Chapter 13

Stand Selection Criteria for Nitrogen Fertilization: Current Practices and Future Needs

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ABSTRACT. Methods used to estimate response potential to nitrogen fertilization in coastal and intermountain forests are discussed, specifically for areas of Washington, Oregon, Idaho, and western Montana served by the Regional Forest Nutrition Research Project (RFNRP) and the Intermountain Forest Tree Nutrition Cooperative (IFTNC). Considering the wide range of soil and climate conditions found in this area, no one set of site and stand variables is universally useful in identifying response potential, even when the focus is narrowed to Douglas-fir or western hemlock. Stand selection criteria applied to subregions or sites that are homogeneous, such as grand fir series in northern Idaho and central Washington, have greater reliability than regionwide criteria. Thus forest managers need criteria that are effective based on local or ecological considerations. Plant associations, soil classification, and humus forms represent areas of study that can provide tools that may be useful in developing the necessary stratifications. The interactive effects of tree nutrition and other growth factors also need to be better understood.

Selecting stands for nitrogen fertilization is not a simple process. Forest managers must simultaneously balance biological, economic, and environmental benefits, costs, and risks—all within a framework of corporate or agency goals and objectives. While each element of the balance is important, this chapter will not deal with environmental issues, economics, or corporate goals and objectives. Our intent is to review site and stand criteria commonly used to select forested areas for fertilizer application in Washington, Oregon, Idaho, and western Montana, specifically the areas in these states served by the Regional Forest Nutrition Research Project (RFNRP) and the Intermountain Forest Tree Nutrition Cooperative (IFTNC).

In deciding which stands to fertilize, the forest manager needs information for each candidate stand on both the probability of response and the expected magnitude of that response. This requires simultaneous analysis of all growth factors—nutrients, light, heat, moisture, and disease. Neither our current understanding of the growth requirements of major commercial species nor our ability to assess them is sufficiently precise to do the required analysis for all commercial species on all sites.

Although research over the past 40 years demonstrates that several site and stand characteristics are useful for estimating the probability and magnitude of response to nitrogen fertilizer for some commercially important species, even here much variation exists and no one approach appears to be universally useful. Some of the most commonly used attributes are site index, basal area, and plant association. This chapter reviews where and how these variables have been used to estimate response potential in coastal and intermountain forests.

Stand and Site Factors Used in Coastal Forests

Nutrition research in coastal forests of the Pacific Northwest began nearly 40 years ago. During this period we have learned much about the response of several commercial species to nitrogen fertilizer application. Western red cedar (*Thuja plicata*) (Harrington and Wierman 1990), noble fir (*Abies procera*), Pacific silver fir (*Abies amabilis*) (Chappell and Bennett 1989), western hemlock (*Tsuga heterophylla*) (Olson et al. 1980), and coast Douglas-fir (*Pseudotsuga menziesii*) (RFNRP 1989; Miller et al. 1986) all show positive fertilizer response at some

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sites. However, Douglas-fir and western hemlock are the only species in coastal forests for which sufficient data exist to assess the value and risk associated with nitrogen fertilizer application.

Western Hemlock

Over one hundred fertilizer trials have been established in coastal western hemlock stands during the past three decades. The results have been disappointing to many who hoped that nitrogen fertilizer would consistently increase yields. Unfortunately, poor response has been the general rule.

Eight-year gross volume response data from RFNRP plots in Washington and Oregon demonstrate that nitrogen fertilizer at rates of 224 and 448 kg/ha, on average, reduced growth in unthinned stands and increased growth slightly in thinned stands of hemlock (Figure 1). Only about 20% of the hemlock stands responded to nitrogen by 10% or more (basal area) four years after fertilizer application (RFNRP 1982). Site and stand variables have not been useful in identifying western hemlock stands that respond to nitrogen over this area stretching from the Canada to California and from the crest of the Cascades to the Pacific Ocean.

Despite generally dismal performance of nitrogen fertilizers in western hemlock, some stands do appear to respond well to fertilizer additions. Responses averaging 15% have been reported for stands in the Cascades of Washington and Oregon and on average are much higher than response in coastal stands (Figure 2).

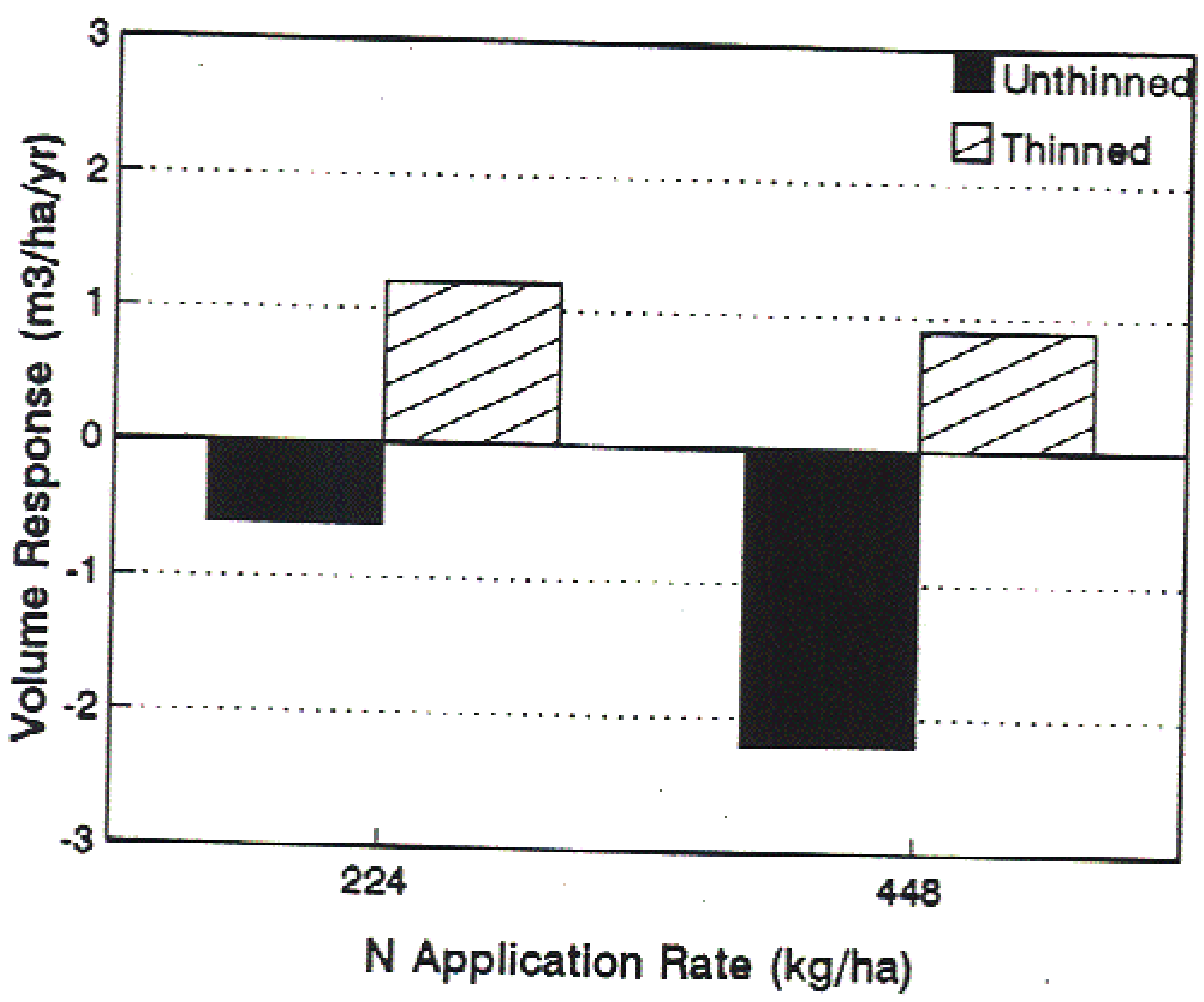

Figure 1. Eight-year gross volume growth response for western hemlock fertilized at two rates. From RFNRP (1982); Phase I (unthinned) and Phase II (thinned) sites only.

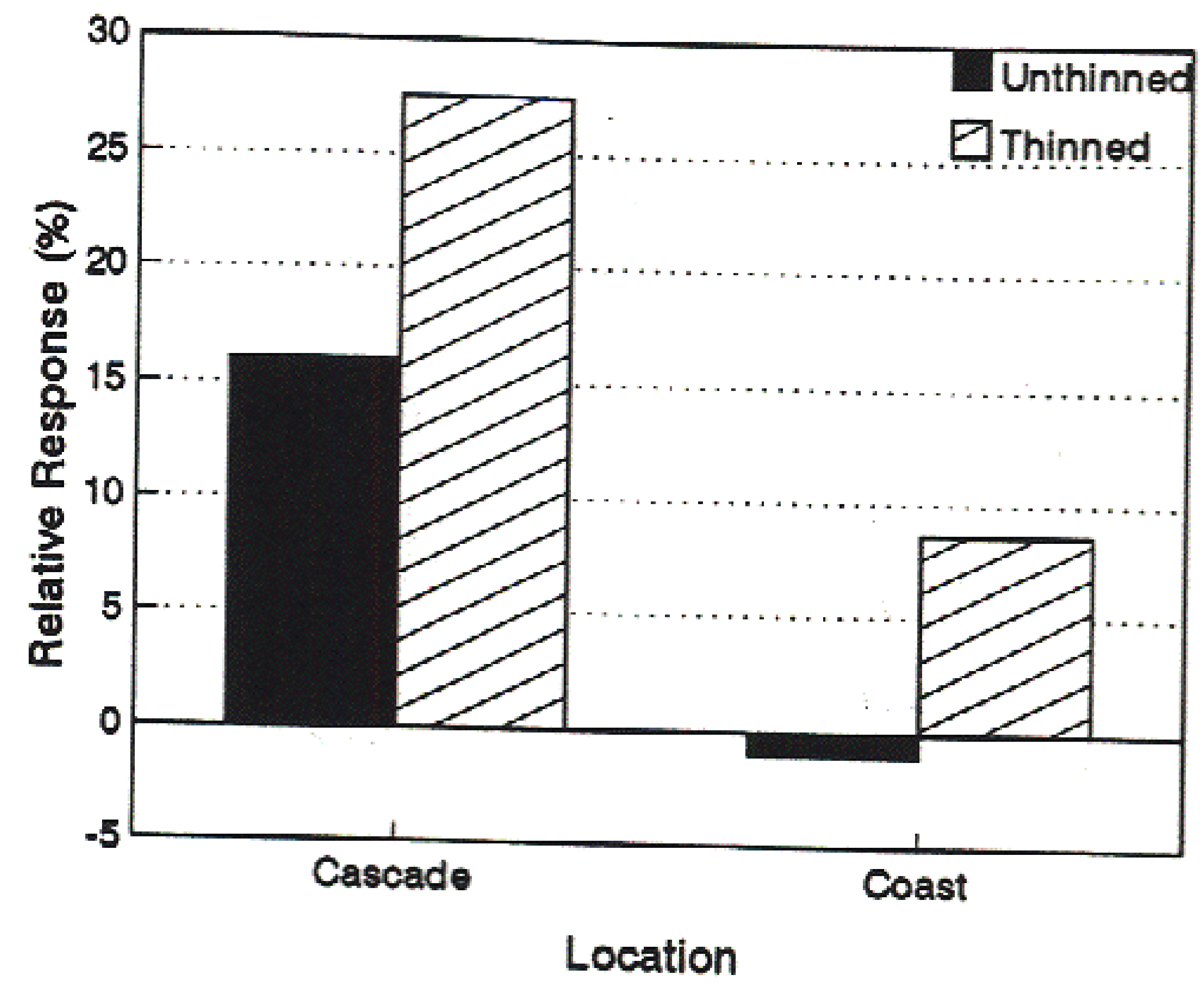

Figure 2. Effect of location on four-year gross basal area growth response of western hemlock fertilized with 224 kg N/ha. From RFNRP (1982); unthinned and thinned stands in Phases I, II, and III.

Inconsistencies in response of western hemlock led Webster et al. (1976) to conclude that their knowledge about the relationship between hemlock response and various site and stand conditions and various fertilizer variables remained poorly quantified. More recent studies have done little to improve response predictions in this species.

Douglas-fir

Nitrogen fertilizer response in coastal Douglas-fir stands is in marked contrast to that observed in hemlock forests. Douglas-fir response is on average greater and much more consistent. Eight-year gross volume growth in both thinned and unthinned Douglas-fir forests increased dramatically when nitrogen was applied at 224 and 448 kg/ha (Figure 3). Risk of poor response on a regionwide basis is also relatively low. Only about one stand in four had basal area response of less than 10% four years after the application of 224 kg/ha of nitrogen (Miller et al. 1986).

Forest managers need not be content with broad regional averages. Several stand factors can be used to help establish treatment priorities. In addition to stand age, which generally defines the investment period, site index and basal area are the attributes most commonly used in setting fertilizer priorities in operational programs (Chappell and Opalach 1984).

Site index is probably the single best diagnostic tool available for selecting Douglas-fir stands for nitrogen treatment. Data on site index are readily available to most forest managers and provide information useful in

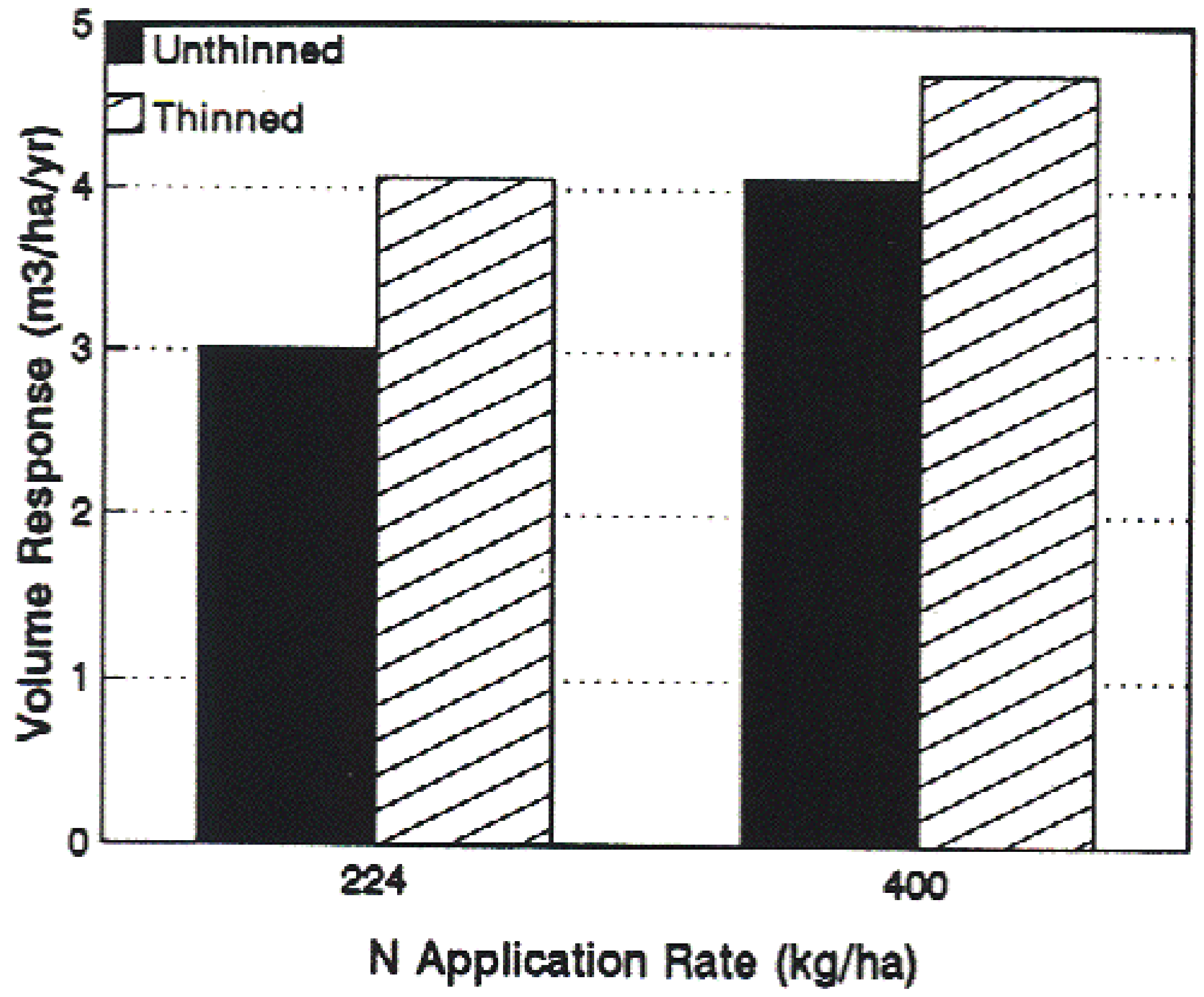

Figure 3. Eight-year gross volume growth response of coast Douglas-fir with and without thinning. From RFNRP (1982).

judging the reliability, magnitude, and duration of fertilizer response. In general, response on poor sites is greater, more consistent, and lasts longer than on higher quality sites (Table 1).

Considerable variation in response has been observed within a given site class. This limits its effectiveness as predictor of response in a given location. Some variation is associated with basal area differences between stands, with greater response occurring at intermediate basal area levels (RFNRP 1988). In addition, mixed stands of Douglas-fir and hemlock tend to respond less than stands of Douglas-fir only (Miller et al. 1986).

Peterson and Hazard (1990) found that even in relatively pure Douglas-fir stands, site and stand variables explained a small but significant portion of the variation in response when applied to all of western Washington and Oregon. Site index, stand basal area, breast-height

Table 1—Effects of 224 kg/ha of nitrogen on sites of varying productivity.

Site Class[1]	Response[2] (m³/ha/yr)	Reliability[3] (percent)	Duration[4] (years)
I	1.3	64	6
II	2.0	66	8
III	3.6	84	8+
IV	2.0	80	8+

[1] King (1966).

[2] RFNRP (1982).

[3] Miller and Fight (1979), percentage with basal area response of 10% or more.

[4] Data from RFNRP.

age, and nitrogen treatment together explained only 17% and 30% of the variation in absolute response in unthinned and thinned stands, respectively.

Edmonds and Hsiang (1987), using multiple regression analysis, reported a low correlation between relative response and soil, site, and stand variables on a regionwide basis. In this study it was reported that factors related to response differed among provinces or groups of provinces (regions) within the RFNRP. Correlations between fertilizer response and soil, site, and stand variables improved in some instances when fertilized stands were stratified into similar groups based on provinces or site class.

Stand and Site Factors Used in the Intermountain Region

The Intermountain region spans a wide geographic area, including the western portion of Montana, northern Idaho, northeastern Oregon, and the eastern portion of Washington State. As one might surmise, this area contains considerable variation in topography, climate, and soils, resulting in a range of physiographic and vegetation zones. More than 10 conifer species are grown commercially in the region, including Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), western white pine (*Pinus monticola*), grand fir (*Abies grandis*), ponderosa pine (*P. ponderosa*), and western larch (*Larix occidentalis*). To add to the complexity of forests in the region, man's influence during the past 80 or more years, through harvesting practices and fire control measures, has contributed dramatically to diversity in both the structure and composition of Intermountain forests. All this leads one to surmise that a universal "cookbook" solution to the amelioration of nutritional imbalances would be doubtful at best.

Fertilization of commercial forest land in the region began in the 1970s with aerial applications of nitrogen, primarily in northern Idaho. Use of this practice was, in large part, justified by the anticipated success of similar treatments being carried out west of the Cascade Mountains. Response data were limited for intermountain species during this period, though several research trials had been established and were being monitored.

Historically, nutrition research in this region has leaned heavily toward empirical trials, intentionally established in uniformly healthy forest stands. In these trials nitrogen alone or in combination with other important macronutrients has generally improved forest growth. However, field tests often bear little similarity

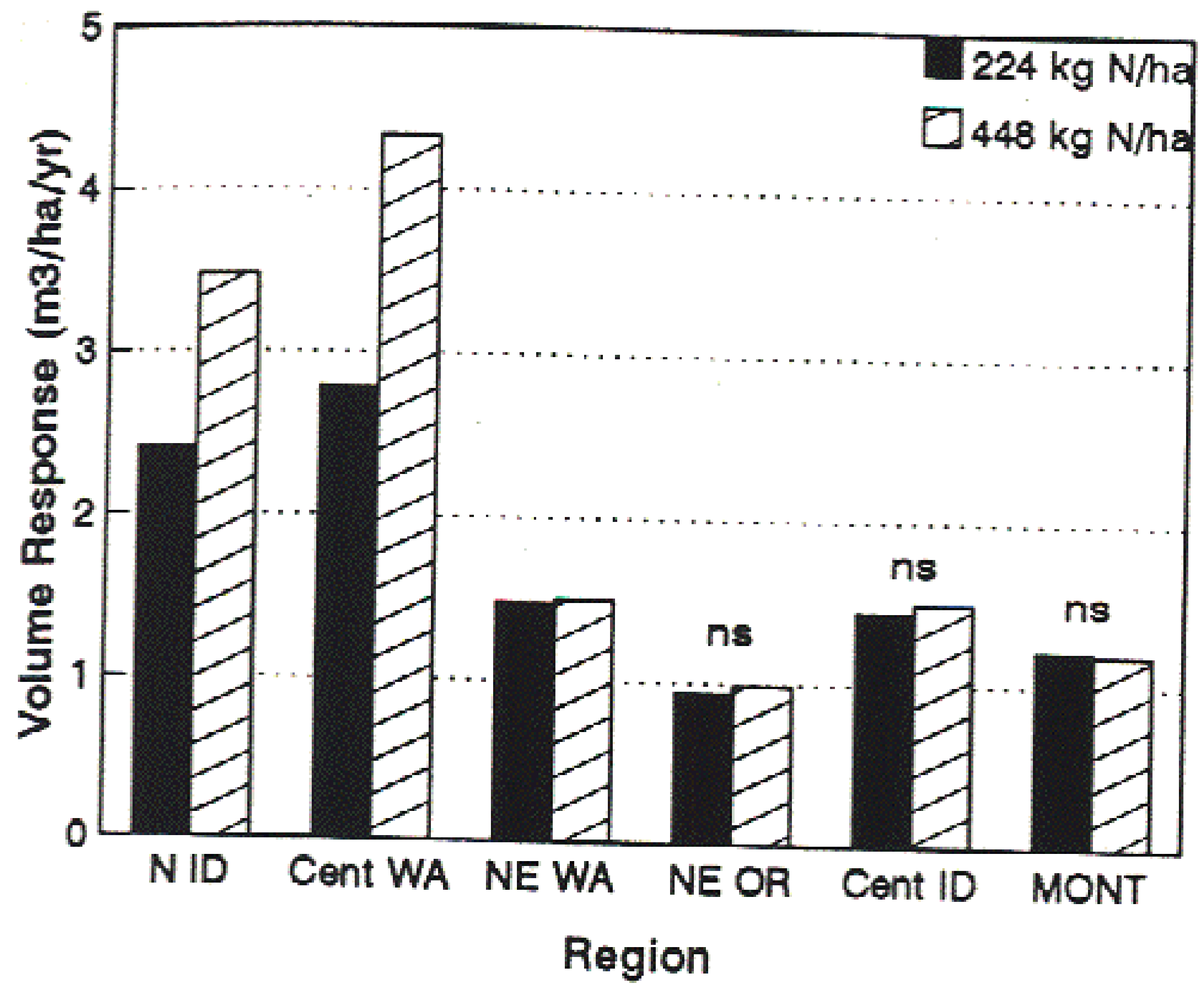

Figure 4. Six-year gross volume growth response of Intermountain region Douglas-fir fertilized at two rates. From IFTNC (1989). ns = not statistically significant.

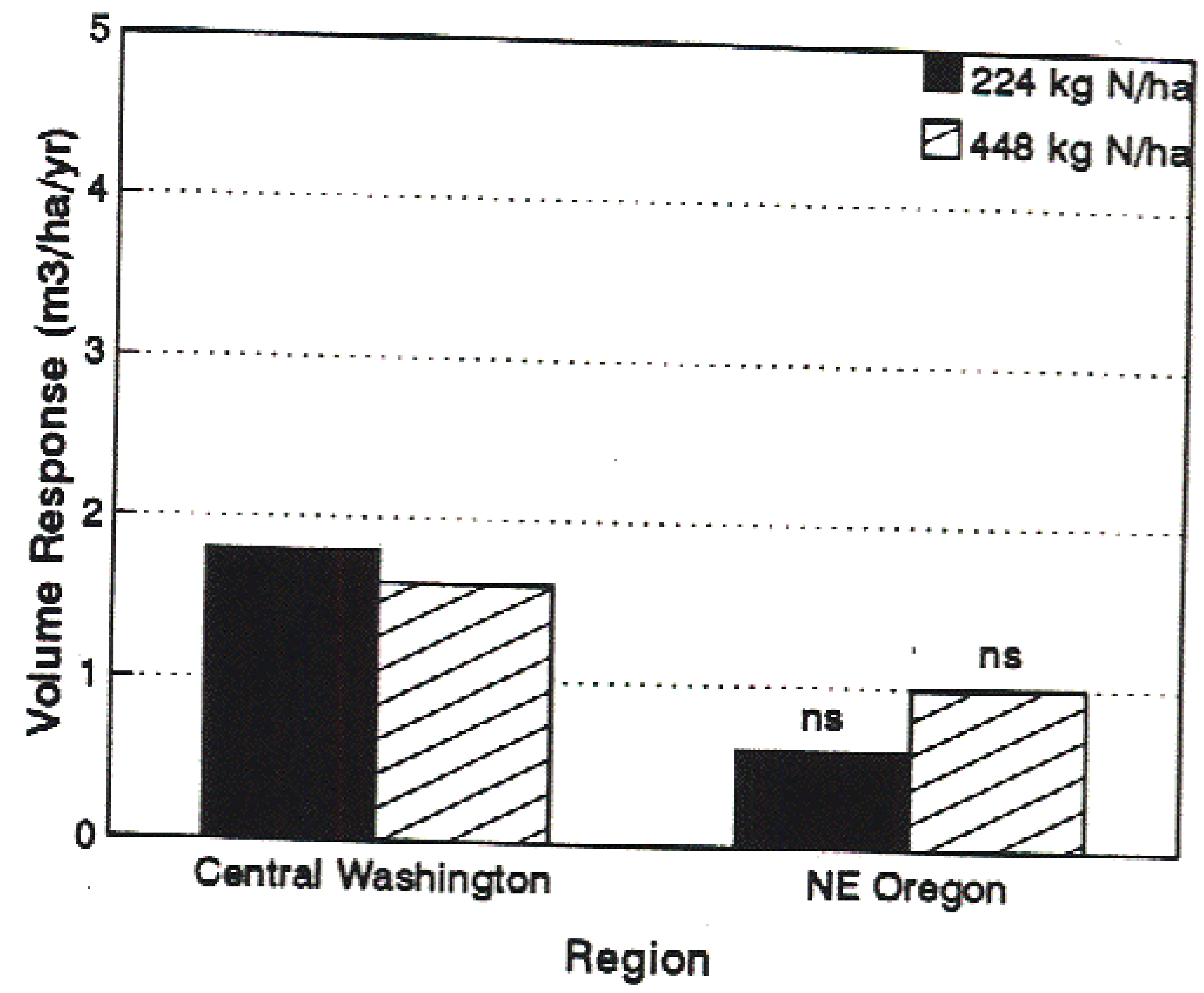

Figure 5. Four-year gross volume growth response of Intermountain region ponderosa pine fertilized at two rates. From IFTNC (1990). ns = not statistically significant.

to "typical" forest conditions, making extrapolation of results, and especially the selection of potentially responding stands, difficult.

To date, more than 150 permanent research trials have been established throughout the region to test the effects of nitrogen additions. These have been targeted primarily at Douglas-fir, ponderosa pine, and grand fir stand types. Absolute response to a single nitrogen application has been significant in some portions of the Intermountain region. Figure 4 summarizes six-year gross volume response estimates to nitrogen applications of 224 kg/ha and 448 kg/ha for six physiographic zones. Response is not statistically significant ($p < 0.05$) for three zones (central Idaho, northeastern Oregon, and Montana). Response to the same treatment applied to stands of ponderosa pine is significant ($p < 0.05$) for central Washington but not for northeastern Oregon (Figure 5). As stressed earlier, regional response averages do not provide the necessary resolution for management decisions. Closer evaluation reveals considerable variation in response between installations within individual physiographic zones, even in those zones where response is reported as nonsignificant. This can be seen more clearly using a cumulative distribution diagram to array installations by their respective response estimates. For example, Figure 6 provides a cumulative frequency distribution of six-year response estimates for installations in the Montana zone. It is apparent that some sites responded dramatically to the nitrogen application, while others did not. Even though the six-year response averaged only 7.3 m^3/ha, approximately 20% of the installations responded in excess of 11 m^3/ha. For the forest manager, it is important to know more about these responding sites and the stand conditions they represent.

Empirical trials are sometimes of limited value when one attempts to uncover reasons for treatment response. This type of information is needed, however, in order to address questions of why one stand responded to treatment while others that appear similar did not. Without a clear understanding of nutritional demand and supply for specific species and sites, and their

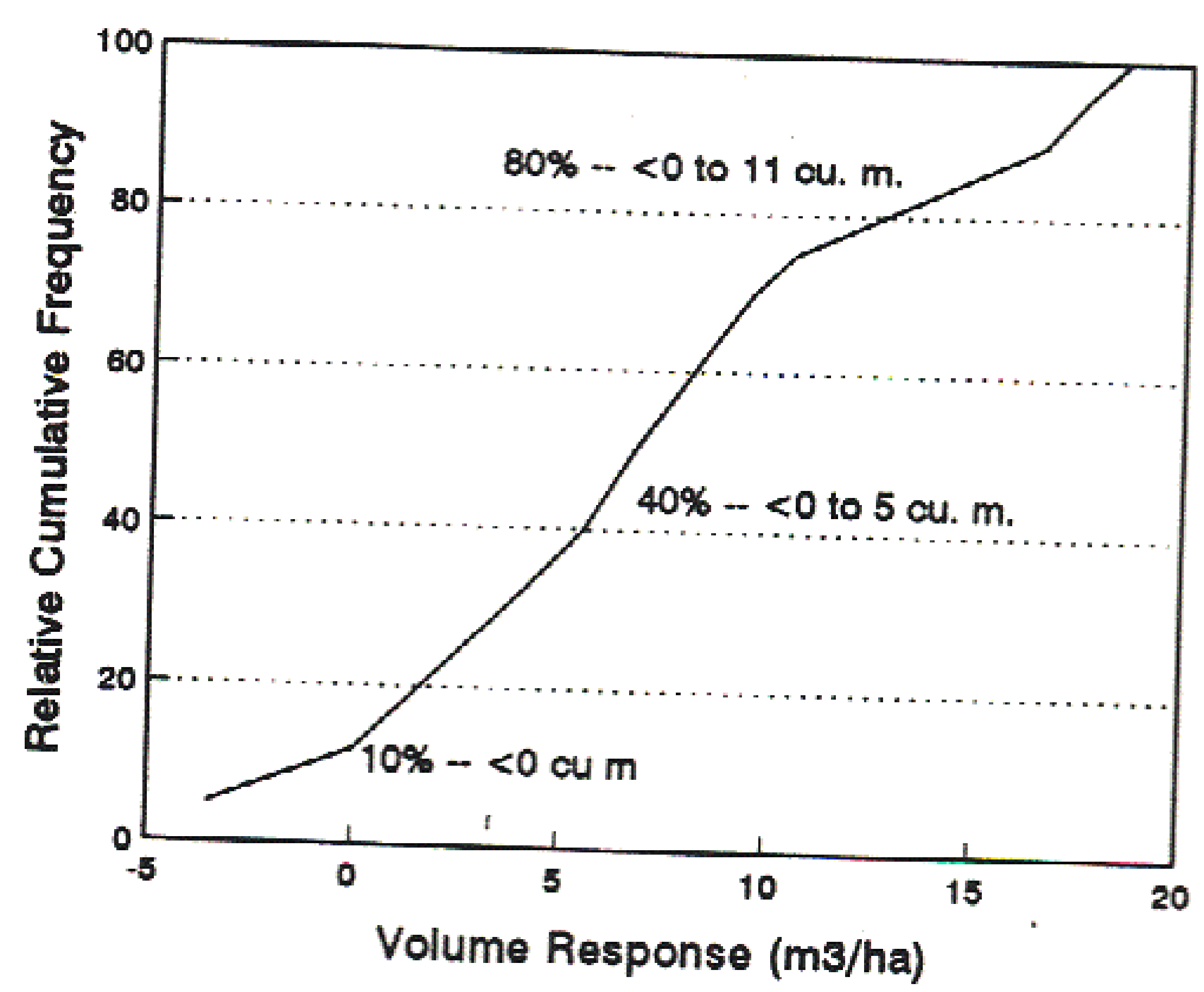

Figure 6. Six-year gross volume growth response of Douglas-fir to 224 kg N/ha in Montana.

relationship to environmental and genetic components, we must rely primarily on simple correlations or multiple regressions between measured response and stand, tree, environmental, or nutritional status attributes. But these correlations and regressions have not proven very useful in the selection and prioritization of candidate stands for treatment (IFTNC 1985; Moore and Mika 1991).

Thus several stand and site characteristics have proved useful in predicting response to nitrogen applications in the Intermountain region. For the central Washington zone, "vegetation series" has been used to identify high priority stands for treatment. Six-year gross volume response of 19 Douglas-fir stands located along the east slopes of the Cascades averaged 6.7 and 10.5 m^3/ha for 224 and 448 kg/ha treatments, respectively (Shumway 1990). Response varied by test site location, and results indicate that some stands responded well above the average. Douglas-fir growing within the grand fir series consistently yielded higher response than stands located on the drier Douglas-fir series. Only 60% of the Douglas-fir series stands exceeded a response of 5.7 m^3 after six years, while all grand fir series sites achieved this level. Though site index did not prove useful in predicting response in IFTNC trials, other variables, such as parent material and basal area, appear to be useful as stand selection criteria in the central Washington zone (Moore and Mika 1991; Shumway 1990; IFTNC 1985, 1986).

In northern Idaho, additional stand variables have been useful in identifying candidate stands for treatment (Olson, personal data, 1991). Predictive models developed using four-year response data from the IFTNC indicate that vegetation series along with basal area, site index, and average stand crown ratio can assist in stratifying potentially responding stands. Results also indicate that, in general, stands classified as grand fir series yield the highest volume response after four years, compared to installations located in cedar or hemlock series.

Within the grand fir vegetation classification, stands of midsite range (21 to 27 m at 50 yr) having a basal area less than 57 m^2/ha responded best to a single 224 kg/ha nitrogen application.

Conclusions

The wide range of soil and climate conditions found in the four-state area encompassed by the RFNRP and IFTNC gives rise to an equally wide range of nitrogen fertilizer responses. At this level of complexity of environments no one set of site and stand variables is universally useful in identifying response potential. Even when the range of site conditions is limited to Douglas-fir or western hemlock, the factors and processes controlling nitrogen fertilizer response are too complex to index response potential consistently.

When stand criteria are applied to smaller subregions or sites which are more homogeneous, such as grand fir series in northern Idaho and central Washington, the use of stand and site factors to identify stands with high response potential becomes more reliable. However, the factors which are useful vary from region to region.

Forest managers faced with maintaining forest production on a shrinking land base with reduced capital for forest management investments need more precise stand selection criteria. The forest manager in Montana needs to know how to identify stands which will respond to nitrogen fertilizer. Forest managers in Washington who now use broad regional averages will need to know if their lands are average with respect to regionwide trials. In addition, many managers would like to be able to consistently identify hemlock stands with a high response potential.

Meeting the forest manager's need for better stand selection criteria will not be easy. It will be necessary to move away from broad regionwide averages and establish criteria locally on an ecological basis. Plant associations, soil classification, and humus forms are among the tools which may be useful in developing these necessary stratifications. The existing plot network could be used as a test population to evaluate these tools for improving diagnostics and response correlations.

We think that it will also be necessary to refine our understanding of basic tree nutrition and the interactive effects of nutrition and other factors controlling growth response in our forests, including temperature, moisture, insects, and disease. Until response, or the lack of response, at a site can be explained in these terms, attempts at refining stand selection criteria, developing fertilizer diagnostics, and improving correlation between site variables and response will continue to be inadequate.

Literature Cited

Chappell, H.N. and W.S. Bennett. 1989. Fertilizer screening trials in noble fir and silver fir stands in the Cascade range of Washington and Oregon: progress report. p. 24-27 *In* Regional Forest Nutrition Research Project biennial report, 1986-1988. College of Forest Resources, Univ. of Washington, Seattle.

Chappell, H.N. and D. Opalach. 1984. Forest fertilization and stand management in western Oregon and Washington: status and prospect. Unpub. RFNRP Rep. 1. College of

Forest Resources, Univ. of Washington, Seattle. 23 p.
Edmonds, R.L. and T. Hsiang. 1987. Forest floor and soil influence on response of Douglas-fir to urea. Soil Sci. Soc. Am. J. 51:1332-1337.
Harrington, C.A. and C.A. Wierman. 1990. Growth and foliar nutrient response to fertilization and precommercial thinning in a coastal western red cedar stand. Can. J. For. Res. 20:764-773.
Intermountain Forest Tree Nutrition Cooperative (IFTNC). 1985. Fifth annual report. College of Forestry, Wildlife, and Range Sciences, Univ. of Idaho, Moscow. 42 p.
_____. 1986. Sixth annual report. College of Forestry, Wildlife, and Range Sciences, Univ. of Idaho, Moscow. 40 p.
_____. 1989. Ninth annual report. College of Forestry, Wildlife, and Range Sciences, Univ. of Idaho, Moscow. 44 p.
_____. 1990. Tenth annual report. College of Forestry, Wildlife, and Range Sciences, Univ. of Idaho, Moscow. 81 p.
King, J.E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Company Forestry Paper 8, West. For. Res. Center, Centralia, Washington. 49 p.
Miller, R.E., P.R. Barker, C.E. Peterson, and S.R. Webster. 1986. Using nitrogen fertilizers in management of coast Douglas-fir: I. Regional trends of response. p. 290-303 *In* Oliver, C.D., D.P. Hanley, and J.A. Johnson, eds. Douglas-fir: stand management for the future. Institute of Forest Resources, Univ. of Washington, Seattle.
Miller, R.E. and R.D. Fight. 1979. Fertilizing Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-83. 29 p.
Moore J.A. and P.G. Mika. 1991. Nitrogen fertilizer response of Douglas-fir by geographic areas across the inland Northwest. Intermountain Forest Tree Nutrition Cooperative Suppl. Rep. 4. College of Forestry, Wildlife, and Range Sciences, Univ. of Idaho, Moscow. 14 p.
Olson, J., W. Atkinson, and M. Rinehart. 1980. Radial increment response of western hemlock to nitrogen fertilization and thinning. RFNRP Tech. Rep. College of Forest Resources, Univ. of Washington, Seattle. 9 p.
Peterson, C.E. and J.W. Hazard. 1990. Regional variation in growth response of coastal Douglas-fir to nitrogen fertilizer in the Pacific Northwest. For. Sci. 36:625-640.
Regional Forest Nutrition Research Project (RFNRP). 1976. Biennial report, 1974-1976. College of Forest Resources, Univ. of Washington, Seattle. 67 p.
_____. 1982. Biennial report, 1980-1982. College of Forest Resources, Univ. of Washington, Seattle. 67 p.
_____. 1989. Biennial report, 1986-1988. College of Forest Resources, Univ. of Washington, Seattle. 58 p.
Shumway, J.S. 1990. An evaluation of fertilizer response on the east slopes of the cascades. Internal Report, Dept. of Natural Resources, Olympia, Washington.
Webster, S.R., D.S. DeBell, K.N. Wiley, and W.A. Atkinson. 1976. Fertilization of western hemlock. p. 247-252 *In* Atkinson, W., and R.J. Zasoski, eds. Proc. Western Hemlock Manage. Conf. Institute of Forest Products Contrib. 34, Univ. of Washington, Seattle.

Questions and Answers

How does age affect response?

The dominant effect of age is economic. The best economic response, all other things being equal, will be obtained in older stands close to rotation age.

How useful are stand basal area and site index in estimating Douglas-fir response on a localized basis?

These variables are useful to the degree they provide a measure of nitrogen availability with respect to the level of other growth factors. In regions where productivity is primarily limited by nitrogen, such as in coast Douglas-fir, they do a fair job. In regions where nitrogen is not the primary limiting factor or where several factors exert major limits on growth, such as the Intermountain region, site index and basal area have not been very useful.