

GROWTH RESPONSE TO FERTILIZATION IN RELATION TO STOCKING LEVELS OF DOUGLAS-FIR

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ABSTRACT

Growing stock levels affect the response of Douglas-fir stands to applications of nitrogen fertilizer. Response is maximum at intermediate stocking levels, and is less at higher or lower levels of stand density. Nitrogen fertilization accelerates growth and therefore increases the rate of buildup of stand density. Thinnings will be required to reduce stocking to appropriate levels if good responses to repeated nitrogen applications throughout a rotation are to be obtained.

INTRODUCTION

As a result of growth response information developed through regional field trials (Institute of Forest Resources 1979a), N application to Douglas-fir stands has become an important silvicultural tool in the Pacific Northwest (Bengtson 1979). Economic aspects of the fertilization option have been explored (Miller and Fight 1979, Institute of Forest Resources 1979a) and land managers can now employ rational strategies to increase the volume and value of these forests. Projected gains from repetitive fertilizations in some intensive management regimes, however, may be unrealistically high due to the relationship between stand stocking and response to fertilizer.

Growing stock levels and response to N applications are closely interrelated in unthinned natural stands of Douglas-fir. Each affects and is affected by the other. Moreover, these relationships have significant implications in forest management planning.

In this paper we will: (1) Explain and document the relationships between growing stock levels and response to fertilization, (2) suggest the biological basis for them, and (3) speculate on the implications of these relationships with respect to management decisions and long-range forest planning.

GROWING STOCK LEVEL AND RESPONSE TO FERTILIZATION

BIOMETRIC AND MENSURATIONAL ASPECTS

Response of Douglas-fir to N fertilization is affected by a

number of stand and site variables as illustrated by the following general equation form:

$$GR = b_1N + b_2A \cdot N + b_3S \cdot N + b_4B \cdot N + b_5B^2N + b_6N^2$$

where GR is volume growth response (CVTS/acre—cubic volume including top and stump)

N: fertilizer N level

A: stand age

Site: site index¹

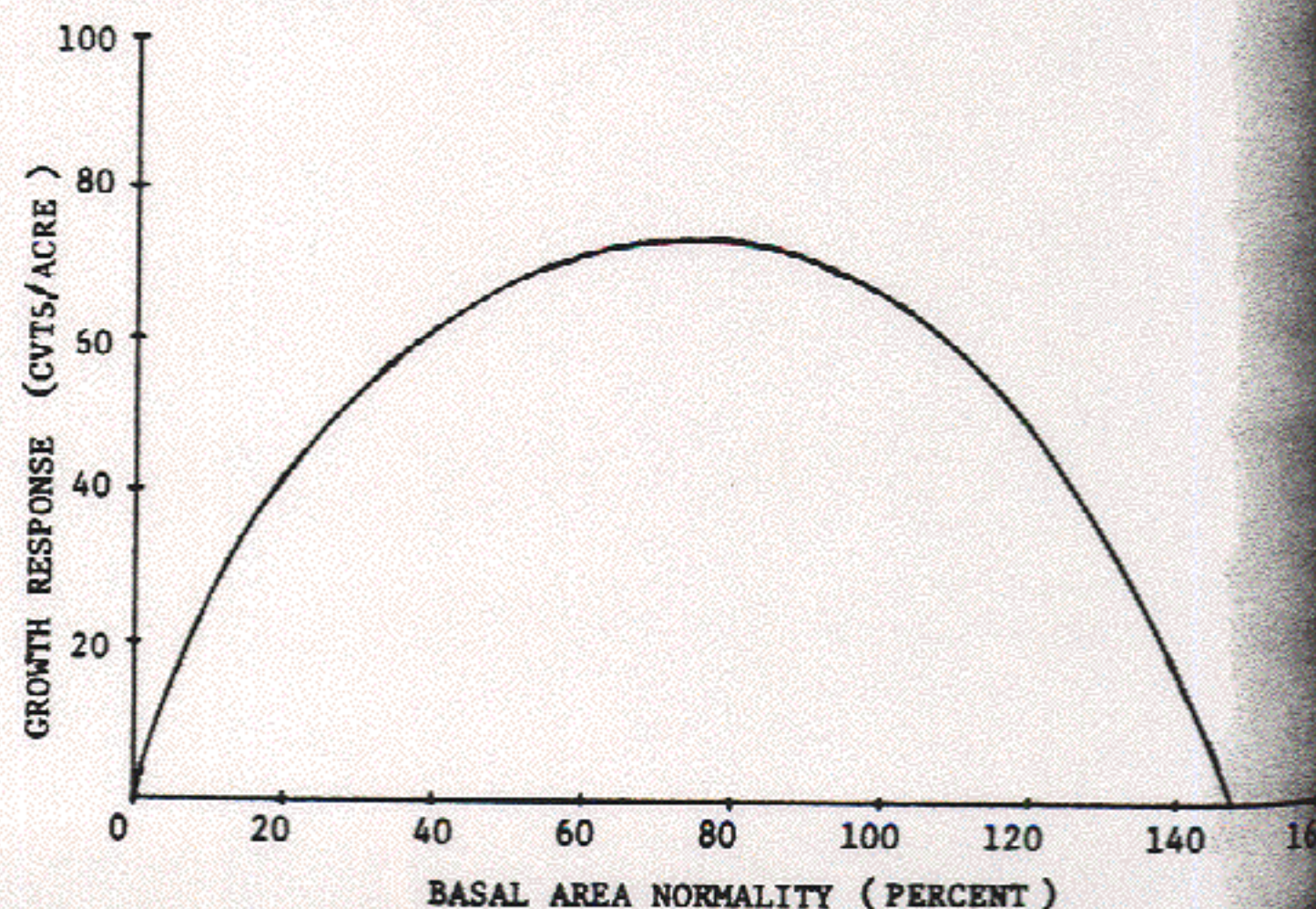
B: stocking level

b₁: through b₆ are coefficients

A specific equation was developed by Crown Zellerbach from a data base consisting of 20 installations and 300 plots; this equation accounted for about 65% of the variation in growth response. The effect of initial stocking on subsequent growth response of Douglas-fir is depicted graphically in Figure 1. Values used for N (200 lb/acre), S (130 ft), and A (40 yr) are

1. All site index values used in this paper are based on 100 yr (McArdle et al. 1961).

Figure 1. The effect of stocking level on total-stem volume growth response of Douglas-fir to N fertilization.



approximately average for our data base. An optimal stocking level ranging from about 60% to 90% normal² is evident in Figure 1. At lower and higher stocking levels growth response decreases to nil at a normality of zero and 150%.

Models used by Turnbull and Peterson (1976) for predicting volume growth response in the University of Washington's Regional Forest Nutrition Research Program (RFNRP) do not decrease at higher levels of stocking. The difference between cooperative research and Crown Zellerbach models probably results from differences in stocking level characteristics of plots included in the data bases.

Effects of understocking on growth response per acre are intuitively recognized by foresters, but these effects have not been well documented (Institute of Forest Resources 1979b). Reductions in response due to overstocking are not so obvious. Recent publications, however, have discussed this phenomenon conceptually (Ballard 1979) and used it quantitatively (Shumway and Atkinson 1978).

BIOLOGICAL BASIS

Nitrogen fertilization increases tree growth primarily through expansion of leaf surface (Brix and Ebell 1969, Turner and Olson 1976, and Tamm 1979). Concurrent root development (Hermann 1977) may also play an important role. Moreover, photosynthetic efficiency per unit leaf area may be enhanced by N fertilization (Brix 1971). At low stocking levels, abundant room for crown and root expansion permits the maximum growth response per tree to N fertilization. Growth response of stands, however, will rise with increasing stand density to an optimum stocking level.

At higher levels of stocking, growth response becomes less and less because space and other resources needed for crown

and root expansion become increasingly limiting. For example, light and/or moisture may become more growth-limiting than N. As such limitations increase in severity, the potential for response to N fertilizer approaches zero.

Thinning in such stands can restore their ability to respond to N applications. One example is some fertilized and unfertilized plots thinned by herbicide injection 2 yr after establishment of the Crown Zellerbach ML-7 fertilizer project. Approximately 200 trees per acre (the smallest stems in the stand) were killed on most of these plots leaving a stand of about 400 trees per acre. For the 10-yr period following fertilization, there was no growth response for the unthinned stand compared to a substantial response for the thinned stand (Table 1).

INFLUENCE OF FERTILIZATION ON BUILDUP IN GROWING STOCK

It is well known that understocked stands increase in stocking density with age (McArdle et al. 1961). Nitrogen fertilizer application increases rate of growth, and in so doing accelerates the buildup in stand density compared to that occurring in unfertilized stands. Data from nine studies (Table 2) illustrate this increase in stand density. As might be expected, the differential development with fertilization is especially pronounced in young stands and in stands with low initial stocking (ML-5, ML-6, and P-54). Lack of response may be due to overstocking (e.g., unthinned plots of ML-7, Table 1) or an adequate supply of mineralizable N (Shumway and Atkinson 1978).

The increased stand densities resulting from accelerated growth after fertilization will likely influence response to subsequent fertilizer applications. The possibility and importance of such effects have not been generally recognized.

Table 1. Growth and estimated growth response after fertilization in thinned and unthinned portions of a Douglas-fir stand.^a

	Basal area normality (%)	Growth 10-yr p.a.i. (CVTS/acre) unfertilized (ft ³)	fertilized (ft ³)	Estimated growth response 10-yr p.a.i. (CVTS/acre) (%)	(ft ³)
Unthinned	146	368	354	-4	-14
Thinned ^b	122	322	379	15	57

^aInitial age, 32 yr; site index 150. ^bThinned from below by herbicide injection two yr after fertilizer was applied.

INFLUENCE OF FERTILIZATION ON MORTALITY

There has been much discussion among foresters regarding the possibility of beneficial thinning effects of N fertilization in overstocked stands. Lee (1972) established a well replicated study to see if high rates of urea fertilization could significantly increase rates of mortality in dense western hemlock stands on Vancouver Island in British Columbia. Results of this study have been conclusive. Miller (1976) reviewed mortality trends of fertilized Douglas-fir and western hemlock stands. He concluded that rates of mortality associated with fertilization were much slower and, in most cases, less beneficial than growing stock reductions due to mechanical thinning.

Plots from the Crown Zellerbach data base were analyzed by multiple regression for trends in mortality. Fifty-five percent of the mortality could be explained by the following general equation:

$$M = b_0 + b_1A + b_2S + b_3N + b_4B + b_5A \cdot S$$

where M is mortality in terms of stand volume (CVTS/acre) and A, S, N, and B are age, site, fertilizer N level, and stocking, respectively.

In this equation, fertilizer application accounted for only 5% of total mortality. Using characteristics of an average, but well stocked stand (age 30, site index 130 ft, initial volume 2800 CVTS/acre), the estimated mortality due to fertilizer is less

than 3 CVTS/acre/yr. When this estimate is compared with a concomitant buildup in stand volume of 54 CVTS/acre/yr due to fertilizer, it is obvious that increased mortality cannot keep stocking levels within the optimal range for good response.

The most likely pattern of development of stocking is that shown in Figure 2. At lower and intermediate levels of stocking, fertilized stands will increase in density much more rapidly than unfertilized stands. Both will ultimately reach a density level at which mortality balances or exceeds growth. Moreover, it seems plausible, however, that fertilized stands could maintain a slightly higher level of density at equilibrium than unfertilized stands (see dashed line in Figure 2).

Figure 2. Probable patterns of stocking development for fertilized and unfertilized stand.

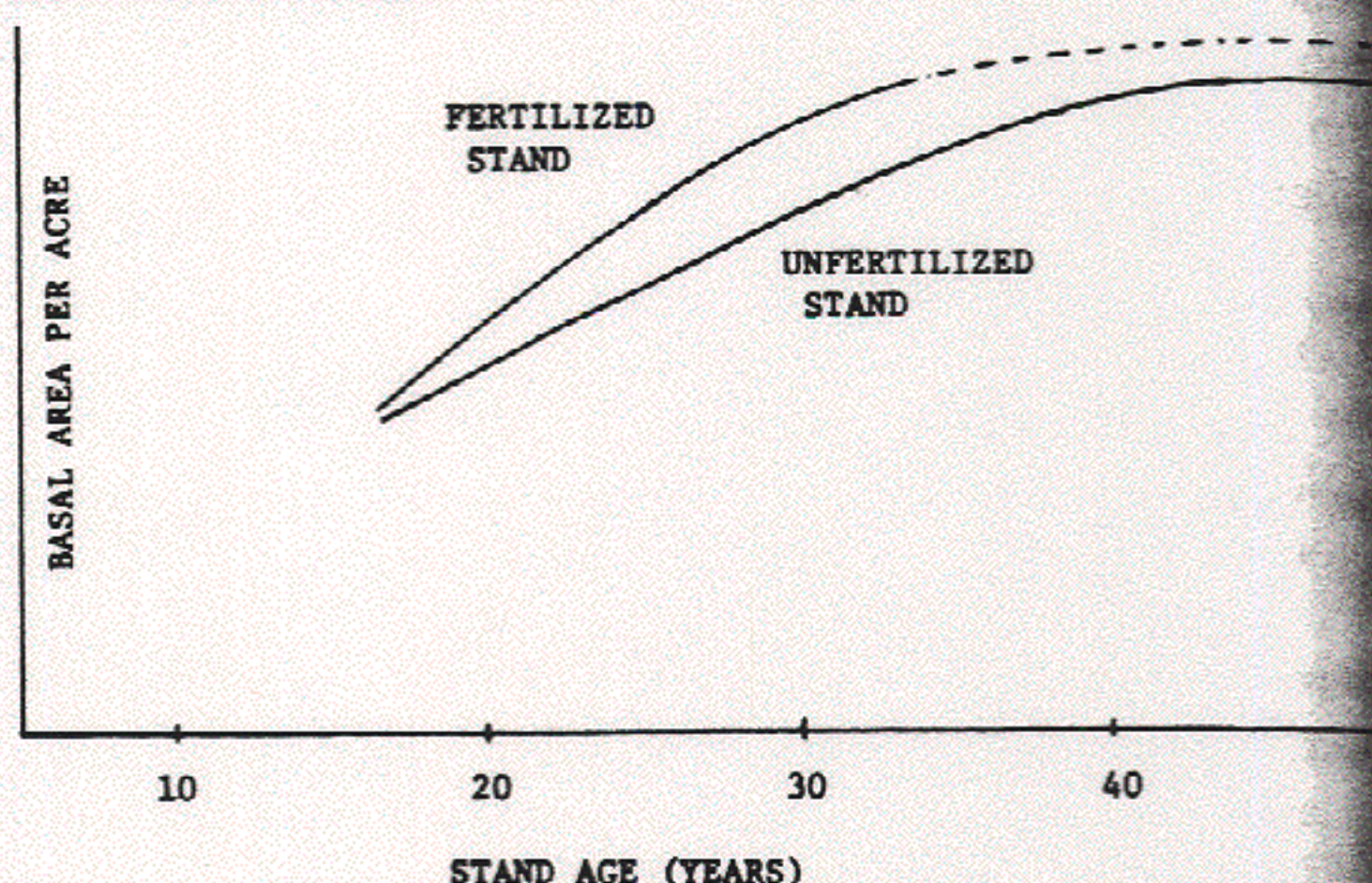


Table 2. Changes in basal area normality measured in Douglas-fir fertilizer trials.

Study	Initial age (yr)	Site index (ft)	Period (yr)	Treatment (lb N/acre)	Normality (%)		
					initial	final	---
CZ ML-5-N	10	130	10	0	25	64	+39
				200	25	77	+52
CZ ML-5-S	15	135	10	0	72	137	+65
				200	65	154	+89
CZ ML-6	20	125	10	0	42	86	+44
				200	39	110	+71
CZ ML-8A	45	140	10	0	116	119	+ 3
				200	110	115	+ 5
CZ ML-8B	45	125	10	0	121	128	+ 7
				200	128	140	+12
USFS P-54 ^a	35	80	15	0	75	85	+10
				200	71	98	+27
USFS C-8	30	95	10	0	101	130	+29
				200	110	153	+43
USFS M-65	60	120	6	0	110	111	+ 1
				150	128	131	+ 3
USFS C-22	60	150	7	0	88	97	+ 9
				200	87	96	+ 9

^aAll USFS data courtesy of Dr. R. E. Miller, Forestry Sciences Laboratory, Olympia, Washington.

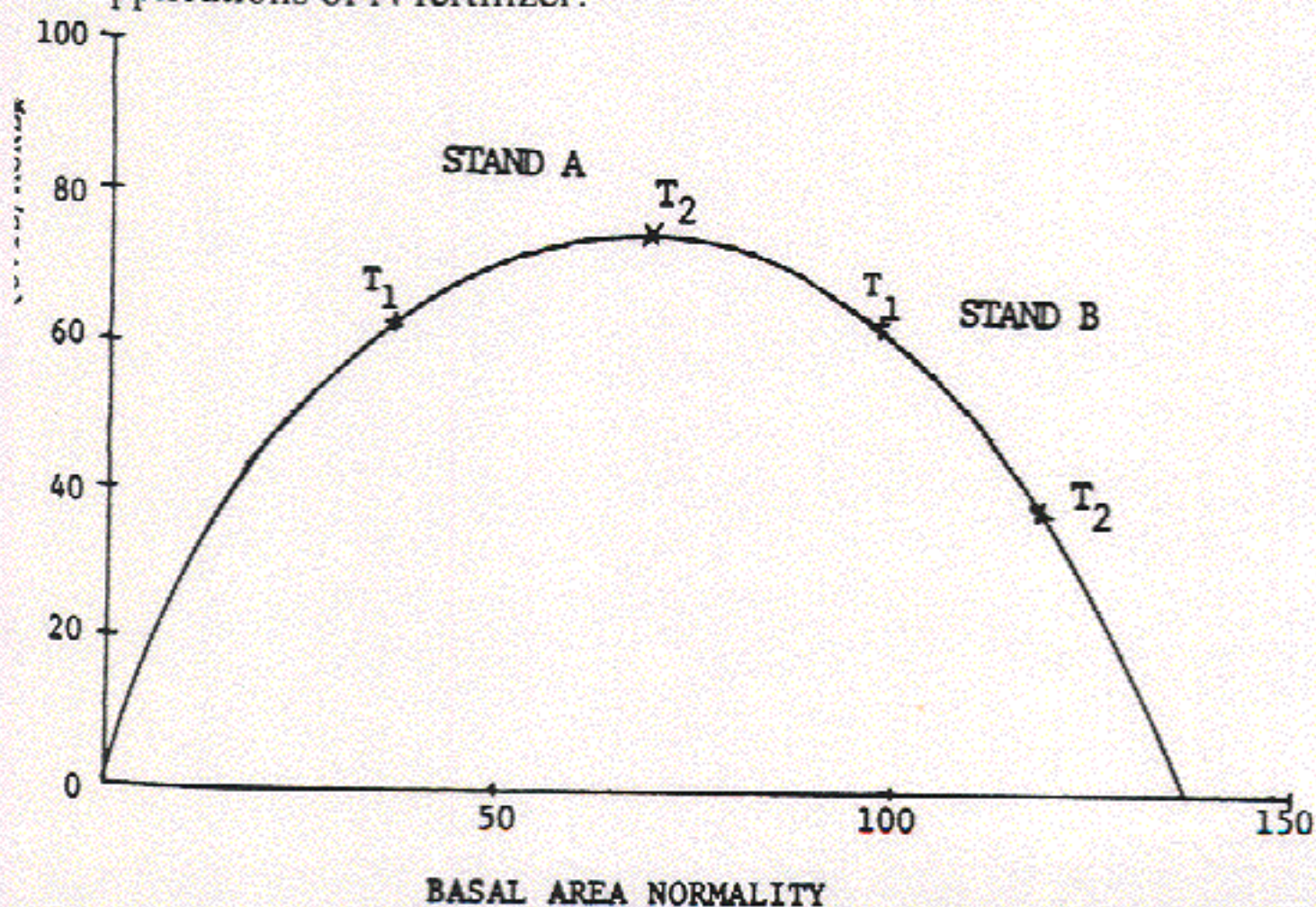
IMPLICATIONS

There has been a great deal of speculation about gains from successive fertilizations of previously fertilized stands. A number of factors may influence such a response, including soil nutrient status and microbial activity which may carry over from initial fertilizer applications (Heilman 1974, DeBell et al. 1979). Changes in stocking level induced by previous fertilizer applications may also enhance or limit response depending on initial stand stocking. Consider two stands (A and B) which are quite different in initial stocking but can be expected to respond similarly to a first application of fertilizer at time T_1 (Figure 3). As a result of the initial fertilization, the two stands will increase in density.

In the case of stand A, density level at the time of a second application of fertilizer (T_2) will be more favorable for response than it was for the initial application. The opposite is true of stand B. As a result, the expected response of stand B to the second fertilization will be only about one-half of that expected of stand A. A young stand may be expected to develop with time along the normality continuum depicted in Figure 3, with similar associated effects on its capacity to respond to applied N.

Any management program that involves repeated fertilization of stands during a rotation should take into account stocking buildup and the effects of growing stock levels on growth response. Beyond some optimal level of stocking (which may vary by site), response to successive applications of fertilizer is likely to be less and less. Thus, assuming that growth can be continually enhanced by repetitive fertilizer applications in the absence of stocking control is rather chancy. Periodic thinning may be required to maintain stands in a stocking range that is responsive to fertilizer applications. This may require commercial thinnings or more than one precommercial thinning.

Figure 3. Hypothetical comparison of response of two stands after two applications of N fertilizer.



CONCLUSION

Fertilization and growing stock control must be considered together in forest management planning. The situation is not simply the possibility of added benefits from combining thinning and fertilization; i.e., the so-called positive interaction or synergism of the combined treatments. Rather it appears that thinning will be essential to provide the best opportunities for gains from fertilization throughout the rotation.

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