GROWTH RESPONSE FALLDOWN ASSOCIATED WITH OPERATIONAL FERTILIZATION

R. F. Strand and L. C. Promnitz

ABSTRACT

Information supporting multimillion dollar expenditures on forest fertilization in the Pacific Northwest has been developed from uniform applications of nitrogen to small, well-stocked plots. Operationally, neither application rate nor stands fertilized are uniform. Differences between research-based projections and growth response achieved in operational applications has been termed "falldown."

This paper presents and illustrates procedures for approximating falldown. Such approximations can be used to develop a more realistic expectation of cost/benefits aspects of fertilization. They can also be used to assess the limits of economic investment to achieve greater degrees of application uniformity.

INTRODUCTION

An estimated half million acres of forest land in the Pacific Northwest will receive aerial applications of N fertilizer in the upcoming decade (Bengston 1979) at an approximate annual expenditure of 25 million dollars. Information supporting this program has been developed mostly from uniform applications to uniform plots of Douglas-fir. Growth response estimates assume an even spread of fertilizer at target rates on uniform, well-stocked stands.

Aerially applied fertilizer rates and forest type conditions, however, are quite variable in operational situations. Variability of fertilizer rates has been well documented (Barker 1979, Olson 1979, Strand 1970). Stand stocking can also be quite variable even in timber types stratified as homogenous for management purposes.

The consequence of application and stand variability is reduction of growth response below the level predicted from uniform applications of fertilizer to uniform stands. The difference between predictions and growth response under actual operational conditions has been termed "falldown." Our paper deals with a mathematical basis for falldown as well as methods for approximating its magnitude.

BACKGROUND

The first estimate of falldown for large scale use was made by Hagner (1966).

> "In some of the experimental tracts fertilized from the air the response value is slightly lower than the theoretical one . . . 23% vs. 29%. This trend was expected and an allowance was made of the response to be expected after practical fertilization, by applying a reduction factor to the theoretical response value."

This reduction factor or falldown is about 20% of predicted response.

More recently, Jonsson (1977) recommended reducing forecast response 20% to 25% when urea N is applied. Moller[1] states that for similar comparisons with ammonium nitrate only slight reductions in growth response can be detected. He identifies crown interception and subsequent volatilization as well as humus complexing of urea as primary factors in falldown from urea applications. Recent identification of "brown" soils as "nonresponsive" to fertilizer N has eliminated one source of reduced growth response previously included with falldown. However, Moller currently advises Swedish companies to use a 15% reduction (falldown) in growth response for applications of ammonium nitrate.

Swedish experience associates falldown with urea fertilizer and nonresponsive soils. It appears, however, that no specific concept has developed relating falldown to stand and application variability. In Idaho, Olson (1979) estimated potential falldown for applications of urea to mixed stands as 14% and 53%. His approach to falldown was based on application variability alone.

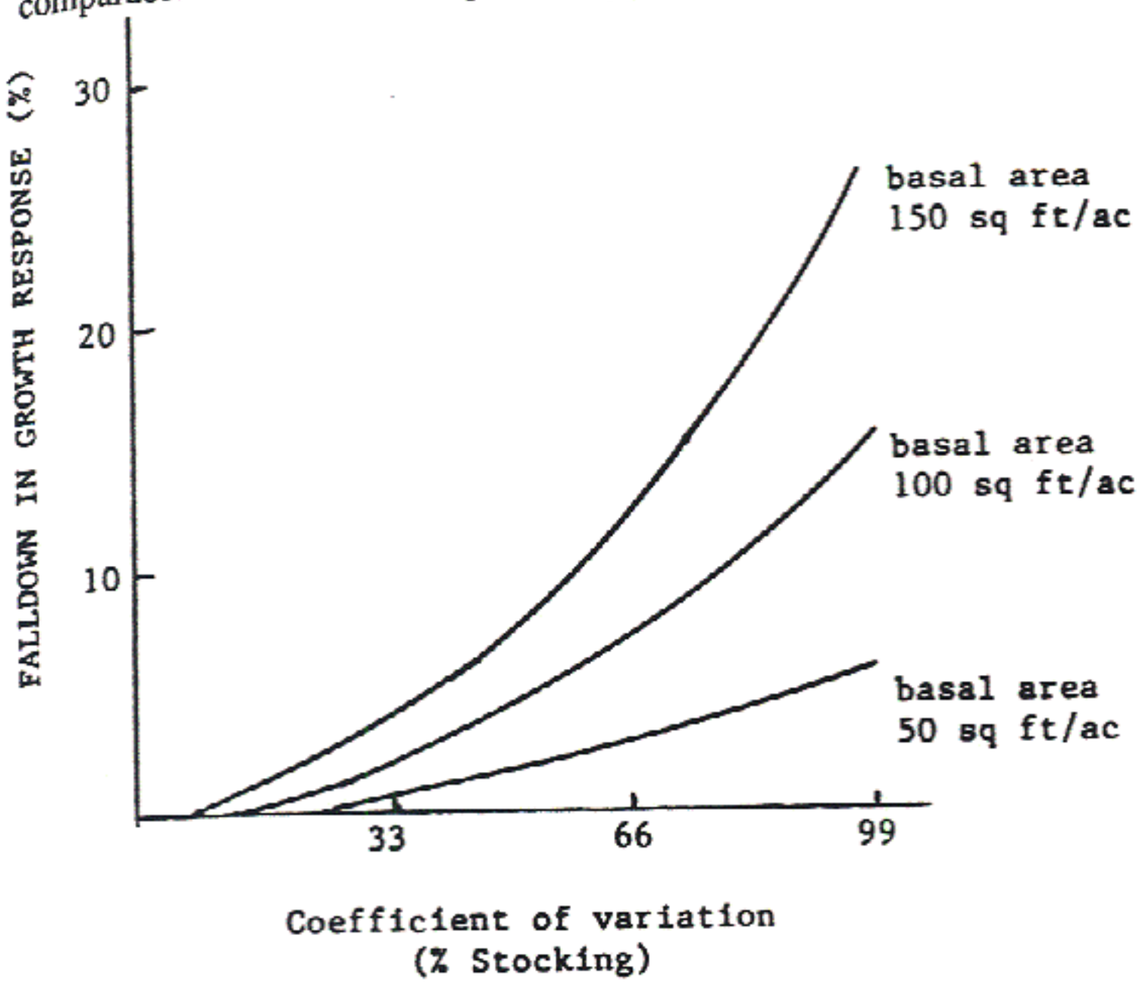
Falldown is a recognized phenomenon of operational fertilization but its cause is not well understood and its magnitude is a crude estimate. In this paper we will develop a conceptual procedure for estimating falldown.

GROWTH RESPONSE AND FALLDOWN

To deal quantitatively with falldown, three attributes of growth response must be stressed: (1) Growth response cannot be measured, it can only be estimated, (2) differences in

1. Moller, Goren, 1979. Personal Communications Institutet for Skogsforbattring, Uppsala, Sweden.

Figure 2. Growth response curves from three response equations for comparable stands over a range of N application levels.



STAND AND APPLICATION VARIABILITY

STAND VARIABILITY

Abundant information from forest inventory sources exists to estimate within forest type variability. This information can be directly applied to falldown estimates if the same type of sample unit used in the forest inventory cruise has been used in the development of growth and growth response models. If this is not the case, additional information will be required to determine stand variability for application planning purposes.

APPLICATION VARIABILITY

Monitoring of application variability can be used as the basis for estimates of falldown in growth response (Table 1).

Table 2 summarizes application variability information in which growth plots were associated with fertilizer rate measurements in the Pacific Northwest. Trap sizes range from 1.0 to 4.4 ft^2 (0.003 to 0.0134 m^2) trap numbers per plot from 1 to 15 and associated growth plots range from 20 factor prism plots to 0.125 acres (0.05 ha) fixed area. Coefficients of variation (CV%) ranged from 23% for a helicopter operation to 110% CV for a fixed-wing application. In general, applications

Table 1. Basic sample units used to measure stand and application variability for CA and CCAC-BCFS fertilization projects.

Trap sizes ft^2	M^2	Traps/plot	Growth plots
1.0	0.093		Variable radius (BAF20)
1.2	0.111	1 -- 15	
2.0	0.186		Fixed radius 0.1–0.125 acres (0.04–0.050 hectares)
4.4	0.409		

Table 2.

Location (samples)	Date applied	Type of aircraft	lb N/acre	Traps Number per/plot	Traps Size ft^2	Coefficient of variation Total	Between plots	Within plots
Oregon—CZ Molalla (154)	March 1968	Fixed wing	172	1	4.4	78		
Vernonia (40)	March 1968	Helicopter	197	1	1.0	23		
Molalla (85)	March 1979	Helicopter	192	5	1.0	42		
Molalla (51)	October 1969	Helicopter	162	5	1.0	81	63	52
Washington—CZ Cathlamet	December 1969	Helicopter	166	5	1.0	42		
Canada BCMOF—CZC Courtenay (29)	October 1974	Fixed wing	221	3	1.2	97	56	79
Courtenay (26)	October 1974	Fixed wing	172	6	1.2	110	77	73
Courtenay (25)	October 1975	Fixed wing	150	15	1.0	65	24	61
Courtenay (9)	October 1975	Fixed wing	160	15	2.0	97	56	79

growth response are difficult to detect, and (3) growth response estimates must be realistic over a wide range of treatment levels.

ESTIMATING GROWTH RESPONSE

Growth response is essentially an abstraction. It can be defined as the growth of an untreated tree or stand compared to its growth following treatment. Measurements of fertilized and unfertilized trees are necessary to develop response estimates.

DETECTING GROWTH RESPONSE DIFFERENCES

The difficulty in detecting differences in growth response comes from the size of difference we are trying to estimate (Figure 1).

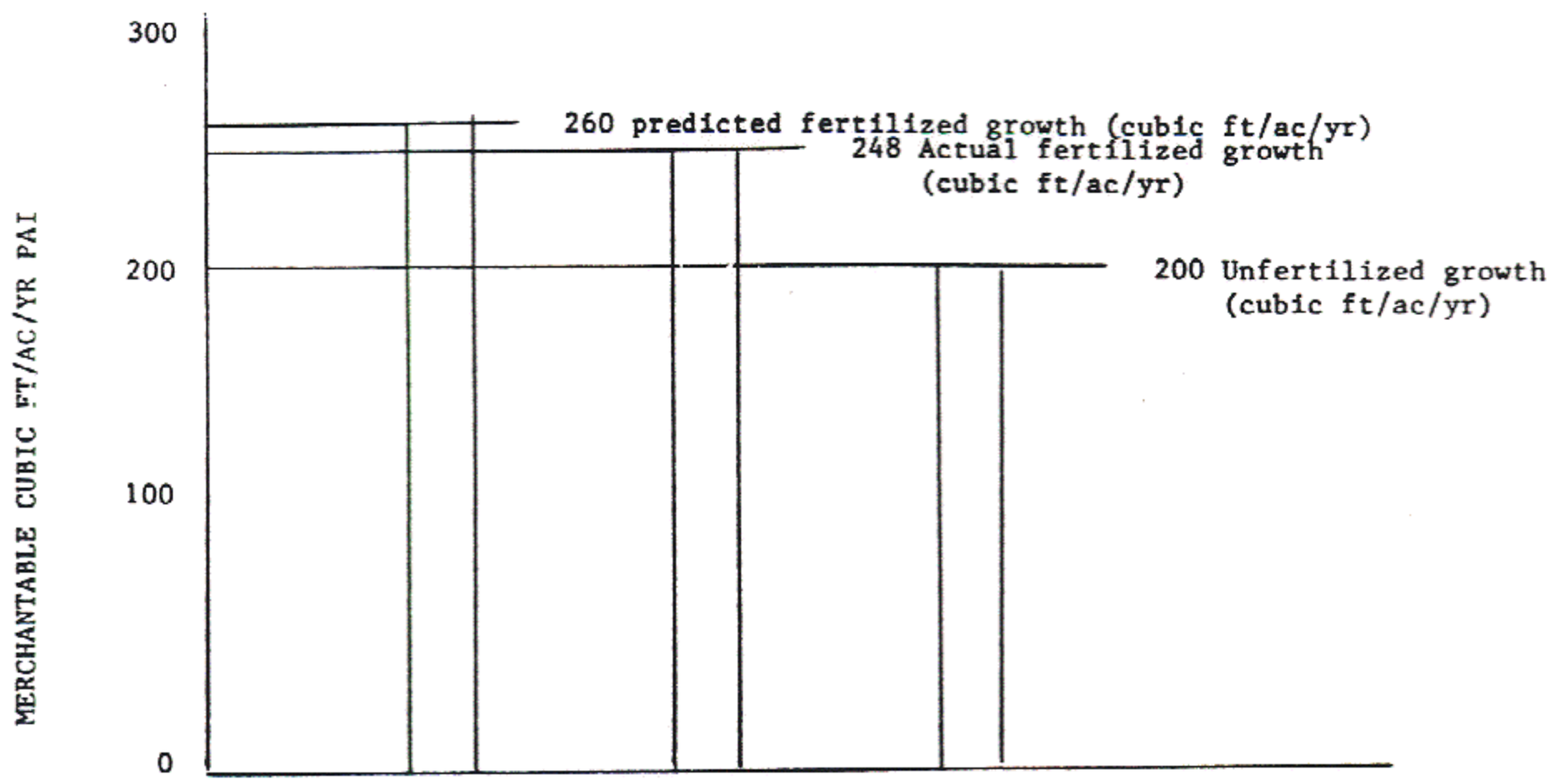
Growth response of 30% with a 20% falldown produces a difference of 6% in terms of total periodic annual increment (p.a.i.). Frequently, the lower limit of significant response detection for field trials in relatively homogenous stands and site conditions is about 10% of p.a.i. for untreated stands. To detect a 20% falldown (6% of total growth) in this case would require a fourfold increase in replications. Efforts to empirically determine falldown for a range of stand and application conditions would be much more costly than determining growth response patterns for the same stand conditions.

GROWTH RESPONSE AND APPLICATION RATES

Growth response values are needed over a broad range application levels to establish a basis for falldown due to fertilizer rate variation (Figure 2).

The equation presented is quadratic with respect to fertilizer rate. A maximum is reached at approximately 600 lb N/acre and then declines at very high application rates. In biological systems, nutrient concentrations range from deficient to toxic (i.e., nutrient imbalance). Thus, quadratic equations are biologically sound in describing growth response to fertilization. Other equation forms describing optimal levels of fertilizer for growth response may also be appropriate.

Figure 1. Relative magnitude of growth, growth response, and falldown for a typical application of fertilizer N.



actual growth response	=	predicted fertilized growth	-	unfertilized growth	-	growth response falldown
(agr)	=	(pfg)	-	(ug)	-	(grf)

48 = 260 - 200 - 12

When ug = 200
pfg = 130% ug = 260
grf = 20% pfg - ug = 12

by helicopter have been less variable than those applied by fixed-wing aircraft. A major consideration is that most rate monitoring efforts deal with single, small traps. Variability in application for falldown estimates, however, needs to be on the same area basis as the growth response equation. To do this requires a cluster of small traps or a relationship between total variation among traps and variation between areas equivalent to growth plot size.

MATHEMATICAL BASIS OF FALLDOWN

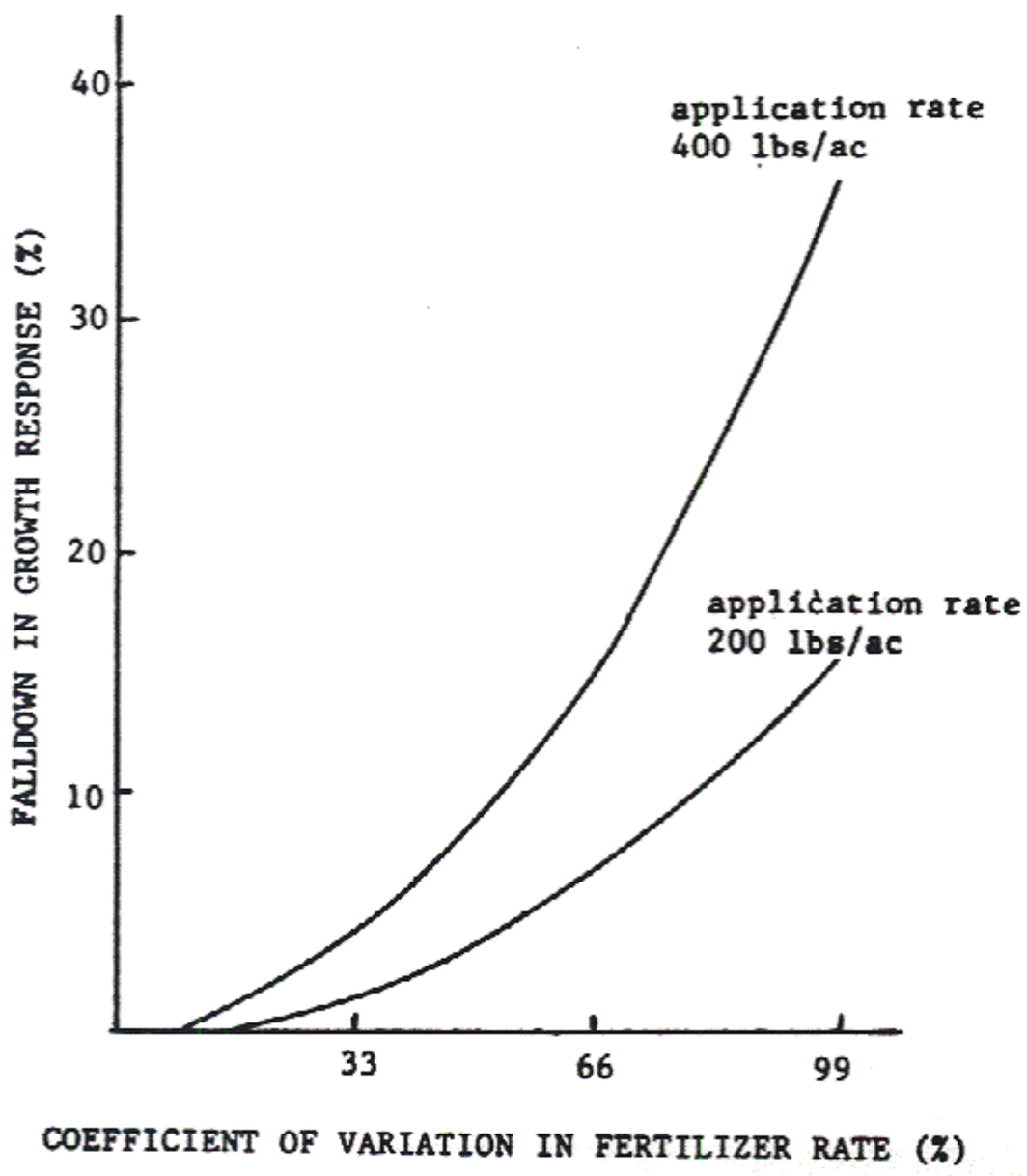
The mathematical basis for falldown comes from the nonlinear variables in the growth response equation. In the case of quadratic models the squared terms are the source of nonlinearity. The equation format used for illustrative purposes is

$$GR = b_1N + b_2B \cdot N + b_3S \cdot N + b_4B^2 \cdot N + b_5N^2$$

$$\text{Falldown} = b_4CV_B^2\bar{B}^2\bar{N} + b_5CV_N^2\bar{N}^2$$

Where: GR: growth response
N: fertilizer level
B: stocking level
S: site index
$b_1 \ldots b_5$: coefficients
CV_B: coefficient of variation for stocking
$\bar{B}$: mean stocking level
CV_N: coefficient of variation for fertilizer application
$\bar{N}$: mean fertilizer application level

Figure 3. The effect of stocking variation on falldown of growth response.



Falldown is seen to have two components rising from stand variability in basal area and application variability. Factors such as site variability dropout of the analysis due to lack of any nonlinear terms.

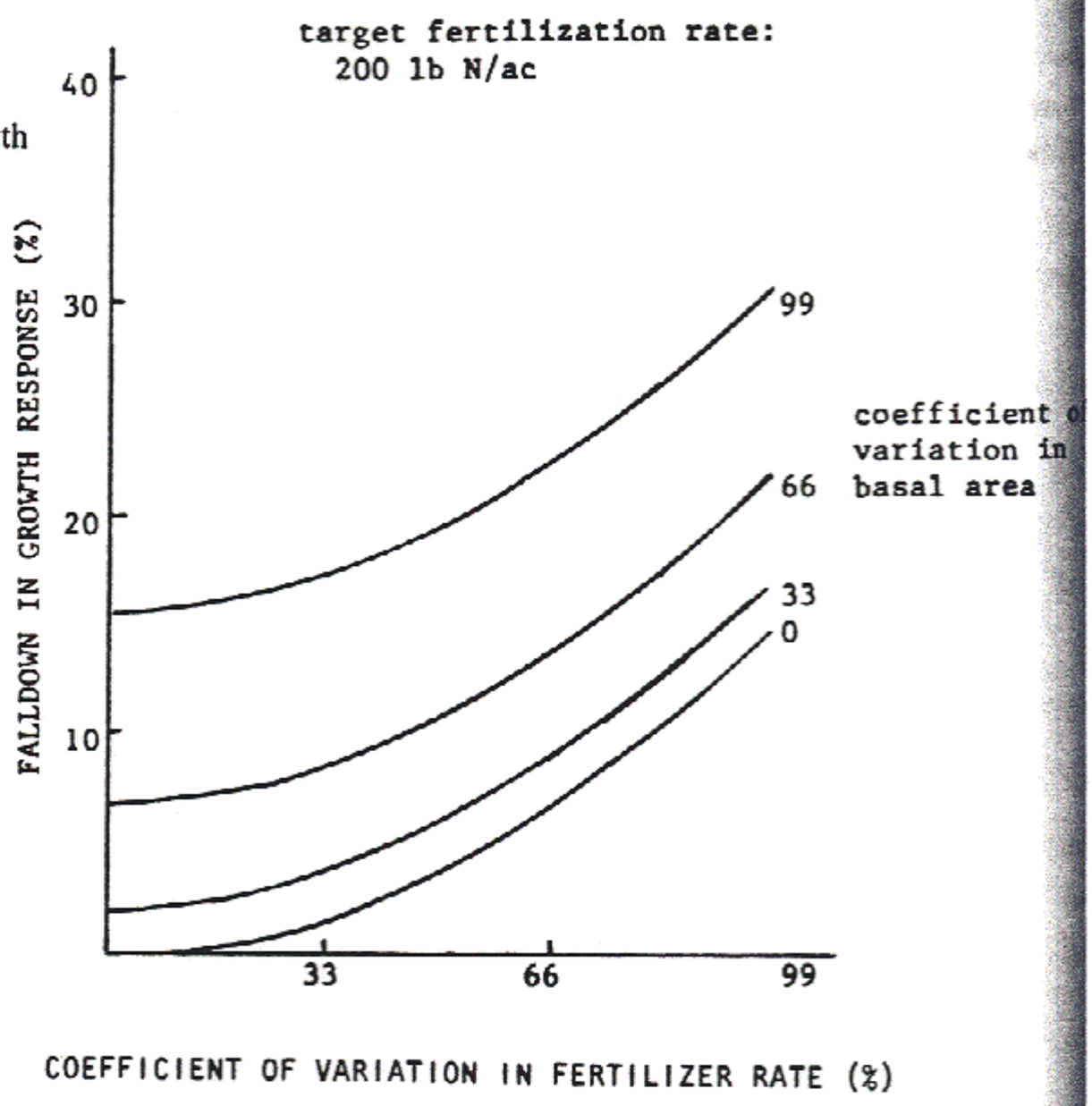
Given uniform application, variation in stocking could conceivably reduce response by 30% (Figure 3). Relatively homogenous stands (CV = 30%–40%) would experience falldown rates less than 10%.

For homogenous stands, application variability can result in up to 35% reduction in growth response (Figure 4). Frequently observed levels of application variability will result in 10%–20% falldown rates.

A 20% falldown would occur at 99% (CV) fertilizer rate and a 53% stocking level. A 90% level in fertilizer rate and a 66% level in stocking also produce a 20% falldown. It appears that a 20% estimate of falldown may be a high rather than an average estimate.

The falldown estimates used in this analysis are conservative. The complete impact of rate variation may not account for between-plot variation. Within-plot variation in stocking and application would tend to increase falldown rates. Conservative falldown values, however, lead to nonconservative estimates of effective growth response.

Figure 4. The effect of application rate variation on falldown of growth response.



A 20% falldown would occur at 99% (CV) fertilizer rate and a 53% stocking level. A 90% level in fertilizer rate and a 66% level in stocking also produce a 20% falldown. It appears that a 20% estimate of falldown may be a high rather than an average estimate.

CONCLUSIONS AND RECOMMENDATIONS

Falldown (reduction in growth response) for operational applications is directly linked to stand and fertilizer rate variability. Examples of falldown levels developed in this paper are conservative because fertilizer rate variation is based on an average value for the plot. This concept of falldown appears to be sound if appropriate response equations are used and meaningful sample units could be developed to provide estimates of rate variation. Uniformity of stocking could be used as a criteria for selecting stands to be fertilized. In addition, an approximation for the economic value of application uniformity could be developed.

Development of falldown forecasts by empirical methods appear to be far more costly than refining the conceptual approach described in this paper. Hopefully, problems with growth response curves and sample units for fertilization rates can be overcome. Appropriate information could then be provided to help select stands, application, systems, and accurately forecast growth response impact of the fertilizer treatment.

LITERATURE CITED

Barker, P.
1979. Factors affecting distribution of fertilizers to forests. *IN* Forest Fertilization Conference. S. P. Gessel and W. A. Atkinson, eds. In press.

Bengston, G. W.
1979. Forest fertilization in the United States: Progress and outlook. J. For. 78(4):222–229.

Hagner, S.
1966. Timber production by forest fertilization. SCA Publ. No. 83. The Fertilizer Society, London.

Jonsson, S.
1977. Resultat av nagra praktiska godslinger III. Godsling Nr 2. 3 p. Institutet for Skogs Forbattring, Uppsala, Sweden.

King, T. E.
1966. Site index curves for Douglas-fir in the Pacific Northwest. 49 p. Weyerhaeuser Forestry Paper No. 8.

McCardle, R. E., W. H. Meyer, and D. Bruce.
1949. Revised Meyer 1961. The yield of Douglas-fir in the Pacific Northwest. USDA Tech. Bull. No. 201. 74 p. Washington, DC.

Olson, J. R.
1979. Assessment of biological falldown associated with aerially applied fertilizers. Forestry Research Note RN–79–4. 4 p. Potlatch Corp., Lewiston, ID.

Staebler, G. R.
1948. Use of dominant tree heights in determining site index for Douglas-fir. 3 p. Pac. Northwest For. and Range Exp. Stn. Res. Note 44.

Strand, R. F.
1970. Distribution monitoring and application quality as seen by the landowner. *IN* Proceedings Forest Fertilization Workshop. H. W. Anderson, R. E. Miller, and R. T. Bergland, eds., p. 39–47. Washington State ONR Report No. 18. Olympia.

APPENDIX

$$E\,(\text{Growth Response}) = E(B_1(N_i + n_i) + B(B_i + b_i)(N_i + n_i) + B_3(S_i + s_i)(N_i + n_i) + B(B_4(B_i + b_i)^2 (N_i + n_i) + B_5(N_i + n_i)$$

$N_i = N + n_i$ N = 1b N/acre
$B_i = B + b_i$ B = ft²/acre stocking
$S_i = S + s_i$ S = SI 100 yr[1]
$E(n_i) = E(b_i) = E(s_i) = O$
$E(n_i^2) = \sigma_n^2$:w/o variation $\sigma_n^2 = O$
$E(b_i^2) = \sigma_b^2$:w/o variation $\sigma_b^2 = O$
$E(b_i n_i) = E(s_i n_i) = O$
i.e. $\sigma_b^2 = \sigma_n^2 = O$

$$\text{Falldown} = \frac{\text{Response w/o variation—Response with variation}}{\text{Response w/o variation}} \times 100$$

$$\text{Falldown} = E(B_1(N_i + n_i) + B_2(B_i + b_i)(N_i + n_i) + B_3(S_i + s_i)(N_i + n_i) + B_4(B_i + b_i)^2(N_i + n_i) + B_5(N_i + n)^2$$

Where: $\sigma_b^2 + \sigma_n^2 = O$

$$-E\,B_1(N_i + n_i) + B_2(B_i + b_i)(N_i + n_i) + B_3(S_i + s_i) + (N_i + n_i) + B_4(B_i + b_i)^2(N_i + n_i) + B_5(N_i + n_i)^2$$

Where: σ_b^2 and $\sigma_n^2 \neq O$

$$\text{Falldown} = -B_4 CV_B^2 \bar{B}^2 \bar{N} - B_5 CV_N^2 \bar{N}^2$$

Falldown % = Falldown Response

$$\frac{(-B_4 CV_B^2 B^2 N - B_5 CV_N{}^2 \bar{N}^2)}{(B_1 N + B_2 BN + B_3 SN + B_4 B^2 N + B_5 N^2)} \times 100$$

1. Measured on dominant trees and calculated at 50 yr. bh age (King 1966) converted to 100 yr total age. McCardle et al. (1961) using Staebler's (1948) relationship between dominant vs. dominant-codominant height conversion.