INSTITUTE OF FOREST RESOURCES
CONTRIBUTION No. 46

Regional Forest Nutrition Research Project

Biennial Report

1980–1982

UNIVERSITY OF WASHINGTON
COLLEGE OF FOREST RESOURCES

NOVEMBER 1982

Table of Contents

Table of Contents (cont'd.)

Foreword (S. Gessel)

We wish to thank all Cooperators for the confidence expressed in this project by continuing membership. We had a welcome addition when Burlington Northern Timberlands joined us this year. We have received many comments to the effect that the University, Industry, and Agency Cooperative system is an effective and economical approach to needed research, and that we should be exploring other kinds of research under this format. We intend to follow these suggestions (e.g., development of research plans and a specific proposal for the next phase). Although we have made good progress on many fronts and can provide you with information to guide fertilizer application, there are still many questions about forest tree nutrition and how to achieve better production from our forest areas. Our next proposal will address some of these questions, not the least of which is the economic justification of investing in any kind of forest practice when money is in short supply and under intense competition for other uses. This means that each practice must be targeted for specific forest conditions and with reasonable expectation of a good rate of return. The data base we have for fertilization is probably better than for any other forest practice, and our response estimates provide an excellent basis for recommendations. One of our goals in the next phase will be to make these as specific as possible.

In addition to our data collecting and summary activities, we have been busy on a number of other things designed to provide the Cooperators with the best information possible. During the past year I traveled extensively to review fertilizer programs in other parts of the world, with very little expenditure of project funds. I spent 5 months in Australia and New Zealand reviewing most of the fertilizer work in these countries. I also attended the IUFRO Congress in Japan, including a specific forest fertilization field trip, and visited Chile to review forest productivity and fertilizer programs in that country.

We have also benefited from the visits of many scientists from throughout the United States and the world. In August of this year, the College, along with the Forest Service PNW station and the Weyerhaeuser Company, hosted an IUFRO meeting on Forest Productivity. About 150 scientists attended representing the principal forest areas of the world. A specific section of the program dealt with forest fertilization research programs which now operate in several regions of the United States and a number of other countries. A copy of the proceedings of this conference (available about June 1983) will be furnished to each Cooperator.

One area of special interest has been the productivity of forests in southern Oregon. The project participated in the field meeting of the Northwest Forest Soils Council where a day was devoted to a review of fertilizer installations and the relationship of soil and stand conditions to response. This is an area that Dr. Richard Miller of the Forest Service has been researching with the goal of providing recommendations for fertilizing and thinning to improve productivity. The project has been cooperating with Dr. Miller by providing data and advice.

Our program of basic research to provide a better understanding of growth response and nutritional requirements of forest trees has been successful in several areas. An account on some of the specific accomplishments will be found in this report. We will have several project personnel attending the Forest Soils Section of the Soil Science Meeting to present some of the other results from this research. These presentations will be published in the future. Dr. Bruce Bare has been working on an economic analysis of forest fertilization that is presented in this report. Dr. Charles Grier is also continuing his work on productivity and a progress report is included.

There have been several personnel changes in the past 2 years. Dr. Ian Morison left the University in January of 1980 to take on new responsibility as a research administrator at the University of Hawaii. Mr. William Bizak, a longtime member of the field crew, left to pursue his own private business. He has been replaced by Mr. Michael Rinehart. Steve Archie, budget coordinator who has served since the initiation of the project, was asked by Dean Thorud to assume greater responsibilities in the College. We miss Steve's constant watch over us, but he is available when we need him. Mr. Robert Gonyea is now in charge of budgeting.

The limited resources available for research require the project to evaluate different courses of action. To help us make these decisions we have enlisted the help of several committees and we wish to acknowledge their contribution. The rethinning group of Pete Farnum, Steve Webster, Jerry Hoyer, Don Reukema, and Charlie Peterson provided recommendations for stocking control of our thinned plots. The hemlock committee, consisting of Bob Zasoski, Jim Boyle, Steve Webster, Denis Lavender, M.A. Radwan, Paul Heilman, Robert van den Driessche, and myself, have held a workshop and several meetings to come up with recommendations for special research and additional treatments. We also thank Bill Atkinson and Bob Strand for sponsoring a workshop on the relationship between nitrogen mineralization and fertilizer response. Results of this workshop are being summarized by Bob and should be available soon.

My final point is that this Cooperative continues to be a success only because it provides members with useful information and in a manner in which they can use it. Both our basic research and field programs are designed to this end. Your support so far (even in depressed times) indicates we may be meeting some of the goals. We need your continued support and advice to achieve all of them.

Introduction (A. Becker)

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:

(a) To establish and maintain a service of fertilizing and thinning field trials on participants' lands in western Washington and western Oregon under various conditions of soils, climate, age, and site;

(b) to collect and analyze response data from these plots and report results to subscribers;

(c) 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;

(d) to report findings regularly to subscribers and to advise them on fertilization problems and practices;

(e) 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. Two further extensions, Phase III and Phase IV, have established a data base which now totals nearly 1900 permanent sample plots.

Phase I (fertilization only) 1969-1970

Plots established in this phase currently have twelve years of growth measurements. Approximately half of the Douglas-fir plots were treated with fertilizer after the eighth and twelfth growing seasons. Half of the hemlock plots have been refertilized after ten growing seasons as part of Phase IV.

Phase II (fertilization and thinning) 1971-1972

Plots in Phase II have ten years of measurements as of this report. Half of the thinned Douglas-fir plots have been re-treated to coincide with the Phase I treatments. In addition, one-half of the fertilized, thinned hemlock plots were refertilized with nitrogen and the remaining half were refertilized with phosphorus and nitrogen. All thinned plots were checked for stocking density after eight years and rethinned if necessary to keep the trees in a free growing state.

Phase III (fertilization and thinning in young stands, and fertilization in areas of low productivity) 1975

These plots now have six seasons of growth data that are currently being analyzed and combined with Phase I and Phase II data to improve response estimates.

Phase IV (low stocking and young spaced stands) 1980

Part of the plots established in Phase IV are in areas of low natural stocking to help answer questions in two areas:

(a) What is the effect of fertilizer in low- and under-stocked stands? and

(b) Do thinned stands react to fertilizer in the same way as do natural stands of the same stocking?

Other plots have been established in young stands that have had some form of stocking control, in order to assess the effect of fertilizer on the type of intensively managed stand that is expected to be increasingly prevalent in the future.

Surviving installations at the time of publication of this report, together with the number of growing seasons after establishment which they will have accumulated by September 30, 1982 are as follows:

Date of establishment	Type of installation	Number of installations	Growth Seasons after establishment Sept.30,1982
1969	Phase I	39DF, 10WH	13
1970	Phase I	40DF, 9WH	12
1971	Phase II	9DF, 7WH	11
1972	Phase II	26DF, 1WH	10
1973	B. L. M.	6DF	9
1975	Willamette National Forest	4DF	7
1976	Mt. Hood National Forest	1DF	6
1977	Siskiyou National Forest	8DF	5
1977	B. L. M.	6DF	5
1977	Phase III intensive hemlock	1WH	5
1977	Old growth	1DF	5
1978	Colville National Forest	4DF	4
1978	Melamine	2DF	4
1980	Weyerhaeuser contract	3DF	2
1980	Phase IV	27DF, 8WH	2

Total = 240 installations

2 Regional Growth and Response Analysis for Unthinned Douglas-fir (C. Peterson)

Gross response data are presented as estimates (from regressions based on initial age, site index, and stocking) in all instances except when compared with net growth and response. The net and gross comparisons are made from raw data averages. All gross response estimates are statistically significant at 95% confidence level, unless otherwise noted. Nitrogen source was urea, unless specified differently.

Response[1], measured as the increase in growth rate due to fertilizer application, may be thought of as

RESPONSE = [Unthinned Fertilized Total Stand Growth Rate] minus [Growth Rate as in Unthinned Unfertilized Total Stand]

This increase was tested as being greater than zero using standard statistical techniques.

Current 10-year response results are presented in Section 2.1 and include effects of a second application of nitrogen. More detailed analyses have been completed on 8-year response to supplement the information given in the last Biennial Report (1978-1980). These are presented in Section 2.2, and include net total response, duration of total gross response by site class, and gross total response on merchantable stands. Section 2.3 presents 4-year analyses that include installations established in 1975 to augment the existing data base. The purpose of these analyses was to determine if a wider array of sites and ages could improve previous estimates[1] of 4-year response.

2.1 10-year growth period

Original (Phase I) unthinned plots were established in 1969-1970 and received nitrogen application at that time. After 8 growing seasons, approximately half of the plots received a second 200 lb-N/ac urea application. The resultant plot distribution for analysis is shown in Figure 2-1.

[1]Turnbull, K.J. and C.E. Peterson (1976). Analysis of Douglas-fir Growth Response to Nitrogenous Fertilizer (Part I: Regional Trends); Contr. No. 13, Inst. For. Prod., Coll. For. Res., University of Washington

2.1.1 Total gross response from one N-application

Ten-year growth rates of fertilized (1 application) and unfertilized Douglas-fir stands are in the Appendix. These increments provide the basis for response estimation. Data reported below are response estimates based on growth in 182 plots which received only initial treatment prescription:

Units of 10-year p.a.i.	Response by Treatment (lb-N/ac) 200	400
sq ft/ac/yr	1.09	1.39
(% response)	(18%)	(24%)
cu ft/ac/y	40	50
(% response	(12%)	(15%)

The standard error associated with estimate of mean volume increment response is about > 10 cu ft/ac/yr. That is to say, average 10-year p.a.i. response is 40 ± 10 cu ft/ac/yr and 50 ± 10 cu ft/ac/yr for 200 lb-N and 400 lb-N applications respectively. Relative (percent) response would vary by ± 3% for each level of nitrogen application. Estimates of untreated basal area growth increment are presented in Table 2-1 with basal area response estimates by age and site in Table 2-2. Estimated volume growth is summarized in Table 2-3.

2.1.2 Duration from one N-application

The first 8 years of duration (by 2-year periods) are based on all (377) plots, while the last 2 year period of the 10-year growth interval was analyzed with data from 182 plots. The difference in numbers of plots used for each analysis resulted from re-treatment (Figure 2-1).

(i) Gross p.a.i. - total basal area.

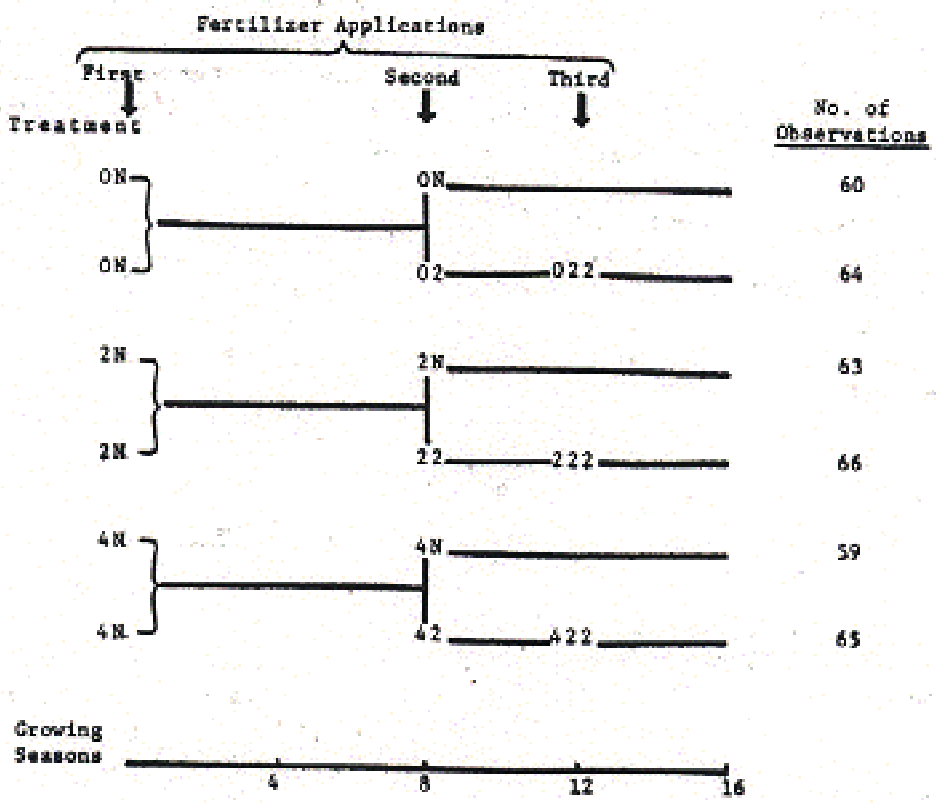
Figure 2-2 shows that response has clearly declined after 4 years (the second 2-year period); however, total response from a single application of urea is statistically significant in the fifth 2-year period for both 200 lb-N and 400 lb-N applications.

(ii) Gross p.a.i. - total volume.

Volume p.a.i. response declines after 4 years (the second 2-year period) as shown in Figure 2-3. A 400 lb-N application clearly elicits much more response than 200 lb-N, but in the fifth 2-year period response to either N-application is not statistically significant (95% confidence level).

Figure 2-1

Re-fertilization scheme for unthinned Douglas-fir (≥80%) and resultant split in data base.



Where ON = no fertilizer
2N = 200 pounds of nitrogen in urea form
4N = 400 pounds of nitrogen in urea form
02 = 2N added to previous controls
22 = initial 2N plus another 2N
42 = initial 4N plus 2N
022 = 02 plus another 2N
222 = 22 plus another 2N
422 = 42 plus another 2N

Table 2-1. Estimated mean 10-year gross total basal area growth for unthinned Douglas-fir control stands. (sq ft/ac/yr; min d.b.h. = 1.55 inches)

B.H. AGE CLASS (yrs)	50-year SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	15.4	15.2	14.9	--
20	7.5	7.6	7.7	7.8
30	5.7	5.8	5.8	5.8
40	5.1	5.0	4.9	4.7
50	4.7	4.4	4.1	3.8

Table 2-2. Estimated mean response of 10-year gross total basal area growth for unthinned Douglas-fir.
(sq ft/ac/yr; min. d.b.h. = 1.55 inches)

B.H. AGE CLASS (yrs)	TREATMENT (lb-N/ac)	50-year SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	200	1.1	1.6	2.1	--
	400	1.3	1.6	1.9	--
20	200	0.5	1.0	1.4	1.9
	400	1.0	1.3	1.6	1.9
30	200	0.4	0.8	1.3	1.7
	400	0.9	1.2	1.6	1.9
40	200	0.3	0.8	1.2	1.7
	400	0.9	1.2	1.5	1.8
50	200	0.3	0.7	1.2	1.6
	400	0.9	1.2	1.5	1.8

Average response to 200 lb-N: 1.1 sq ft/ac/yr } Across all sites and ages
Average response to 400 lb-N: 1.4 sq ft/ac/yr }

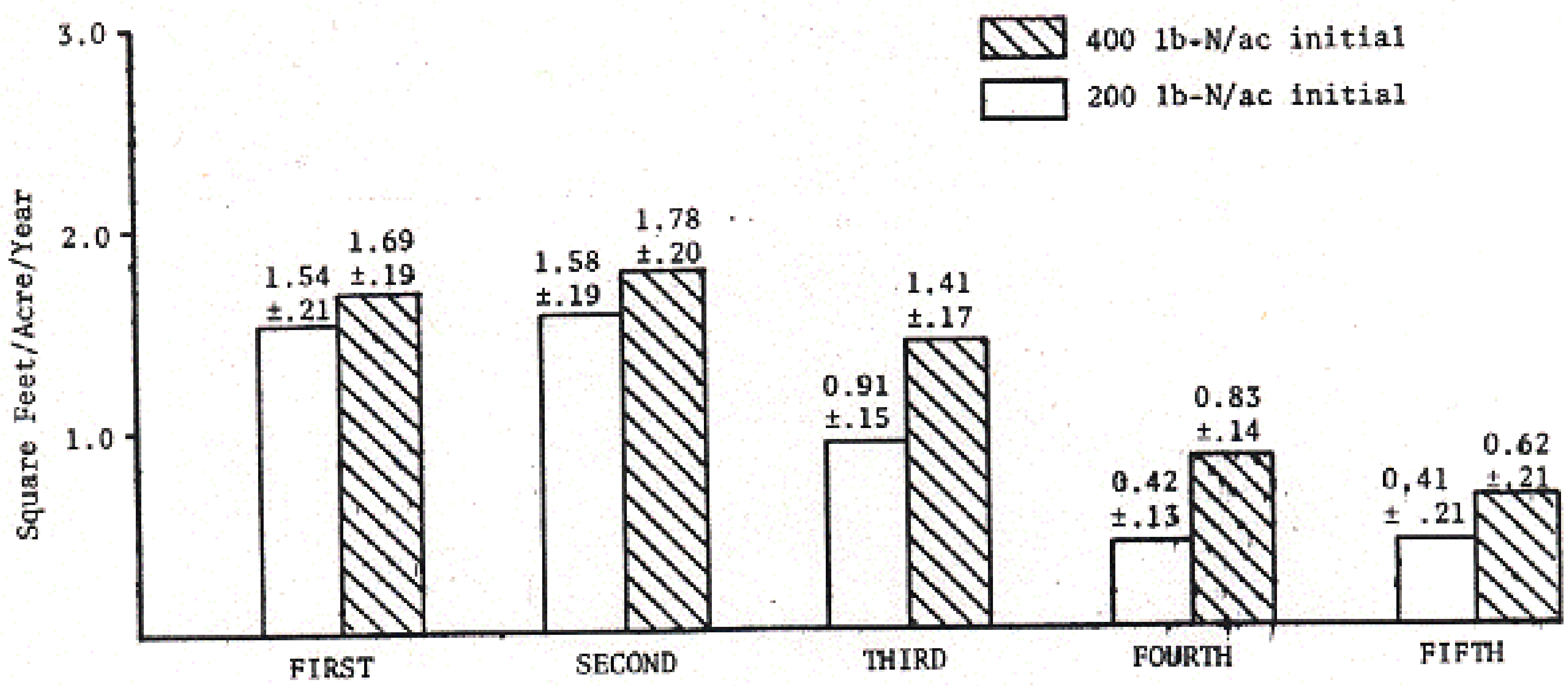
Table 2-3. Estimated mean 10-year gross total volume growth for unthinned Douglas-fir control stands.
(cu ft/ac/yr; min d.b.h. = 1.55 inches)

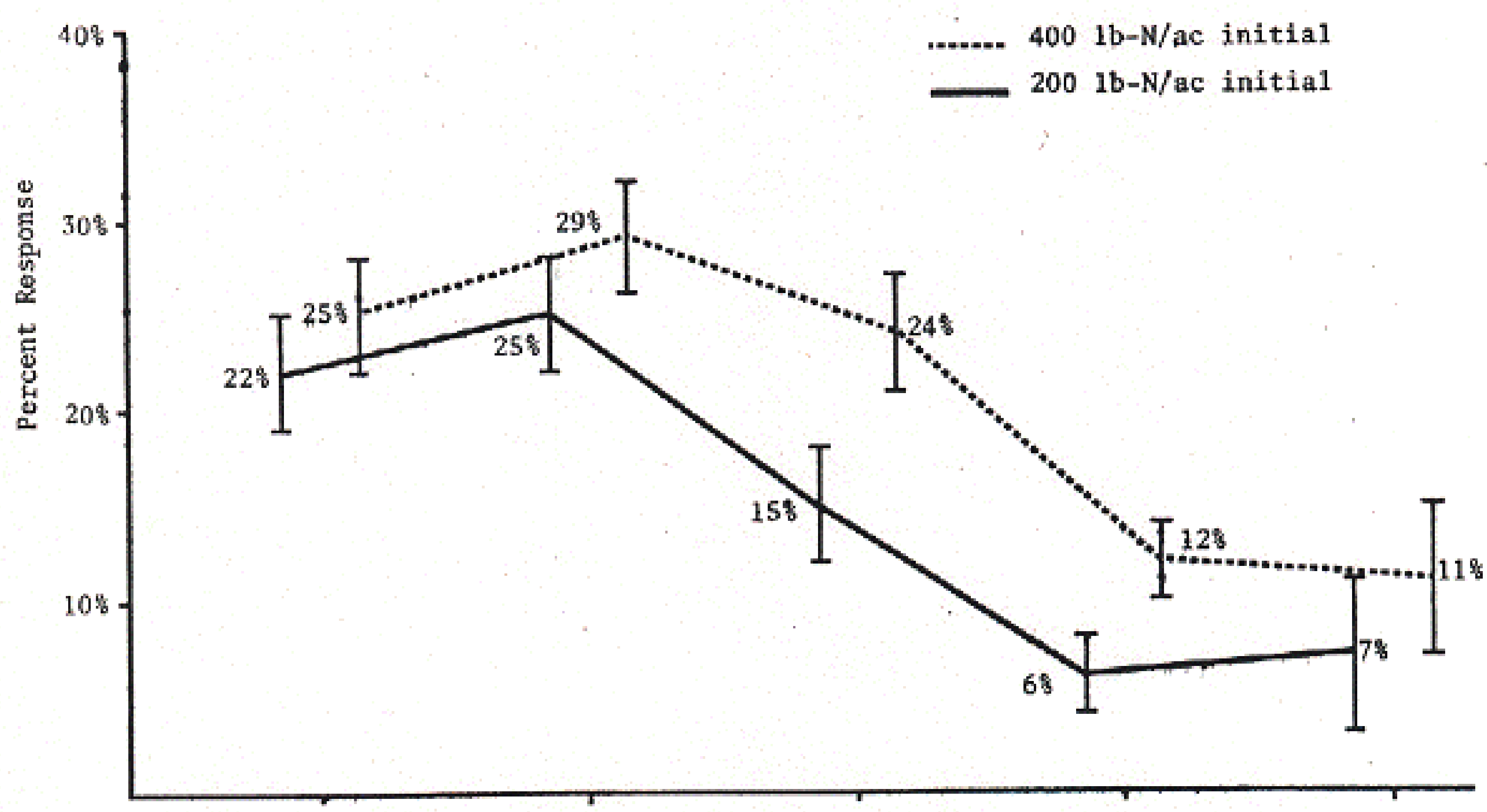
B.H. AGE CLASS (yrs)	50-Year SITE CLASS I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
10	359	319	277	--
20	408	358	308	256
30	405	355	304	252
40	394	345	295	244
50	382	334	285	235

Average response to 200 lb-N: 40 cu ft/ac/yr } Across all sites
Average response to 400 lb-N: 50 cu ft/ac/yr }

Figure 2-2

Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for unthinned Douglas-fir based on stands with 1 N-application (sq ft/ac/yr; min d.b.h.=1.55 inches)

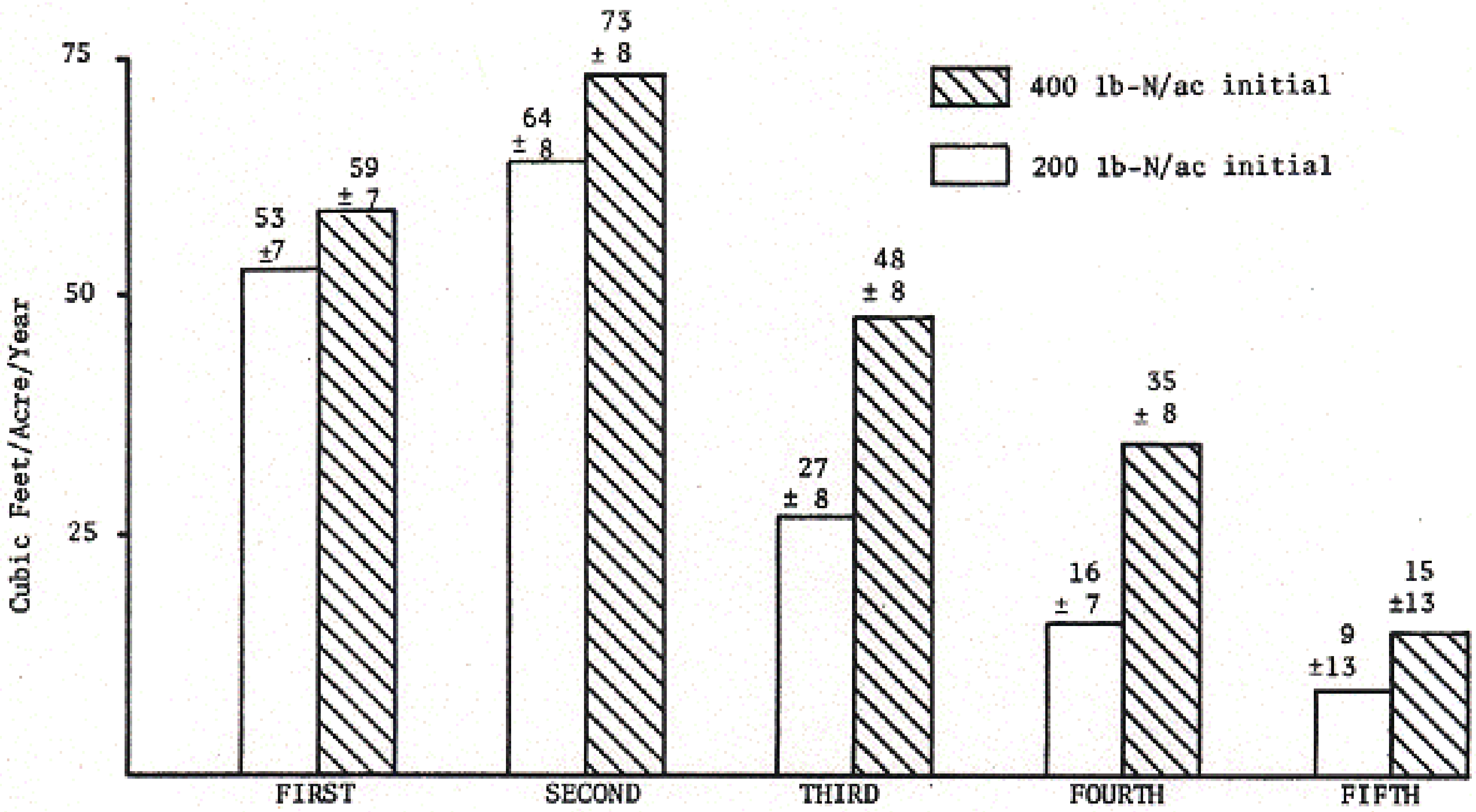


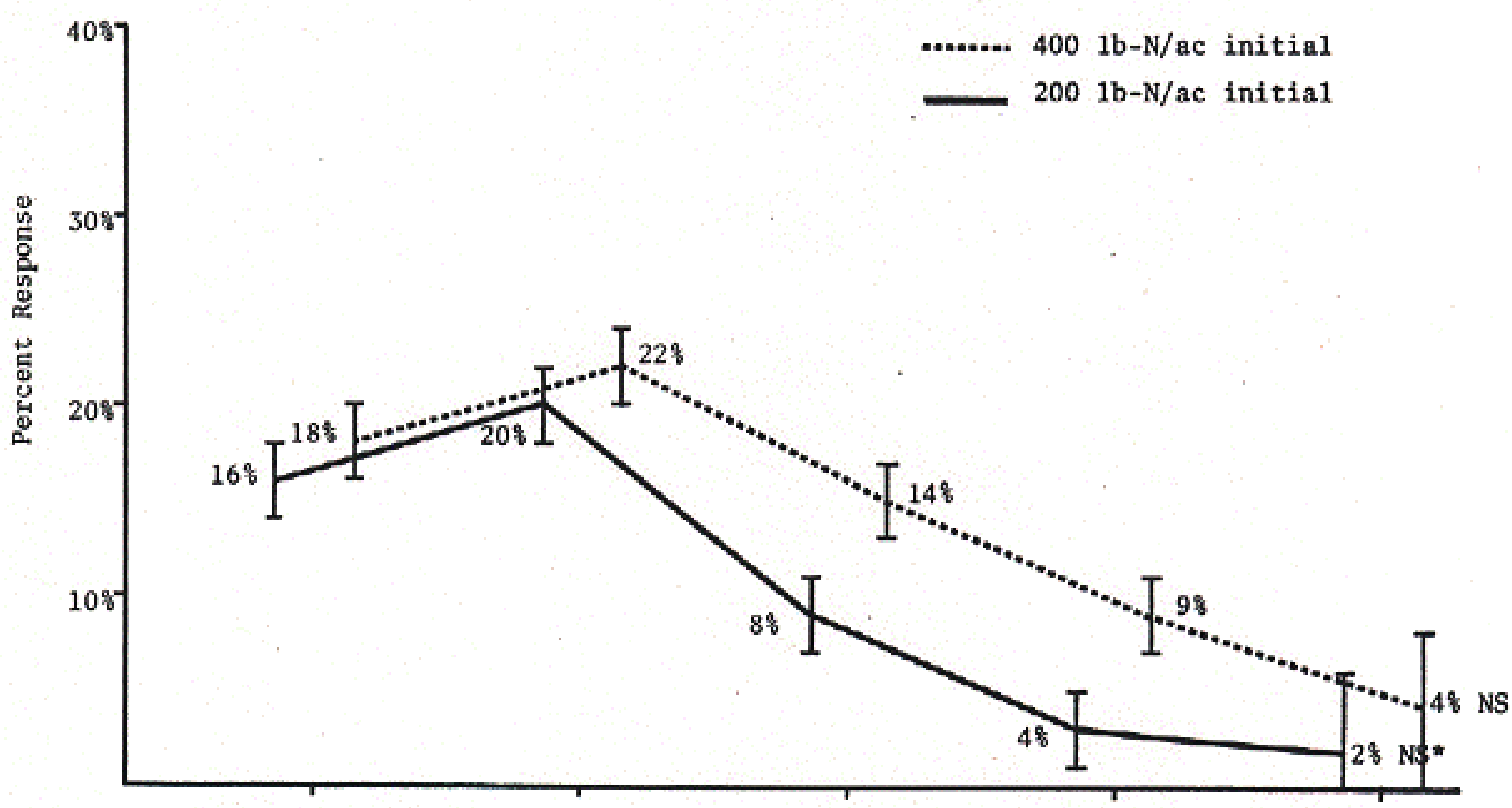


Sample by treatment code, periods 1-4: ON=124 plots, 2N=129 plots, 4N=124 plots
Sample by treatment code, period 5: ON=60 plots; 2N=63 plots; 4N=59 plots

Figure 2-3

Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for unthinned Douglas-fir based on stands with 1 N-application (cu ft/ac/yr; min d.b.h.=1.55 inches)





NS = nonsignificant at 95% CL but significant at 80% CL

NS*= nonsignificant at 80% CL

Sample by treatment code, periods 1-4: 0N=124 plots; 2N=129 plots; 4N=124 plots
Sample by treatment code, period 5: 0N=60 plots; 2N=63 plots; 4N-59 plots

2.1.3 Total gross response from two N-applications

Data reported below are response estimates based on growth in 191 plots. Response is measured as a difference between the re-treated (2 applications of nitrogen) stand growth rate and average growth rate in untreated stands. Only the last 2 years of this measured 10-year period were affected by re-treatment. Thus response from the last 2-year period is somewhat masked when estimated over the entire interval of 10 years. Subsequent growth periods should reflect the re-treatment more strongly.

Units of 10-year p.a.i.	Response by Treatment 200N + 200N	400N + 200N
sq ft/ac/yr	1.28	1.48
(% response)	(21%)	(24%)
cu ft/ac/yr	49	59
(% response)	(15%)	(18%)

The standard error of average volume increment response is approximately ± 10 cu ft/ac/yr. Relative response could be expected to vary by ± 3%.

2.1.4 Duration from two N-applications

As in section 2.1.2, the first 8 years of duration are based on growth in 377 plots. A total of 191 plots were used to estimate response in the fifth 2-year period.

(i) Gross p.a.i. - total basal area.

Two-year response to re-treatment (Figure 2-4) is increased, as evidenced by the upswing in the fifth 2-year period over response in the fourth 2-year period. The response in the fifth 2-year period is slightly greater than that estimated for the first 2-year period, but any differences between the two are not significant.

(ii) Gross p.a.i. - total volume.

Figure 2-5 shows the volume response to a second fertilizer application. In the fifth 2-year period, an 18% response in the 200 lb-N (+200 lb-N) and a 16% response in the 400 lb-N (+200 lb-N) correspond closely to respective responses in the first 2-year period.

2.2 8-year growth period

All analyses reported across 8 growing seasons pertain to growth and response of the unthinned stands from an initial application of urea fertilizer. Eight-year growth rates of fertilized (1 application) and unfertilized Douglas-fir stands are shown in the Appendix. These increments provide the basis for response estimation.

The 1978-1980 Biennial Report summarized the 8-year growth and response. Subsequent analyses have been completed which supplement the previous report.

These include:

(a) net and gross response (2.2.1)
(b) duration by site class (2.2.2)
(c) total growth and response on the merchantable portion of the stand (2.2.3)
(d) response in mixed stands (2.2.4)

2.2.1 Total net and gross volume response

Net and gross response estimates are both computed as differences between treatment and control for net p.a.i. and gross p.a.i. respectively. Net p.a.i. and gross p.a.i. correspond to G_{n+i} and G_{g+i} as defined by Husch, et al., (1972)[2].

Response data are based on 377 plots of 1/10-acre or larger, comprised of at least 80% Douglas-fir type stocking. Initial breast-height age classes range from 10 to 50, and site classes range from site 1 to site 4. These increment figures are unadjusted.

(i) Eight-year p.a.i. response.

Gross response to 400 lb-N is significantly greater than the response to 200 lb-N by 4% (Figure 2-6). The difference in net response (2%), is not significant between N levels.

(ii) Response by 4-year periods.

Eight-year response, shown in Figure 2-7, is divided into two 4-year periods. The greatest response from both 200 lb-N and 400 lb-N applications occurred in the first 4-year period (Figure 2-7a). In fact, gross and net response in the first 4-year period were not significantly different between N rates. However, response to 400 lb-N was twice that of 200 lb-N in the second 4-year period (Figure 2-7b). Net response of 200 lb-N in the last 4 years (9 cu ft/ac/yr) was not significantly different from zero.

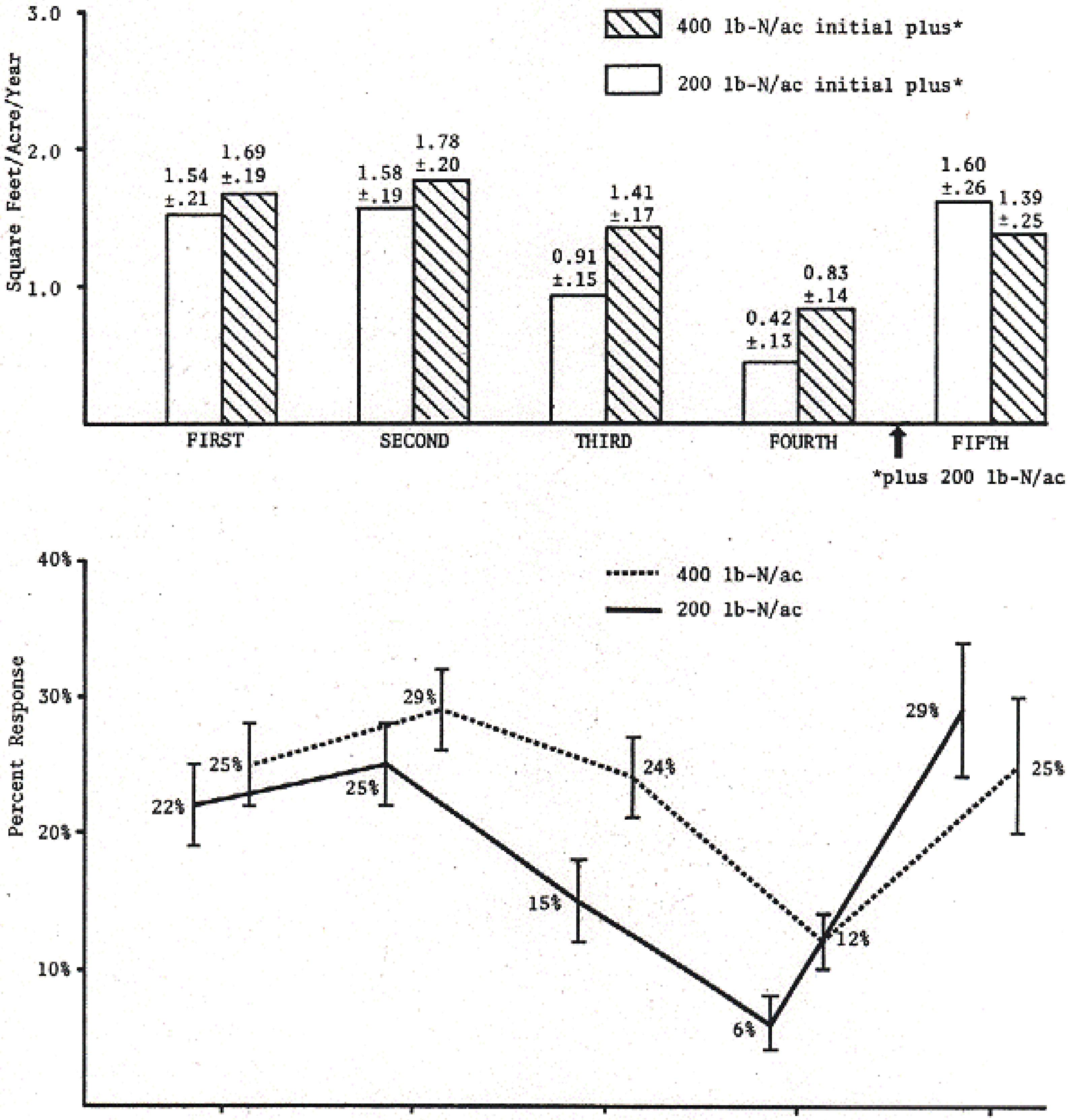
2.2.2 Total gross response duration by site class

Response duration in different site classes has been computed for both basal area and volume. These analyses clearly depict the significant effect of site index on basal area growth response and lack of significance in explaining volume growth response after the first 4 years.

[2] Husch, B., C.I. Miller, and T.W. Beers (1972). Forest Mensuration, New York: The Ronald Press Co.

Figure 2-4

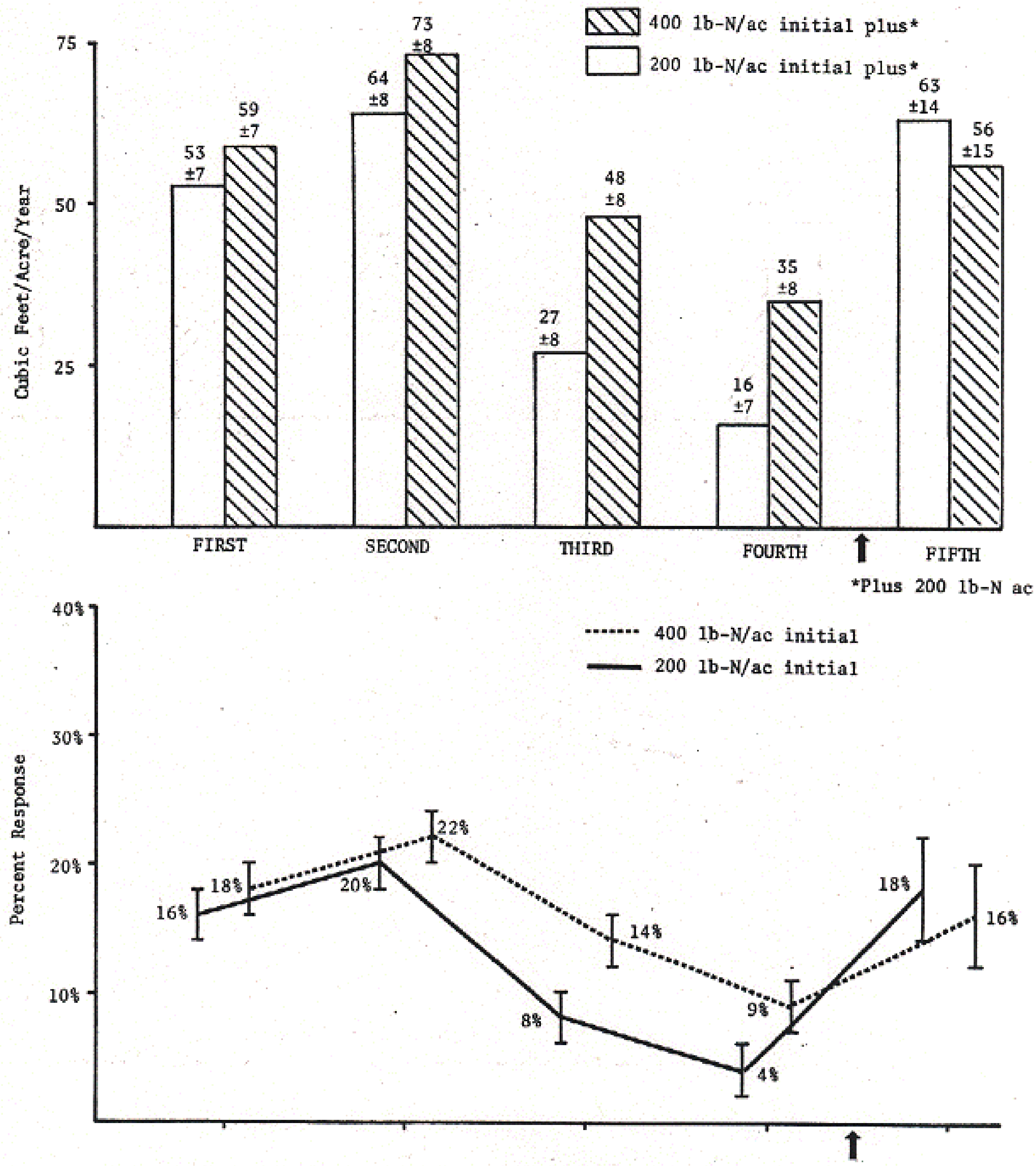
Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for unthinned Douglas-fir based on stands with first and second N-application; (sq ft/ac/yr; min d.b.h.=1.55 inches)



Sample by treatment code, periods 1-4: 0N=124 plots; 2N=129 plots; 4N=124 plots
Sample by treatment code, period 5: . 02=64 plots; 22=66 plots; 42=65 plots

Figure 2-5

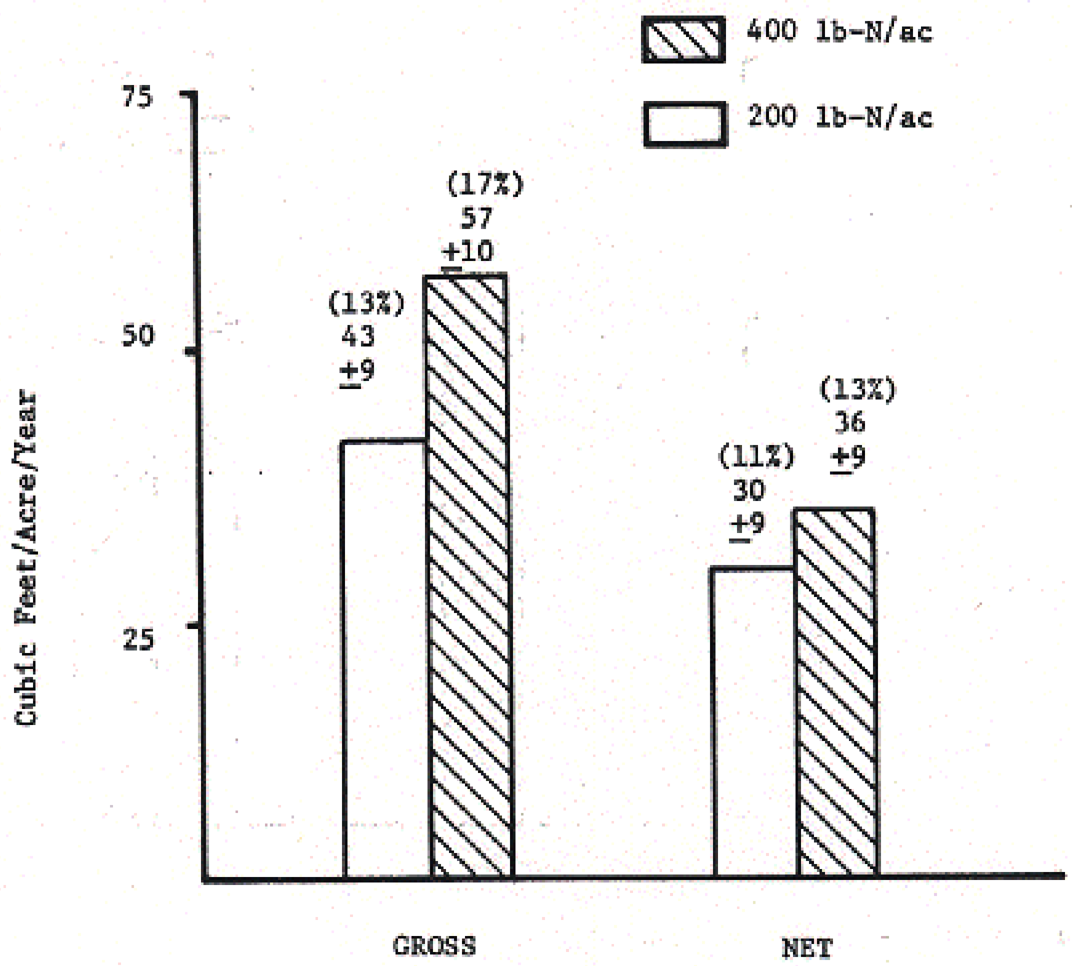
Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for unthinned Douglas-fir based on stands with first and second N-application (cu ft/ac/yr; min d.b.h.=1.55 inches)



Sample by treatment code, periods 1-4: 0N=124 plots; 2N=129 plots; 4N=124 plots
Sample by treatment code, period 5: 02=64 plots; 22=66 plots; 42=65 plots

Figure 2-6

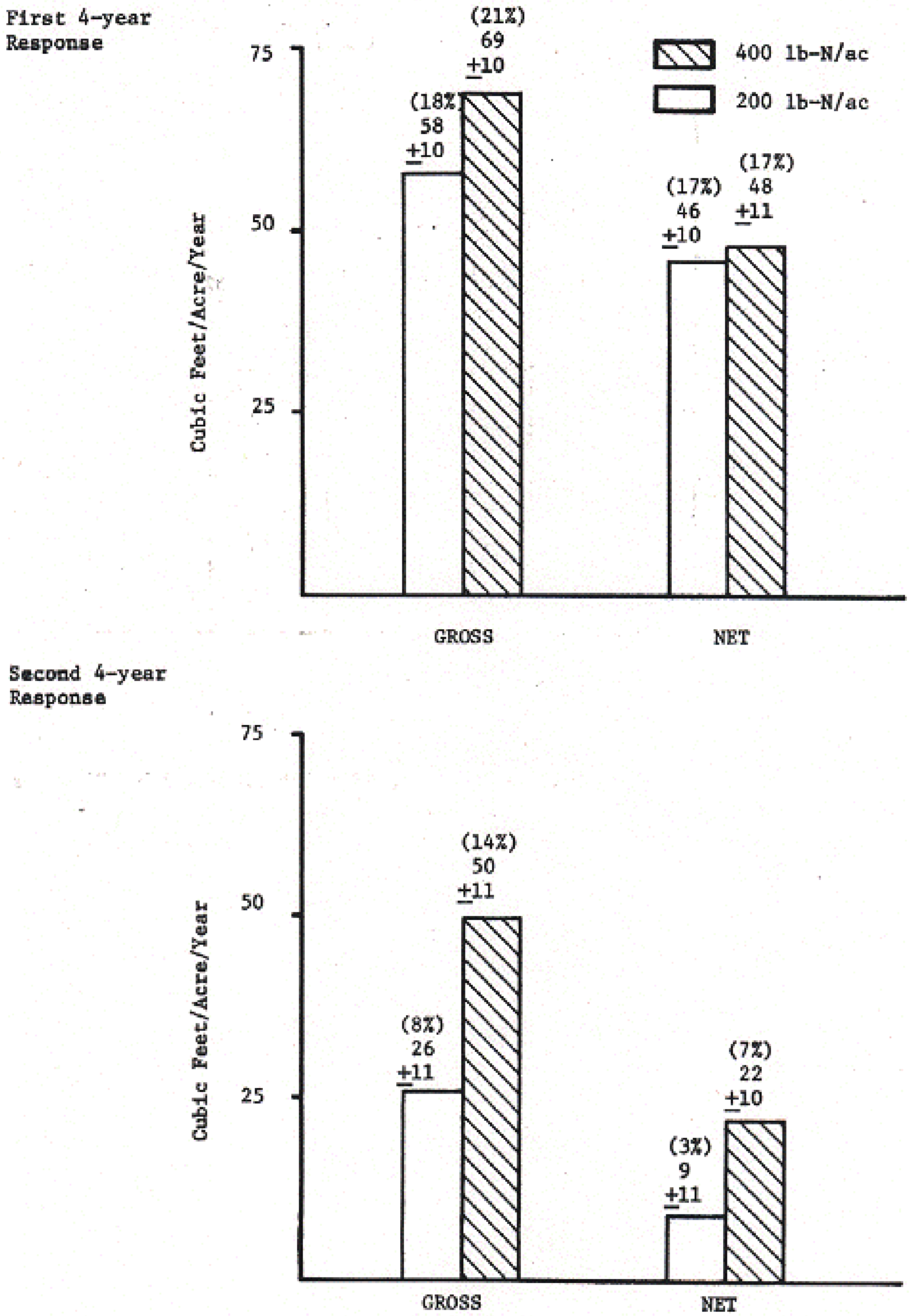
Unadjusted differences (±1 standard error) between average treated growth rates and average untreated growth rates; 8-year total volume growth for unthinned Douglas-fir; (cu ft/ac/yr; min. d.b.h. = 1.55 inches).



Sample by treatment code: ON = 128 plots, 2N = 136 plots, 4N = 127 plots.

Figure 2-7

Unadjusted differences (±1 standard error) between average treated growth rates and average untreated growth rates; 4-year total volume growth for unthinned Douglas-fir; (cu ft/ac/yr; min. d.b.h. = 1.55 inches).



Sample by treatment code: ON = 128 plots, 2N = 136 plots, 4N = 127 plots.

Estimates of 8-year p.a.i. response are presented across site classes for both basal area and volume. More detailed information of response duration in 2-year measurement periods according to site class are displayed in Figures 2-8 through 2-15.

(i) Gross p.a.i.- total basal area.

As reported for the 6-year data (1976-78 Biennial Report), site index significantly affects the 8-year response (sq ft/ac/yr). Lower sites have a significantly greater response in basal area p.a.i.:

Dosage	Response (sq ft/ac/yr) by Site Class I	II	III	IV	Regional Average
200 lb-N	.48* (6%)	90 (14%)	1.31 (23%)	1.84 (30%)	1.11 (18%)
400 lb-N	.91 (13%)	1.34 (22%)	1.64 (27%)	2.25 (37%)	1.45 (23%)

*Not statistically significant at 95% confidence level

When growth is considered on 2-year periods (Figure 2-8), Site I stands show significant response to the 200-pound dosage only during the second measurement period. Response to the 400 pound application on Site I stands is consistent albeit quite small in both absolute and relative (%) amounts, in comparison to lower sites.

The remaining graphs (Figures 2-9: 2-11) demonstrate that lower sites are sustaining a high response for longer periods of time relative to higher sites. The decreasing trend in response over time is much steeper on Site II, for example, than for Sites III or IV. On Sites II-IV, response to 400 pounds nitrogen is longer-lasting than response to 200 pounds nitrogen. This advantage appears to be established more quickly on Site II.

(ii) Gross p.a.i. - total volume.

Previously we reported that site index was nonsignificant in explaining volume growth response (cu ft/ac/yr) for both 6-year and 8-year p.a.i. However, we continued to present smoothed estimates of response by site class at the request of our cooperators. In the last Biennial Report (1978-1980) we presented the average 8-year response by site class:

Dosage	Response by Site Class I	II	III	IV	Regional Average
200 lb-N	28* (7%)	38 (11%)	48 (16%)	59 (23%)	42 (13%)
400 lb-N	39* (9%)	52 (14%)	65 (21%)	79 (31%)	57 (17%)

*Not statistically significant at 95% confidence level.

The reason that this trend is not significant is largely because the early (2-year and 4-year) large responses in the lower site class have diminished somewhat and the overall sample itself is weighted toward site classes II and III. This is more evident when looking at the duration of response by 2-year periods for each site index class (Figures 2-12: 2-15).

Site I response to either level of N-application is nonsignificant (Figure 2-12) in the last 2 measurement periods (last 4 years). Average 8-year response to 200 lb-N or 400 lb-N for Site I is also not significant. Response on all site classes over four 2-year periods decreases after the second 2-year period.

2.2.3 Total gross response on merchantable stand

Estimated response in the merchantable portion of the stand was reported in the 1978-1980 Biennial Report. It is difficult to compare this with response in the total stand due to changes in top diameter limits as well as changes in d.b.h. limits. Yet we would like to know what amount of response in the total stand is going to the larger trees. Therefore we have computed total growth rate on the stems of merchantable diameter to serve as a bridge between the previously reported estimates of total response and merchantable response, where:

ΔT_t = gross p.a.i. based on all trees in the plot to include top and stump.

ΔT_m = gross p.a.i. based on trees in the plot of d.b.h. > 6.55 inches to include top and stump.

ΔM_m = gross p.a.i. based on trees in the plot of d.b.h. > 6.55 inches to a 4-inch top diameter.

Consider volume increment response to 200 lb-N in Table 2-4. Clearly there is no difference in average 8-year response between total growth rate (ΔT_m = 40 cu ft/ac/yr) on the merchantable portion and merchantable growth rate (ΔM_m = 40 cu ft/ac/yr) on the merchantable portion.

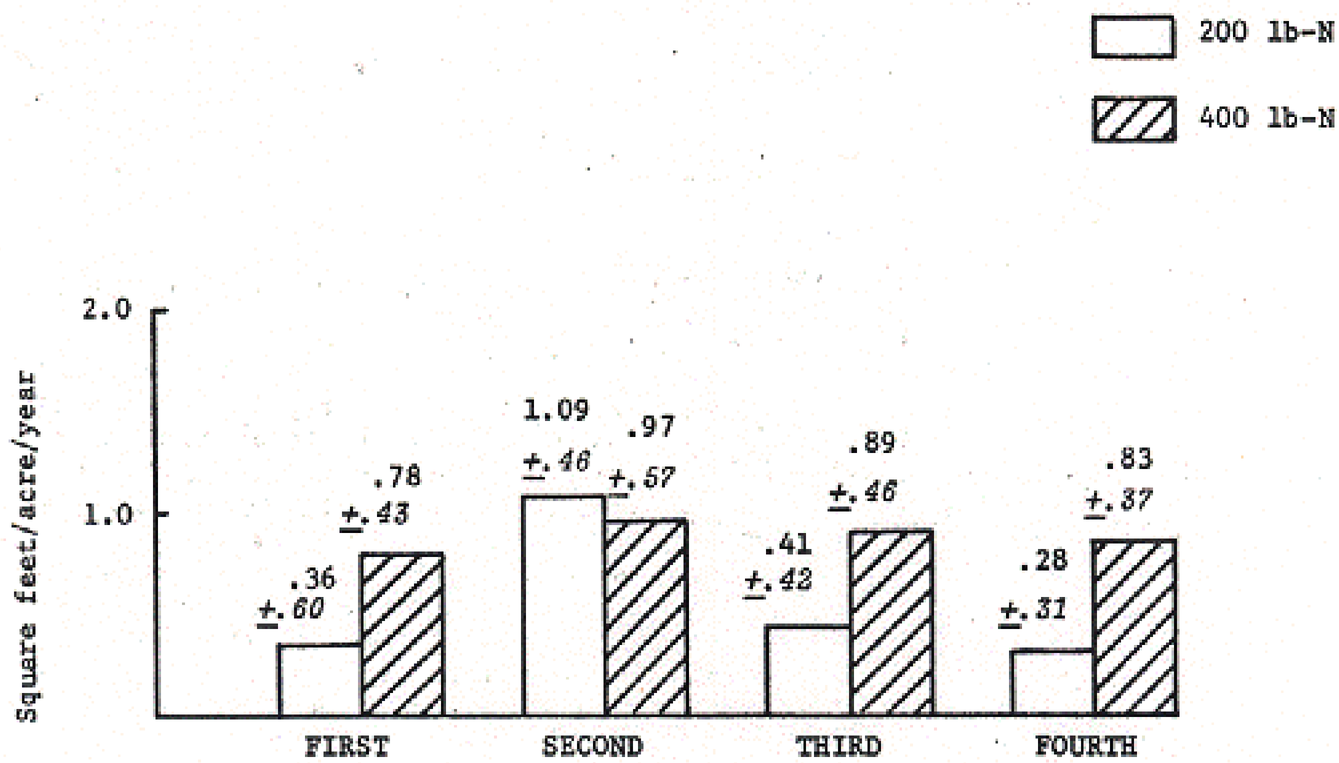
It is interesting to compare the same total growth response on different portions of the stand (ΔT_m vs ΔT_t). Absolute total response on the merchantable stand (40 cu ft/ac/yr) is only slightly less than total response on the total stand (43 cu ft/ac/yr). That is, out of 43 cu ft/ac/yr total gross response to 200 lb-N/ac, approximately 93% (40 cu ft/ac/yr) of that response is being put on by trees of d.b.h. $\geq$ 7 inches. The situation is similar for response to the 400-pound application of nitrogen.

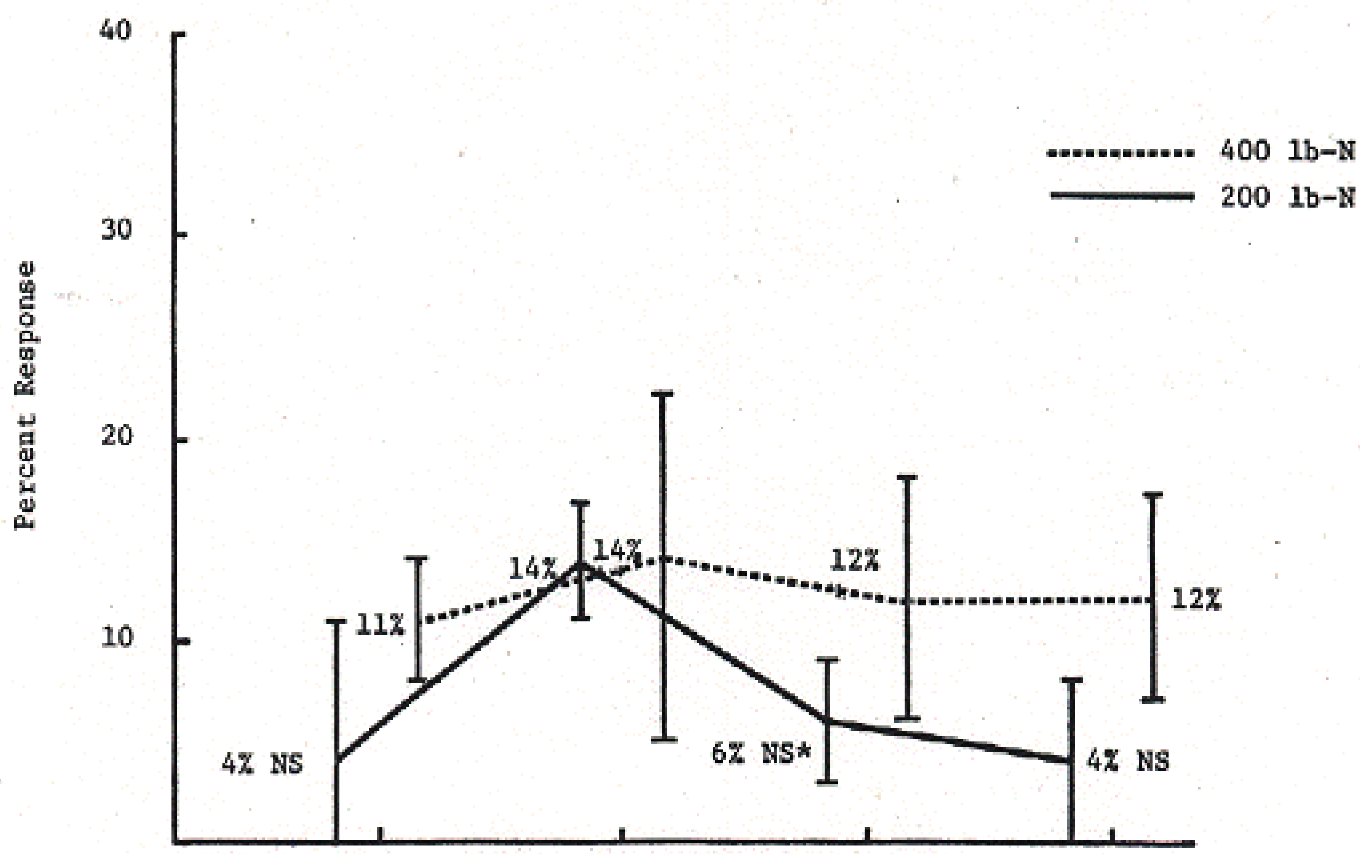
Merchantable response is not significantly related to site index. Estimates of response were obtained in each site class (i.e., not smoothed across sites) for economic analysis (Section 6.0) and so are presented here.

Figure 2-8

Estimated mean response (± 1 standard error) of gross total basal area growth by 2-year periods for Douglas-fir (sq ft/acre/year; minimum d.b.h. = 1.55 inches).

Site I



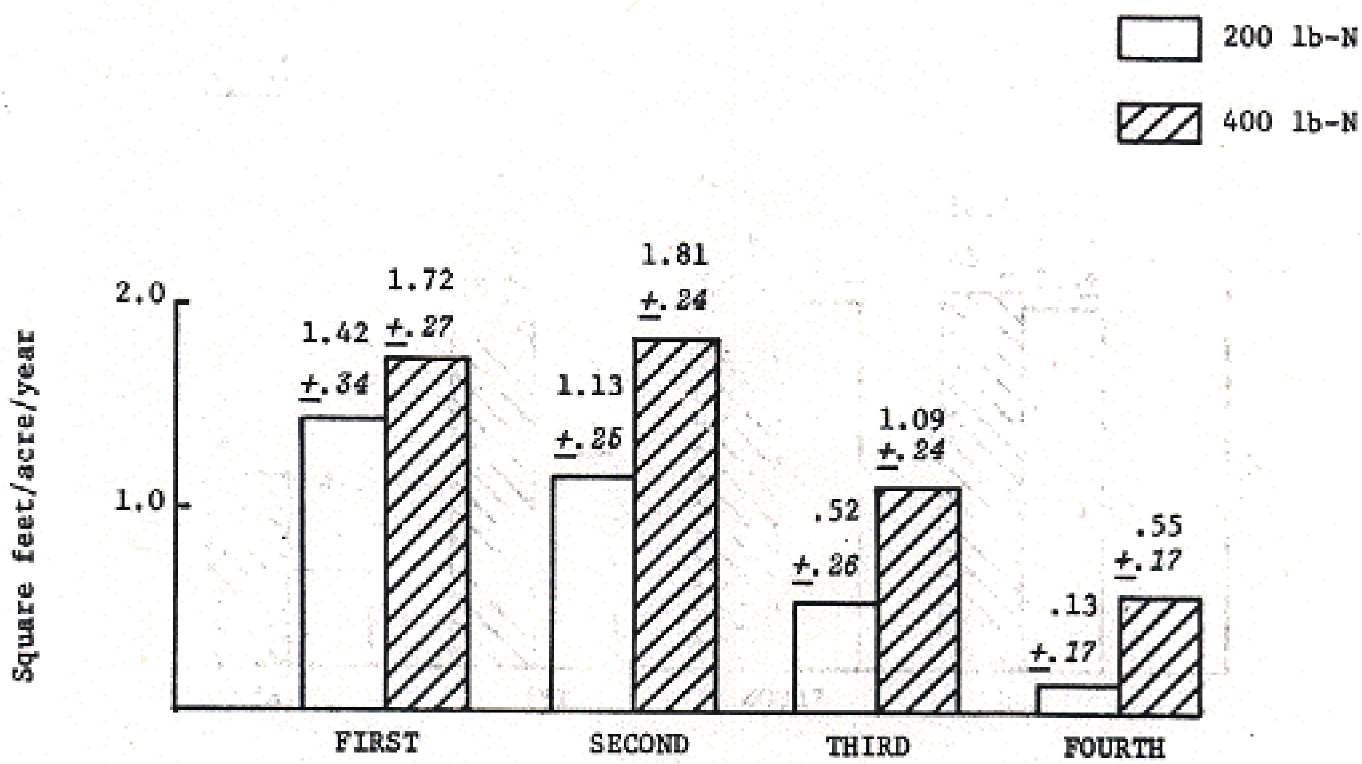


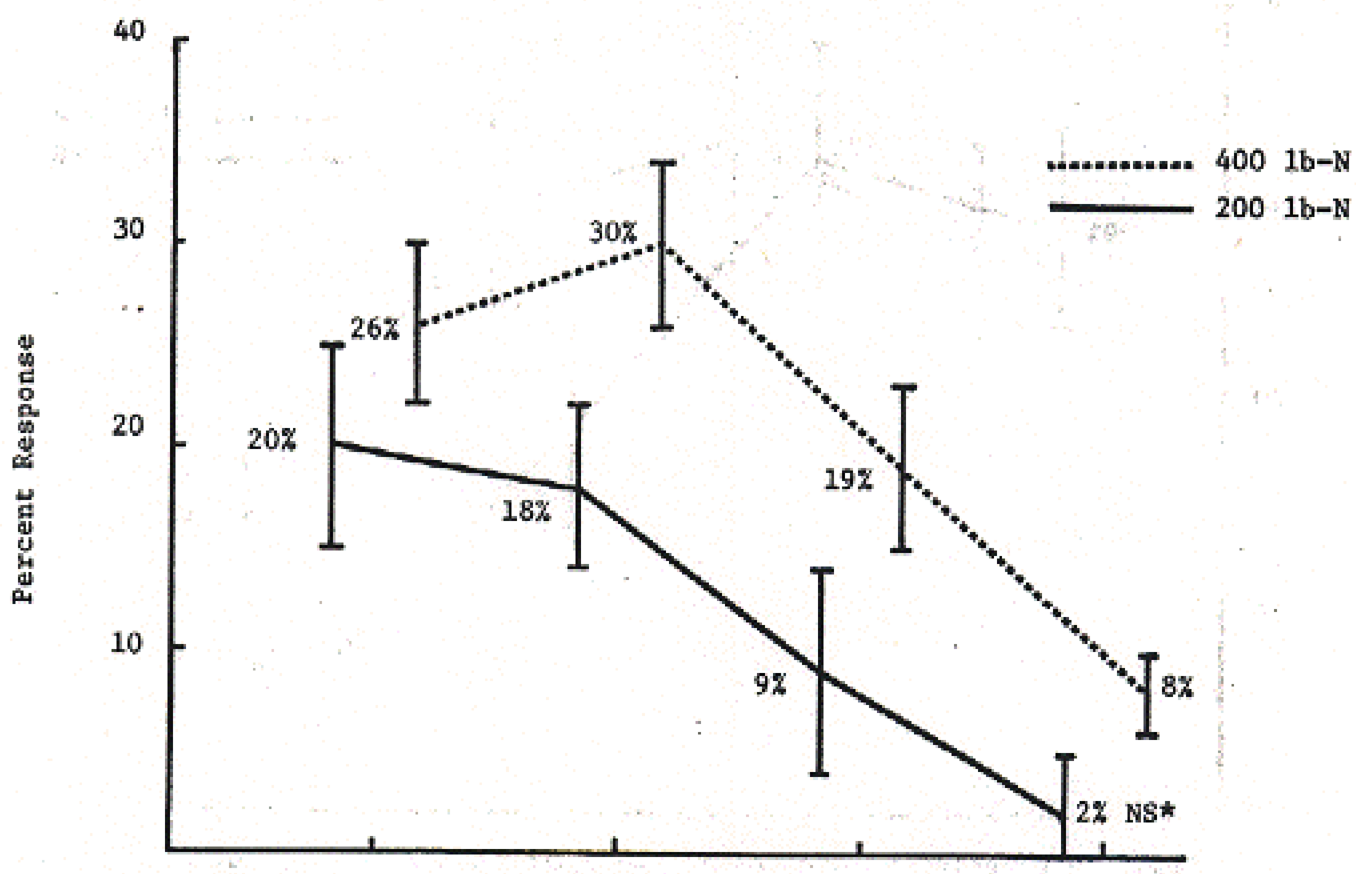
NS* = Significant at 80% CL (confidence level)
NS = Nonsignificant at 80% CL
Sample per period by treatment: ON = 19 plots, 2N = 21 plots, 4N = 19 plots

Figure 2-9

Estimated mean response (± 1 standard error) of gross total basal area growth by 2-year periods for Douglas-fir (sq ft/acre/year; minimum d.b.h. = 1.55 inches).

Site II





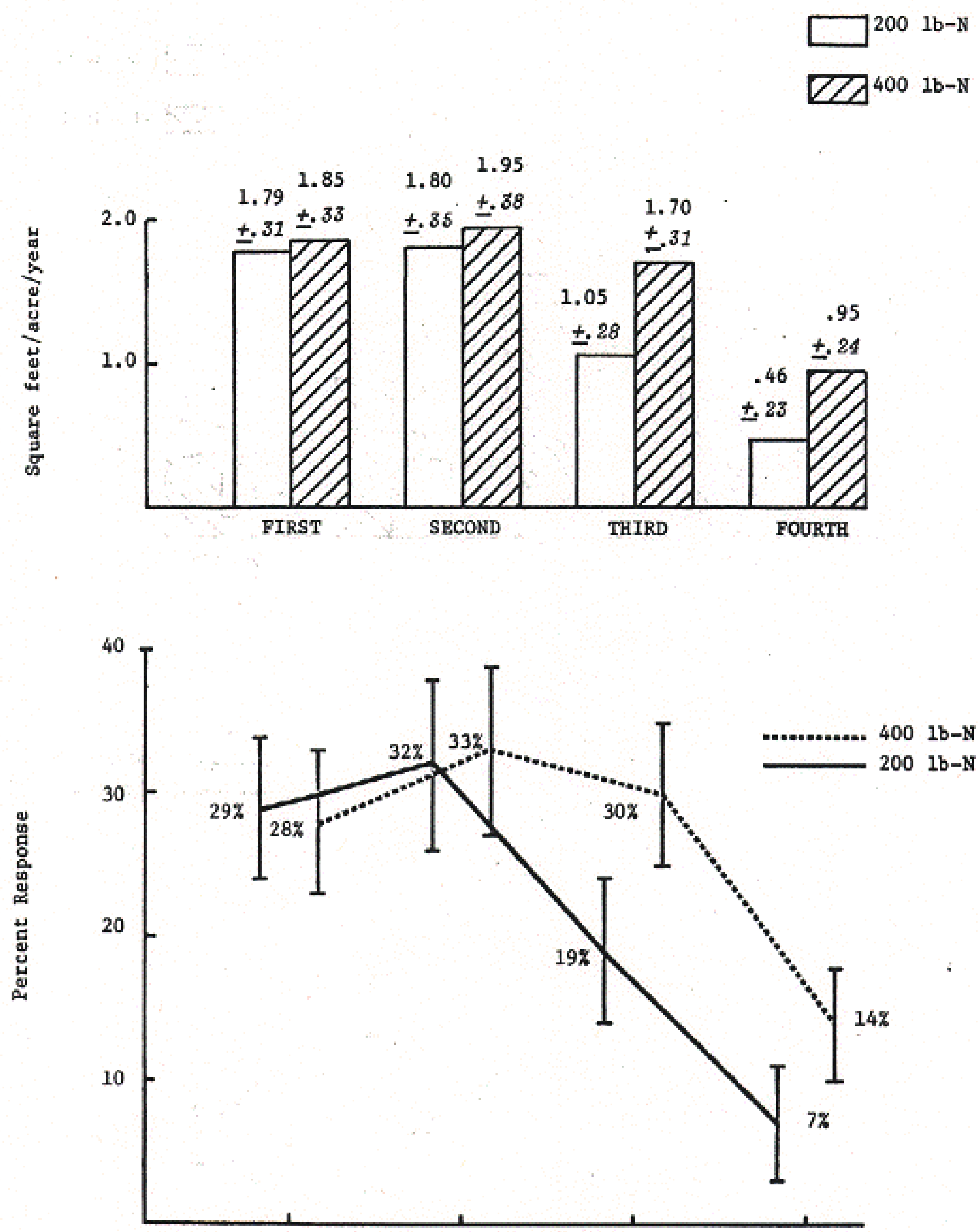
NS* = Significant at 80% CL

Sample per period by treatment: ON = 57 plots, 2N = 54 plots, 4N = 49 plots

Figure 2-10

Estimated mean response (± 1 standard error) of gross total basal area growth by 2-year periods for Douglas-fir (sq ft/acre/year; minimum d.b.h. = 1.55 inches).

Site III

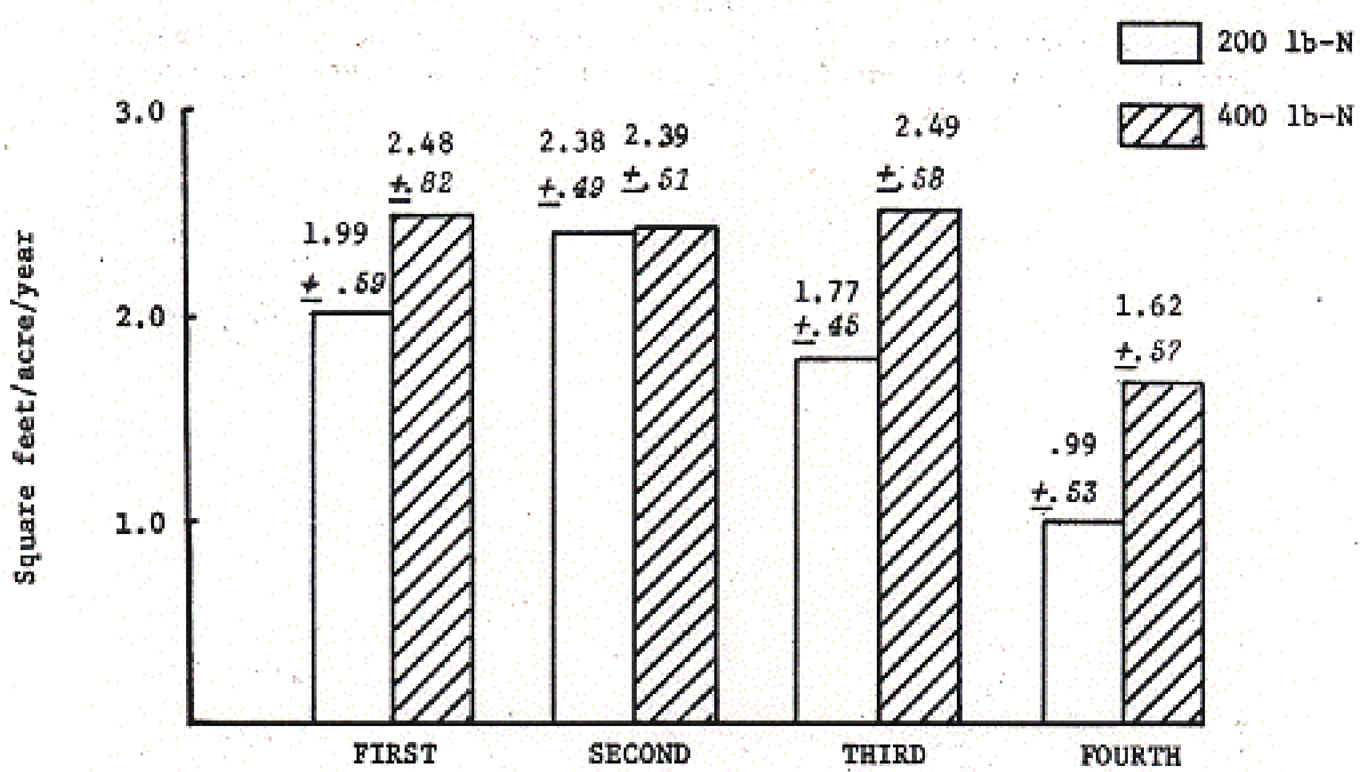


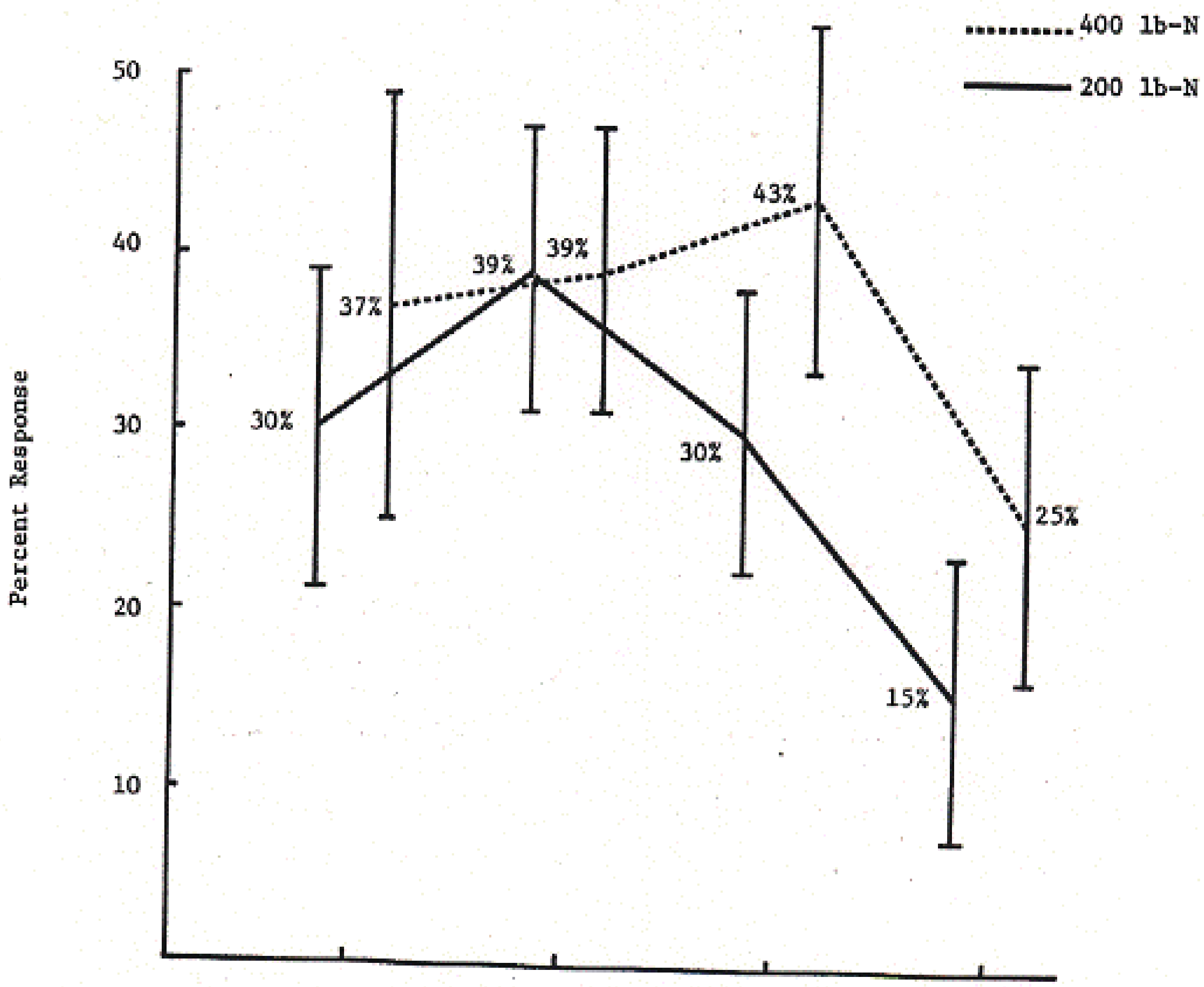
Sample per period by treatment: ON = 37 plots, 2N = 41 plots, 4N = 48 plots

Figure 2-11

Estimated mean response (± 1 standard error) of gross total basal area growth by 2-year periods for Douglas-fir (sq ft/acre/year; minimum d.b.h. = 1.55 inches).

Site IV

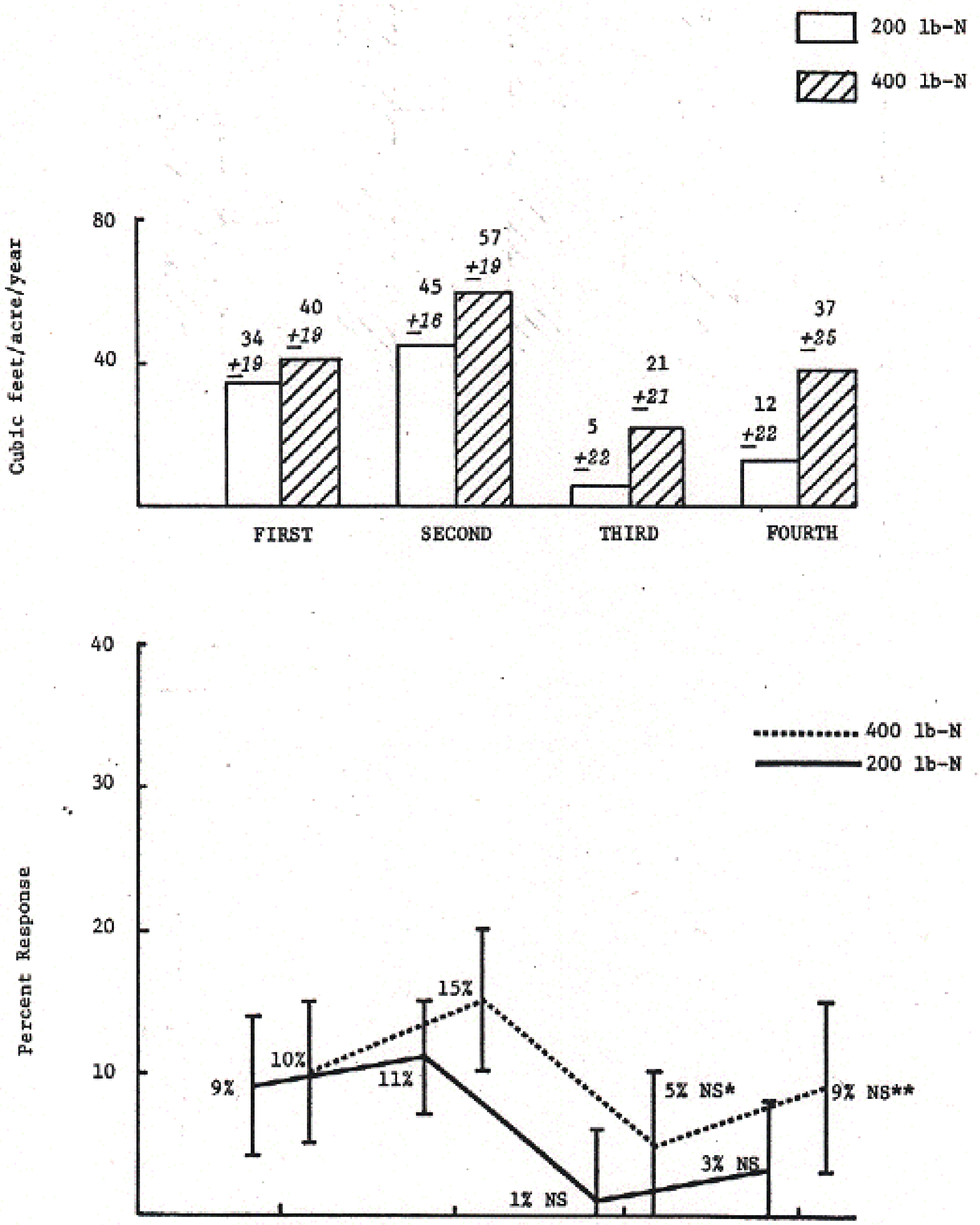




Sample per period by treatment: ON = 12 plots, 2N = 20 plots, 4N = 11 plots

Figure 2-12
Estimated mean response (± 1 standard error) of gross total volume growth by 2-year periods for Douglas-fir (cu ft/acre/year; minimum d.b.h. = 1.55 inches).

Site I

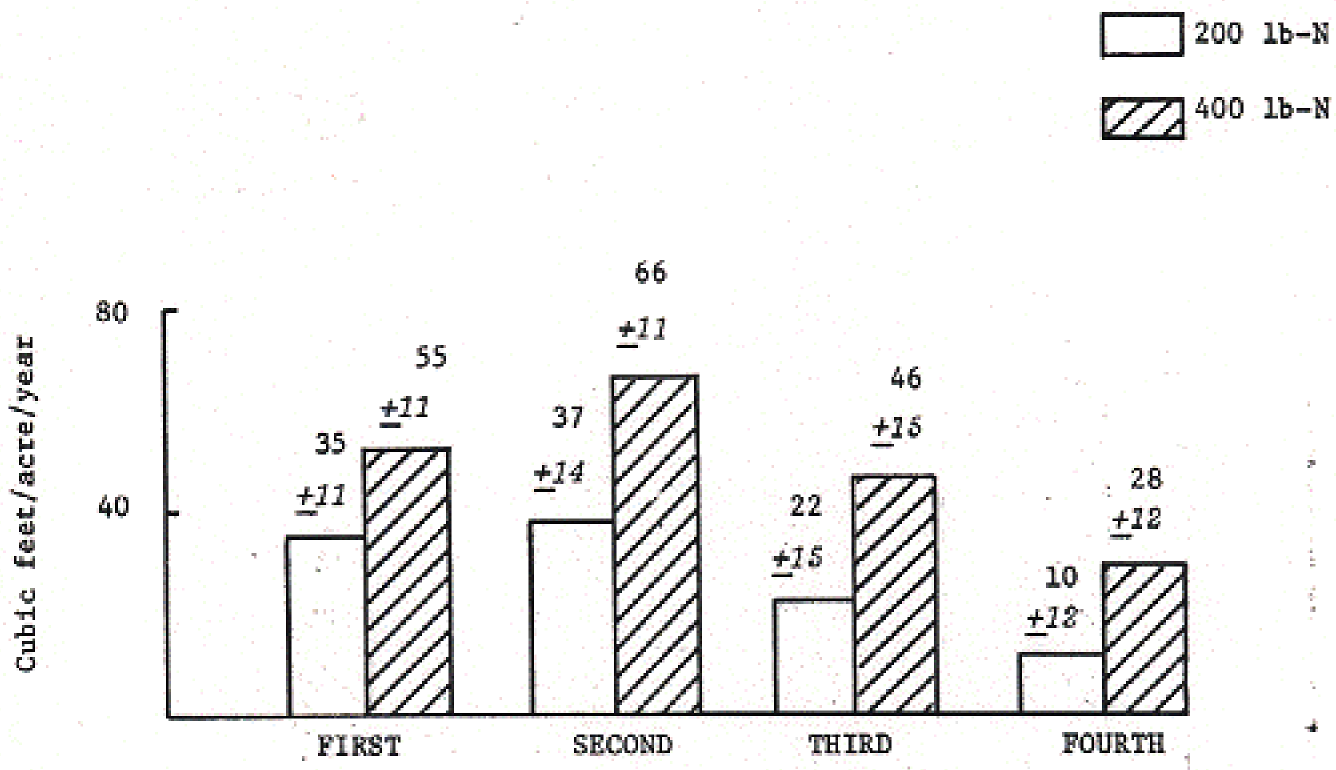


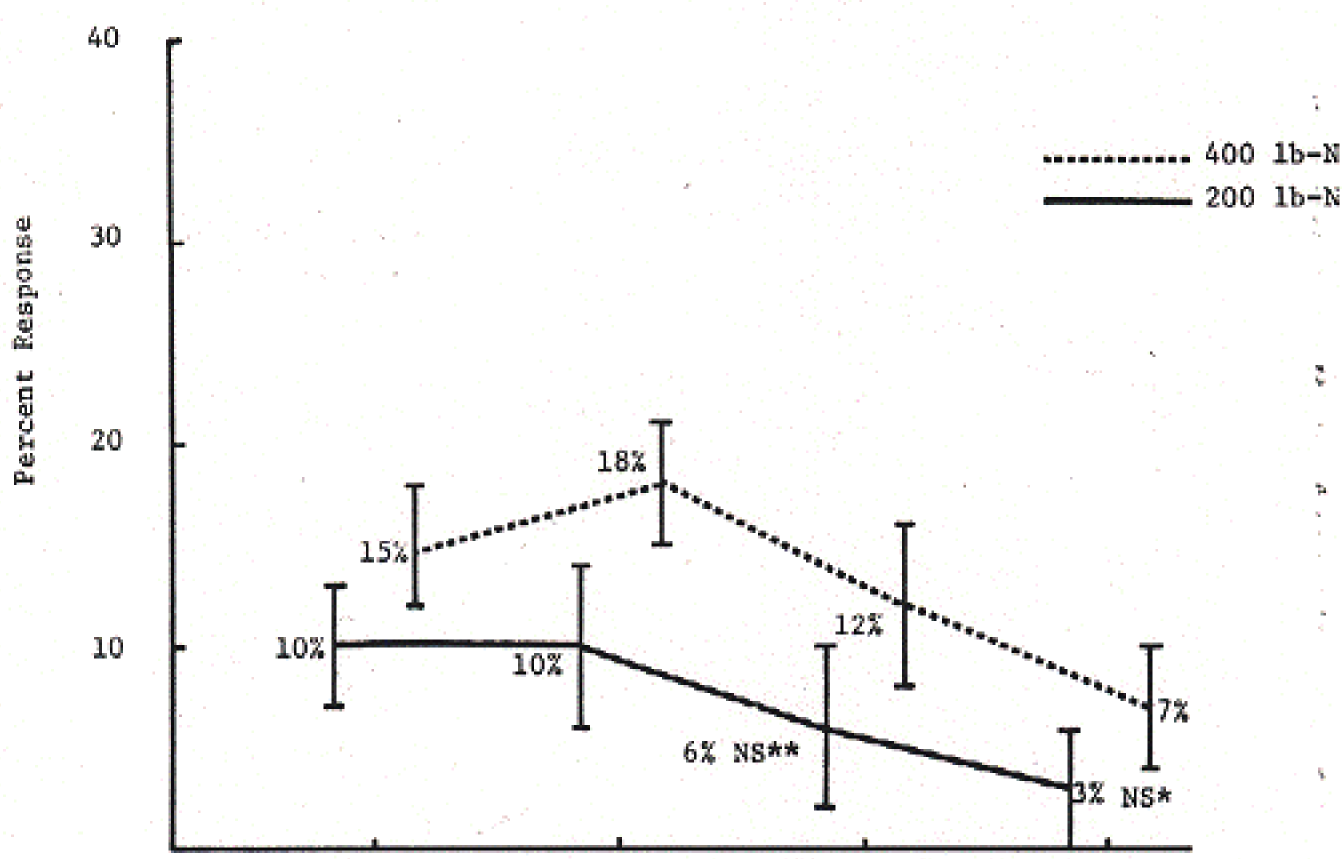
NS** = Significant at 90% CL
NS* = Significant at 80% CL
NS = Nonsignificant at 80% CL
Sample per period by treatment: ON = 19 plots, 2N = 21 plots, 4N = 19 plots

Figure 2-13

Estimated mean response (± 1 standard error) of gross total volume growth by 2-year periods for Douglas-fir (cu ft/acre/year; minimum d.b.h. = 1.55 inches).

Site II



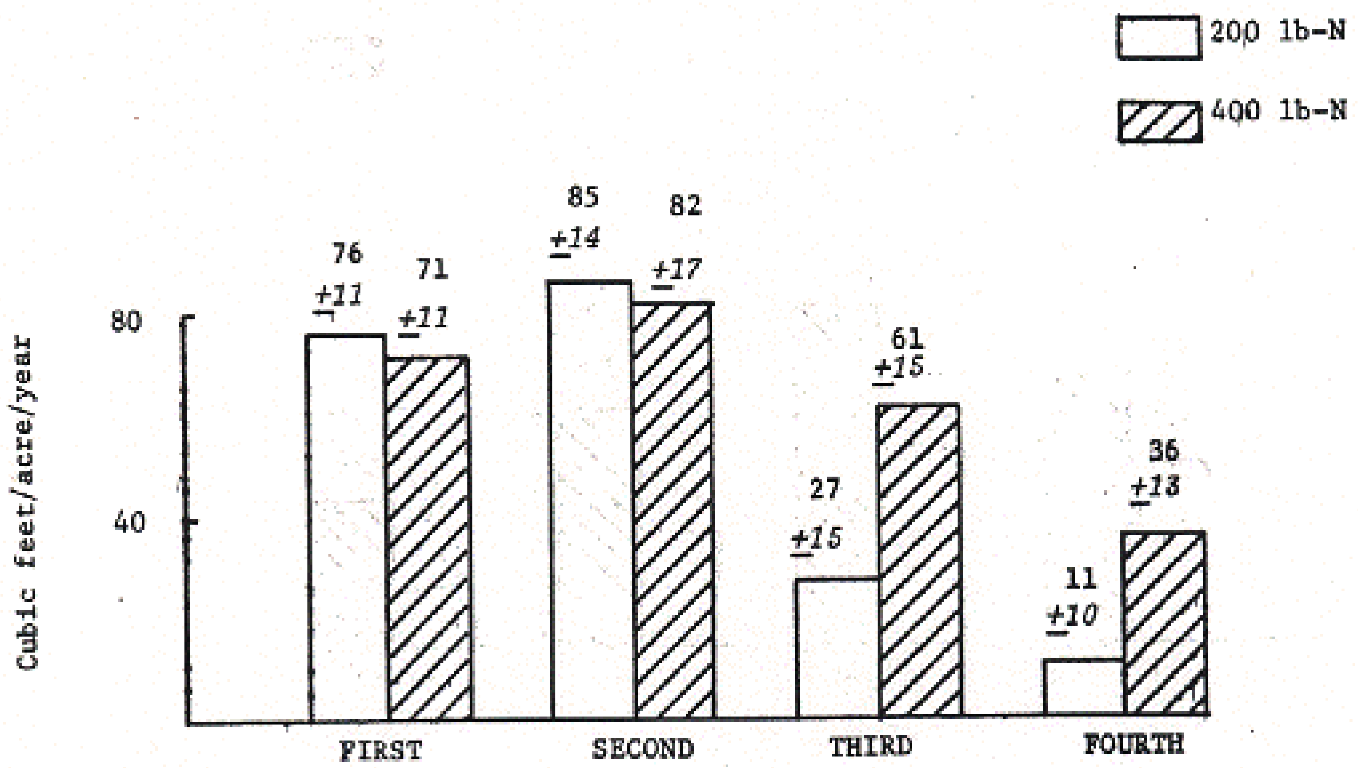


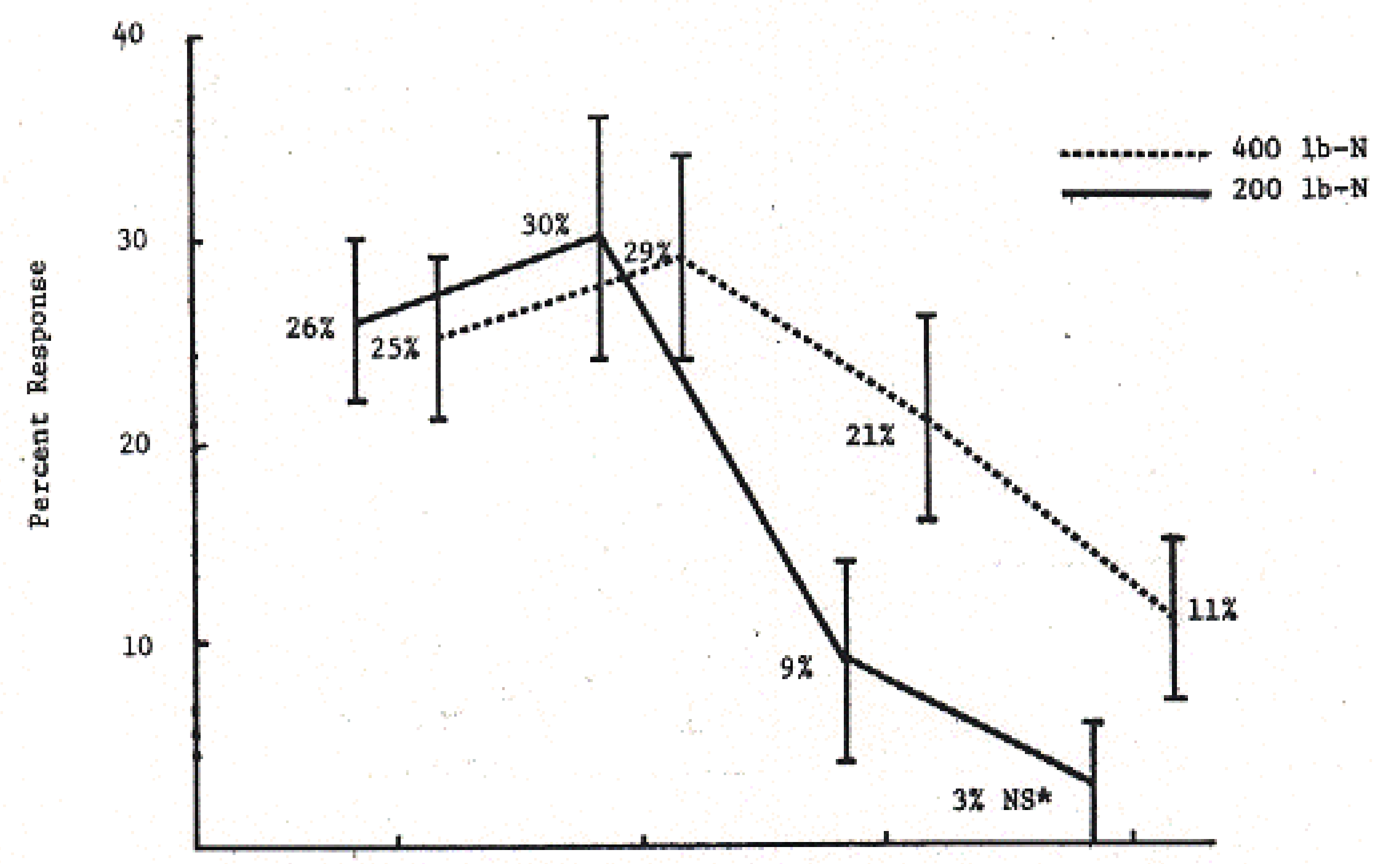
NS** = Significant at 90% CL
NS* = Significant at 80% CL
Sample per period by treatment: ON = 57 plots, 2N = 54 plots, 4N = 49 plots

Figure 2-14

Estimated mean response (± 1 standard error) of gross total volume growth by 2-year periods for Douglas-fir (cu ft/acre/year; minimum d.b.h. = 1.55 inches).

Site III





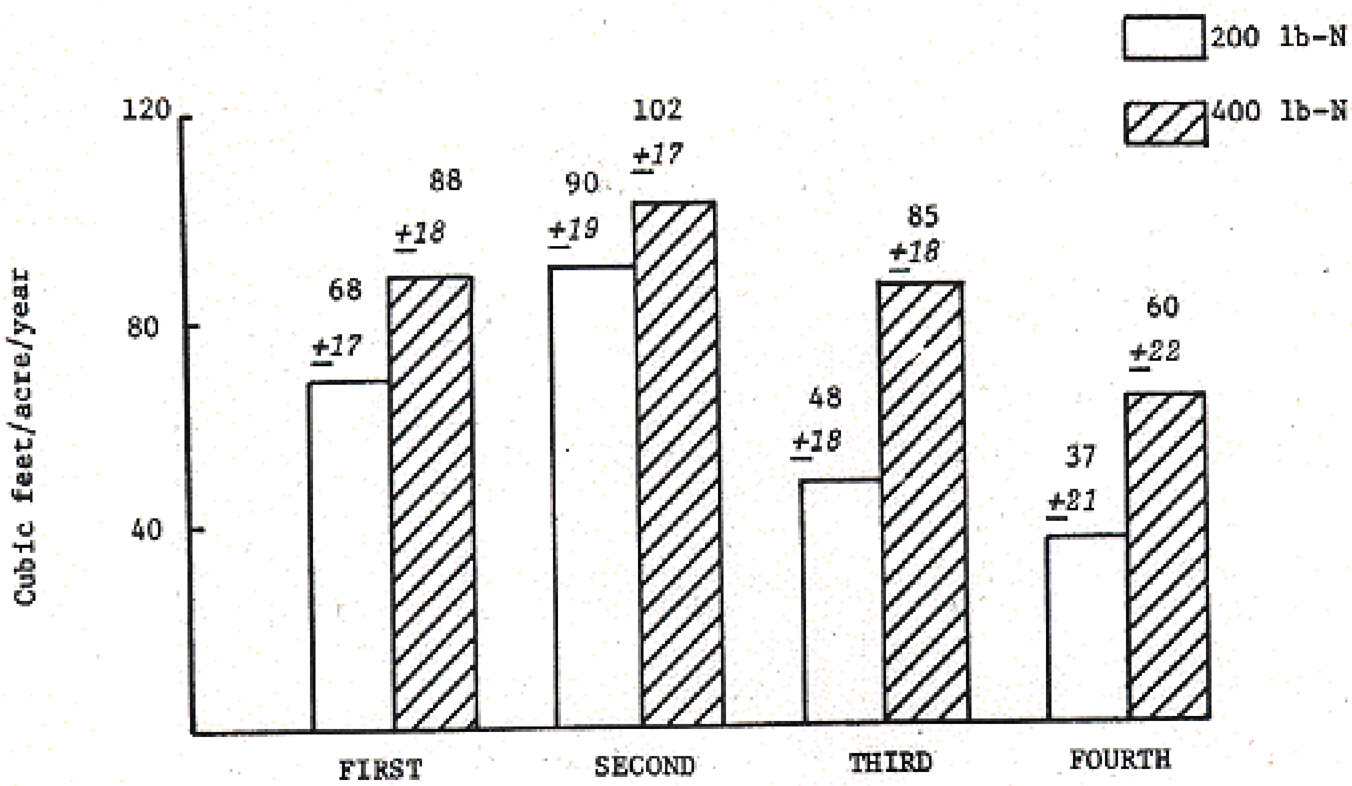
NS* = Significant at 80% CL

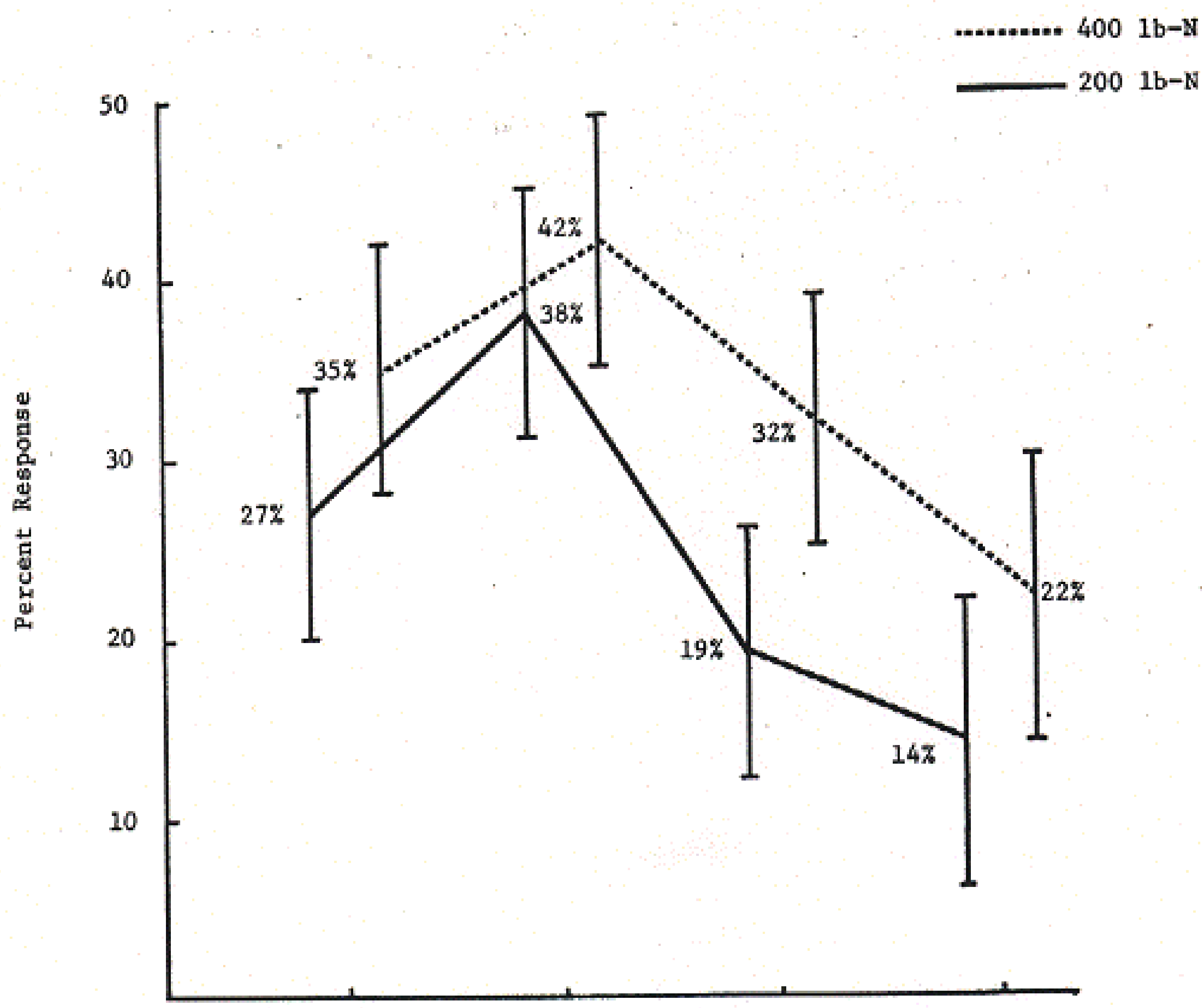
Sample per period by treatment: ON = 37 plots, 2N = 41 plots, 4N = 48 plots

Figure 2-15

Estimated mean response (± 1 standard error) of gross total volume growth by 2-year periods for Douglas-fir (cu ft/acre/year; minimum d.b.h. = 1.55 inches).

Site IV





Sample per period by treatment: ON = 12 plots, 2N = 20 plots, 4N = 11 plots

Table 2-4. Unadjusted average 8-year growth and response of unthinned Douglas-fir; without ingrowth.

Treatment	PAI	ΔM_m	ΔT_m	ΔT_t
ON	ΔB	5.14	5.14	6.19
	ΔV	278	287	324
2N	ΔB	6.11	6.11	7.35
	Difference	(.97; 19%)	(.97; 19%)	(1.16; 19%)
	ΔV	318	327	367
	Difference	(40; 14%)	(40; 14%)	(43; 13%)
4N	ΔB	6.39	6.39	7.57
	Difference	(1.25; 24%)	(1.25; 24%)	(1.38; 22%)
	ΔV	332	341	382
	Difference	(54; 19%)	(54; 19%)	(58; 18%)

ΔM_m = merchantable growth rate on merchantable stand (min. d.b.h. - 6.55 inches to 4-inch top).

ΔT_m = total growth rate on merchantable stand (min. d.b.h. = 6.55 inches).

ΔT_t = total growth rate on total stand (min. d.b.h. = 1.55 inches).

ΔV = volume p.a.i.;cu ft/ac/yr

ΔB = basal area p.a.i. ;sq ft/ac/yr

Merchantable 8-year response (cu ft/ac/yr)
(min d.b.h. = 6.55 in., to 4 in. top)

Dosage	Estimated within Site Class I	II	III	IV	Regional Average
200 lb-N	19* (5%)	26 (8%)	51 (22%)	40 (22%)	35 (12%)
400 lb-N	29* (8%)	45 (14%)	54 (23%)	66 (36%)	49 (17%)

*Not statistically significant at 95% confidence level.

Note that 8% response to 200 pounds of nitrogen in site class II is significant whereas the same amount of response to 400 pounds of nitrogen in site class I is not statistically significant. Response variation is not that much different between site classes I and II but sample size is much larger for site class II, as mentioned in section 2.2.2. Thus the reason for significance or lack thereof appears to be sample size rather than actual response. This is reflected in Figures 2-12 through 2-15 which contain sample size and standard errors of response estimates in the total stand.

2.2.4 Total gross response in mixed stands

In November of 1981 the Technical Advisory Committee agreed that analyses and reporting should concentrate on relatively "pure" stands, while summaries should also be prepared for stands with less than 80% Douglas-fir stocking. Stands retained which are less than 80% Douglas-fir are those stands whose primary mixed species is conifer.

The plot distribution by age and site for these stands is given in Table 2-5 for pure ($\geq$ 80% fir-type) and mixed (< 80% fir-type) components. Response is the difference in observed growth rates between treated and control. Data are presented in Table 2-6 for pure, mix, and all plots (pure + mix).

Response estimates in Table 2-6 are lower for the mixed (<80% fir-type) component than for the "pure" ($\geq$ 80% fir-type) stands. These response differences by mixture are more pronounced in volume growth than in basal area growth. The variation in growth rates is greater in the mixed stand component. Hence a test of significant differences between p.a.i. averages for "pure" and "mix" within a treatment level reveals more difference between "pure" and "mixed" in untreated growth rates than in treated growth rates. That is, the "pure" Douglas-fir stands appear to be much better candidates for fertilizer than do those stands with heavy mix from other conifer species.

2.3 4-year response with supplementary plots

In Phase III, additional installations were established to supplement the age and site distributions of Phase I. The distribution of plots by age and site classes in each Phase is given in Table 2-7. Only stands with 80% or more Douglas-fir stocking are presented. Phase III supplemented Phase I by adding plots of younger ages and lower site. Average regional growth rates are summarized in Table 2-8 for unthinned plots, with and without supplements. It is also evident from Table 2-8 that about 80% of the supplemental plots were control and 200 lb.-N treatments. Wherever stand area was a constraint, priority was given to 200 lb-N treatments over 400 lb-N treatments.

(i) Gross p.a.i. - total basal area.

Response to 200 lb-N is estimated to be 1.78 sq ft/ac/yr and 1.89 sq ft/ac/yr from 400 lb-N. These average estimates represent relative increases of 25% and 30% respectively over respective estimates of untreated growth rate. Treatment significantly increased growth rate. Significant treatment interactions were also found with initial basal area and stems per acre. These improved estimates of response are based on more data than those estimates in the 1974-76 Biennial Report, and are higher.

(ii) Gross p.a.i.- total volume.

Volume response is estimated on a regional average also. Average response to 200 pounds of nitrogren is 60 cu ft/ac/yr, representing a relative increase of 19%. Response to 400 pounds of nitrogen per acre is 68 cu ft/ac/yr, or 21%. Treatment significantly increased growth rate and response was significantly related to site index after 4 years:

4-year response (cu ft/ac/yr) by Site Class

Dosage	I 145	II 125	III 105	IV 85	Average
200 lb-N	33 (8%)	51 (14%)	68 (23%)	86 (36%)	60 (19%)
400 lb-N	37 (9%)	57 (16%)	77 (26%)	97 (41%)	68 (21%)

Average response is a little higher than that estimated in the 1974-76 Biennial Report for 4 years. The 4-year trend of response across site index remains significant after adding the Phase III plots.

These current estimates of volume and basal area 4-year response are improved over previous estimates due to addition of data from the supplementary plots. That is, the estimates of growth and response can be interpreted with greater confidence due to increased sample size.

Table 2-5. Distribution of "pure" and "mixed" 1/10-acre plots for total growth response analysis of Phase I (unthinned) Douglas-fir.

Age Class		Site Index 145	125	105	85	65	Total
10	pure	8	6	2	--	--	16
	mixed	3	4	1	1	2	11
20	pure	9	43	34	5	--	91
	mixed	4	18	6	--	2	30
30	pure	30	45	41	19	--	135
	mixed	1	6	4	9	--	20
40	pure	7	59	37	16	2	121
	mixed	3	1	5	3	2	14
50	pure	5	8	8	3	--	24
	mixed	--	--	1	3	--	4
60	pure	--	--	4	--	--	4
	mixed	--	--	1	1	--	2
Total		70	190	144	60	8	472

Table 2-6. Raw averages of 8-year growth and response of unthinned "pure" and "mixed" Douglas-fir (Phase I) for the total stand (sq ft/ac/yr, cu ft/ac/yr; minimum d.b.h. = 1.55 inches).

	Treatment:	0 lb-N			200 lb-N			400 lb-N		
	Composition:	D-fir	Mix	All plots	D-fir	Mix	All plots	D-fir	Mix	All plots
BASAL AREA	ΔB_1 (1st 4-years)	6.39	7.66	6.62	8.01	8.76	8.12	8.09	9.45	8.34
	Difference	---	---	---	1.62	1.10	1.50	1.70	1.79	1.72
	% Response	---	---	---	25%	14%	23%	27%	23%	26%
	ΔB_2 (2nd 4-years)	6.17	7.50	6.41	6.98	7.98	7.13	7.36	8.52	7.58
	Difference	---	---	---	0.81	0.48	0.72	1.19	1.02	1.17
	% Response	---	---	---	13%	6%	11%	19%	14%	18%
	ΔB (8-years)	6.25	7.54	6.48	7.44	8.31	7.57	7.66	8.91	7.89
	Difference	---	---	---	1.19	0.77	1.09	1.41	1.37	1.41
	% Response	---	---	---	19%	10%	17%	22%	18%	22%
VOLUME	ΔV_1 (1st 4-years)	322	312	320	380	338	373	391	363	386
	Difference	---	---	---	58	26	53	69	51	66
	% Response	---	---	---	18%	8%	16%	21%	16%	20%
	ΔV_2 (2nd 4-years)	342	336	341	369	356	367	392	369	388
	Difference	---	---	---	26	20	26	50	33	47
	% Response	---	---	---	7%	6%	8%	14%	10%	14%
	ΔV (8-years)	325	319	324	368	347	365	383	361	380
	Difference	---	---	---	43	28	41	58	42	56
	% Response	---	---	---	13%	9%	13%	18%	13%	17%

ΔB_1 = basal area p.a.i. (sq ft/ac/yr) over 1st 4 years.
ΔB_2 = basal area p.a.i. (sq ft/ac/yr) over 2nd 4 years.
Difference* = observed treated p.a.i. minus observed 0 lb-N p.a.i. for respective composition.
Mixture is comprised of conifers (i.e., plots with significant hardwood mix are not included).

Table 2-7. Distribution of 1/10-acre plots for total gross response analysis of unthinned Douglas-fir by Phases (I and III).

Age class	Phase	50-year Site Index 145	125	105	85	65	All
5	1	-	-	-	-	-	-
	3	-	4	4	-	-	8
10	1	8	6	2	-	-	16
	3	4	12	14	4	-	34
20	1	9	43	34	5	-	91
	3	-	-	3	1	-	4
30	1	30	45	41	19	-	135
	3	-	-	4	5	-	9
40	1	7	59	37	17	2	122
	3	-	1	6	18	3	28
50	1	5	8	8	3	-	24
	3	-	-	1	5	5	11
60	1	-	-	4	-	-	4
	3	-	-	-	-	-	0
All	1	59	161	126	44	2	392
	3	4	17	32	33	8	94

392 Phase I (established 1969-70)
94 Phase III (established 1975)

Total = 486

Table 2-8. Summary of unadjusted mean 4-year growth of thinned Douglas-fir (Phases I + III) for the total stand (sq ft/ac/yr; minimum d.b.h. = 1.55 inches).

Increment	Treatment lbs-N/ac	Phases I + III No. of plots	Average p.a.i.	Std. dev.	Phase I No. of plots	Average p.a.i.	Std. dev.
Gross ΔB	0	164	6.96	2.95	128	6.39	2.12
	200	175	8.78	3.64	136	8.01	2.72
	400	147	8.15	2.60	128	8.09	2.66
Net ΔB	0	164	5.39	3.63	128	4.58	2.79
	200	175	6.71	4.34	136	5.61	3.20
	400	147	5.38	3.33	128	5.32	3.31
Gross ΔV	0	164	307	90	128	322	82
	200	175	367	92	136	380	80
	400	147	384	86	128	391	86
Net ΔV	0	164	267	90	128	275	88
	200	175	317	87	136	321	80
	400	147	317	91	128	322	93

ΔB = basal area p.a.i.
ΔV = volume p.a.i.

3 Regional Growth and Response Analysis for Thinned Douglas-fir (C. Peterson)

Gross response data are presented as smoothed estimates (from regressions based on initial age, site index, and stocking) throughout, except when compared to net responses. That comparison is made with differences between unadjusted stand growth rates for treated and untreated conditions. All tests for statistical significance were made at the 95% confidence level unless otherwise noted.

As for the unthinned stands, response is estimated as increased growth rate due to nitrogen fertilizer:

RESPONSE = [Treated Thinned Stand Growth Rate] minus [Growth Rate as in Untreated Thinned Stand]

Analysis of thinned stands for differences in 6-year growth rates between provinces is summarized in Section 3.1. The 8-year growth and response data are summarized in Section 3.2. Current results pertain to 1 (initial) application of nitrogen.

Section 3.3 contains an update of 4-year growth and response. The overall data base was augmented by establishment of supplemental installations in 1975 under Phase III.

3.1 Province analysis

The thinned Douglas-fir data was analyzed for significant differences in 6-year volume p.a.i. (treated and untreated) among the Provinces. That is, the initial differences between provinces in b.h. age, site index, and basal area were adjusted in analysis of covariance. A treatment-province interaction was not significant ($F=1.90<F_{.05}=1.99$). No significant differences in average growth rates were found among provinces ($F=1.74<F_{.05}=2.42$). The effect of fertilizer application on growth was significant ($F=50.8$) as expected.

The province analysis for Phase II (thinned) Douglas-fir is not as detailed as province analysis for Phase I (unthinned) Douglas-fir (1974-1976 Biennial Report) since there was no response-site interaction in Phase II volume increment. There is no evidence that volume response in thinned stands interacts with age, site index, or stocking variables.

3.2 Response of total stand after 8 growing seasons

Eight-year growth rates of fertilized (1 application) Douglas-fir stands are in the Appendix. These increments provide the basis for response estimation.

All growth and response data presented in this section are total stand results (i.e., no merchantable limits imposed), based on plots with at least 80% Douglas-fir stocking.

3.2.1 Total net and gross volume response

Net and gross response estimates are both computed as differences between treatment and control for net p.a.i. and gross p.a.i. respectively. Net p.a.i. and gross p.a.i. correspond to G_{n+i} and G_{g+i} as defined by Husch, et al., (1972)[2].

Analysis of total stand response was based on 194 plots of 1/10-acre or larger. Initial breast-height ages range from about 15 to 50 and site classes range from I through IV. The data are not adjusted for any differences in initial stand conditions such as site index, basal area, etc.

(i) Eight-year response.

Figure 3-1 shows both gross and net response to 200 lb-N and 400 lb-N applications. There is no significant difference between net and gross responses and no significant difference between 200 lb-N response and 400 lb-N response.

(ii) Response by 4-year periods.

As was the case in unthinned stands, the greatest response occurred in the first 4 years following nitrogen application (Figure 3-2a). However, the decrease in response over the second 4-year period is not as great as it was for unthinned stands. There is no significant difference between 200 lb-N and 400 lb-N responses nor between gross and net response in Figure 3-2a. The same is true in Figure 3-2b.

3.2.2 Total gross smoothed response

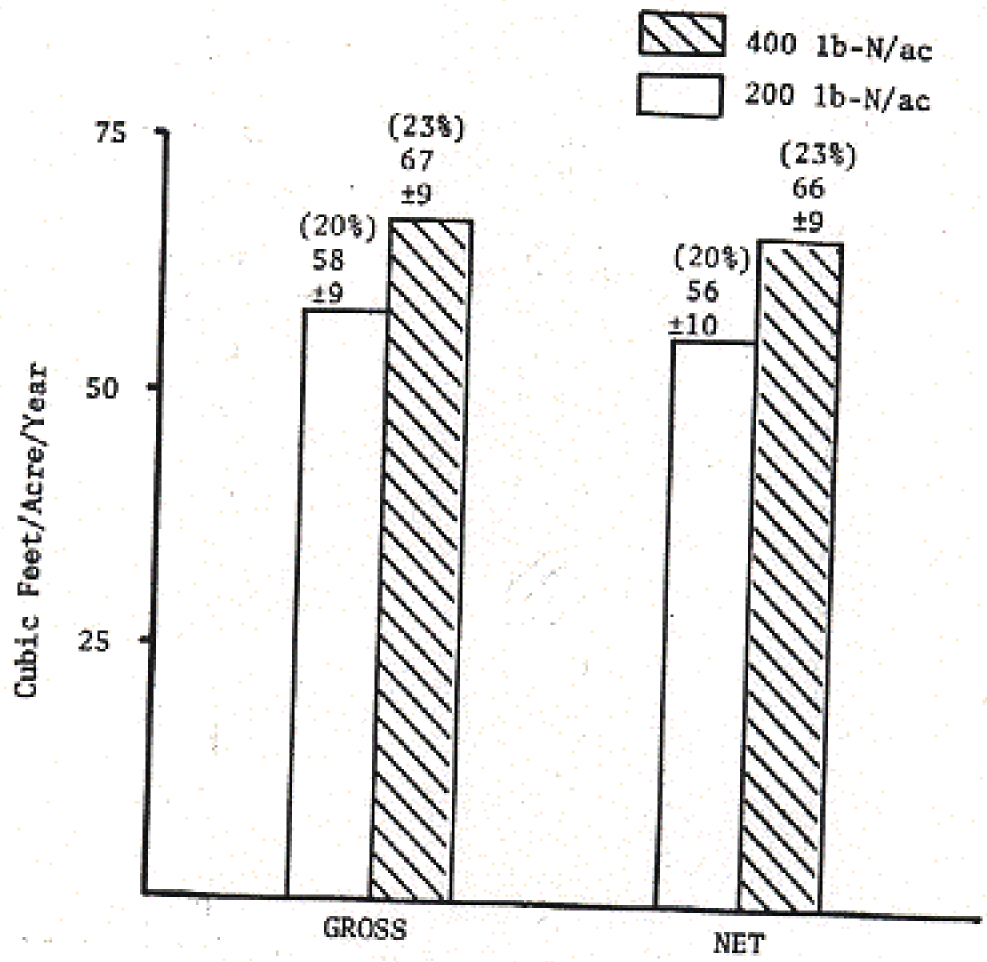
Periodic annual increment over 8 growing seasons was smoothed to estimate response to nitrogen fertilizer. Smoothed estimates of basal area p.a.i. and response may be found in Tables 3-1 and 3-2. Smoothed volume increment is presented in Table 3-3.

(i) Gross p.a.i.- total basal area.

Response of basal area p.a.i. is estimated at 1.45 sq ft/ac/yr to 200 pounds of nitrogen and 1.82 sq ft/ac/yr to 400 pounds of nitrogen. Relative magnitudes of these estimates are 22% (± 2%) response and 27% (± 2%) response for respective levels of nitrogen application.

Figure 3-1

Unadjusted differences (±1 standard error) between average treated growth rates and average untreated growth rates; 8-year total volume growth for thinned Douglas-fir; (cu ft/ac/yr; min. d.b.h.=1.55 inches)



Sample by treatment code: 0T=65 plots, 2T=62 plots, 4T=66 plots

(ii) Gross p.a.i. - total volume.

Response of volume p.a.i. was 55 cu ft/ac/yr to 200 pounds of nitrogen, representing an 18% response over p.a.i. estimated for untreated stands. Response to 400 pounds of nitrogen is estimated at 66 cu ft/ac/yr or 23% relative increase in p.a.i. Standard error associated with volume p.a.i. response is about ±6 cu ft/ac/yr and ± 2% relative response. Response did not interact significantly with stand variables such as age, site index, and stocking.

3.2.3 Total response duration

The 8 growing seasons in the thinned stands were separated into 2-year growth periods for analyzing longevity of response to 200 lb-N and 400 lb-N applications. This response is based on 1 application of nitrogen.

(i) Gross p.a.i. - total basal area.

Figure 3-3 shows that response to 400 lb-N is greater than 200 lb-N response after the first 2-year period; however both treatments exhibit converging trends and in the last 2-year period significance of 400 lb-N response is marginal.

(ii) Gross p.a.i.- total volume.

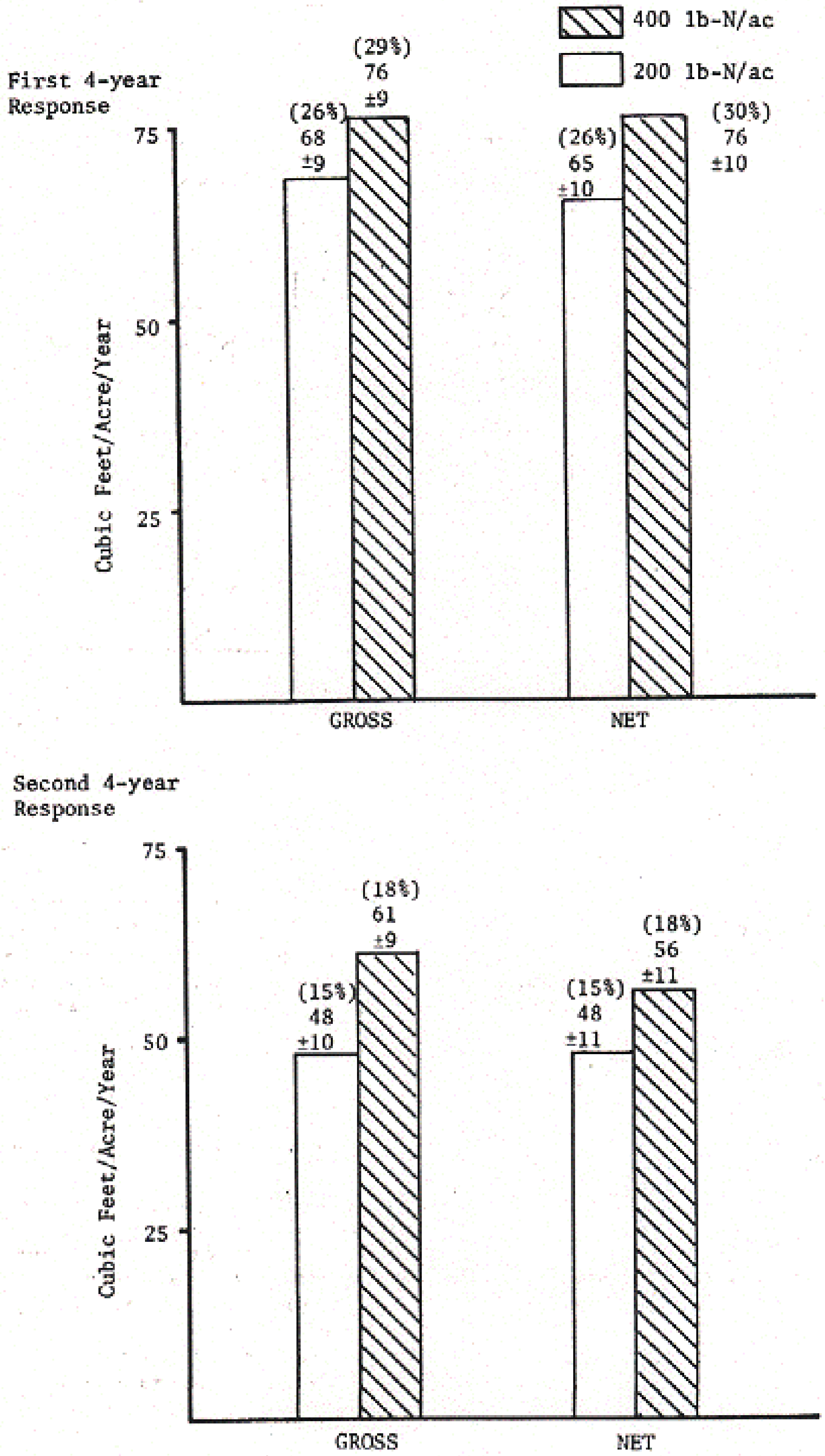
Response to 400 lb-N (Figure 3-4) is greater than that of 200 lb-N, except in the fourth 2-year period where response to both N treatments is small but significant. These response trends are similar to those for basal area.

3.3 4-year response with supplementary plots

In Phase III we augmented the Phase II design for thinned stands. The plot distribution for each Phase (II and III) is shown in Table 3-4. Supplementary plots were concentrated in young (5-15 years) stands with at least 80% stocking by Douglas-fir. Average regional growth rates are summarized in Table 3-5 where the effects of the additional plots (younger in breast-height age) are easily seen; basal area increment increased while volume increment was generally less than before. Supplemental plots were established with 200 lb-N and control treatments. Increases in installation size due to priorities for other kinds of information limited the levels of nitrogen to be tested. Comparisons between the two data bases are limited to the differences in p.a.i. between 0N and 200N.

Figure 3-2

Unadjusted differences (±1 standard error) between average treated growth rates and average untreated growth rates; 4-year total volume growth for thinned Douglas-fir; (cu ft/ac/yr; min d.b.h.=1.55 inches)



Sample per period by treatment code: 0T=65 plots; 2T=62 plots; 4T=66 plots

(i) Gross p.a.i. - total basal area.

Basal gross response is estimated to be 2.07 sq ft/ac/yr from 200 pounds of nitrogen. This represents an increase of 29% over p.a.i. estimated for an untreated stand, and is somewhat lower than that based solely on Phase II stands (1976-1978 Biennial Report). Response increased significantly with increased number of stems.

(ii) Gross p.a.i. - total volume.

Gross volume response for 4 years was 59 cu ft/ac/yr to 200 pounds of nitrogen, representing a 24% increase over estimated untreated growth rate. This estimate is very close to that from the 1976-78 Biennial Report. Response was not found to interact significantly with age, stocking, or site index.

Response (4-year) to 200 lb-N reported here is less than that reported in the 1976-78 Biennial Report, for both basal area and volume. Since these current estimates are based on a larger data set, we consider them to be improved and our best estimates to date of 4-year response to 200 lb-N in thinned stands.

Table 3-1. Estimated mean 8-year gross total basal area growth for thinned Douglas-fir control stands (sq ft/ac/yr; min. d.b.h. = 1.55 inches).

B.H. Age Class (yrs)	50-year Site Class			
	I	II	III	IV
	P.A.I.	P.A.I.	P.A.I.	P.A.I.
15	-	9.3	9.2	9.0
25	6.9	7.0	7.0	7.0
35	5.3	5.6	5.8	6.0
45	-	4.7	5.0	5.3

Table 3-2. Estimated mean response of 8-year gross total basal area growth for thinned Douglas-fir (sq ft/ac/yr; min. d.b.h. = 1.55 inches).

B.H. Age class (yrs.)	Treatment (pounds of N per acre)	50-year Site Class I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
15	200	-	2.3	2.5	2.6
	400	-	2.8	3.0	3.2
25	200	1.2	1.4	1.7	2.0
	400	1.5	1.8	2.1	2.5
35	200	0.6	0.9	1.3	1.7
	400	0.7	1.1	1.6	2.0
45	200	-	0.5	0.9	1.4
	400	-	0.7	1.2	1.7

Average response to 200 lb-N: 1.4 sq ft/ac/yr.
Average response to 400 lb-N: 1.8 sq ft/ac/yr.
} Across all sites

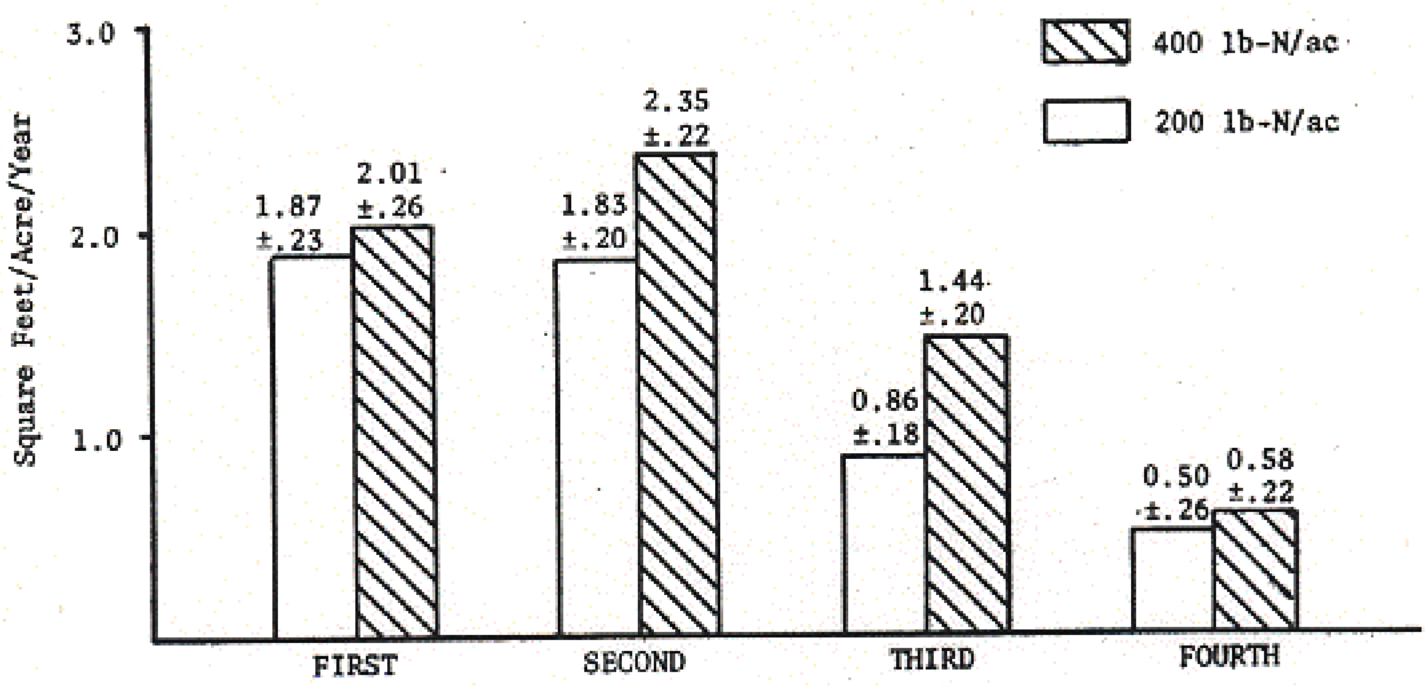
Table 3-3. Estimated mean 8-year gross total volume growth for thinned Douglas-fir control stands (cu ft/ac/yr; min. d.b.h. = 1.55 inches).

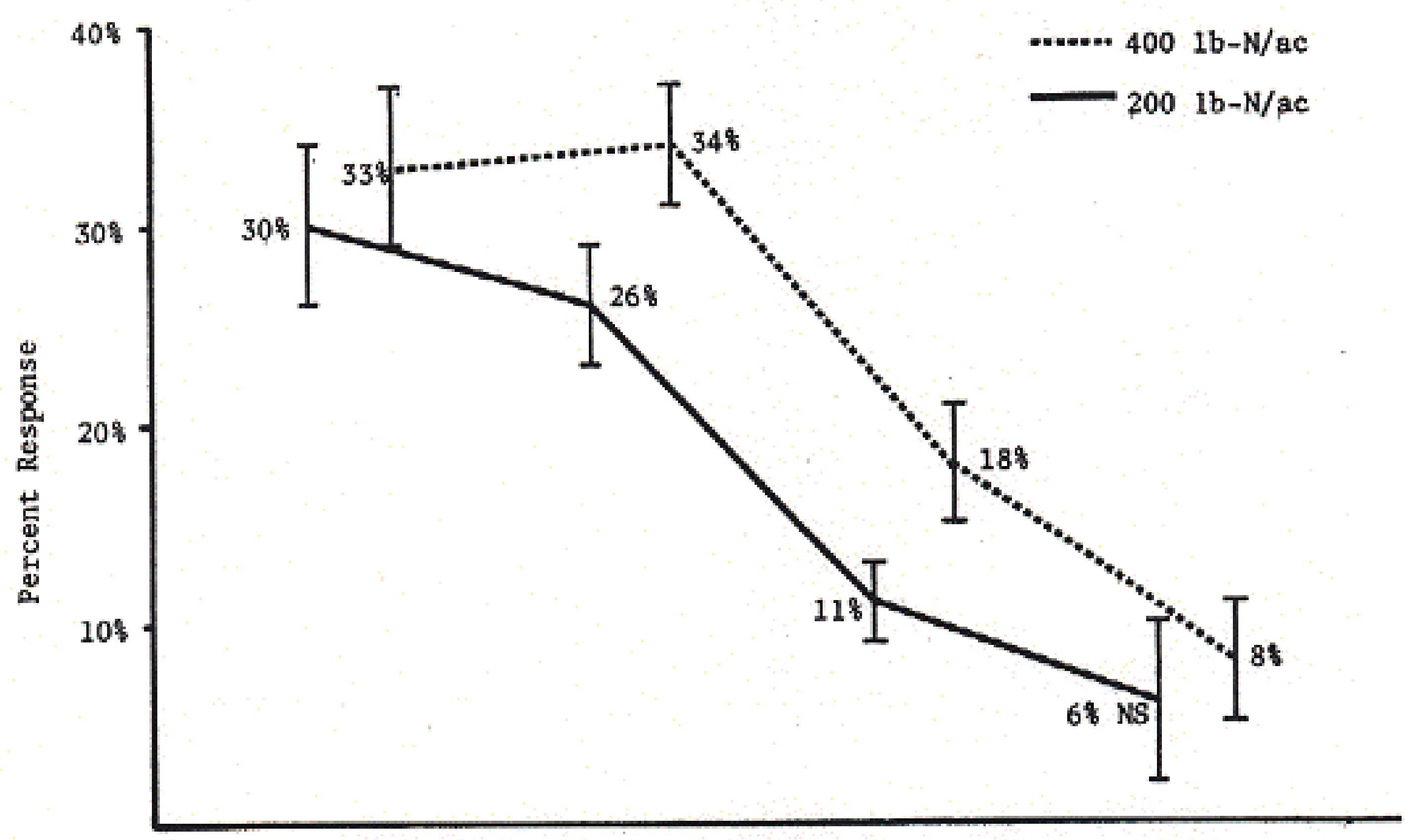
B.H. Age Class (yrs)	50-year Site Class I P.A.I.	II P.A.I.	III P.A.I.	IV P.A.I.
15	-	327	286	243
25	368	326	282	238
35	349	308	266	223
45	-	290	250	209

Average response to 200 lb-N: 55 cu ft/ac/yr.
Average response to 400 lb-N: 66 cu ft/ac/yr.
} Across all sites

Figure 3-3

Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for thinned Douglas-fir (sq ft/ac/yr; min d.b.h.=1.55 inches)



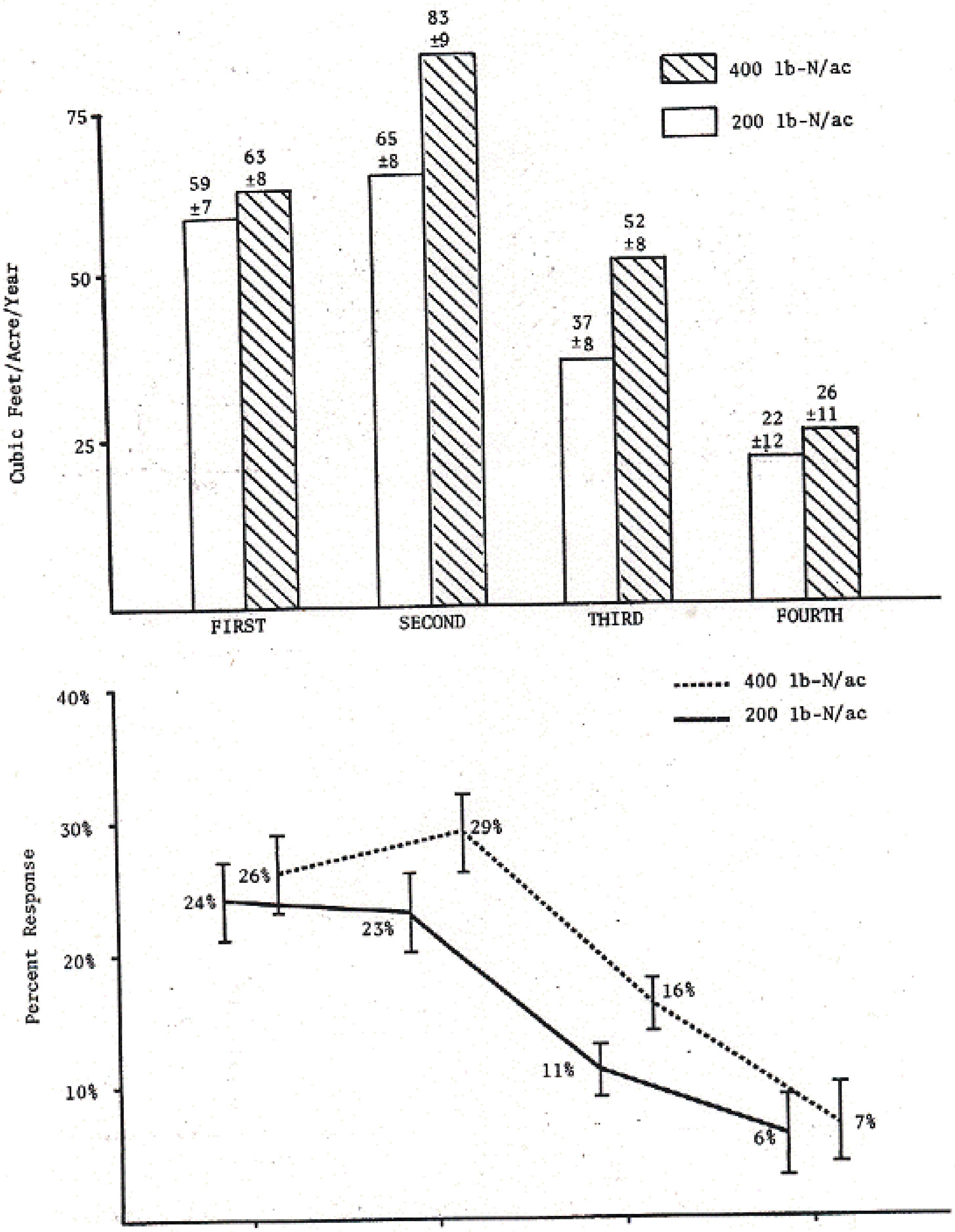


NS = Nonsignificant at 95% CL but significant at 90% CL

Sample per period by treatment code: 0T=65 plots; 2T=62 plots; 4T=66 plots

Figure 3-4

Estimated mean response (±1 standard error) in gross total stand growth by 2-year periods for thinned Douglas-fir (cu ft/ac/yr; min. d.b.h.=1.55 inches)



Sample per period by treatment code: 0T=65 plots, 2T=62 plots, 4T=66 plots

Table 3-4. Distribution of "pure" 1/10-acre plots for total gross response analysis of unthinned Douglas-fir by Phases (II and III).

Age class	Phase	50-year Site Index 145	125	105	85	65	All
5	2	-	-	-	-	-	-
	3	-	4	4	-	-	8
10	2	-	7	14	1	-	22
	3	6	12	12	4	-	34
20	2	5	21	3	8	4	41
	3	-	-	1	3	-	4
30	2	17	23	29	9	-	78
	3	-	-	-	-	-	-
40	2	1	22	16	2	-	41
	3	-	-	-	-	-	-
50	2	-	-	8	3	-	11
	3	-	-	-	-	-	-
All	2	23	73	70	23	4	193
	3	6	16	17	7	-	46

193 Phase II (established 1971-72)
46 Phase III (established 1975)

Total = 239

Table 3-5. Summary of unadjusted mean 4-year growth of thinned Douglas-fir (Phases II + III) for the total stand (sq ft/ac/yr; minimum d.b.h. = 1.55 inches).

Increment	Treatment lbs-N/ac	Phases II + III No. of plots	Average p.a.i.	Std. dev.	Phase II No. of plots	Average p.a.i.	Std. dev.
Gross ΔB	0	86	7.08	2.69	64	6.34	2.23
	200	86	9.18	3.09	62	8.30	2,85
	400*	67	8.66	3.06	67	8,66	3,06
Net ΔB	0	86	6.79	2.92	64	5.97	2.47
	200	86	8.77	3.44	62	7.83	3.19
	400	67	8.26	3.27	67	8.26	3.27
Gross ΔV	0	86	248	91	64	262	77
	200	86	304	89	62	328	72
	400	67	338	75	67	338	75
Net ΔV	0	86	239	93	64	250	83
	200	86	293	93	62	314	82
	400	67	327	81	67	327	81

*No supplemental plots in Phase III thinned stands received 400 pounds of nitrogen.

ΔB = basal area p.a.i.

ΔV = volume p.a.i.

4 Regional Growth and Response Analysis for Unthinned Western Hemlock (Peterson)

These results are based on unadjusted data averages of basal area p.a.i. Overall means were analyzed first and subsequently the data were stratified for more analysis. One stratum was geographical (Coast and Cascade), since sampled stands of higher site index tended to exist near the coast while low sites were largely inland toward the Cascades.

The data were also stratified by younger (12-23 years) and older (24-35 years) breast-height ages. This facilitated comparisons with thinned stands (section 5.0), which had a bimodal age distribution. Unthinned stands ranged in initial age 10-45 years, however stratification by 10-year age classes did not alter results. Therefore analyses of response for unthinned stands retain the same age strata as do analyses of thinned stands.

4.1 10-year response

A total of 25 installations were established in 1969-1970 under Phase I. Each installation was composed of six 1/10 acre or larger plots, receiving the same treatment as unthinned Douglas-fir installations:

50 plots - unthinned with no fertilizer

50 plots - unthinned with 200 pounds nitrogen per acre

50 plots - unthinned with 400 pounds nitrogen per acre

The average 10-year p.a.i. is based on a total of 82 plots which survived 10 growing seasons and received only initial application of fertilizer:

Treatment (lb-N.ac)	No. of plots	10-year p.a.i. (sq ft/ac/yr)	std. dev.
0	29	9.09	2.54
200	25	9.37	2.96
400	28	9.05	3.25

Ten-year growth rates of fertilized (1 application) and unfertilized western hemlock stands are further summarized in the Appendix.

Initial treatment has no significant effect on basal area increment averaged over 10 growing seasons; however, after data were stratified (Table 4-1), significant differences in p.a.i. were detected between untreated and treated plots. Younger stands (12-23 years breast-height age) in the Cascade area exhibited significant increases in p.a.i. to both 200 pound and 400 pound nitrogen applications. The decrease (negative difference) to 400 lb-N in young coastal stands was significant.

4.2 4-year response updated with supplementary plots

Hemlock data from the original 150 plots which survived the first 4 growing seasons were supplemented with 4-year data from plots established in 1975 to broaden the hemlock data base:

11 plots - unthinned with no fertilizer

11 plots - unthinned with 200 pounds nitrogen per acre

When 4-year basal area p.a.i. is averaged over the region, there is no significant effect of treatment:

Treatment (lb-N/ac)	No. of plots	4-year p.a.i. (sq ft/ac/yr)	std. dev.
0	61	9.61	3.90
200	61	9.96	4.24
400	50	8.79	3.62

This data was then stratified (Table 4-2) as in section 4.1. Younger stands in the Cascade stratum showed significant increases in basal area p.a.i. from both levels of fertilizer application.

Perhaps the most noticeable observation of the hemlock data is the large variation (std. dev.) associated with the averages.

Table 4-1. Phase I (unthinned) western hemlock; 10-year p.a.i. Results of 2-tailed t-tests for significant (95% confidence level) differences between average total growth rate of unfertilized stands and average total growth rate of fertilized stands (sq ft/ac/yr).

Treatment: 200 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 3.20 (29%) s.e. = 0.2850 n = 6 significant	diff = 0.42 (6%) s.e. = 0.4446 n = 11 nonsignificant
COAST	diff = -0.68 (6%) s.e. = 0.5522 n = 10 nonsignificant	diff = -0.34 (5%) s.e. = 0.7270 n = 19 nonsignificant

Treatment: 400 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 2.89 (23%) s.e. = 0.7597 n = 8 significant	diff = 0.30 (4%) s.e. = 0.6580 n = 13 nonsignificant
COAST	diff = -1.40 (11%) s.e. = 0.5176 n = 10 significant	diff = -0.90 (11%) s.e. = 0.6154 n = 18 nonsignificant

diff = average treated p.a.i. minus average control p.a.i.
s.e. = standard error of difference between average control p.a.i. and average treated p.a.i.
n = $n_1 + n_2 - 2$ where n_1 = untreated sample size and n_2 treated sample size.

Table 4-2. Phases I + III (unthinned) western hemlock; 4-year p.a.i. Results of 2-tailed t-tests for significant (95% confidence level) differences between average total growth rate of unfertilized stands and average total growth rate of fertilized stands (sq ft/ac/yr).

Treatment: 200 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 2.19 (16%) s.e. = 0.844 n = 16 significant	diff = 1.17 (16%) s.e. = 0.692 n = 12 nonsignificant
COAST	diff = 0.41 (3%) s.e. = 1.006 n = 27 nonsignificant	diff = -0.60 (7%) s.e. = 0.572 n = 24 nonsignificant

Treatment: 400 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 2.72 (20%) s.e. = 1.122 n = 13 significant	diff = 0.20 (3%) s.e. = 0.778 n = 14 nonsignificant
COAST	diff = -1.29 (10%) s.e. = 0.836 n = 19 nonsignificant	diff = -0.58 (7%) s.e. = 0.606 n = 28 nonsignificant

diff = average treated p.a.i. minus average control p.a.i.
s.e. = standard error of difference between average control p.a.i. and average treated p.a.i.
n = $n_1 + n_2 - 2$ where n_1 = untreated sample size and n_2 treated sample size.

5 Regional Growth and Response analysis for Thinned Western Hemlock (C. Peterson)

Analyses completed for thinned hemlock are based on unadjusted averages of basal area p.a.i. Overall means are reported for the region and then stratified for further analysis. As was outlined in section 4, stratification was made geographically (Coast - Cascade) and according to breast height age (younger - older). Age stratification was considered because of a bi-modal distribution of age in the sample, rather than any notion of age-treatment interaction in response. Geographical stratification was made since low sites tended to be located further inland and coastal stands were predominantly higher in site index.

5.1 8-year response

A total of eight western hemlock installations, each with 6 plots 1/10 acre or larger in area, were thinned and fertilized in 1970-1971 under Phase II:

16 plots - thinned and unfertilized

16 plots - thinned and 200 lbs N/acre

16 plots - thinned and 400 lbs N/acre

The difference in observed growth rates averaged over the entire sample is not statistically significant among treatments:

Treatment (lb-N/ac)	No. of plots	8-year p.a.i. (sq ft/ac/yr)	std. dev.
0	16	9.71	2.33
200	16	10.82	3.58
400	16	11.09	4.26

Eight-year growth rates of fertilized (1 application) and unfertilized western hemlock stands are further summarized in the Appendix.

Average increment progresses with increasing levels of nitrogen, but variation does also (standard deviation). Growth increment (11.09 sq ft/ac/yr) in stands receiving 400 lb-N/ac is 14% higher than that of controls (9.71 sq ft/ac/yr). However, the std. dev. of 400-N stands (4.26 sq ft/ac/yr) is nearly double that of controls (2.33 sq ft/ac/yr).

These data were then stratified and analyzed for differences of growth rates between treated and untreated stands (Table 5-1). Only young coast stands responded significantly, and that was to 200 lb-N/ac. Response differences in all young stands were of some positive magnitude, but large variation tends to preclude any significant results.

5.2 4-year response updated with supplementary plots

Original 4-year hemlock data were supplemented with 4-year data from thinned plots established in 1975:

12 plots - thinned with no fertilizer

12 plots - thinned with 200 pounds nitrogen per acre

Basal area increment, averaged across the region, did not differ significantly among treatments:

Treatment (lb-N/ac)	No. of plots	4-year p.a.i. (sq ft/ac/yr)	std. dev.
0	28	9.44	3.06
200	28	10.79	3.39
400	16	10.66	4.74

Data were then stratified (Table 5-2) and tested for significant differences in growth rates. Older Cascade stands showed a significant effect from 200 lb-N/ac while younger Cascade stands exhibited a significant increase in growth rate due to 400 lb-N/ac. All stratified differences were positive but statistical significance or lack thereof does not clearly indicate a pattern of response.

Table 5-1. Phase II (thinned) western hemlock; 8-year p.a.i. Results of 2-tailed t-tests for significant (95% confidence level) differences between average total growth rate of unfertilized stands and average total growth rate of fertilized stands (sq ft/ac/yr).

Treatment: 200 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 2.58 (22%) s.e. = 1.900 n = 6 nonsignificant	diff = 0.15 (2%) s.e. = 0.380 n = 6 nonsignificant
COAST	diff = 1.98 (17%) s.e. = 0.806 n = 6 significant	diff = -0.25 (3%) s.e. = 0.700 n = 6 nonsignificant

Treatment: 400 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 3.68 (31%) s.e. = 1.650 n = 6 nonsignificant	diff = -0.28 (4%) s.e. = 0.480 n = 6 nonsignificant
COAST	diff = 2.58 (23%) s.e. = 1.566 n = 6 nonsignificant	diff = -0.42 (5%) s.e. = 0.86 n = 6 nonsignificant

diff = average treated p.a.i. minus average control p.a.i.
s.e. = standard error of difference between average control p.a.i. and average treated p.a.i.
n = $n_1 + n_2 - 2$ where n_1 = untreated sample size and n_2 treated sample size.

Table 5-2. Phases II + III (thinned) western hemlock; 4-year p.a.i. Results of 2-tailed t-tests for significant (95% confidence level) differences between average total growth rate of unfertilized stands and average total growth rate of fertilized stands (sq ft/ac/yr).

Treatment: 200 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 3.02 (29%) s.e. = 1.642 n = 10 nonsignificant	diff = 1.63 (26%) s.e. = 0.590 n = 9 significant
COAST	diff = 0.88 (8%) s.e. = 0.860 n = 22 nonsignificant	diff = 0.65 (11%) s.e. = 0.658 n = 7 nonsignificant

Treatment: 400 lb-N/acre

	Younger stands 12-23 years	Older stands 24-35 years
CASCADE	diff = 5.57 (54%) s.e. = 1.543 n = 8 significant	diff = 0.56 (9%) s.e. = 0.577 n = 7 nonsignificant
COAST	diff = 2.05 (18%) s.e. = 1.760 n = 14 nonsignificant	diff = 0.52 (9%) s.e. = 0.641 n = 7 nonsignificant

diff = average treated p.a.i. minus average control p.a.i.
s.e. = standard error of difference between average control p.a.i. and average treated p.a.i.
$n = n_1 + n_2 - 2$ where n_1 = untreated sample size and n_2 treated sample size.

6 Economic Analysis of the Merchantable Stand for Unthinned Douglas-fir; 8 years after initial N-application (B. Bare)

In the last economic analysis published by the RFNRP (1976), stands of Douglas-fir were compared using 6-year unthinned and 4-year thinned response data measured in total stem cubic foot volume for the total stand. Also, it was assumed that 200 lbs. of N/acre was applied as urea fertilizer and that the excess wood grown in response to the fertilizer was harvested ten years after the treatment. Results of this and other RFNRP analyses gave highest priority to stands close to final harvest on medium and low sites which were previously thinned.

The present analysis differs from previous analyses in several important respects. First, an 8-year gross merchantable cubic foot volume to a 4-inch top for trees greater than 6.5 inches in diameter is used. Second, only unthinned stands of Douglas-fir are analyzed. Third, treatments of 200 and 400 lbs. of N/acre are included in the analysis and stands may be retained up to two investment intervals (16 years) beyond the treatment date. Fourth, before- and after-tax net present values are calculated to capture the effects of the federal income tax treatment of fertilization. Lastly, both an incremental and absolute form of investment analysis are included to demonstrate the significance of carefully formulating the type of analysis required to answer typical questions posed by management.

Underlying Assumptions

All analyses presented herein assume that stands are considered independently on a per acre basis and that only financial criteria are used in the decision process. In order to simulate a typical corporate land owner, all net present values are expressed using an after-tax cash flow criterion. Fertilization expenditures are capitalized and amortized over a five year period (Bare, 1979). A surplus ordinary income is assumed in calculating the after-tax cash flow. Economic parameters used in the analysis are:

(a) 6 percent real interest rate,

(b) constant real stumpage prices over time,

(c) a fertilization cost of \$0.35/lb.N/acre,

(d) estimated current stumpage prices as shown in Table 6-1,

(e) an ordinary federal income tax rate of 46 percent and a long-term capital gains tax rate of 28 percent,

(f) a state yield tax rate of 6.5 percent and

(g) a five year fertilization amortization period.

By expressing all economic parameters in real terms we avoid the necessity of predicting future rates of inflation, thus removing one element of uncertainty from the analysis. Further, since real rates of interest historically have been relatively steady, another element of variation which contributes to uncertainty is removed. The cost of fertilization used in the present analysis (i.e., \$0.35/lb.N/acre) represents an average figure. Current stumpage prices represent prices as of July, 1982, and are derived from a 120 quarter data base as compiled by the Washington State Department of Natural Resources.

Mensurational Data

As previously stated, the present analysis uses an 8-year gross merchantable cubic foot periodic annual increment (p.a.i.) for unthinned Douglas-fir stands to measure the physical effects of fertilization. These data come from unthinned RFNRP plots and include trees greater than 6.5 inches in diameter and measure volume to a 4 inch top.

The estimated mean response of 8-year gross merchantable cubic foot volume is shown below:

8-year Response (CF/A/Yr)					
	Site Class				
Treatment	1	2	3	4	All
200 lb. N	19 (5%)	26 (8%)	51 (22%)	40 (22%)	35 (35%)
400 lb. N	29 (8%)	45 (14%)	54 (23%)	66 (36%)	49 (17%)

Previous analyses determined that the trend in 8-year p.a.i. across site class is not statistically significant at the 95% level of confidence. Further, neither the 200 lb. nor the 400 lb. treatment provides a significant response for site class 1 (cf. Sec. 2.2.3). From this we conclude that site class 1 should not be fertilized and that an average 8-year response of 35 and 49 CF/A/Yr can be used for the 200 lb. and 400 lb. treatments, respectively. As reported in the 1978-80 Biennial Report, the 8-year gross p.a.i. was not significantly related to age basal area or site class.

Thus, it follows that the additional merchantable cubic foot volume due to fertilization eight years after treatment is

200 lb. N - 280 CF/A
400 lb. N - 392 CF/A

A BF/CF ratio is used to convert these cubic foot responses to a board foot measure to facilitate the use of stumpage prices listed in Table 6-1. The ratio is a function of average stand diameter and tarif and is shown on p. 12 of Washington State Department of Natural Resources Report No. 20R (Chambers and Wilson, 1972).

Although an average cubic foot volume response to fertilization is used across all site classes, the value of the incremental wood added because of fertilization is computed as a function of the average stand diameter. In order to compute the mean stand diameter 8 years after fertilization the following diameter equation is used:

$$D_8 = f(D_0, A, S, N)$$

where

D_8 = Quadratic mean stand diameter 8 years after treatment
D_0 = Initial quadratic mean stand diameter (no treatment)
A = Initial breast-height stand age
S = Kings 50-year site index
N = A dummy variable representing the level of nitrogen fertilization

An additional piece of mensurational data required to perform the investment analysis is the initial merchantable cubic foot volume per acre for non-fertilized stands.

Incremental Net Present Value Analysis

One form of investment analysis often used to evaluate forest management activities is to compare the incremental benefits of an activity against the incremental costs of undertaking the activity. In such an analysis we are only concerned with measuring the change in our measure of economic efficiency as it relates to a single treatment activity. No attention is given to the economic viability of the base investment--only to the incremental costs and benefits. In essence, we compute the incremental net present value as:

$$\Delta \text{ NPV} = (\text{NPV of } \Delta \text{ Benefits}) - (\text{NPV of } \Delta \text{ Costs})$$

In our analysis, the (NPV of Δ Costs) is simply the NPV of the costs of applying fertilizer. The (NPV of Δ Benefits) is computed as shown below

$$\text{NPV of } \Delta \text{ Benefits} = \frac{\text{Future Value of } \Delta \text{ Benefits}}{(1+i)^n}$$

But,

$$\left[\begin{matrix}\text{Future Value}\\ \text{of } \Delta \text{ Benefits}\end{matrix}\right] = \left[\begin{matrix}\text{Future Value}\\ \text{with fertilizer}\end{matrix}\right] - \left[\begin{matrix}\text{Future Value}\\ \text{without}\\ \text{fertilizer}\end{matrix}\right]$$

Now,

$$\left[\begin{matrix}\text{Future Value}\\ \text{of } \Delta \text{ Benefit}\end{matrix}\right] = (V_F \cdot P_F) - (V_N \cdot P_N)$$

Where,

V_F = Cubic foot volume/acre if fertilized
P_F = Price/cubic foot if fertilized
V_N = Cubic foot volume/acre if not fertilized
P_N = Price/cubic foot if not fertilized

However,

$$P_F = P_N + \Delta P$$

And,

$$V_F = V_N + \Delta V$$

Therefore,

$$V_F \cdot P_F = (V_N + \Delta V) \cdot (P_N + \Delta P)$$

So,

Future Value of Benefits

$$= (V_N + \Delta V) \cdot (P_N + \Delta P) - (V_N \cdot P_N)$$

$$= V_N P_N + P_N \Delta V + \Delta V \Delta P + V_N \Delta P - V_N P_N$$

$$= P_N \Delta V + V_N \Delta P + \Delta V \Delta P$$

Then by substitution,

$$\Delta NPV = \left[\frac{(P_N \Delta V + V_N \Delta P + \Delta V \Delta P)}{(1+i)^n}\right] - (\text{NPV of } \Delta \text{ Costs})$$

In the analyses conducted in this report, n is either 8 or 16 years. Furthermore, all variables in the numerator of the first term of the NPV equation are expressed at the end of the 8- or 16- year investment period.

In order to demonstrate the use of the above procedure for computing incremental net present values, consider the following example. Assume a 40-year old stand growing on site class 2 which is to be fertilized with 400 lb. N at age 40 and harvested at age 48. All economic and mensurational parameters previously discussed are applicable, and both before and after-tax cash flows are shown. A worksheet summarizing the needed calculations is shown in Table 6-2. The procedure shown in Table 6-2 was embodied in a computer program where it was used to explore a number of fertilization treatments.

Results of Incremental Analysis

Using previously presented economic and mensurational parameters, a series of incremental net present value calculations were completed. Two types of fertilization treatments were examined. The first involved one fertilization 8 years prior to final harvest while the second included one or two fertilizations 8 or 16 years prior to final harvest. It was assumed that response to the second fertilization was identical to the first treatment response. Furthermore, only a limited number of treatment schedules were examined. For instance, 24-year old stands were only subjected to one or two treatments before final harvest at age 40. The possibility of extending the rotation to 48 years was not evaluated, as all treatment schedules were limited to either one or two periods. Only rotations

Table 6-1. Estimated Stumpage Prices ($/MBF)-Tractor Logging-July 1982 (120 qtr. av.)

Quadratic mean stand diameter	$/MBF
6	39.32
9	65.50
10	88.68
11	109.13
12	127.08
13	142.79
14	156.49
15	168.44
16	178.89
17	188.08

Source: Charles Chambers, Washington State Department of Natural Resources, Olympia, August 27, 1982.

Table 6-2. Worksheet for Sample Incremental Net Present Value Analysis ($/A)

End of Year	Item	Cash Flow Before-tax	Cash Flow After-tax	Present Value Before-tax	Present Value After-tax
0	Fertilization	-140.00	-140.00	-140.00	-140.00
1	Fert. Amortization[1]	28.00	12.88	---	12.15
2	Fert. Amortization	28.00	12.88	---	11.46
3	Fert. Amortization	28.00	12.88	---	10.81
4	Fert. Amortization	28.00	12.88	---	10.20
5	Fert. Amortization	28.00	12.88	---	9.62
8	Incr. Harvest Inc.[2]	579.24	417.05	363.42	261.66
8	Incr. Yield Tax[3]	-37.65	-20.33	-23.62	-12.76
Total Incremental NPV				199.80	163.14

1] Annual Fert. Amortization before tax = F/n, where F = Fert. Expenditure and n = Number of years required to amortize expenditure. The after-tax cash flow = F/n *.46

2] Before-Tax Incremental Harvest Income = $P_N \Delta V + V_N + \Delta P + \Delta V \Delta P$

$$= (0.50286)(392)+(9629.4)(0.03813) + (392)(0.03813) = 579.24$$

After-Tax cash flow = 579.24 * .72.

3] Before-Tax Incremental Yield Tax = 6.5% of before-tax incr. harvest income. The after-tax cash flow = 0.54 * before-tax value.

of either 40 or 48 years were examined, as the RFNRP data base did not permit extrapolation to 56 years. Tractor logging was assumed for all harvest operations. Results of these calculations are shown in Tables 6-3 and 6-4, where they are summarized by site class and treatment.

By inspecting Tables 6-3 and 6-4 the following conclusions can be verified:

(a) irrespective of fertilization treatment, fertilize site classes 2, 3, and 4 in that order,

(b) site class 4 is not profitable to fertilize under several of the treatment schedules examined,

(c) if only one fertilization is desired, then fertilizations occurring nearest to final harvest are most profitable,

(d) if stands are to be held for two investment periods (i.e., 16 years) then two fertilizations generally are more profitable than one,

(e) older age classes are more profitable to fertilize than younger stands (note: In the analysis, fertilization was only applied to stands between the ages of 24-40 years), and

(f) 400 lb. N/acre generally appears to be more profitable than 200 lb. N/acre but the optimal dosage level decreases across decreasing site class.

Perhaps the most striking results of the incremental net present value analysis in comparison with earlier RFNRP studies are: (a) the recommended treatment of stands growing on high site class over low site class and (b) the recognition that treatments greater than 200 lb. N/acre generate higher incremental net present values than previously acknowledged. The first result follows from assuming constant volume response across site; stumpage prices which increase with increasing diameter; and tree diameters which increase with increasing site class. The second result indicates that the optimum dosage of fertilization is in excess of 200 lb. N/acre. Results indicate that 400 lb. N/acre produces higher incremental net present values than the previously recommended 200 lb. N/acre. However, it is not possible to determine if the optimal dosage level exceeds 400 lb. N/acre or is between 200 and 400 lbs. N/acre. Previous RFNRP results reported in the 1974-76 Biennial Report indicate an optimal application rate of 175 lb. N/acre. This earlier study used 4-year response data where response differed significantly across site class but not between the 200 and 400 lbs. N/acre treatments. Thus, these results are difficult to compare to the results presented in this report.

Results shown in Tables 6-3 and 6-4 apply only if the economic and mensurational parameters used in the analysis remain valid for any particular user. Any change in these parameters is likely to affect results of the analysis. For example, if the cost of fertilizing an acre is reduced from \$.35/lb. N/acre to \$.28/lb. N/acre, the incremental net present value associated with a single treatment of 400 lb. N/acre eight years prior to final harvest will increase by \$17.16/acre on an after-tax basis and \$28.00/acre on a before-tax basis. While such a cost change will not alter the priorities shown in Tables 6-3 and 6-4, many of the negative incremental net present values in Table 6-3 become positive at the lower cost. Similar results can be expected as other input parameters used in the analysis are changed.

Absolute Net Present Value Analysis

In an incremental investment analysis such as that discussed above we account only for incremental costs and returns. Accordingly, if incremental returns exceed incremental costs we consider the investment to be worthwhile. This form of analysis is appropriate only if the base investment is worthwhile, or if investment (disinvestment) decisions concerning the base investment are not under control of the manager making the fertilizer decision.

With respect to fertilization, this means we should not fertilize stands with positive incremental net present values unless: (a) the net present value of the base investment is also positive or (b) we have no control over the timing of the final harvest cut in the stand. If we fertilize a stand with a positive incremental net present value but a negative absolute (base) net present value, we are essentially minimizing our losses by spending more funds when we should be harvesting the stand to maximize returns.

Thus, unless one of the two above conditions is assumed, we can not unequivocally make a decision concerning fertilization (or any stand management treatment) unless an absolute net present value analysis is undertaken.

In conducting an absolute investment analysis we attempt to evaluate the total costs and benefits associated with a proposed treatment, and not just the incremental costs and benefits as previously discussed. Only in this manner can we determine if a stand should be fertilized and held for several years, or terminated immediately.

To illustrate the structure of the absolute net present value analysis, consider the 40-year-old stand on site class 2 we previously examined. The incremental net present value analysis has shown that a treatment of 400 lb. N/acre generates a net present value of \$163/acre if the stand is harvested at age 48. Thus, if the decision is made to hold the 40-year old stand for 8 more years, we are better off if we fertilize. If we wish to determine if the 40-year old stand should be held 8 more years--with or without fertilization--we then need to undertake an absolute analysis.

Table 6-3. Comparison of Incremental Net Present Value Analyses by Site Class (Tractor Logging: After-Tax)

Current age/ Harvest age	Treatment Schedule	Incremental NPV ($/A) Site Class 2	3	4
32/40	200	95	57	4
	400	131	71	-11
40/48	200	116	82	38
	400	163	109	42
24/40	200/0	51	25	-11
	0/200	59	36	3
	200/200	114	64	-5
	400/0	63	22	-35
	0/400	82	45	-7
	400/400	154	75	-34
	200/400	139	75	-13
	400/200	128	63	-27
32/48	200/0	65	42	12
	0/200	73	51	24
	200/200	141	97	40
	400/0	85	47	2
	0/400	102	69	26
	400/400	194	124	38
	200/400	172	116	45
	400/200	162	104	32

Note: The top portion of the table assumes a fertilization treatment at the current stand age with final harvest eight years later. The lower portion of the table provides for either one or two fertilization treatments. The first may occur at the current stand age <u>or</u> eight years later. If two treatments are specified one occurs at the current stand age and the other eight years later. For example, a 0/200 treatment schedule for a 24 year old stand to be harvested at age 40 indicates a fertilization treatment at age 32 with 200 lb. N.

To begin the absolute analysis, we first wish to determine the best type of management strategy to use to grow future crops of timber on the acre in question. In short, we need to calculate a series of soil expectation values for different management strategies and rotation lengths. In 1980, the Washington State Department of Natural Resources did such an analysis and published a series of soil expectation values (Larson and Wadsworth, 1980). From this analysis we observe that for a 6 percent real rate of interest, forest industry lands are valued at $1212, $499 and $116/acre, for high, medium and low sites, respectively. These after-tax soil expectation values assume a real price and cost appreciation rate increase of 2 percent. Optimal financial rotations range from 55-65 years over the three site classes.

Continuing our illustrative example for the 40-year old stand on site class 2 land, we have three alternatives to examine:

Alternative I: Harvest the 40-year old stand immediately with an absolute NPV of:

$$\text{NPV} = \underset{\text{CF}}{(8680.4)}\ \underset{\$/\text{CF}}{(.39521)} + 1212 = \underset{\$/\text{A}}{\$4643/\text{acre}}$$

Alternative II: Hold the present stand for eight years without fertilization:

$$NPV = \left[\frac{(9629.4)\ (.50286)\ +\ 1212}{(1.06)^8}\right] - \left[\frac{4}{.06}\left[\frac{(1.06)^8 - 1}{(1.06)^8}\right]\right]$$

$$= \$3774/\text{acre}$$

Note: We have included a $4/acre annual cost for the eight years between fertilization and final harvest. This is the same annual cost included in the soil expectation values.

Alternative III: Fertilize the present stand with 400 lb. N/acre and hold for eight years:

NPV = $3774 + $163 = $3937/acre

Our conclusion now is to harvest the 40-year old stand immediately and forego the fertilization. However, if we must hold the stand for eight more years our incremental net present value is maximized by fertilizing.

Results of Absolute Analysis

Using the above described methodology, a series of absolute net present values were calculated. Treatment opportunities and economic parameters presented earlier for the incremental analysis were used during the absolute analysis. Results are summarized in Table 6-5 where three possible treatments are evaluated for each stand type. The results show that: (a) for site classes 2 and 3--fertilize 24- and 32-year old stands and harvest at age 40; harvest 40-year old stands immediately and carry no stands beyond this age; fertilize 24-year old stands twice before final harvest at age 40; and (b) for site class 4--fertilize 32- and 40-year old stands and harvest at age 48; fertilization in 24-year old stands on site class 4 is marginal if harvested at age 40. However, a different conclusion may be reached if such stands are held until age 48. As discussed earlier, this comparison was not undertaken.

Conclusions

Results presented in Tables 6-3, 6-4 and 6-5 indicate probable financial consequences of fertilizing young-growth stands of Douglas-fir in the Pacific Northwest. These results hold for only the particular input parameters used in the analysis and are likely to change if these parameters change. Thus, readers are cautioned to avoid endorsing the results shown above unless they believe the input parameters apply to their situation. The structure of the two forms of analysis used to derive the financial results are, however, generally applicable to all classes of forest landowners.

Table 6-4. Summary of Results of Incremental Net Present Value Analyses by Treatment (Tractor Logging: After-Tax)

	Incremental NPV ($/A)		
	Site Class		
Current age/ Harvest age	2	3	4
	One Treatment		
32/40	$131 (4N)	$71 (4N)	$4 (2N)
40/48	$163 (4N)	$109 (4N)	$42 (4N)
24/40	$ 82 (0N/4N)	$ 45 (0N/4N)	$3 (0N/2N)
32/48	$102 (0N/4N)	$ 69 (0N/4N)	$26 (0N/4N)
	Two Treatments		
24/40	$154 (4N/4N)	$ 75 (2N/4N)	$-5 (2N/2N)
32/48	$194 (4N/4N)	$124 (4N/4N)	$45 (2N/4N)

Table 6-5. Comparison of Absolute Net Present Value Analyses by Site Class (Tractor Logging: After-Tax)

Current age/ Harvest age	Alter-native[a]	Treatment Schedule Site Class 2	3	4	Absolute NPV ($/A) Site Class 2	3	4
32/32	I	--	--	--	2889	1394	409*
32/40	II	ON	ON	ON	2888	1475	342
32/40	III	4N	4N	2N	3019*	1546*	346
40/40	I	--	--	--	4643*	2391*	585
40/48	II	ON	ON	ON	3774	2157	844
40/48	III	4N	4N	4N	3937	2266	886*
24/24	I	--	--	--	1740	761	155
24/40	II	ON	ON	ON	1787	901	190T
24/40	III	ON/4N	ON/4N	ON/2N	1869*	946*	193T
32/32	I	--	--	--	2889*	1394T	409
32/48	II	ON	ON	ON	2343	1328	505
32/48	III	ON/4N	ON/4N	ON/4N	2445	1397T	531*
24/24	I	—	—	—	1740	761	155
24/40	II	ON	ON	ON	1787	901	190*
24/40	III	4N/4N	2N/4N	2N/2N	1941*	976*	185
32/32	I	--	--	--	2889*	1394	409
32/48	II	ON	ON	ON	2343	1328	505
32/48	III	4N/4N	4N/4N	4N/4N	2537	1452*	550*

* Denotes best alternative for a given site class-current age-harvest age combination.

T Denotes tie between alternatives for a given site class-current age-harvest age combination.

a I= Harvest Stand at current age - no fertilization

II= Harvest stand at designated harvest age - no fertilization

III= Fertilize as specified and harvest at designated harvest age.

Note: A fertilization treatment schedule of ON/4N for a stand currently 24-years old with a harvest age of 40 means apply one 400 lb. N/acre application at age 32 and harvest in eight years. No fertilizer is applied at age 24.

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7 Additional Topics and Pilot Studies

7.1 4-year response of Douglas-fir to ammonium nitrate (C. Peterson)

Phase III (1975) brought about establishment of numerous installations for purposes of supplementing the original design. In 11 of these installations, an additional source of nitrogen was added for comparison with urea (all treatments were replicated within an installation):

ON: 22 plots - unthinned with nitrogen

200A: 22 plots - unthinned with 200 pounds nitrogen per acre (source: ammonium nitrate)

200N: 22 plots - unthinned with 200 pounds nitrogen per acre (source: urea)

400N: 22 plots - unthinned with 400 pounds nitrogen per acre (source: urea)

Average stand age (breast height) was near 40 years and 50-year site index averaged 90 feet (site class IV+). Table 7-1 summarizes the gross periodic annual increment observed in treated stands, growth rate estimated as if untreated (based on controls), and resultant estimates of response.

Average response estimates are quite high for both absolute (cu ft/ac/yr) and relative (percent) figures. This overall response is not unlike that of earlier reported 4-year regional response to urea (1974-76 Biennial Report), when the low sites represented by these installations are considered; however, it is worthy of note that response to 200 pounds of nitrogen in the form of ammonium nitrate (2A) is greater than response from a like amount of nitrogen applied as urea. In fact, the 2A response (109 cu ft/ac/yr) is equal to 4N response (107 cu ft/ac-/yr).

These results suggest that further considerations should be given to alternative nitrogen sources for the Pacific Northwest and further review of N-source fertilizer work throughout the world. The 6-year growth and response data, currently being analyzed, should provide information as to comparable durations of response between nitrogen sources.

7.2 2-year fertilizer response 4 years after thinning (Peterson)

A delayed fertilizer treatment after thinning was applied and replicated under Phase III in 1975:

OT: 6 plots - initial thinning with no fertilizer.

Table 7-1. Estimated 4-year total gross response (±1 standard error) for unthinned Douglas-fir to both urea and ammonium nitrate (min. d.b.h. = 1.55 inches).

Treatment per acre	Obs. ΔB treated	Est. ΔB untreated	Estimated response	Obs. ΔV treated	Est. ΔV untreated	Estimated response
	(square feet per acre per year)			(cubic feet per acre per year)		
2A	8.17	5.64	2.53 ± 0.2 (45% ± 4%)	345	236	109 ± 9 (46% ± 4%)
2N	7.56	5.49	2.07 ± 0.2 (38% ± 4%)	314	235	79 ± 9 (34% ± 4%)
4N	8.46	5.56	2.90 ± 0.2 (52% ± 4%)	339	231	107 ± 9 (46% ± 4%)

Where 2A = 200 pounds of nitrogen in ammonium nitrate form.
2N = 200 pounds of nitrogen in urea form.
4N = 400 pounds of nitrogen in urea form.
Average site index = 90 feet.
Average initial d.h. age = 37 years.
ΔB = basal area p.a.i.
ΔV = volume p.a.i.
Obs = observed (actually measured).
Est = estimated (regression smoothed).

Table 7-2. Unadjusted 4-year total gross basal area p.a.i. for Douglas-fir stands fertilized 2 years past initial thinning (sq ft/ac/yr; min. d.b.h. = 1.55 inches).

Treatment	p.a.i. first 2 years	p.a.i. second 2 years	p.a.i. over 4 years
2D	10.17	14.10	12.08 = 48.3 sq ft/ac
2T	12.87	12.95	12.87 = 50.7 sq ft/ac

Where 2D = initial thin with delayed application of 200 pounds nitrogen per acre

2T = initial thin with initial application of 200 pounds nitrogen per acre

Average b.h. age = 12 years
Average site index = 112 feet

2T: 6 plots - initial thinning and 200 pounds nitrogen per acre.

2D: 6 plots - initial thinning and 200 pounds nitrogen per acre added 2 years after thinning.

Treatments selected for comparison in Table 7-2 are 2T and 2D. Note in the first 2 growing seasons 2D is essentially a thinned control treatment. Total growth over 4 years, however, is not too different between the two treatments. The more "standard" fertilizer research application (2T) gave only 2.4 square feet per acre (50.7 - 48.3) more than the delayed treatment (2D). The increase in p.a.i. from the first 2-year period to the second is more substantial with treatment 2D than with treatment 2T.

This suggests that biological response to fertilizer in thinned stands may peak or at least be higher than expected if a stand is not fertilized immediately after thinning. Six plots are hardly conclusive, however, and this treatment type may warrant further study.

7.3 Stem analysis of western hemlock (A. Becker)

Introduction

Traditionally the regional analyses of western hemlock are not unlike the procedures used in analyzing Douglas-fir response; however, response in western hemlock has not been as pronounced as in Douglas-fir, and occurs with a great deal more variability. This has led to speculations that fertilized hemlock may be responding, but perhaps in a way which has not been detected by conventional measurements of diameter at breast height. That is to say, additional wood may be distributed non-uniformly over the bole, resulting in a change of form. This in turn suggests that the overall "form" of a fertilized tree might be different from a tree of the same diameter (and approximate height) which grew to that size without fertilizer application.

The RFNRP currently uses the B.C. volume equation[1] to calculate a tariff number which estimates stand volume. The trees used to develop the B.C. equation were from unfertilized stands. Therefore, a deviation from normal growth (i.e., due to fertilizer) may result in a deviation from correct volume estimation.

Stem analysis of an unthinned western hemlock stand with apparent response to urea fertilization was conducted in installation #24 near Bellingham. Actual whole-tree volumes were calculated from this data, using Smalian's formula. The B.C. Forest Service used a similar method for collecting and calculating tree volumes to derive the B.C. volume equation. Estimated total cubic foot volumes were also computed from the B.C. equation. The two calculations were compared to determine if the B.C. equation was providing adequate volume estimates for both fertilized and unfertilized trees.

Methods

Sample trees were taken from all three treatments: control, 200 lb-N/ac urea, 400 lb-N/ac urea. Six codominants and 6 dominants with similar final (at last measurement) DBH's were selected from each treatment. Total height and DBH were recorded and each tree was cut into two-foot lengths. In each section, the rings

[1]Standard Cubic Foot Volume Tables. B.C. Forest Service, Forest Surveys and Inventory Division, 1962.

were counted and radial growth was measured in five-year increments, for the period ten years before and ten years after fertilization. Actual volumes and the estimated volumes were calculated at the time of fertilization and five years after fertilization, since the greatest possible response to treatment generally occurs during this period. Any variation in the response calculated by the two methods should be most apparent over this period.

Preliminary analyses compared average basal area and post-fertilizer growth. Average growth charcteristics of sampled trees are shown in Table 7-3. Selection of sample trees was based on basal area 12 years after fertilizer application, although average basal area after 5 years (BA_5) is not significantly different between treatments.

Results

Post-treatment growth rates (ΔB post) were compared after adjusting for differences in pre-treatment growth rates (ΔBpre) and BA_0. The post-treatment growth rates of fertilized trees were significantly ($F=6>F_{.05} = 3.29$) greater than post-treatment growth rates of control trees. This analysis confirmed apparent response in trees sampled, which was a primary assumption for analysis.

Volume at time of fertilization was subtracted from the volume 5 years after fertilization to obtain the average growth shown in Table 7-4. Response was computed by subtracting the average growth on control plots from average growth of each fertilizer application plot. Responses obtained for actual volumes were compared to

Table 7-3. Average growth characteristics of sampled hemlock trees (installation #24).

Treatment (lbs-N/ac)	n	BA_{-5} (S.D.)	BA_0 (S.D.)	BA_5 (S.D.)	ΔBpre (S.D.)	ΔBpost (S.D.)
0	12	0.0597 (0.0305)	0.1097 (0.0452)	0.1614 (0.0587)	0.0500 (0.0208)	0.0517 (0.0176)
200	12	0.0506 (0.0236)	0.0991 (0.0428)	0.1620 (0.0690)	0.0485 (0.0230)	0.0628 (0.0284)
400	12	0.0455 (0.0237)	0.0841 (0.0318)	0.1519 (0.0504)	0.0386 (0.0114)	0.0677 (0.0269)

BA_{-5} = basal area (sq ft/ac) 5 years prior to fertilizer.
BA_0 = basal area (sq ft/ac) at time of fertilization.
BA_5 = basal area (sq ft/ac) 5 years post-fertilization.
ΔBpre = BA_0 minus BA_{-5}.
ΔBpost = BA_5 minus BA_0.
S.D. = standard deviation.

Table 7-4. A comparison of actual and estimated single tree volume growth for a young western hemlock installation (24) in the Cascades.

	Growth (cu ft/tree)			Response (cu ft)	
	Control	200 lb/ac	400 lb/ac	200 lb/ac control	400 lb/ac control
Actual[1] growth	1.11 s.e. = 0.126 n = 12	1.50 s.e. = 0.188 n = 12	1.62 s.e. = 0.233 n = 12	0.39 s.e. diff = 0.226	0.51 s.e. diff = 0.265
Estimated[2] growth	1.05 s.e. = 0.126 n = 12	1.36 s.e. = 0.209 n = 12	1.37 s.e. = 0.199 n = 12	0.31 s.e. diff = 0.244	0.32 s.e. diff = 0.235

Where s.e. = standard error of the mean.
s.e. diff = standard error of the difference between two means.
Growth is computed as the difference in volume at time of fertilizer application and volume 5 years later.
Response is computed as difference between treated growth and control growth.
[1]Growth as measured from stem analysis.
[2]Growth as estimated from B.C. volume equation.

estimated volume responses. No significant differences were obtained at the 95% confidence level between actual and estimates.

This suggests that response at this installation may be adequately determined from volume estimates based on diameter at breast height. The same analyses should be performed on an apparent non-responding installation.

Results of further analyses of this installation address additional topics covered in subsequent sections of this report.

7.4 Foliar analysis of western hemlock (P. Ryan)

Introduction

Variable response of western hemlock to nitrogen fertilization with urea has prompted more detailed studies of site and stand characteristics which may affect growth and response. Foliar analysis is a standard method used to assess the nutrient status of forest stands and individual trees. There is, however, little data or standardized sampling procedures for a foliar analysis program in western hemlock (van den Driessche, 1976). It is therefore difficult to interpret nutrient status and potential growth limitations for western hemlock from available data in the literature. Questions that require investigation in regard to a sampling procedure include:

(a) What is the optimal position in the crown for foliage sampling?

(b) What age foliage is the more indicative of nutrient status of a particular tree?

(c) How does stand structure affect an individual tree's nutrient status?

(d) Are there similar crown foliage distribution patterns for all essential elements?

(e) Can foliage analysis explain differences in response of western hemlock to urea fertilization?

Destructive sampling of installation #24 at Bellingham (September, 1981) was described in the previous section. This presented an opportunity to address the above-mentioned questions. Installation #24 is a young, unthinned western hemlock stand of particular interest because of its apparent response to fertilization (previous RFNRP reports; Olsen et al., 1980).

Methods

Table 7-5 presents mensurational data for one of the dominant and two of the codominant western hemlock trees felled and sampled in the control plots of installation #24. Figure 7-1 diagrams how the live crown was subdivided into six equal levels. The leader was collected separately from the other foliage of the sixth crown level. These samples were packed into plastic bags and stored in ice chests for transportation. Samples from each level were separated into current season's growth (J) and older foliage (M) and dried at 70°C for 24 hours. Ground samples were digested using two techniques: (1) H_2O_2 – H_2SO_4 – Li_2SO_4 digest (Parkinson and Allen, 1975) from

Table 7-5. Mensurational data for the three western hemlock trees from which foliage samples were collected.

	Control Plot Tree Number		
	830	886	912
Height (ft)	53.1	52.8	44.0
A-Height to lower crown (ft)	15.5	27.6	12.0
L-Crown level interval (ft)	6.7	4.2	5.3
Crown class	DOM	CODOM	CODOM
Basal area (ft^2)	0.252	0.183	0.147
B.H. age (yr)	30	32	29

which N, P, Ca, Mg and K could be determined, and (2) HNO digest (Havlin and Soltanpour, 1980) from which Cu, Zn, Mn, Fe and Al could be determined. Total N and P were measured colorimetrically by auto analyser, while the other elements were analyzed by atomic absorption spectrophotometer. National Bureau of Standards orchard leaves (SRM 1571) were used to check each analytical batch of samples.

Results and Discussion

1. Elemental profiles within western hemlock crowns:

Foliar nutrient analyses for installation #24 are presented in Figures 7-2 and 7-3. The ordinate axes represent live crown height, subdivided into six equal levels plus the leader. Foliar concentration of each analyzed element is along the abscissa. For each crown position the concentration of a specific element is given for juvenile (open symbols) and mature foliage (closed symbols).

Figure 7-1. Western hemlock foliage sampling scheme: The live crown (A) was divided into 6 equal levels (L1 to L6), plus the leader.

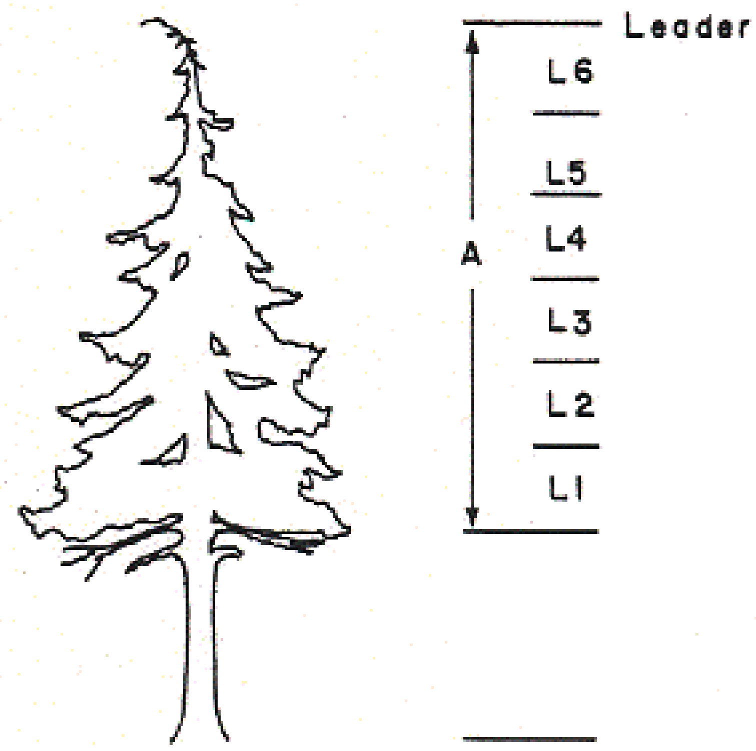


Figure 7-2. Concentration of Ca, Mg, K, N, and P (%) in the leader (L), juvenile (J: open symbols), and mature (M: closed symbols) foliage at 6 equally spaced positions vertically through the crowns of three western hemlock trees of different crown class: #830, a dominant; #886, a codominant; and #912, a codominant.

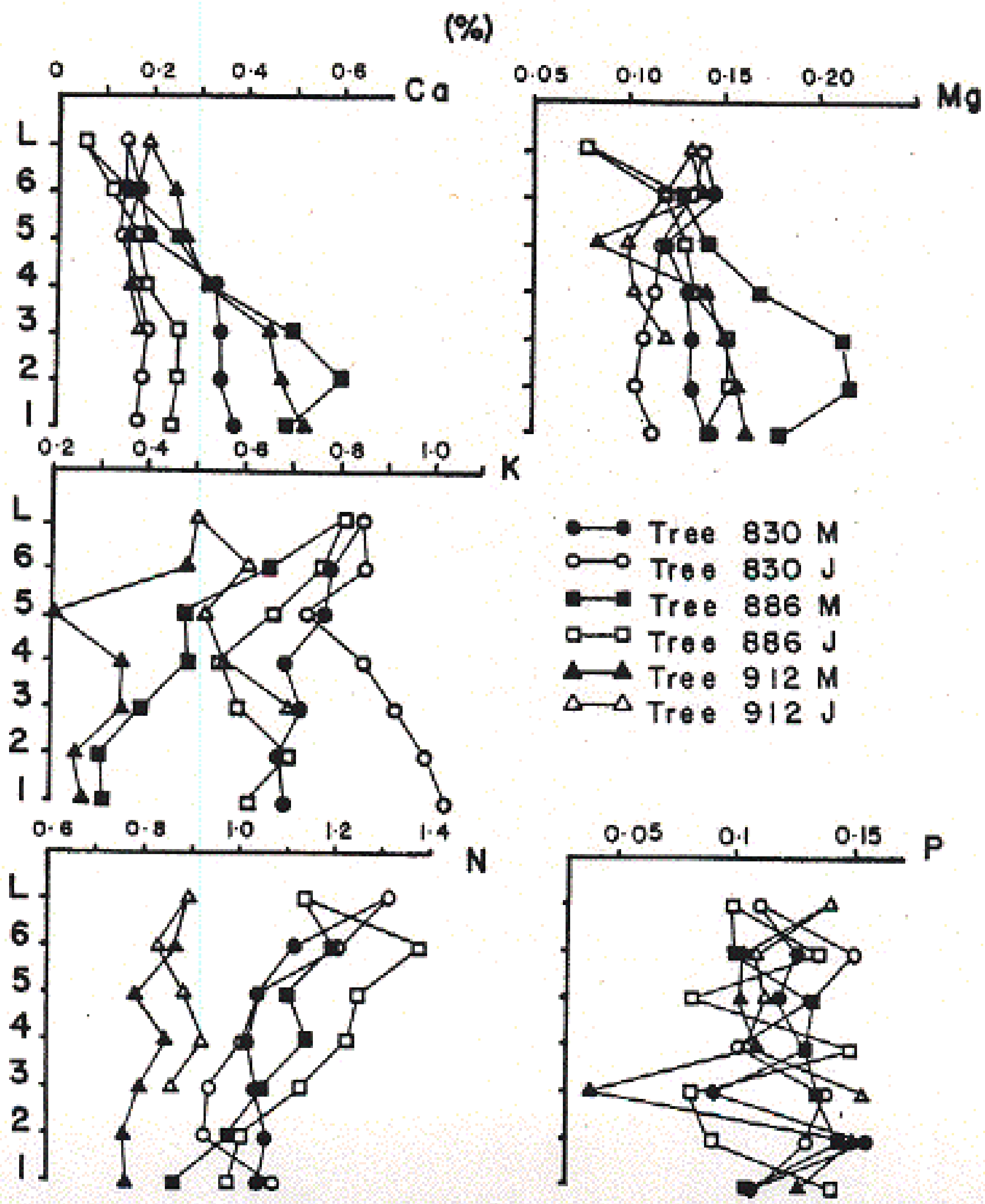
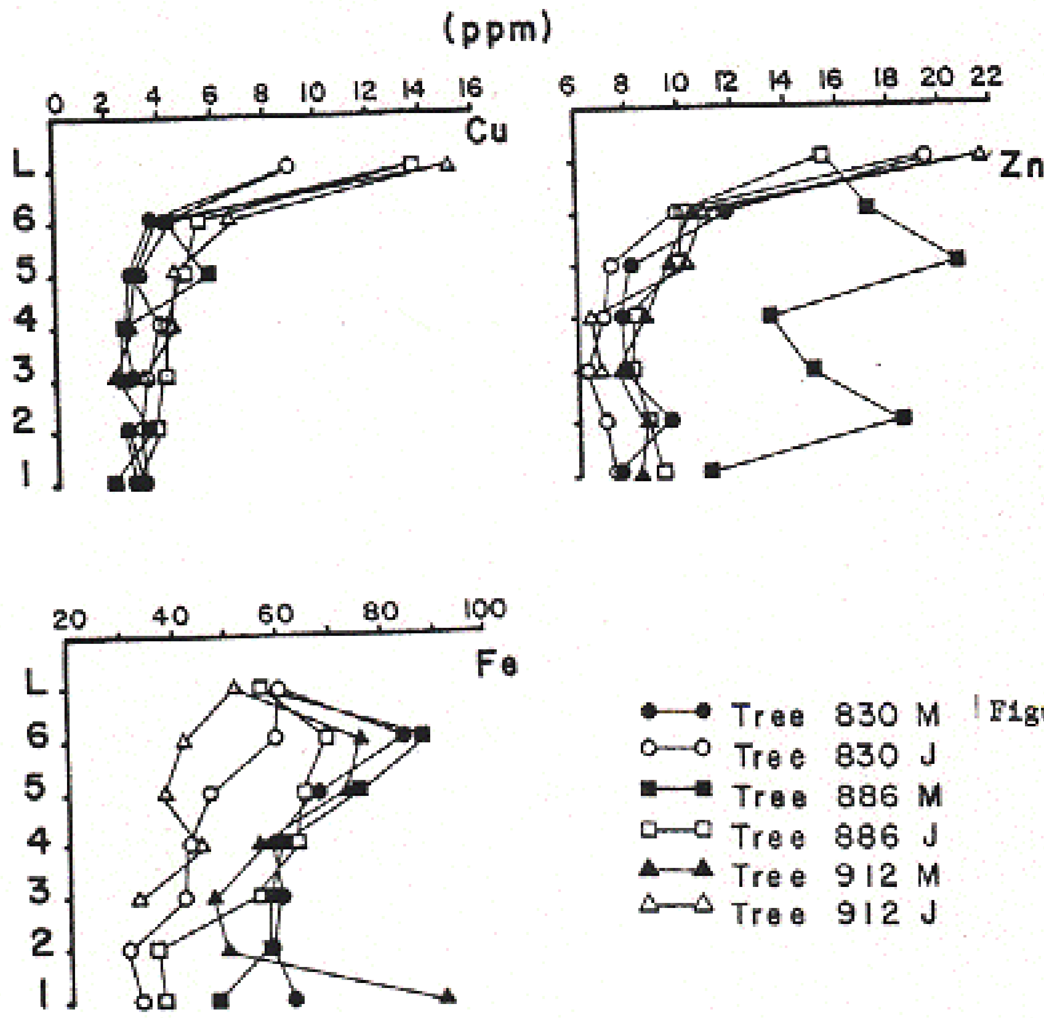


Figure 7-3. Concentration of Cu, Zn, and Fe (ppm) in the leader (L), juvenile (J: open symbols), and mature (M: closed symbols) foliage at 6 equally spaced positions vertically through the crowns of three western hemlock trees of different crown class: #830, a dominant; #886, a codominant; and #912, a codominant.



Certain elements display similar vertical distribution patterns or "profiles" of concentration through the live tree crown which may or may not differ between juvenile and mature foliage. Ca, Mg and Mn levels were highest in mature foliage of the lower crown and decreased with crown height while levels in juvenile foliage were relatively uniform throughout the crown. N and K in mature foliage increased as crown height increased. Juvenile foliage had higher N and K concentrations. N concentration in current foliage followed the same pattern as did the older foliage, but K in juvenile foliage was highest in the lower crown.

The reverse of the Ca-Mg-Mn profile was seen in the profiles of Fe and Al (Figures 7-3 and 7-4). In this case, the highest values were found in mature foliage of the upper crown. Both mature and current foliage had decreasing levels in lower crown positions. Patterns for Zn and Cu (Figure 7-3) were very similar (except for unusually high values for Zn in mature foliage of tree #886); high concentrations occurred in the leaders but this sharply decreased within the bulk of the crown to a relatively constant level. Cu and Zn showed a consistent difference between mature and current foliage. Zn was higher in older foliage while Cu was higher in juvenile foliage.

2. Effect of crown class on nutrient status:

Crown class of the sampled trees appears to affect concentration and distribution patterns of the nutrients. Foliar nitrogen was the most obvious example of this effect. Tree #912 was the smaller of the two codominants and, in comparison to the older two trees, had much lower N levels throughout the crown. The effect of crown class on nutrient patterns was evident for Ca, Mg and Mn. The two codominants (tree #886 and #912) had higher concentrations of these elements in mature, lower crown foliage than did the dominant tree #830.

3. Diagnosis of foliar nutrient status:

Table 7-6 compares nutrient levels in samples from installation #24 with foliar data from the same installation reported by Radwan and Debell (1980). These data are also compared to the cumulative probability distribution ranking of western hemlock foliar analyses compiled by Zinke (1981). Table 7-6 shows that there is general agreement between the current sample of

Figure 7-4. Concentration of Mn and Al (ppm) in the leader (L), juvenile (J: open symbols), and mature (M: closed symbols) foliage at 6 equally spaced positions vertically through the crowns of three western hemlock trees of different crown class: #830, a dominant; #886, a codominant; and #912, a codominant.