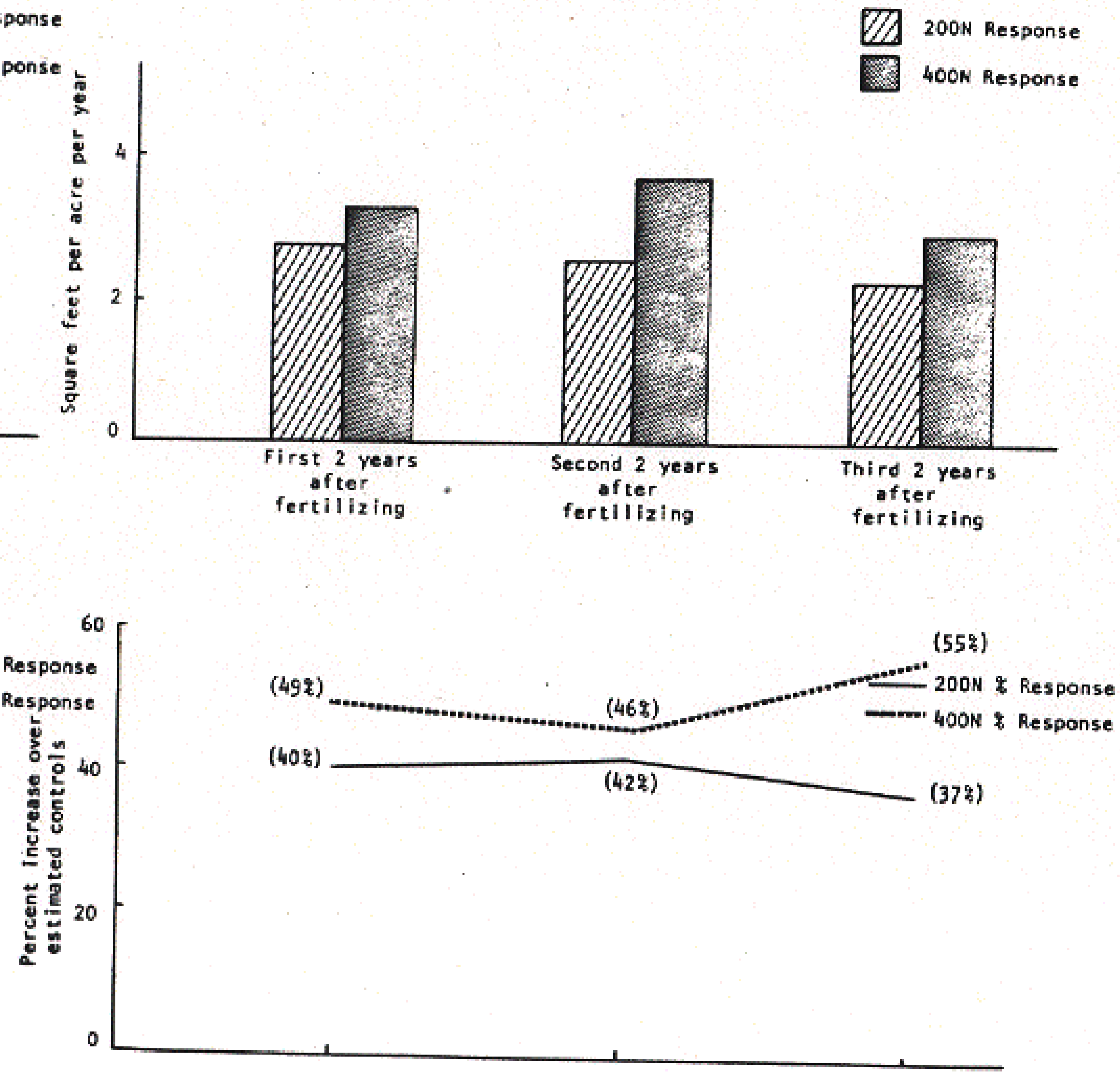


Figure B-5.

Estimated mean response of gross total basal area growth by 2-year periods for Douglas-fir (square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site III; Age 20

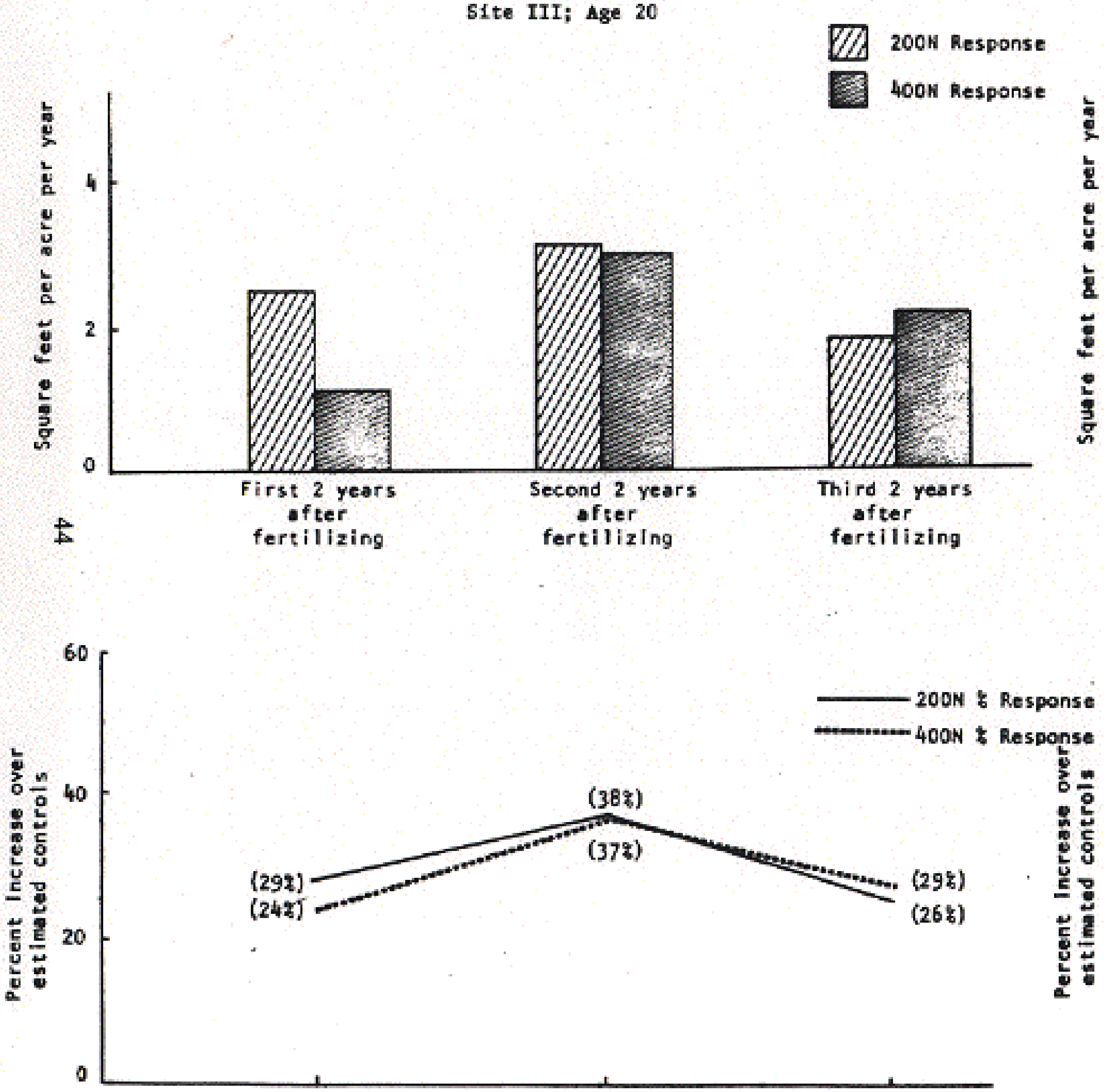


Figure B-6.

Estimated mean response of gross total basal area growth by 2-year periods for Douglas-fir (square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site III; Age 30

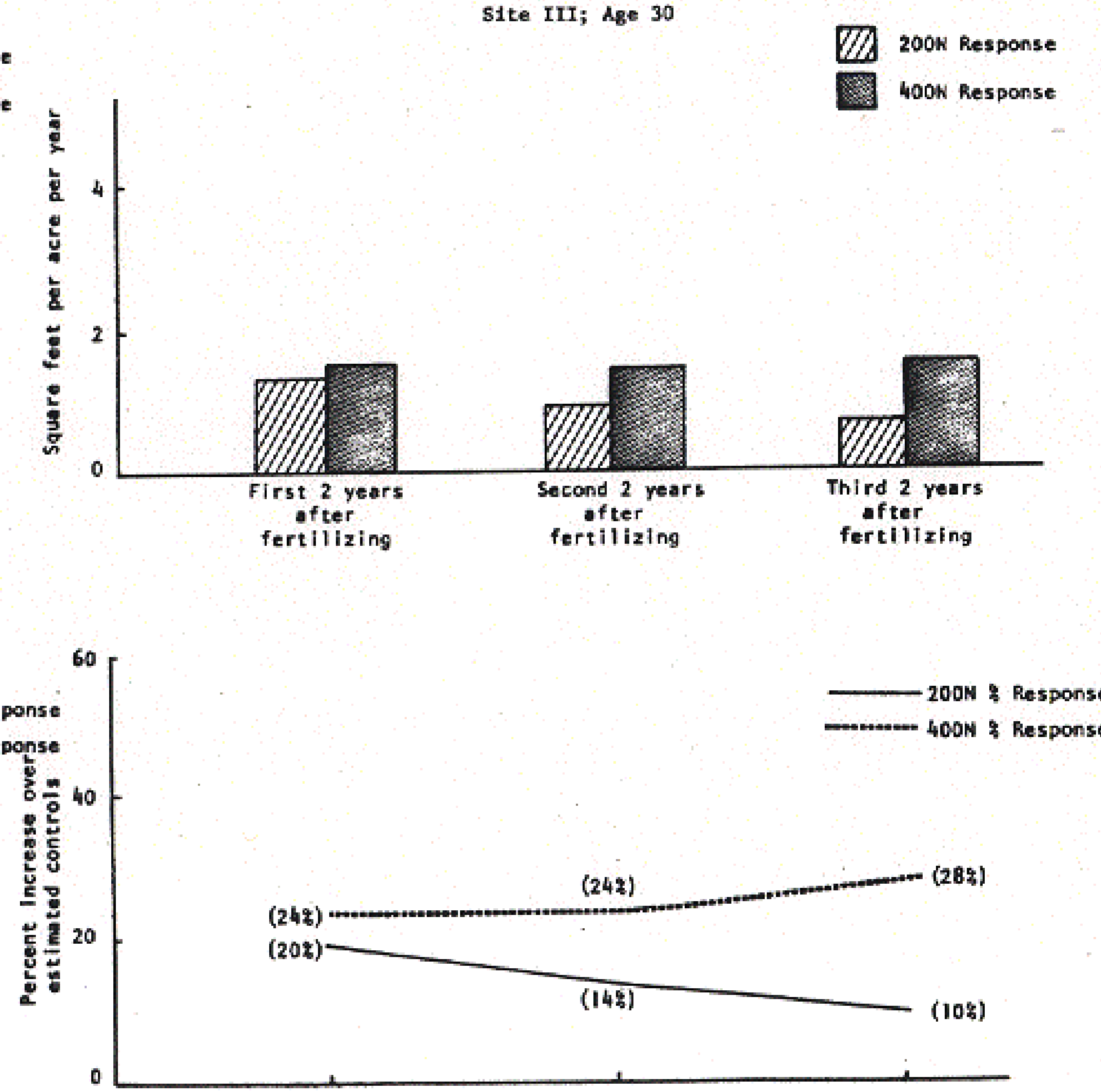


Figure B-7.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site III; Age 40

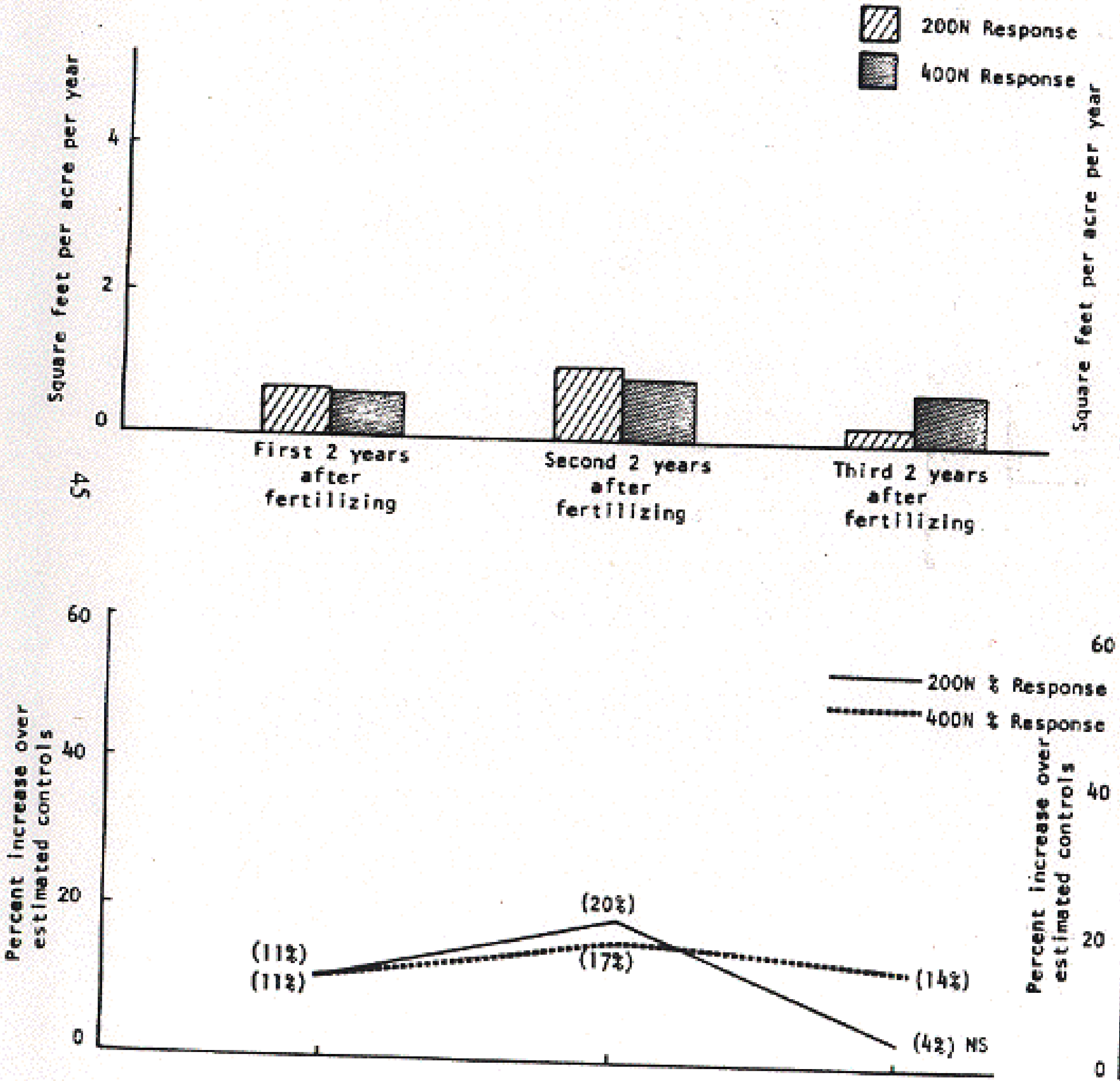


Figure B-8.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site IV; Age 30

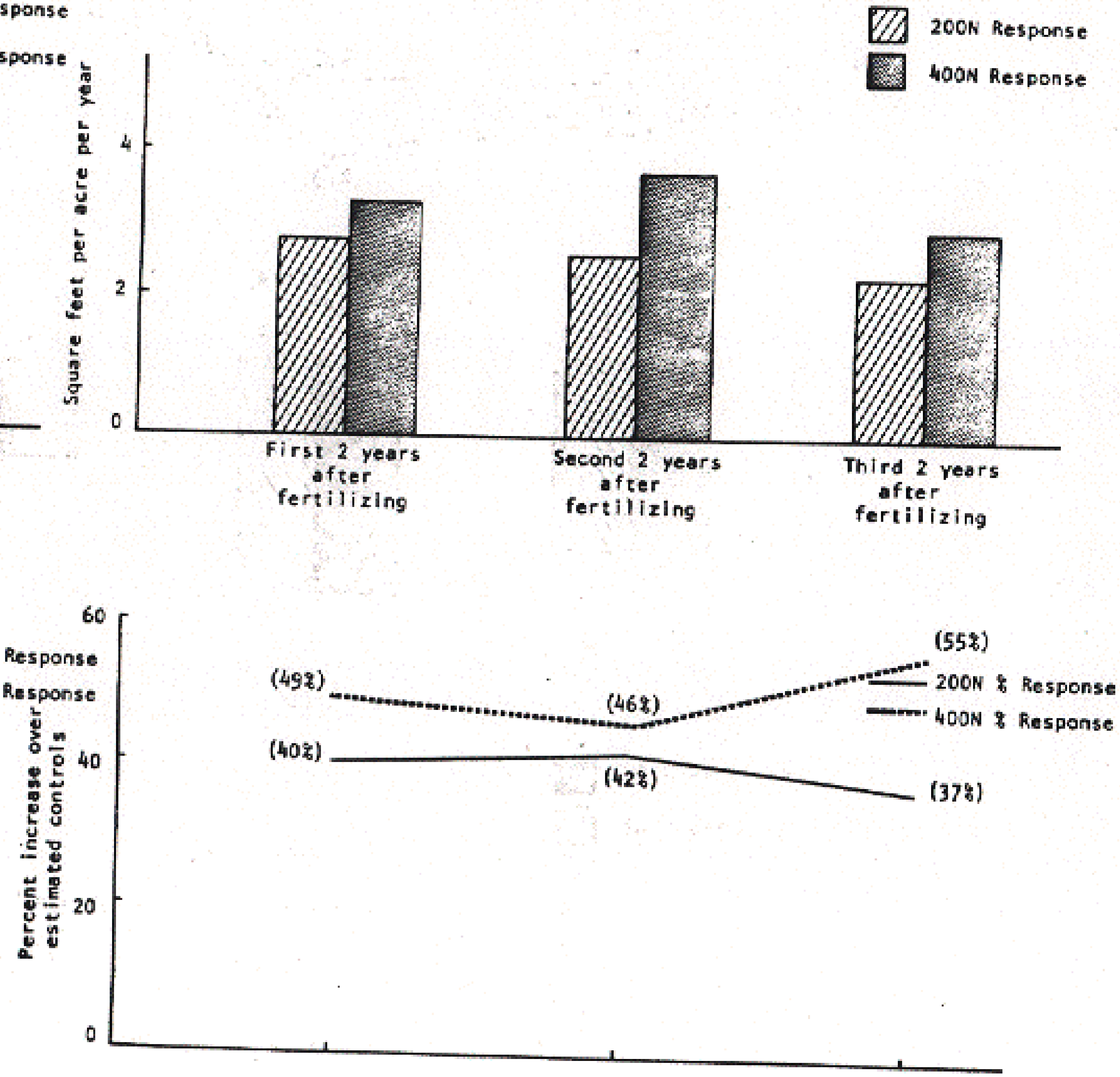


Figure B-9.

Estimated mean response of gross total basal area growth
by 2-year periods for Douglas-fir
(square feet/acre/year; minimum d.b.h. = 1.55 inches)

Site IV; Age 40