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GROWTH RESPONSE TO SINGLE AND MULTIPLE NITROGEN FERTILIZER APPLICATIONS IN THINNED DOUGLAS-FIR STANDS

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

SUMMARY

Basal area growth response and volume growth response to single and multiple nitrogen (N) fertilizer applications in thinned, second-growth Douglas-fir installations were estimated for six two-year periods. The installations comprised replicated treatments of 0, 200, and 400 lbs N/A applied as urea (46% N). A second fertilizer treatment of 200 lbs N/A was applied to one plot of each initial treatment before the fifth period. Plots were thinned to 60% of their original basal area at the time of installation establishment and lightly rethinned before the sixth period.

These stands responded significantly to both the initial fertilization and a second fertilization eight years later. Duration of response to the initial fertilization was approximately eight years. The response to the second fertilization was smaller than the response to the initial fertilization.

Volume growth response to either fertilization was not related to site index or basal area.

The effects of basal area and site index on basal area growth response were not estimated satisfactorily with one analysis of covariance model. Basal area and site index variables were highly correlated and their effects on response could not be disentangled. Therefore, these effects were estimated with separate models.

Basal area growth response to the first fertilization was inversely related to basal area. The effect was greater and lasted longer for stands treated with 400 lbs N/A than for stands treated with 200 lbs N/A. The effect could not be detected ten years after the initial fertilization. Basal area growth response to two fertilizations was not related to basal area.

Basal area growth response to the first fertilization was also inversely related to site index. The effect lasted at most four years. Results for stands fertilized twice were inconsistent: basal area growth response was related to site index for only those stands initially treated with 200 lbs N/A and then retreated with 200 lbs N/A.

INTRODUCTION

Thinning and nitrogen (N) fertilization are two management practices that can be used to increase the value of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) stands. Thinning redistributes growth potential of the stand to selected crop trees and N fertilization stimulates the growth of trees by increasing both foliage mass and photosynthesis per unit foliage (Brix 1983). The effects of thinning and one application of N fertilizer on Douglas-fir stands have been evaluated in many studies, a number of which have been summarized by Miller and others (1979; 1986).

Few studies provide information about the effects of multiple N fertilizer applications on Douglas-fir stands. The Regional Forest Nutrition Research Project (RFNRP) completed a report which included results on the effect of multiple N fertilizer applications on growth response in unthinned Douglas-fir stands (Peterson and Heath 1986; see also Peterson and others 1986). Barclay and Brix (1985) presented results on growth response to multiple N fertilizer applications in a Douglas-fir ecosystem of low site quality.

OBJECTIVES

1. To report gross basal area and gross volume growth responses to single and multiple N fertilizer applications in thinned Douglas-fir stands for six two-year growth periods.

2. To investigate the effects of basal area and site index on growth response to single and multiple N fertilizer applications. These findings represent an extension of results given in RFNRP (1982) where, based on eight years of data, it was reported that volume growth response to a single application of N fertilizer was not related to age,

site index, or stocking.

3. To evaluate growth response duration for each initial fertilizer treatment.

4. To compare growth responses to initial fertilization with growth responses to refertilization.

METHODS

Data Collection

Tree measurement data were collected over a 12-year period from 34 second-growth Douglas-fir field installations established in western Washington and Oregon by the RFNRP. Each installation comprised six 0.1-acre or larger plots that were thinned from below to 60% of their original basal area at the time of installation establishment. Two plots served as controls (treatment 0T), two plots were fertilized with urea (46% N) at a level of 200 lbs N/A (treatment 2T), and two plots were fertilized with urea at a level of 400 lbs N/A (treatment 4T). After eight growing seasons, one replicate of each treatment in each installation was refertilized with urea at a level of 200 lbs N/A. Thus, one of the two 0T plots became a 02 plot, one 2T plot became a 22 plot, and one 4T plot became a 42 plot (Figure 1). All treatments were assigned randomly and urea fertilizer was broadcast by hand. Average stand conditions (post-thinning) for these plots are summarized by treatment in Table 1. For more information about treatment design, see Hazard and Peterson (1984).

Plots were rethinned from below after ten growing seasons to provide the trees with an unconstrained environment for growth.

A plot was not rethinned if it contained less than 25 trees or if its relative density (Curtis 1982) was less than 40. Since all plots were subjected to the same thinning guideline, the data cannot be used to estimate the effect of rethinning on either growth or growth response.

For each plot, initial diameter at breast height (DBH) measurements were taken for all trees greater than 1.55 inches in DBH. The heights of ten dominant and codominant trees were also measured to estimate site index (King 1966) and to estimate volume (CVTS) using tarifs (Turnbull and others 1972). Diameter and height were remeasured initially and at two-year intervals following plot establishment. These data were used to compute a sequence of six two-year total gross basal area periodic annual increments (PAIs) and a sequence of six two-year total gross volume PAIs.

Direct and Indirect Fertilizer Response

Several researchers have partitioned fertilizer response into direct and indirect effects (Comerford and others 1980; Miller and Tarrant 1983; Auchmoody 1985). The direct effect is that part of the response due to improved nutrition. The indirect effect is the remaining portion of the response due to altered stocking brought on by the fertilizer in previous periods.

The growth response estimation procedure described below produces response estimates of direct fertilizer effects. The indirect effect is mathematically removed by using basal area at the beginning of the period as a covariate. A similar procedure was used by Miller and Tarrant (1983) to estimate the direct effects in a Douglas-fir stand treated with ammonium nitrate fertilizer. The indirect effects will be presented and discussed in a future RFNRP report.

Growth Response Analysis

Analysis of covariance was used to determine the effects of N fertilizer on total gross basal area PAI and total gross volume PAI for each two-year period.[1] Response estimates obtained in this fashion have been called "smoothed" responses in prior RFNRP reports (e.g., see RFNRP 1982). For each of the first four periods, the form of the equation was

$$PAI = f(AGE, SI, BA, BA/AGE, BA/AGE^2) + b_{2T}I_{2T} + b_{4T}I_{4T}$$

where PAI = basal area PAI or volume PAI
$f(\cdot)$ = expected growth of unfertilized stand
AGE = breast height age at beginning of period
SI = site index at plot establishment
BA = basal area at beginning of period
b_{2T}, b_{4T} = treatment effects which were interpreted as regional growth responses to N fertilizer
I_{2T} = 200 lbs N/A treatment indicator variable
I_{4T} = 400 lbs N/A treatment indicator variable.

The equations for data from periods 5 and 6 contained additional indicator variables to account for effects due to the application of N fertilizer eight growing seasons after

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[1]As a matter of convenience, total gross basal area and total gross volume will be referred to as basal area and volume in the remainder of this report.

installation establishment. The form of the equation was

$$PAI = f(\cdot) + b_{2T}I_{2T} + b_{4T}I_{4T} + b_{02}I_{02} + b_{22}I_{22} + b_{42}I_{42}$$

where b_{02} = growth response to treatment 02
b_{22} = growth response to treatment 22
b_{42} = growth response to treatment 42
I's = treatment indicator variables.

Growth response to two applications of N fertilizer was partitioned into two components: (1) growth response due to the initial application of N fertilizer (carry-over growth response) and (2) growth response due solely to the second application of N fertilizer (retreatment growth response). This can be expressed as

$$\text{growth response to two N fertilizations} = b_{22}$$
$$= (b_{22} - b_{2T}) + b_{2T}$$
$$= \text{retreatment growth response} + \text{carry-over growth response.}$$

A similar set of equations can be developed for growth response where the first fertilizer treatment is applied at 400 lbs N/A and the second is applied at 200 lbs N/A.

Effects of Basal Area and Site Index on Growth Response

Analysis of covariance was also used to evaluate the effects of basal area and site index on growth response. The form of the equations used for data from periods 1, 2, 3, and 4 was

$$PAI = f(\cdot) + b_1I_{2T} + b_2I_{4T} + b_3I_{2T}BA + b_4I_{4T}BA + b_5I_{2T}SI + b_6I_{4T}SI$$

where the b_i's are treatment effects and all other variables are as defined above. Coefficients b_3, b_4, b_5, and b_6 represent interaction effects. The form of the equations for periods 5 and 6 was similar to the above but included additional variables to account for effects due to application of N fertilizer eight growing seasons after installation establishment. The presence of significant site index or basal area interaction variables in an analysis of covariance model implies response is related to site index or basal area.

RESULTS

Basal Area Growth Response

Basal area growth responses to treatments 2T and 4T attained maximums in periods 1 and 2, respectively, and declined thereafter (Table 2). Basal area growth responses to treatments 2T and 4T were significant ($p < 0.05$) in periods 1, 2, 3, and 4.

Basal area growth response to treatment 02 (a delayed fertilizer treatment) was significant ($p < 0.05$) in period 5 (Table 2) and was smaller in magnitude than the response to treatment 2T in period 1.

Basal area growth responses to treatments 22 and 42 (two applications of N fertilizer) were significant ($p < 0.05$) in periods 5 and 6. Growth responses to treatments 22 and 42 were partitioned into retreatment growth responses (b_{22} minus b_{2T} and b_{42} minus b_{4T}) and carry-over growth responses (b_{2T} minus b_{0T} and b_{4T} minus b_{0T}) (Table 2) and are graphically displayed in Figure 2. Growth responses to treatments 22 and 42 were primarily composed of significant ($p < 0.05$) retreatment growth responses.

All carry-over growth responses (responses to treatments 2T and 4T in periods 5 and 6) were not significant.

<u>Volume Growth Response</u>

Volume growth responses to treatments 2T and 4T were greatest in period 2 (Table 3). Volume growth response to treatment 2T was significant at the 0.05 level in periods 1, 2, and 3, whereas volume growth response to treatment 4T was significant at the 0.05 level in periods 1, 2, and 3 and significant at the 0.10 level in period 4.

Volume growth response to treatment 02 in period 5 was significant ($p < 0.05$) and was similar to the response to treatment 2T obtained in period 1 (Table 3).

Volume growth responses to treatments 22 and 42 were significant ($p < 0.05$) in periods 5 and 6. Growth responses were partitioned into retreatment growth responses and carry-over growth responses (Table 3) and are graphically displayed in Figure 3. The growth response to treatment 22 was primarily composed of retreatment growth response. The growth response to treatment 42 was approximately one-half carry-over growth response and one-half retreatment growth response. The only significant ($p < 0.05$) retreatment volume growth responses were to treatment 22 in periods 5 and 6.

Effects of Basal Area and Site Index on Growth Response

When both site index x treatment and basal area x treatment interaction variables were included in the model, site index had no significant ($p > 0.10$) effect on basal area growth response, but basal area did have a significant ($p < 0.10$) effect. However, when separate models were used, both were found to have significant effects on response. Since cooperators are interested in both variables, results for each model are presented below.

Basal area had a significant effect on basal area growth response to treatment 2T in periods 1 and 2 (Table 4). In comparison, basal area had a significant effect on basal area growth response to treatment 4T in periods 1, 2, 3 and 4 (Table 4). In periods 5 and 6, basal area had no significant effect on growth response to any treatment.

Site index had significant effects on basal area growth responses to treatment 2T in period 2 and to treatment 4T in periods 1 and 2 (Table 5). In period 5, growth response to treatment 22 was significantly related to site index (Table 5).

Volume growth response to any treatment was not significantly ($p > 0.10$) related to site index or basal area in any period.

DISCUSSION

Growth response estimates listed in this report (Tables 2 and 3) for the first four two-year growth periods differ slightly from those given in the 1980-82 Biennial Report (RFNRP 1982). The two sets of estimates differ because the RFNRP database has been updated with corrections since the publication of that report. It should be noted that the results and conclusions presented in the 1980-82 Biennial Report pertaining to thinned Douglas-fir installations do not change substantially as a result of the corrections.

It should also be noted that response estimates and their standard errors are affected by f(.). A poor choice for f(.) could lead to incorrect conclusions concerning response. For a check on the influence of f(.) on response estimates, an analysis of covariance was performed using indicator variables for installations and treatments with a stocking variable as the covariate.[2] Response estimates and their standard errors were not substantially different than those reported here.

Duration of Growth Response Due to Improved Nutrition

Growth response duration to a single application of 200 lbs N/A was approximately eight years: basal area growth response was significant ($p < 0.05$) in period 4 and volume growth response was not. Also, in period 5, neither basal area nor volume growth response to treatment 2T was significant. Growth response duration to a single application of 400 lbs N/A was also approximately eight years: basal area growth response and volume

[2]Results pertaining to this analysis are discussed by Opalach and Heath (1987).

growth response to treatment 4T were significant at the 0.05 and 0.10 levels, respectively, in period 4 and neither was significant in period 5. Peterson and Heath (1986), in an analysis of RFNRP data for unthinned Douglas-fir stands, found that the duration of response to either 200 lbs N/A or 400 lbs N/A applied as urea was at least 12 years. It appears growth response duration for thinned stands may be shorter than for unthinned stands.

Effect of Basal Area on Growth Response

Ballard (1980) reported that there was a strong modifying effect of stocking on net growth response to N. Stands with room for crown expansion were likely to show a growth response to N. Overstocked stands, unless severely N deficient, generally show little or no response to N.

Inspection of Table 4 reveals that the data from the thinned stands support Ballard's statements (assuming net growth approximately equals gross growth in thinned stands) and also provide some insight into the nature of the basal area growth response-basal area relationship over time. The effect of basal area on basal area growth response diminished over time for treatments 2T and 4T. The magnitude and duration of the effect were greater for treatment 4T than for treatment 2T. This diminution was most likely a consequence of increasing stocking and decreasing response.

No significant relationships were found between basal area growth response to treatments 42, 22, and 02 and basal area in period 6 even though the plots were rethinned at the end of period 5. On average, stocking was much greater in period 6 than in period 1 or 2. Stocking might have been so great as to preclude the possibility of detecting significant relationships.

Growth Response to the Second N Fertilizer Application

Growth responses due solely to the second N fertilization (retreatment growth responses) were much smaller than growth responses to the initial N treatment (Figures 2 and 3). However, this result was not unexpected given the following two observations: (1) the plots, on average, had a much greater degree of stocking in periods 5 and 6 than in periods 1 and 2 (Table 1) and, (2) as reported above, growth response to N was inversely related to stocking.

Retreatment growth responses associated with treatment 22 were larger than those associated with treatment 42 (Tables 2 and 3). In fact, volume growth response to treatment 22 was significantly different than volume growth response to treatment 42 in period 6 (Table 3). Retreatment volume growth responses for unthinned Douglas-fir exhibited a similar pattern (Peterson and Heath 1986). These results suggest that a thinned or unthinned stand's retreatment growth response may be inversely related to the amount of N fertilizer applied initially.

CONCLUSIONS

The thinned second-growth Douglas-fir stands analyzed in this study responded significantly to two applications of N fertilizer applied eight years apart. When the total growth response to two applications of N fertilizer was partitioned into carry-over growth response and retreatment growth response, the larger component was the retreatment growth response. Retreatment growth response was smaller than the response to the initial application of fertilizer.

Response duration was approximately eight years for both levels of N fertilization examined in this study. Peterson and Heath (1986) found that response duration in unthinned stands was approximately 12 years. Thus, response duration may be shorter in thinned Douglas-fir stands than in unthinned stands.

Basal area growth response to the initial application of N fertilizer was inversely related to basal area. No relationship was detected between basal area growth response to two applications of N fertilizer and basal area. Basal area growth response was also inversely related to site index, but the relationship was not as strong or as consistent for basal area. No relationship could be detected between volume growth response and site index or basal area.

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Table 1. Average stand conditions for each treatment at the beginning of each two-year growth period.

Period	Stand Attribute	Treatment 0T	2T	4T	02	22	42
1	Site index	113	115	114	--	--	--
	Age	30	30	30	--	--	--
	Trees/A	345	339	336	--	--	--
	Basal area	120	120	119	--	--	--
	Volume	3782	3801	3716	--	--	--
	BA PAI	5.97	7.95	8.04	--	--	--
	Volume PAI	243	306	306	--	--	--
	Rel. density	40	40	39	--	--	--
	Sample size	65	62	67	--	--	--
2	Site index	113	115	114	--	--	--
	Age	32	32	32	--	--	--
	Trees/A	344	338	336	--	--	--
	Basal area	132	136	135	--	--	--
	Volume	4252	4407	4323	--	--	--
	BA PAI	6.56	8.61	9.14	--	--	--
	Volume PAI	276	350	365	--	--	--
	Rel. density	43	44	44	--	--	--
	Sample size	65	62	67	--	--	--
3	Site index	113	115	114	--	--	--
	Age	34	34	34	--	--	--
	Trees/A	340	330	328	--	--	--
	Basal area	144	151	152	--	--	--
	Volume	4772	5050	5005	--	--	--
	BA PAI	7.20	8.48	9.15	--	--	--
	Volume PAI	319	373	386	--	--	--
	Rel. density	46	48	48	--	--	--
	Sample size	65	62	67	--	--	--
4	Site index	113	115	114	--	--	--
	Age	36	36	36	--	--	--
	Trees/A	339	327	325	--	--	--
	Basal area	158	167	169	--	--	--
	Volume	5394	5767	5754	--	--	--
	BA PAI	6.74	7.52	7.86	--	--	--
	Volume PAI	346	379	389	--	--	--
	Rel. density	49	51	52	--	--	--
	Sample size	65	62	67	--	--	--

where units of measurement are

Site index - feet, base age = 50 years (King 1966)
Age - years, measured at breast height
Basal area - ft^2/A
Volume (CVTS) - ft^3/A
BA PAI - $ft^2/A/yr$
Volume PAI - $ft^3/A/yr$
Rel. density - Curtis (1982)

Table 1. Continued

Period	Stand Attribute	Treatment 0T	2T	4T	02	22	42
5	Site index	113	116	114	115	116	115
	Age	38	38	38	38	38	38
	Trees/A	363	315	327	305	335	317
	Basal area	173	186	185	175	183	187
	Volume	6075	6660	6524	6287	6622	6676
	BA PAI	6.55	7.14	7.39	7.82	7.88	8.06
	Volume PAI	342	392	391	408	422	416
	Rel. density	54	56	56	53	55	56
	Sample size	31	30	34	30	28	29
6[3]	Site index	114	116	116	115	117	117
	Age	39	38	39	40	39	39
	Trees/A	251	229	225	231	231	213
	Basal area	159	176	177	168	175	176
	Volume	5926	6635	6641	6304	6700	6657
	BA PAI	6.13	6.65	6.83	7.40	7.40	7.23
	Volume PAI	308	347	361	381	393	377
	Rel. density	47	50	50	48	50	49
	Sample size	30	30	31	29	27	27

where units of measurement are

Site index	-	feet, base age = 50 years (King 1966)
Age	-	years, measured at breast height
Basal area	-	ft^2/A
Volume (CVTS)	-	ft^3/A
BA PAI	-	$ft^2/A/yr$
Volume PAI	-	$ft^3/A/yr$
Rel. density	-	Curtis (1982)

[3]Apparent discrepancies in the average stand conditions for period 6 are due to the loss of two older installations after period 5.

Table 2.

Total gross basal area growth response estimates ($\pm$ 1 standard error) for each two-year growth period, with levels of statistical significance (min. DBH = 1.55 inches).

Response (sq ft/A/yr)	Two-year Growth Period					
	1	2	3	4	5	6
2T minus 0T percent significance	1.87 $\pm$ 0.24 31% $\pm$ 4% $p < 0.001$	1.82 $\pm$ 0.23 26% $\pm$ 3% $p < 0.001$	0.94 $\pm$ 0.19 12% $\pm$ 2% $p < 0.001$	0.49 $\pm$ 0.21 7% $\pm$ 3% $p < 0.05$	0.23 $\pm$ 0.35 3% $\pm$ 5% $p > 0.25$	-0.07 $\pm$ 0.32 -1% $\pm$ 5% $p > 0.25$
4T minus 0T percent significance	1.95 $\pm$ 0.24 32% $\pm$ 4% $p < 0.001$	2.29 $\pm$ 0.22 33% $\pm$ 3% $p < 0.001$	1.56 $\pm$ 0.19 20% $\pm$ 2% $p < 0.001$	0.74 $\pm$ 0.21 10% $\pm$ 3% $p < 0.001$	0.43 $\pm$ 0.34 6% $\pm$ 5% $p < 0.25$	0.07 $\pm$ 0.32 1% $\pm$ 5% $p > 0.25$
22 minus 2T percent significance	--	--	--	--	0.95 $\pm$ 0.36 14% $\pm$ 5% $p < 0.01$	1.06 $\pm$ 0.33 17% $\pm$ 5% $p < 0.01$
42 minus 4T percent significance	--	--	--	--	0.74 $\pm$ 0.34 10% $\pm$ 5% $p < 0.05$	0.65 $\pm$ 0.33 10% $\pm$ 5% $p < 0.05$
22 minus 0T percent significance	--	--	--	--	1.18 $\pm$ 0.36 18% $\pm$ 5% $p < 0.005$	0.99 $\pm$ 0.33 16% $\pm$ 5% $p < 0.01$
42 minus 0T percent significance	--	--	--	--	1.17 $\pm$ 0.36 17% $\pm$ 5% $p < 0.005$	0.72 $\pm$ 0.33 11% $\pm$ 5% $p < 0.05$
02 minus 0T percent significance	--	--	--	--	1.37 $\pm$ 0.35 21% $\pm$ 5% $p < 0.001$	1.23 $\pm$ 0.32 20% $\pm$ 5% $p < 0.001$

Table 3.

Total gross volume (CVTS) growth response estimates ($\pm$ 1 standard error) for each two-year growth period, with levels of statistical significance (min. DBH = 1.55 inches).

Response (cu ft/A/yr)	Two-year Growth Period 1	2	3	4	5	6
2T minus 0T	59.2 $\pm$ 8.0	65.6 $\pm$ 9.2	37.3 $\pm$ 8.2	13.4 $\pm$ 11.3	21.6 $\pm$ 15.5	2.8 $\pm$ 16.1
percent	24% $\pm$ 3%	23% $\pm$ 3%	11% $\pm$ 2%	4% $\pm$ 3%	6% $\pm$ 4%	1% $\pm$ 5%
significance	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p > 0.25$	$p < 0.25$	$p > 0.25$
4T minus 0T	61.7 $\pm$ 7.8	82.4 $\pm$ 9.0	51.8 $\pm$ 8.1	21.0 $\pm$ 11.2	23.0 $\pm$ 15.1	15.6 $\pm$ 16.0
percent	25% $\pm$ 3%	29% $\pm$ 3%	15% $\pm$ 2%	6% $\pm$ 3%	6% $\pm$ 4%	5% $\pm$ 5%
significance	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.10$	$p < 0.25$	$p > 0.25$
22 minus 2T	--	--	--	--	37.9 $\pm$ 15.7	55.4 $\pm$ 17.0
percent					10% $\pm$ 4%	17% $\pm$ 5%
significance					$p < 0.05$	$p < 0.01$
42 minus 4T	--	--	--	--	21.6 $\pm$ 15.2	22.2 $\pm$ 16.9
percent					5% $\pm$ 4%	6% $\pm$ 5%
significance					$p < 0.25$	$p < 0.25$
22 minus 0T	--	--	--	--	59.6 $\pm$ 15.7	58.2 $\pm$ 16.4
percent					17% $\pm$ 4%	18% $\pm$ 5%
significance					$p < 0.001$	$p < 0.001$
42 minus 0T	--	--	--	--	44.5 $\pm$ 15.7	37.8 $\pm$ 16.4
percent					12% $\pm$ 4%	12% $\pm$ 5%
significance					$p < 0.005$	$p < 0.05$
02 minus 0T	--	--	--	--	61.7 $\pm$ 15.4	61.9 $\pm$ 16.0
percent					18% $\pm$ 4%	20% $\pm$ 5%
significance					$p < 0.001$	$p < 0.001$

Table 4. Significant levels for basal area x treatment interaction terms in basal area PAI models.

Growth Period	Treatment x Basal Area Interaction Term	Significance Level
1	$I_{2T}BA$	$p < 0.01$
	$I_{4T}BA$	$p < 0.01$
2	$I_{2T}BA$	$p < 0.01$
	$I_{4T}BA$	$p < 0.01$
3	$I_{2T}BA$	$p < 0.25$
	$I_{4T}BA$	$p < 0.05$
4	$I_{2T}BA$	$p < 0.25$
	$I_{4T}BA$	$p < 0.10$
5	$I_{2T}BA$	$p > 0.25$
	$I_{4T}BA$	$p < 0.25$
	$I_{02}BA$	$p > 0.25$
	$I_{22}BA$	$p > 0.25$
	$I_{42}BA$	$p > 0.25$
6	$I_{2T}BA$	$p < 0.25$
	$I_{4T}BA$	$p < 0.25$
	$I_{02}BA$	$p > 0.25$
	$I_{22}BA$	$p > 0.25$
	$I_{42}BA$	$p > 0.25$

Table 5. Significant levels for site index x treatment interaction terms in basal area PAI models.

Growth Period	Treatment x Site Index Interaction Term	Significance Level
1	$I_{2T}SI$	$p < 0.25$
	$I_{4T}SI$	$p < 0.05$
2	$I_{2T}SI$	$p < 0.01$
	$I_{4T}SI$	$p < 0.05$
3	$I_{2T}SI$	$p > 0.25$
	$I_{4T}SI$	$p < 0.25$
4	$I_{2T}SI$	$p > 0.25$
	$I_{4T}SI$	$p > 0.25$
5	$I_{2T}SI$	$p > 0.25$
	$I_{4T}SI$	$p > 0.25$
	$I_{02}SI$	$p > 0.25$
	$I_{22}SI$	$p < 0.10$
	$I_{42}SI$	$p > 0.25$
6	$I_{2T}SI$	$p > 0.25$
	$I_{4T}SI$	$p > 0.25$
	$I_{02}SI$	$p > 0.25$
	$I_{22}SI$	$p > 0.25$
	$I_{42}SI$	$p > 0.25$

Figure 1. Fertilization and thinning schedule for thinned Douglas-fir installations. Fertilizer applications and thinning operations occurred at the end of the indicated growing seasons. Also displayed in the figure is the split in the experimental design as a result of the refertilization at the end of the eighth growing season.

```
                                           0T plot ---------
          two 0T plots -------------|
                                           02 plot ---------

                                           2T plot ---------
          two 2T plots -------------|
                                           22 plot ---------

                                           4T plot ---------
          two 4T plots -------------|
                                           42 plot ---------

thinning        ↑                                  ↑

fertilizer
application     ↑                            ↑

growing
season          0-----2-----4-----6-----8----10----12
```

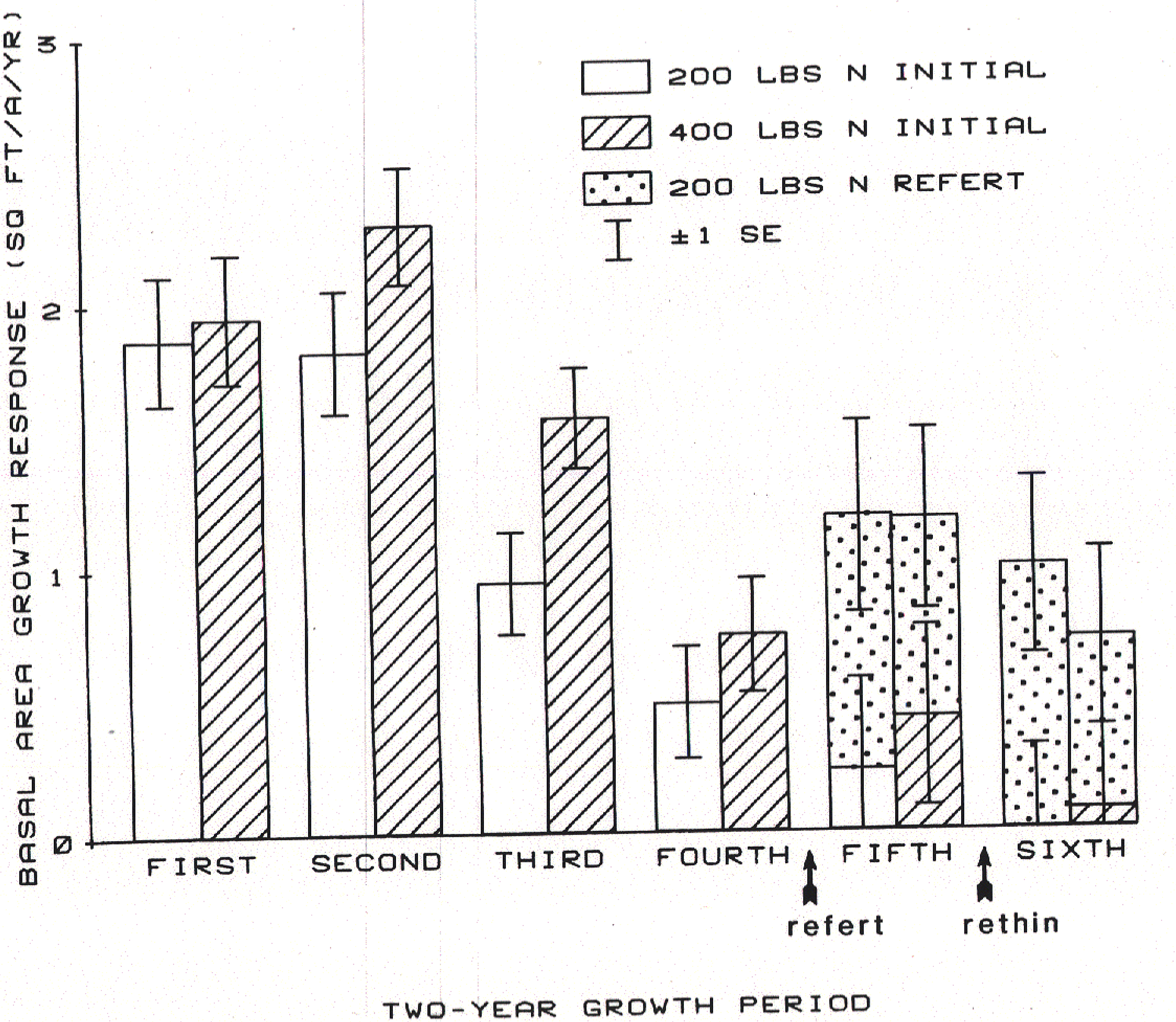

Figure 2. Total gross basal area growth response by two-year growth period (data from Table 2).

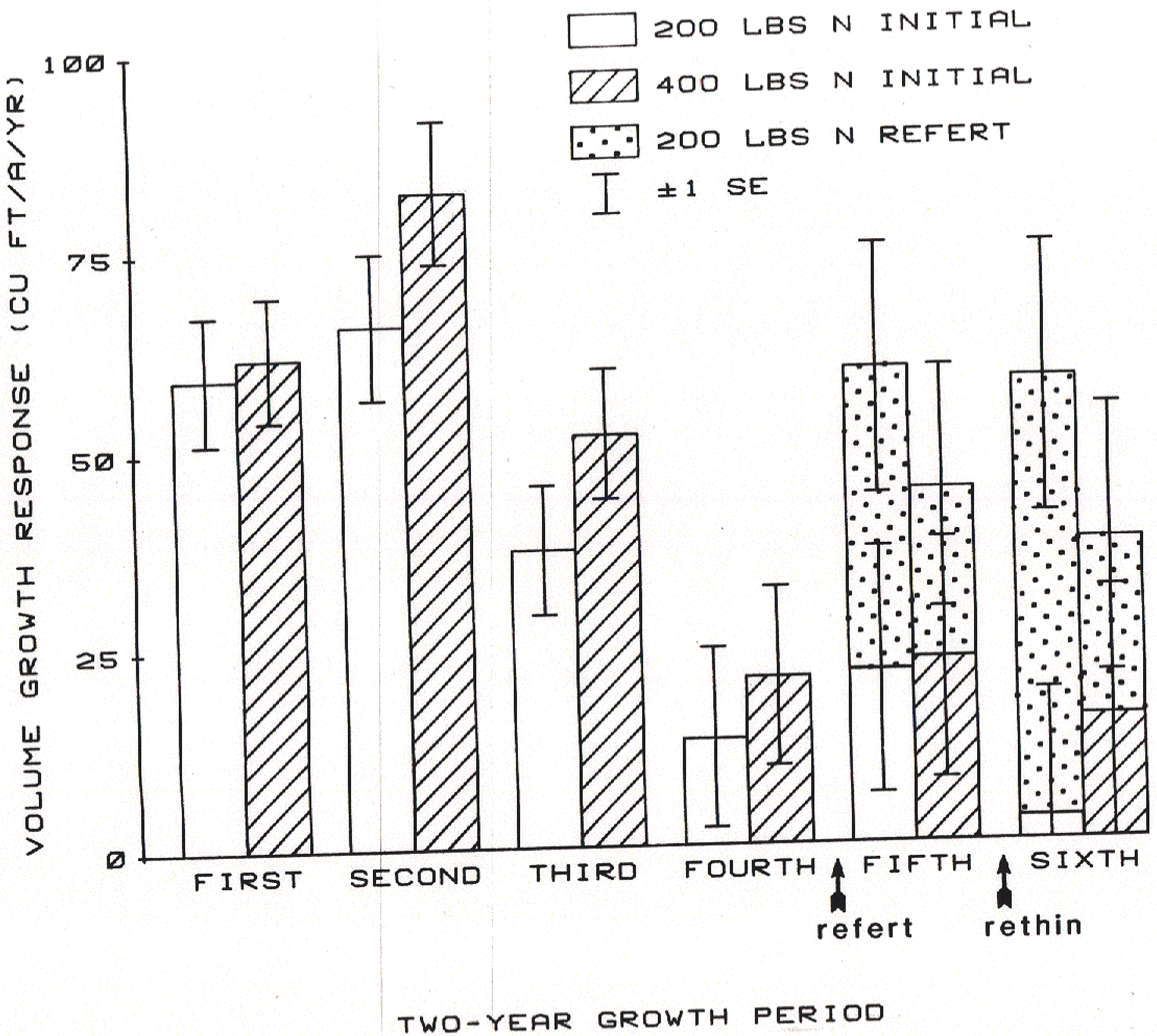

Figure 3. Total gross volume (CVTS) growth response by two-year growth period (data from Table 3).