REGIONAL FOREST NUTRITION RESEARCH PROJECT

BIENNIAL REPORT

1982-1984

January 1985

University of Washington
College of Forest Resources

EXECUTIVE SUMMARY

Forest fertilization is a silvicultural practice utilized by nearly all private and public forest managers in the Pacific Northwest. A survey conducted in 1983 found that a cumulative total of nearly 2 million acres had been fertilized in the Pacific Northwest, and most newly established stands are slated for fertilization. Area fertilized in the region is projected to be about 250,000 acres annually in the near future. Fertilization is a biologically and economically sound stand management practice that appears to be viable in the future.

It also appears that repeated fertilizer applications are a viable technique for increasing yield. Response to refertilization in previously fertilized unthinned Douglas-fir stands approximated the initial 4-year response to urea applications. It was also found that six-year response in thinned and unthinned Douglas-fir stands was related to several soil properties. Forest floor C:N ratios were best correlated to response in unthinned Douglas-fir, while total forest floor N was better related to response in thinned Douglas-fir stands.

Fertilization response in younger age classes of Douglas-fir have been found. Two-year basal area growth in urea treated Douglas-fir plantations ranged from 25-37% greater than controls while sporadic response in Western hemlock plantations were found. Western hemlock plantations growing in coastal locations had little or no response to urea as opposed to stands in the Cascades where response was more consistent. Ongoing research is investigating reasons for these differences in hemlock response. Outplanted hemlock seedlings have shown very significant responses to N and P applications in aluminum rich soil. Aluminum and H^+ had differing effects on western hemlock and Douglas-fir growth in solution culture.

Other efforts during the past biennium include thorough documentation of Project objectives and analytical methods as well as descriptions of the current database management system. An externally funded research evaluation project which focused on the RFNRP was completed during the past two years. This case history study concluded that investments in the cooperative realized after-tax incremental rates of return in excess of 9%.

This edition of the continuing biennial report series departs from the previous format by providing brief summaries and abstracts of RFNRP projects and results. The more detailed information and analyses contained in previous biennial reports are available in the newly constituted internal report series, journal articles and other publications.

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FOREWORD

This report is the tenth in the series covering 15 years of operation of the Regional Forest Nutrition Research Project, a forerunner of many research cooperatives now established across the United States. This cooperative and others have clearly demonstrated the economy and efficiency of this research approach.

The RFNRP has contributed a great deal of useful information for better management of Northwest forests. It has also contributed to the development of scientific knowledge about the growth and mineral nutrition of forest trees, a contribution recognized throughout the world. Graduate student training has been an integral part of the Project, and these students bring new ideas and contributions to the program each year.

The Project has accumulated a database on forest growth and yield which is unique in the world. A most valuable aspect of the database is reliability, as great effort has been expended to ensure that the data are as error free as possible. The database has utility for supplying growth and yield information beyond the original intent of the cooperative.

This report updates significant developments over the past two years and calls your attention to the important resources of the Cooperative. We have attempted to make it concise with important points presented in a brief, understandable form.

The next research phase will develop information necessary for efficient forest management during the next 20 years. We firmly believe that our Northwest forests are a national and international resource which will continue to form a major economic base for the region. Fertilizing the highly productive Northwest forests is economically viable. The Cooperative effort is dedicated to the transfer of improved fertilizer technology and providing sound data for fertilizer investments. The Project represents a very good research investment and the next 5 years promise to be the most productive era of the RFNRP.

S. P. Gessel
Principal Investigator

INTRODUCTION

Events during the biennium reported here characterize the long-standing stability of the Project. New directions in RFNRP projects are balanced by long-term data collection and analysis efforts, and changes in Project staff are matched by ongoing participation by faculty and staff of the College of Forest Resources. These complements of change and constancy are summarized in this biennial report, which outlines the accomplishments of the past two years and the foundations for future Project directions.

During 1982-84, remeasurement and refertilization continued on the extensive set of RFNRP field trials. As of June 1984, there were 207 active installations in western Washington and western Oregon, including newly established studies and those with 14 years of growth and response measurements. A brief status report on RFNRP fertilization trials is included in this report. The extensive database resulting from the series of field trials has been thoroughly documented, and the database management systems utilized by the Project are continually upgraded.

Analyses of RFNRP data include ongoing monitoring and evaluation of long-term studies and efforts directed toward site-specific response information. Recent and ongoing Douglas-fir analyses consider growth responses after two fertilizer applications in unthinned stands, fertilization response in precommercially thinned stands, correlation of growth response and soil properties, growth and response as influenced by geographic province, and fertilization effects on stand structural development. Stand and tree growth and response after nitrogen and phosphorus fertilization, seedling growth responses after fertilization, and foliar nutrient levels are among topics under investigation for western hemlock. Results from a number of other analyses underway will improve selection of stands for operational fertilization programs.

Results from RFNRP analyses will be transmitted to cooperators as they become available in a new series of internal reports begun in 1984. The RFNRP Report series was initiated to provide direct and timely dissemination of Project results to cooperators, and is intended to complement presentations at annual meetings and articles in technical journals. Three RFNRP Reports have been produced, and several more are in preparation. Other Project publications include the RFNRP Newsletter, reactivated in 1982, and a 1983 brochure summarizing RFNRP results.

Several important meetings relevant to forest nutrition were held in the region during 1982-84. RFNRP personnel were active in planning and coordination of two meetings; RFNRP participation in other meetings is indicated in the listing of reports and presentations in this Biennial Report. In May 1982, the Northwest Forest Soils Council sponsored the Nitrogen Assessment Workshop, a meeting organized to improve forecasting of site-specific growth responses to nitrogen fertilization in PNW forests. Dr. Robert Strand of Crown Zellerbach prepared a summary and compiled the materials presented at this workshop for publication as RFNRP Report No. 2. The I.U.F.R.O. Symposium on Forest Site and Continuous Productivity was held on the University of

Washington campus in August 1982. This meeting brought together forest fertilization researchers from around the world. The meeting and field trip provided a forum for discussions between PNW researchers and practitioners and their colleagues working in other forest types and countries. Proceedings of the I.U.F.R.O. Symposium were published by the PNW Forest & Range Experiment Station.

Several new projects were initiated in the biennium in addition to efforts included in the Phase IV plan. Three contract installations supported by Melamine Chemicals, Inc., in young Douglas-fir stands were established to examine response after fertilization with urea and a melamine-urea fertilizer. New work supported by the Gifford Pinchot and Willamette National Forests will evaluate growth after fertilization for installations located on selected soil types. Previous trials of nitrogen and sulphur fertilization have been remeasured and refertilized in a collaborative effort of the RFNRP, Weyerhaeuser Company, the Sulphur Development Institute of Canada (SUDIC), and several cooperators. Plans for N + S fertilization research include foliar analysis and S mineralization studies.

"RFNRP: Past, Present, and Future", a research review and planning meeting, was held in November 1983. Project cooperators considered a range of topics for future RFNRP efforts and provided direct input for research planning. Following direction and priorities established at the meeting, Project staff and Technical Advisory Committee members developed a five-year plan for extension of research (Phase V, 1985-90). Five topic areas have been identified for future research work:

1. Selection criteria for Douglas-fir fertilization prescriptions
2. Fertilization response in relation to stand density and structure in young Douglas-fir stands
3. Effects of multiple nitrogen applications on Douglas-fir growth and yield
4. Fertilization response in western hemlock stands and western hemlock/Douglas-fir mixed stands
5. Fertilization response in mixed-species stands in the Pacific silver fir zone.

In addition to the Phase V planning effort, the RFNRP Technical Advisory Committee (TAC) has been called upon numerous times during the biennium to provide review and counsel on Project reports and plans. The biometrics subcommittee has been active in reviews of experimental design, mensurational efforts, and data analyses. Other TAC members have reviewed study plans and manuscripts and have actively participated in several studies. The willingness of TAC members to contribute their time and expertise is essential to the continued success of the RFNRP.

The format of the 1982-84 Biennial Report differs from previous reports by presenting highlights and summaries of information developed during the two year period. This change reflects emphasis on distribution of results as they become available, through the RFNRP Report series or other media, as recommended by cooperators. This Biennial Report includes summaries of reports presented in 1982-84, abstracts of journal papers, a fieldwork overview, reports on RFNRP staff and graduate students, and a listing of publications, reports, and presentations. Detailed results for technical summaries are available in RFNRP Reports and scientific journals.

RFNRP OBJECTIVES AND ANALYTICAL METHODS*

John W. Hazard and Charles E. Peterson

Since 1969, results from the Regional Forest Nutrition Research Project have been presented in numerous publications, yet without complete documentation of the research objectives and analytical methods. This report summarizes a paper that: (1) documents the original research objectives presented in 1969 and subsequent research objectives of the RFNRP in the context of scientific hypotheses, and (2) provides a model and analysis format for directing present and future primary analyses of the RFNRP data. The hypotheses of interest and project design are summarized from the paper.

Hypotheses

The primary objective of the project is to fit a single model to predict volume and basal area growth response to classification variables (province, fertilizer dosage, and thinning) and continuous variables (age, site, stocking, and initial volume) for each forest type (Douglas-fir or western hemlock).

The information generated from this analysis answers the following questions or hypotheses:

1. Do differences exist in fertilizer response among provinces?
2. Do differences exist in fertilizer response between thinned and unthinned stands?
3. Do differences exist in fertilizer response between levels of fertilizer application?
4. Do interactions exist among these factors?

The target populations of the study are Douglas-fir and western hemlock stands in western Oregon and Washington; the answers to the above questions will identify one or more prediction models for the strata in these two populations. Because of the regional design the prediction models will not constitute "site-specific" prescriptions of nitrogen fertilizer, although the models should provide a basis for extending research in that direction.

Design

Douglas-fir and western hemlock stands in western Oregon and Washington were stratified into six distinct Douglas-fir provinces (strata) and three hemlock provinces. Within each province,

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*Summarized from Hazard & Peterson (1984) installations were chosen from a matrix of site indices and ages. The assumption was that installations are random independent samples of their respective site class x age class substrata within provinces. The original samples of thinned and unthinned installations, together with the samples resulting from more recent RFNRP installations, were assumed to constitute a single representative sample of the target population.

Within each installation, three treatments were assigned, at random, to six, 1/10-acre plots. This generated representative samples (size two) of growth increment after applications of 0, 200, and 400 pounds of nitrogen per acre. In the past, estimates of response were derived from a regression approach that utilized each 1/10-acre plot as an independent observation. The individual plot method provided numerous useful answers to questions regarding regional growth and response and will likely be used to some extent in the future. Some situations have arisen, however, in which it is more advantageous to have an "installation response," rather than plot growth, as the experimental unit. Installation response can be a direct measure of PAI for the 0, 200, and 400 pounds of nitrogen per acre, or it can be an expression of fertilizer response; that is, the mean increment of the 0-pound plots (controls) subtracted from the average of the 200- and 400-pound levels. This produces an unbiased estimate of installation growth response to 200- and 400-pound treatments referred to in the paper as Δ200 and Δ400 responses.

The full model (without covariance variables) for one species is:

$$Y_{ijkm} = \mu + P_i + T_j + PT_{ij} + I_{k(ij)} + [F_m + PF_{im} + TF_{jm} + PTF_{ijm} + e_{ijkm}]$$

where the portion in brackets is the split-plot portion of the model and:

Y_{ijkm} is the growth response of m^{th} level of fertilizer on the k^{th} installation with the j^{th} thinning level in the i^{th} province,

μ is the general mean,

P_i is the province effect,

T_j is the thinning effect,

PT_{ij} is the province x thinning interaction,

$I_{k(ij)}$ are the installations within thinning and provinces,

F_m is the split-plot effect of Δ200 vs. Δ400,

PF_{im} is the interaction effect between provinces and fertilizer,

TF_{jm} is the interaction effect between thinning and fertilizer,

PTF_{ijm} is the interaction effect between provinces, thinning, and fertilizer, and

e_{ijkm} is the random variation among installations within the split-plot design.

The expanded model is a split-plot experimental design model because the installations (experimental units for provinces and thinning) are split fertilizer treatments resulting in Δ200 and Δ400 growth responses. The model is further expanded with introduction of the covariance variables. Although we have limited our covariates to stand variables (site index, age, basal area, and initial volume) for initial analyses, these variables could later be supplemented with, or even replaced by, other variables such as foliar or soil factors, if the latter are found to be significant in explaining response. We also recommend that "fertilizer response" of the installation rather than plot PAI be used as the dependent variable. PAI itself could be tested for treatment effects under the same general split-plot format, however.

THE RFNRP INFORMATION MANAGEMENT SYSTEM*

Rick Ells

Large scale cooperative research projects create complex data management problems because many different types of measurements are taken from many locations over long time periods. Relationships between different types of measurements can be complex. Uses of the data can change with time, requiring constant adjustments in retrieval and analysis programs. Over the fifteen years of its existence, the RFNRP has developed an information management system for meeting these problems. The purpose of RFNRP Report 3 is to describe this system, policies on the use of the data it contains, and the standard reports and files that can be generated by the system.

At the heart of the RFNRP system is a simple relational database named "Manager" containing basic installation and plot description and history information. This central database is purposely kept small and simple to increase the speed of its operation and to lower costs. Information contained in Manager includes installation name and number, owner, dates of establishment and treatments, location, stand age, site index, slope, and elevation. In addition, Manager contains plot history information such as disturbances and special studies.

Lists may be generated by Manager selecting on and sorting by any of the variables. The lists may then be used for planning further information retrievals and analyses.

The actual measurements data are stored in two much larger database systems, one for tree measurements and the other for soils data.

The tree measurements are handled by the "Permanent Sample Plot" (PSP) system, which consists of a large data file and a set of associated FORTRAN programs. The data file is organized by installation and plot, and contains plot size, measurement years, tree number, tree species, crown class, total age, diameters and heights at each measurement, and notes on the condition of each tree. At present, the PSP data file contains measurements from over 110,000 trees, including 600,000 diameter and 65,000 height measurements. The FORTRAN programs are used for adding new data, making corrections, and for generating reports on the data in the PSP data file. Figure 1 depicts the PSP system. The system is built around a single main data file. One set of programs generates field cards on which new measurements are recorded, which are then loaded into the main data file. Other programs generate reports or data files.

Soils data are stored in "Soils", a database implemented on the Scientific Information Retrieval (SIR) heirarchical database management

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* Summarized from Ells (1984)

package. Soils contains four general types of information, (1) general installation descriptions, (2) forest floor data, (3) qualitative soils descriptive information, and (4) soil profile chemical and physical data. Figure 2 depicts the organization of the soils database.

In RFNRP Report 3, each of the three systems - Manager, PSP, and Soils - is described in detail. The variables in each are listed and defined. Also, examples of the listings and reports produced by each system are provided.

Appendices of the report include a statement of the RFNRP data sharing policy, a detailed listing of codes used in the RFNRP database, and a list all RFNRP installations.

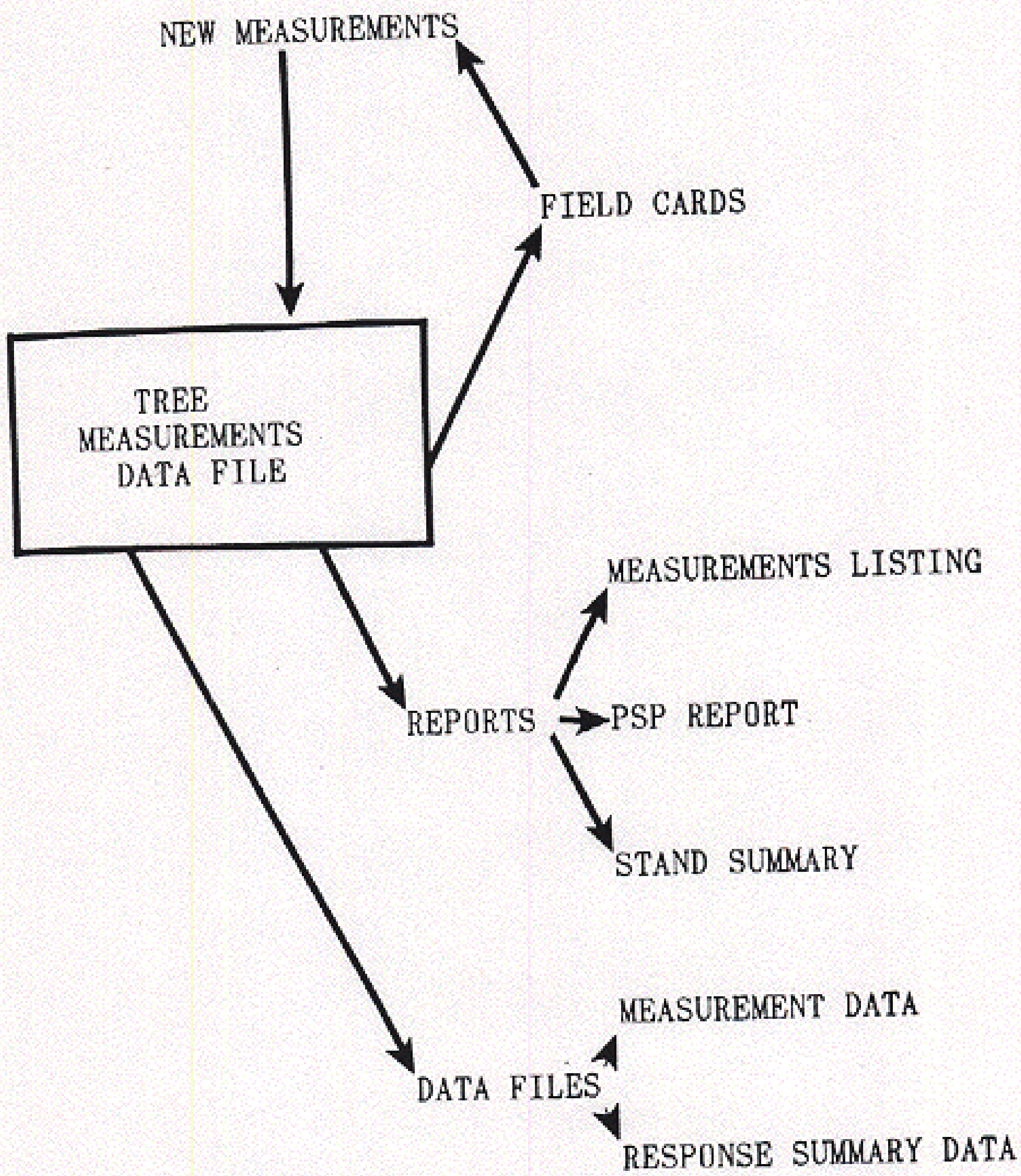

Figure 1. PSP data management system

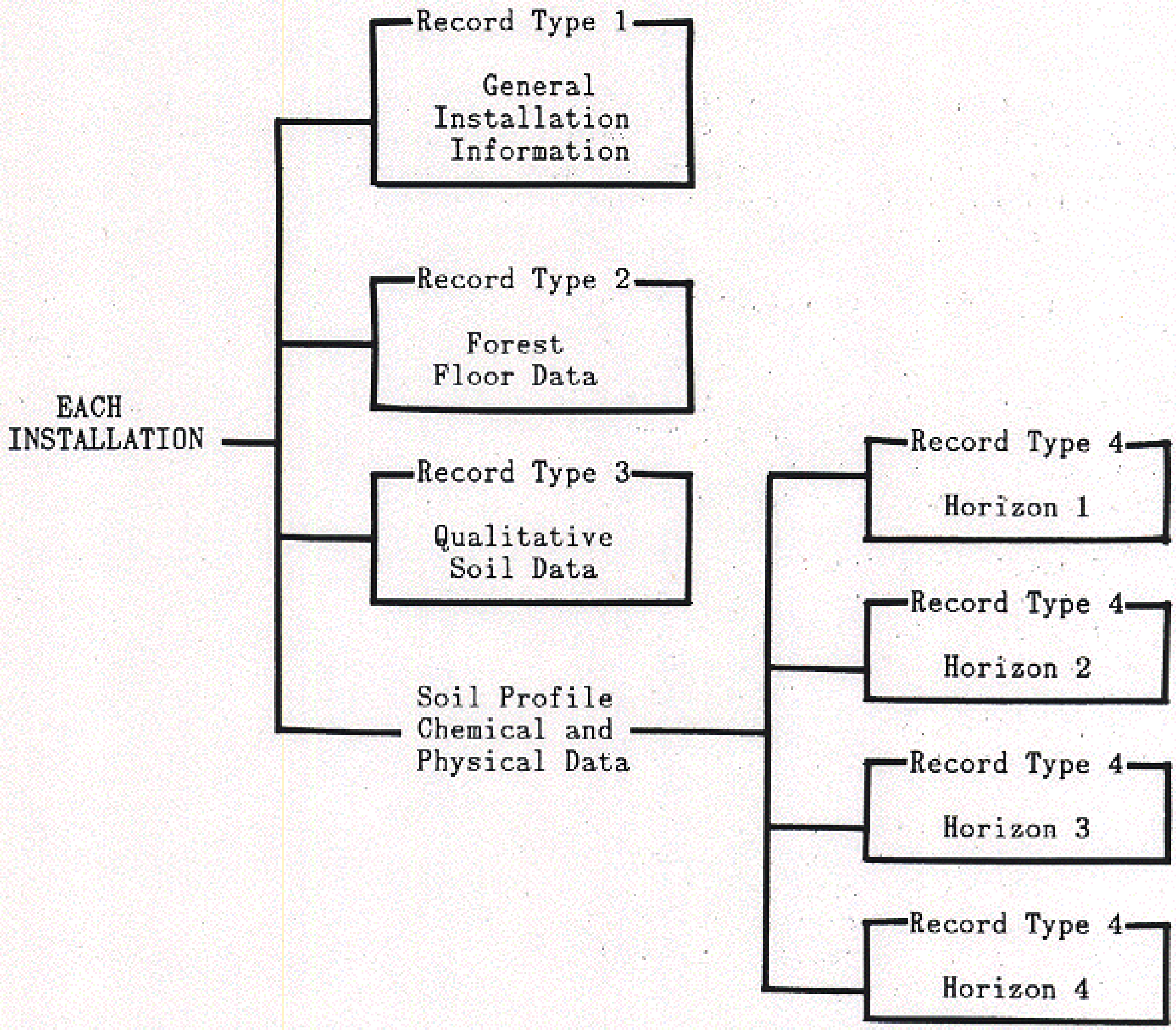

Figure 2. Heirarchical Organization of Data in the Soils SIR Database. Each box represents a record.

FOREST FERTILIZATION AND STAND MANAGEMENT*

H. N. Chappell and D. Opalach

The Regional Forest Nutrition Research Project (RFNRP) surveyed member organizations in September 1983 regarding stand management and fertilization practices. Twenty-six organizations managing forest land in western Washington and Oregon responded, representing 18.5 million acres of public and industry-owned timberland.

As expected, the Douglas-fir forest type dominates PNW managed forests (56% of the timberland area). Douglas-fir was planted on 1.2 million acres of the 1.5 million acres of plantations established in the period 1978-1982. Silviculture planned for plantations established today includes precommercial thinning, commercial thinning, and fertilization (70%, 56%, and 36%, respectively, of total area planted) (Table 1). Survey data reveal several differences in management planned for public and private timberlands.

Prescriptions for forest fertilization call for 200 pounds of nitrogen per acre aerially applied as granular urea (46-0-0) to thinned and naturally well-spaced Douglas-fir stands. In general, fertilization priority decreased with increasing site class and fertilization of stands 7-20 years before final harvest was preferred. Most respondents do not link fertilization prescriptions to soil survey information, and most desired more information on soil and foliage tests as site-specific diagnostic tools.

Nearly 1.6 million acres of timberland in western Washington and Oregon was fertilized in the past 10 years (1973-1982) (Figure 3). Prior to 1973, about 460,000 acres were fertilized. Projection of survey respondents' plans yields a cumulative total area fertilized of over 3 million acres in 1986. During the next 4-5 years timberland area fertilized is not expected to exceed 300,000 acres annually.

Table 1. Silvicultural activities planned for recently planted stands.

	Area planted 1978-1982	Planned Silviculture: Precommercial thinning	Commercial thinning	Fertilization
	acres x 1000	acres x 1000 (%)		
Forest industry	670.1	491.0 (73)	281.2 (42)	399.2 (52)
State and federal agency	833.0	561.8 (67)	562.1 (67)	195.0 (23)
Total[1]	1503.1	1052.8 (70)	843.3 (56)	544.2 (36)

[1] Totals may be off due to rounding.

* Summarized from Chappell and Opalach (1984)

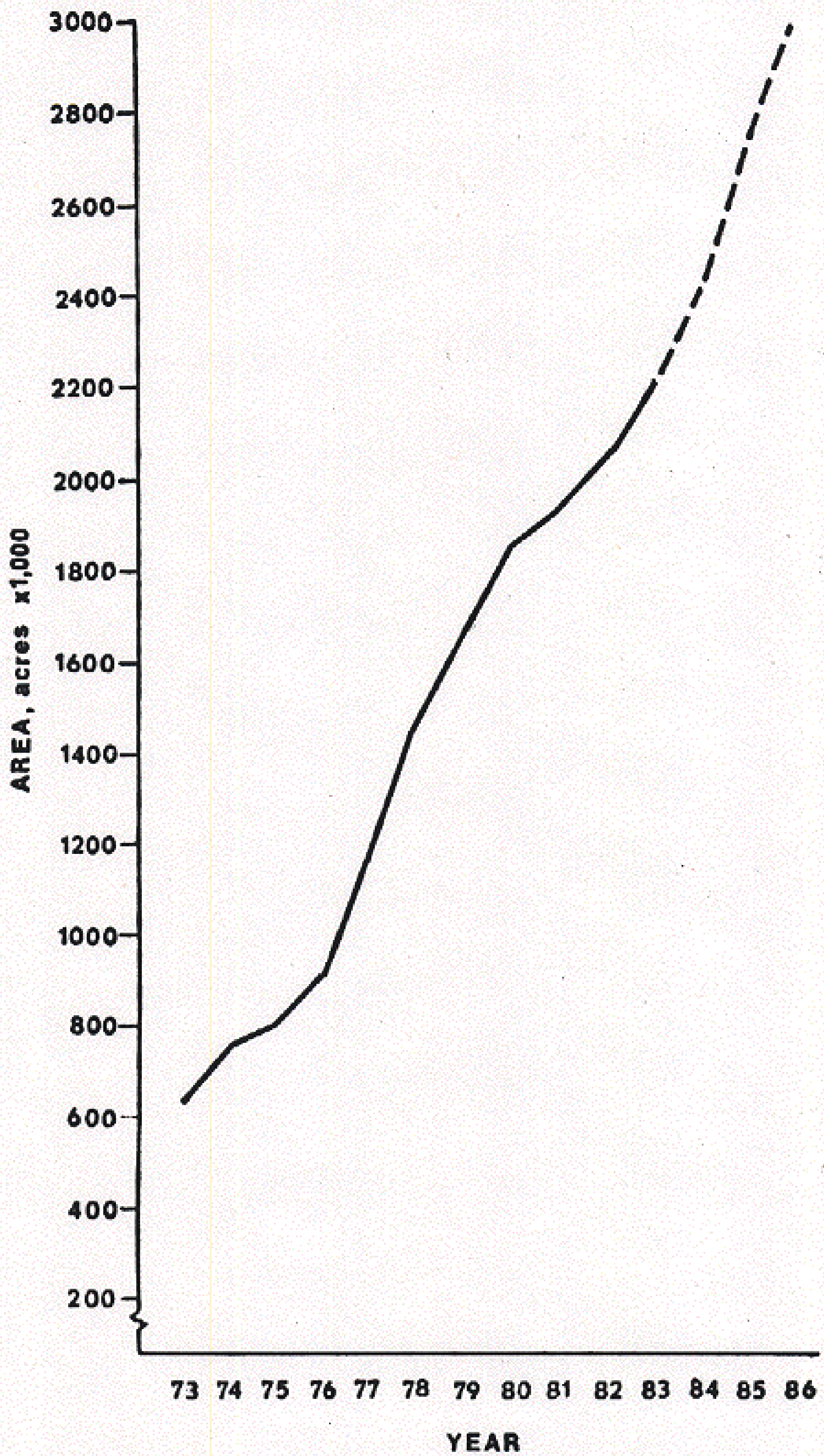

Figure 3. Cumulative area fertilized through 1982 in western Oregon and Washington. Planned fertilization indicated by broken line.

FERTILIZATION OF DOUGLAS-FIR PLANTATIONS*

C. E. Peterson

Since 1970, nitrogen fertilizers have been applied to approximately 2 million acres of second-growth Douglas-fir in the U.S. Pacific Northwest. A major source of growth response information over this period has been the Regional Forest Nutrition Research Project (RFNRP). Recently however, landowners have expressed a need for information, including the effects of nitrogen fertilizer, to enhance the management of young plantations which represent the third rotation. Since 1975, the RFNRP has established 26 installations in young widely spaced planatations of Douglas-fir for testing response to 200 lbs N/A. These plantations ranged in breast-height age from 3 to 23 years, and although response to fertilization was favorable in all Douglas-fir plantations, those which were spaced to 400 trees/acre(TPA) responded significantly better than plantations of 300 TPA in both absolute and relative 2-year basal area increment (sq ft/A/yr).

CONCLUSIONS

The young spaced Douglas-fir plantations established in 1975 at 400 TPA and in 1980 at near 300 TPA are both responding significantly to 200 lbs N/A. The first 2-year period following application of fertilizer shows basal area growth response to be significantly higher for stands at 400 TPA on a per acre basis than stands at 300 TPA, and approximately the same response per tree for the 2 levels of stocking.

A large portion of future research and operational efforts in the U.S. Pacific Northwest will focus on Douglas-fir plantations, whereupon other sources and rates of nitrogen application will most likely be tested, as well as elemental nutrients other than nitrogen. The question of delaying fertilization after thinning may also be an important consideration for maximizing biological growth potential, and, at this juncture, the application rate of 200 lbs N/A as urea is clearly arbitrary. Hopefully, the results presented here demonstrate the usefulness of current research efforts and the need for more information regarding growth response to ferilizer with other stocking levels stocking in order to maximize the growth potential young plantations.

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* Summarized from Peterson (1984)

Table 2. Estimated mean 2-year response to 200 lb. N/A of young spaced Douglas-fir plantations (min. d.b.h. = 1.55 inches)

Establishment year of plots	1980	1975
Density trees/A	300	400
Basal area control growth $ft^2/A/yr$	7.70	8.48
Basal area response $ft^2/A/yr$	2.07 (25%)	3.16 (37%)
Height control growth ft/yr	2.7	
Height response ft/yr	0.3 (11%)	

VOLUME RESPONSE AFTER REFERTILIZATION OF UNTHINNED DOUGLAS-FIR STANDS

C. E. Peterson

Unthinned fertilized Douglas-fir installations were refertilized with 200 lbs-N/A after eight growing seasons. Growth responses over four years following the second fertilizer application are summarized, and compared with results from a once-only fertilization. The first four years of volume growth response to 200 lbs-N/A (treatment 2N in Figure 4) are significant ($p < 0.001$) to either initial fertilization (first period) or refertilization (third period). Growth response by 2-year growth periods is depicted in Figure 5 for all stands fertilized once and those stands refertilized.

For the moment, consider the 2-year growth responses (Figure 5) in stands fertilized only once. Growth response to initial fertilization was nonsignificant ($p > 0.25$) in the fifth period, only to be followed by a larger ($p < 0.10$) carry-over in the sixth period. The 2-year growth rates (p.a.i.) in stands of <u>all</u> treatments increased from period five to period six. This increase was greater for once-fertilized stands than for controls (unfertilized stands). The resultant response increase was unexpected, however, considering the decline of growth response from period two through period five. In the absence of unusual changes in stand structure or mensuration, the reasons for increased stand growth rate are attributed to short-term climatic changes. Although growth response to urea-N diminished after about 8 years, it appears that the once-fertilized stands (without additional treatments) have greater capacity for growth response to favorable climatic changes than unfertilized (control) stands.

Growth response to refertilization is significant ($p < 0.005$) for both 2-year periods after refertilization (periods five and six in Figure 5). Response declines from period five to six, an indication that refertilization response might be of shorter duration than response to one fertilizer application. The decline in refertilization response coupled with carry-over from initial fertilization in period six might also suggest that a maximum attainable growth response to urea-N is possible for these unthinned stands.

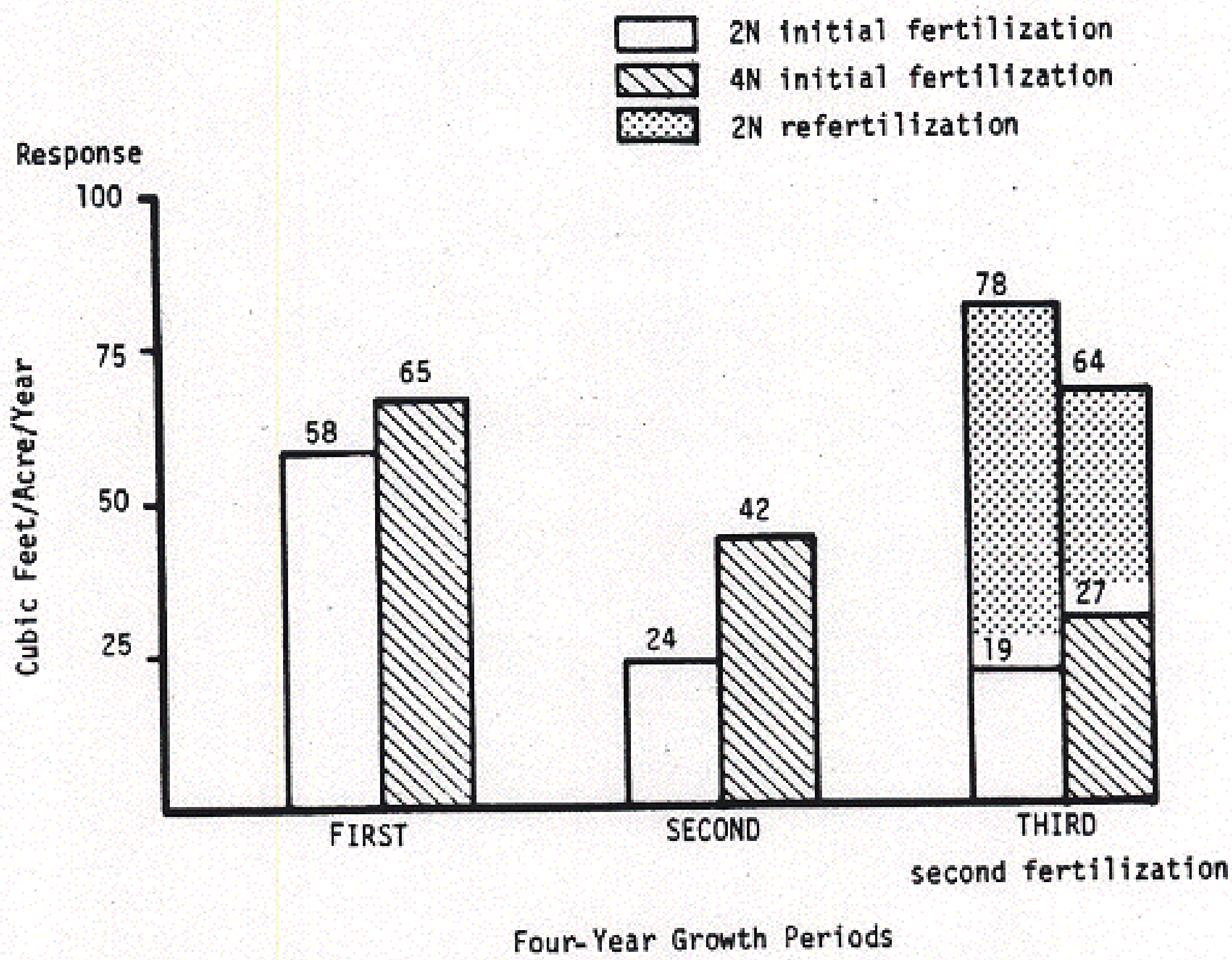

Figure 4. Estimated average total gross volume response for each 4-year growth period of unthinned Douglas-fir (ft^3/A/yr; min. dbh = 1.55 in.)

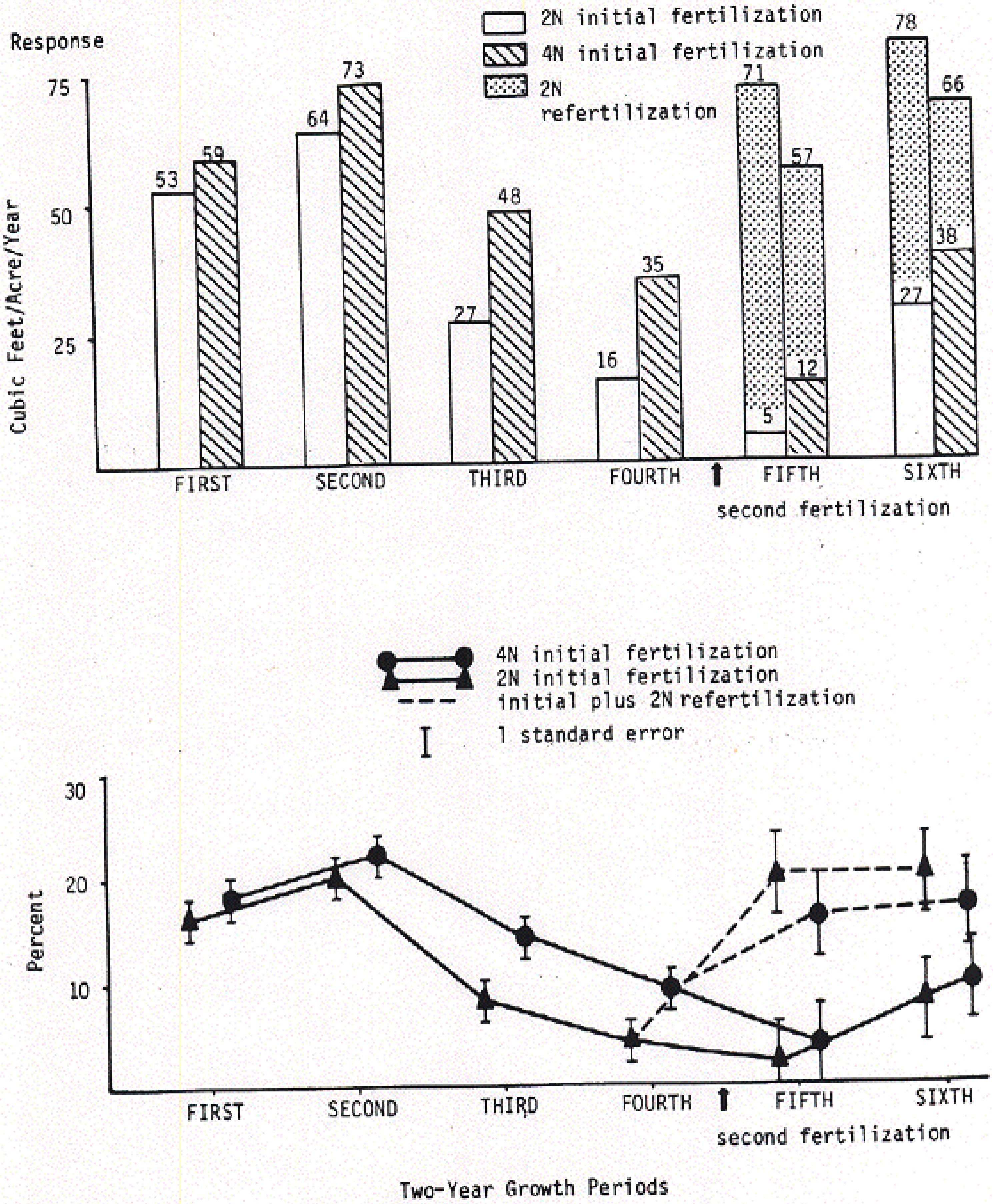

Figure 5. Estimated average total gross volume response for each 2-year growth period of unthinned Douglas-fir (ft^3/A/yr; min. dbh = 1.55 in.)

RESEARCH EVALUATION: A CASE HISTORY OF THE RFNRP*

B. Bruce Bare and Robert Loveless

In October, 1982, the U.S. Forest Service funded a two-year project at the University of Washington. The objectives of the project were to describe the inputs, outputs, application of results and the impacts of the RFNRP on society. This case history collates all available information relative to the cooperative including: (a) the history of the RFNRP from its inception to the present, (b) the importance of strong leadership in founding and guiding the cooperative over time, (c) the total dollar investment, (d) the allocation of the total investment to salaries, supplies and travel, (e) the number of staff and graduate students supported, (f) the number of plots established, (g) publications produced by the project, (h) the principal research findings of the cooperative and their societal impacts and (i) a benefit/cost analysis of the cooperative.

Several factors are necessary for any cooperative to be successful in its formative years: (a) recognition that the research endeavor is too large for any single organization to successfully conduct, (b) presence of a widely recognized leader who can channel the forces which often divert cooperative endeavors from their central focus, and (c) an organizational vehicle which can facilitate the communication of ideas to researchers in different organizations. All three of these critical elements were present during the early stages of the RFNRP and led to the establishment of a successful cooperative.

Since 1969, the RFNRP has established almost two thousand permanent growth plots at a total direct cost of $2.5 million. Twenty-two cooperators have financed the project on a continuing basis. Approximately 71 percent of the total investment has been contributed by industry; 9 percent by the states of Oregon and Washington, and 20 percent by the Federal government and Indian nations. Funds have been expended on salaries, benefits and overhead (71 percent); travel (16 percent); and supplies and contractual services (13 percent). The cooperative has supported 2-5 graduate students and 6-14 staff per year. Approximately 70 publications and reports have been produced. A key element has been the involvement of University faculty who have contributed their expertise to the success of the cooperative.

Benefits of the RFNRP include the actual research findings and their subsequent adoption and application by land management agencies. Although no one knows how many acres were fertilized in the Pacific Northwest because of the presence of the RFNRP, an average of about 155,000 acres have been fertilized annually since the early 1970's. Generally, these acres are fertilized with 200 lbs. of nitrogen as urea per acre at an average cost of $53/acre (in 1983). Economic analysis has shown that the fertilization of thinned and

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* Summarized from Bare and Loveless (1984)

unthinned Douglas-fir stands has generated "incremental" rates of return in excess of six percent (real) on an after-tax basis (varying by site class and age of stand fertilized).

However, results of an "absolute" economic analysis for both thinned and unthinned Douglas-fir stands clearly show that some stand types with acceptable incremental rates of return should not be fertilized. Rather, they should be harvested today since the stand type is already at or beyond its point of financial maturity. Generally, however, if a stand is worth holding for another time period, it is more profitable to fertilize it rather than to leave it untreated. This, of course, assumes that investment funds are available and that they can not earn higher rates of return if invested elsewhere.

One of the more important issues confronting budget analysts and managers of research programs is the evaluation of the benefit/cost performance of research expenditures. These questions arise when new programs are being considered as well as when past or existing programs are being evaluated. In both instances, the critical question is one of measuring the costs of a research program against the benefits which are expected to flow from the program. To answer this question, a benefit/cost analysis measuring the benefit of fertilization as a joint product of the investment in the cooperative plus the application cost of the fertilizer was conducted.

The benefit of fertilization was assumed to be the value of the increased wood yield resulting from the fertilization activity. For simplicity, this incremental approach was limited to one fertilization of 200 lbs. of nitrogen as urea per acre in an unthinned stand of Douglas-fir. The 10-year periodic annual increment as measured in total gross CF volume was assumed to be 40 CF/A. Since response was not significantly related to stand age, density or site productivity, the economic analysis applies to an average acre. The 400 CF/A of additional wood is harvested at the end of the 10th year following fertilization. The stumpage value of the incremental wood yield is held constant (in real terms) at \$0.50/CF. This is equivalent to approximately \$110/MBF using a BF/CF ratio of 4.5/1.0.

As previously noted, the cost of fertilizer averaged \$53/acre (in 1983 dollars). This cost was held constant at \$50/acre (in real terms) beginning with 1984. However, a trend-line analysis of past fertilizer application costs clearly shows a decreasing cost from 1973-1983. Thus, fertilizer treatments initiated prior to 1984 were estimated using the results of the trend-line analysis.

It was assumed that no fertilization decisions were based on results produced by the cooperative until the beginning of the fifth year after initiation of the cooperative. Thus, the first application of fertilizer does not appear until the beginning of year five. Accordingly, the first benefit of \$200/acre does not occur until the end of year fourteen. Similarly, the analysis assumes that a second acre is fertilized at the beginning of year six, with benefits being realized in year fifteen. This sequence of application investments and lagged benefits was assumed to continue until the present value of the last benefit falls below \$1/acre. Investments in the cooperative were assumed to terminate in year twenty.

The investment in the cooperative was expressed on a per acre fertilized basis. Because there was no way to determine the number of acres fertilized because of the cooperative's presence, four scenarios were considered. It was assumed that 100, 50, 20 or 10 percent of the 155,000 acres fertilized annually during the past five years could be attributed to the cooperative. Thus, per acre investments in the cooperative ranged from $1.54/acre (in constant 1983 dollars) under the 100 percent scenario to $15.40/acre under the 10 percent scenario.

Results of the benefit/cost analysis of investments in the cooperative clearly show that, under the assumptions employed, the incremental investment in the cooperative plus the cost of application have generated real after-tax rates of return in excess of nine percent (1983 dollars). The real after-tax rates of return for the four fertilizer scenarios are 9.3, 10.7, 11.7 and 12.1 percent, respectively.

From this preliminary assessment, it appears that investments in the RFNRP (including both the investment in the cooperative and the cost of application) have produced acceptable incremental real rates of return. However, the incremental analysis does not reveal whether investors are: (a) minimizing losses or maximizing profits or (b) earning the maximum rate of return on their investment in the cooperative. An "absolute" analysis recognizing all costs and opportunities would be necessary to answer these questions.

USE OF FERTILIZERS IN SUSTAINED PRODUCTIVITY OF DOUGLAS-FIR FORESTS*

S. P. Gessel and W. A. Atkinson

Fertilizing forests for sustaining or accelerating production is an established management alternative in many forest regions of the world. Although Douglas-fir forests are described as among the world's most productive, nitrogen deficiency has been established as a factor reducing growth, and nitrogen fertilization programs have developed. Research leading to establishment of these programs is reviewed, as are factors which determine productivity of Douglas-fir forests. Data from a number of long-term nitrogen fertilizer trials are presented to examine the question of sustained productivity. Results support the conclusion that nitrogen deficiency is frequently a controlling factor in growth of Douglas-fir and that additions can result in long-term growth increases.

Because fertilizing is a long-term monetary investment, the economics of fertilizing is discussed along with models of investment analysis. A discussion of future supply of fertilizer is included along with alternative practices to maintain productivity of Douglas-fir forests.

CONCLUSIONS

We have reached the following conclusions on use of fertilizers in sustained productivity of Douglas-fir forests:

1. Adequate elemental supply is important in long-term productivity of Douglas-fir forests; this is especially true for nitrogen.

2. Although nitrogen seems to be the principal element, others may become limiting under more intensive forest use and after correction of nitrogen deficiency.

3. Other soil and environmental factors do affect productivity of Douglas-fir forests. However, adequate nitrogen availability can increase the forest's ability to deal efficiently with other limitations.

4. Research needs to be accelerated on factors which determine availability of essential elements (especially nitrogen) for forest trees.

5. The nutrient-supplying ability of forest soils may be decreased by current and future management practices which must be modified to conserve nitrogen supply. Fertilizer is no substitute for soil.

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* Summarized from Gessel and Atkinson (1984)

6. Complete tree utilization and short rotations need to be examined with regard to their impact on soil fertility.

7. Our capability to predict long-term productivity effects resulting from forest practices must be improved. Ability to predict fertilizer response on specific sites must be developed so that forest managers can better use scarce money and fertilizer resources.

8. A major challenge to foresters, soil scientists and tree nutritionists is to quantify the values involved in projections of productivity and to forcefully present these arguments to managers of forest properties in terms they can understand--namely dollars. Most managers are enlightened enough to respond positively, but they now see only current operating cost data.

9. Nitrogen can be added to the ecosystem and result in both a biological and economic response. Additions can be made directly, as in the case of helicopter-applied fertilizer, or through appropriate biological techniques. Growth response can continue over relatively long periods, but results can be augmented by periodic additions.

10. And, finally, nitrogen fertilizer will be available and affordable and will become a standard practice to maintain and enhance long-term productivity of Douglas-fir forests.

RESPONSE OF NORTHWEST DOUGLAS-FIR STANDS TO UREA: CORRELATIONS WITH FOREST SOIL PROPERTIES*

C. E. Peterson, P. J. Ryan, and S. P. Gessel

Replicated forest floor and surface soil (0-6 in) samples were obtained in each of the two control plots of the 160 installations in Washington and Oregon of the Regional Forest Nutrition Research Project. Of these, the thinned and unthinned Douglas-fir installations having 6-year post-urea fertilization growth and response data were selected for detailed analysis. Eighteen measured forest floor and surface soil properties of the control plots were correlated to the Douglas-fir basal area and volume growth of plots receiving 0, 200, and 400 lbs of N-urea per acre. Individual installation response estimates were obtained by differencing observed growth rate in treated stands from estimates of growth rate for untreated stands. These response estimates were used to classify installations into three arbitrary levels of response: "low" (10%), "average" and "high" ($2\bar{X}$-10%). The response estimates in each of the three classes were then correlated to their respective forest floor-soil data hoping that additional site-specific growth and response variation could be explained. Results of these correlations are discussed.

CONCLUSIONS

The method of response classification used in this study has illustrated how sample size and initial stand conditions (unthinned or thinned) might affect both the properties correlated with growth response and the magnitude of the correlation coefficients.

The correlation of site index, surface soil, and forest floor properties to various categories of urea fertilizer response of thinned and unthinned Douglas-fir stands has allowed the identification of (i) those soil properties consistently (independent of growth response expression) and significantly related to response and (ii) those soil properties whose correlations with response were affected when the stands were both fertilized and thinned. Nitrogen and carbon properties (primarily from the forest floor) were variables showing the highest correlations with response. Forest floor C/N ratio had the highest correlation with all measures of unthinned Douglas-fir response. Forest floor C/N ratio was also consistently correlated with thinned Douglas-fir response. In these latter stands, however, the high correlations of forest floor weight or total N with response indicated a probable interaction between increased decomposition from thinning and urea fertilization.

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* Summarized from Peterson, Ryan, and Gessel (1984)

WESTERN HEMLOCK GROWTH AND NUTRITION

R. J. Zasoski and H. Porada

During the past two years the emphasis in western hemlock studies has been on the growth and nutrition of young stands with less effort devoted to older stands. Growth results for young plantations (Phase III and Phase IV) are presented below (Table 3).

These results are similar to previous growth results, where coastal locations did not respond to nitrogen fertilization while Cascade sites showed a positive response. This stratification between coastal locations and Cascade sites crosses soil boundaries, climatic zones and site qualities. A better method of stratification between western hemlock sites appears necessary. Differences in chemical properties of some soils from the Cascades and coast have been investigated (Ryan 1983) and other differences between hemlock sites warrant further investigation. These include:

a. differences in stand structure and stocking prior to N fertilization.

b. differences in micronutrient levels. There is increasing evidence that some micronutrients, especially Cu, Zn, and B, are low or deficient in coastal locations. Boron deficiency in Douglas-fir plantations has been reported in British Columbia.

c. phosphorus levels in some coastal locations are low and may contribute to reduced responses to nitrogen additions. Interactions with Al in the more acidic soils may also be involved.

Effects of acid and aluminum-rich media on western hemlock growth were investigated by Ryan (1983). He found a marginal growth response to added N and P in treated soils compared to N or P treatments alone. Studies on micronutrient status of western hemlock, aluminum influences on hemlock nutrition, nitrogen and phosphorus interactions on growth and nutrition are currently being investigated.

Table 3. Mean gross total growth of young western hemlock plantations in Washington

Plots	Treatment	Basal area growth Coast	Basal area growth Cascade	Volume growth Coast	Volume growth Cascade
		$ft^2/A/yr$		$ft^3/A/yr$	
Phase III*	0	11.9	8.6	466	221
	200 lbs N/A	12.0	10.8	447	258
	Difference	0.1(1%)	2.2(25%)	-19(-4%)	37(17%)
Phase IV**	0	9.0	8.2	Not computed	
	200 lbs N/A	9.7	9.5		
	Difference	0.7(8%)	1.3(16%)		

*6-year PAI. 4 plots/treatment.
**2-year PAI. 6 plots/treatment.

RESPONSE OF WESTERN HEMLOCK SEEDLINGS TO N, P AND S FERTILIZATION*

R. J. Zasoski and S. P. Gessel

Western hemlock seedlings growing in Mopang soil (Medial, mesic, Andic Haplumbrept) were treated with 200 lbs N/A, 400 lbs P/A and 100 lbs S/A in varying combinations. Growth and foliar nutrient contents were measured for two years following treatment. A significant height growth response was observed when both N and P were applied. In the first year this treatment doubled growth relative to the controls, and in the second year height increment was three times greater than the controls. Foliar analyses showed that added N was taken up but that P levels were deficient in the N treatments. Phosphorus treatment in addition to N increased growth and foliar P levels. In the second year, foliar N was deficient in those treatments where growth caused a dilution effect. Micronutrients (Fe, Mn, Cu, Zn) were low but appeared to be adequate.

Table 4. Two-year foliar N and P levels and height growth for western hemlock seedlings

TREATMENT	GROWTH (cm)		NITROGEN (%)		PHOSPHORUS (%)	
	1980	1981	1980	1981	1980	1981
Control	10.3 a	7.1 a	0.88 a	0.97 ab	0.08 a	0.04 a
Urea	10.0 a	9.7 ab	1.68 c	1.06 ab	0.09 a	0.05 a
Amm - nitrate	9.9 a	5.9 a	2.60 d	1.44 b	0.06 a	0.05 a
Amm - sulfate	10.5 a	7.4 ab	1.58 b	1.39 b	0.05 a	0.05 a
Urea + dical	21.8 b	23.8 c	1.48 b	0.59 a	0.18 b	0.08 c
Urea + dical + S	22.5 b	21.4 c	1.31 ab	0.58 a	0.14 b	0.07 b
Foliar - P + N	8.4 a	11.2 b	—	0.90 ab	—	0.05 a

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* Summarized from Zasoski and Gessel (1982)

THE EFFECT OF ALUMINUM CONCENTRATION AND SOLUTION ACIDITY ON THE GROWTH AND NUTRITION OF THREE NORTHWEST CONIFERS[1]

P. J. Ryan, S. P. Gessel and R. J. Zasoski

Seedlings of three northwest conifers species (*Pseudotsuga menziesii*, *Tsuga heterophylla* and *Thuja plicata*) were grown in acid nutrient solutions with and without aluminum present. The acid treatments were paired so as to differentiate the effects of aluminum from the hydrogen ion concentration that a specific level of Al^{3+} induces via hydrolysis reactions. The relative differences in growth and nutrition of the three conifers to H^+ and Al^{3+} treatments varied between species, between different aged seedlings of the same species, and between solution and sand culture experiments. All the conifers were tolerant of the acid solutions and to the high levels of aluminum in solution (10 to 175 ppm Al^{3+}) in varying degrees. Douglas-fir and western redcedar both displayed similar or better growth in nutrient culture solutions containing 175 ppm Al^{3+} than in solutions at the same pH (3.05) without aluminum. In contrast, western hemlock had higher mortality and poorer growth in acid solutions containing aluminum but grew and survived in solutions at the same pH without aluminum. The effect of high H^+ and Al^{3+} solution concentrations on seedling nutrient levels are discussed.

EFFECT OF UREA FERTILIZATION ON ALLOMETRIC RELATIONS IN YOUNG DOUGLAS-FIR[2]

Charles C. Grier, Katharine M. Lee, and Ruth M. Archibald

The effect of nitrogen fertilization on allometric relations was examined for 23-year-old Site Class III Douglas-fir trees two years after urea fertilization. Logarithmic regression equations using stem diameter (cm) to predict tree biomass components (kg) were not significantly ($p = 0.05$) different between fertilized and control trees for total foliage, total branch, dead branch, stembark or stemwood. New foliage and new twig components, however, were higher in fertilized trees than in control trees. Analysis of data from this and earlier studies suggests fertilization will increase leaf biomass per tree relative to control trees on sites having low nitrogen availability; however, this response will decrease with increasing nitrogen availability. Regression equations based on regional analysis of unfertilized trees yield estimates of foliage biomass for average trees on average sites. If N-fertilization brings the site above average in terms of nitrogen availability then these regression equations will underestimate foliage biomass. However, on sites that are initially very nitrogen deficient, N-fertilization will bring the site closer to average in terms of nitrogen availability, resulting in more accurate predictions of foliage biomass for fertilized stands than for control stands.

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[1] Summarized from Ryan, Gessel, and Zasoski (1982)

[2] Summarized from Grier, Lee, and Archibald (1984)

FIELD WORK OVERVIEW

Michael L. Rinehart

Definition of Phases

Reference to "Phases" is common practice to identify a particular portion of the Database or field installations. These are:

Phase I: Natural, unthinned stands of Douglas-fir and western hemlock established in 1969-70.

Phase II: Natural, thinned stands of Douglas-fir and western hemlock established in 1971-72.

Phase III: Planted, young thinned stands of Douglas-fir and western hemlock; low site quality stands of Douglas-fir---both established in 1975.

Phase IV: Plantations of spaced Douglas-fir and western hemlock; Douglas-fir stands of natural low stocking---both established in 1980.

Fertilization treatments for Phase I and II Douglas-fir installations are summarized below. Notable exceptions include: refertilization for Western hemlock after 10 growing seasons contained phosphorus; Phases III and IV have more replications; Phase III contains an ammonium nitrate trial.

Douglas-fir Phases I and II Fertilization Schedule
lbs N/A as urea

Plot Number	Initial	1st - after 8 Growing Seasons	2nd - after 12 Growing Seasons	3rd after 16 Growing Seasons
1	0	0	0	0
2	0	200	200	200
3	200	0	0	0
4	200	200	200	200
5	400	0	0	0
6	400	200	200	200

Status of Field Trials

The RFNRP has established over 260 research installations since 1969. Six to thirty-five permanent growth plots make up an installation, for experimental designs utilized in Phases I-IV and recent contract work. The status of RFNRP installations is summarized in Table 5.

Table 5. Status of RFNRP field trials.

Establishment Year	Installation Type	Number Established	Number Surviving, 6/84
1969	Phase I	57	36
1970	Phase I	60	40
1971	Phase II	16	15
1972	Phase II	27	25
1973	Contract (BLM)	6	0
1975	Phase III	29	28
1975	Contract (USFS)	4	2
1976	Contract (USFS)	2	0
1977	Contract (USFS, BLM)	16	14
1978	Contract (USFS)	5	3
1979	Contract (SUDIC)	3	3
1980	Phase IV	34	33
1980	Contract (SUDIC)	2	2
1983	Contract (MCI)	3	3
1984	Contract (USFS)	3	3
		267	207

GRADUATE STUDENTS

Phil Ryan completed his graduate studies in 1983 and returned to New South Wales, Australia, where he is currently employed by the N.S.W. Forests Commission. His Ph.D. thesis project was titled "The role of acid and aluminum-rich media in the growth and nutrition of Pacific Northwest conifers"; an abstract is included at the end of this section.

Ruth Archibald completed her M.S. degree in 1983 (thesis: "Effect of nitrogen fertilization on allometric relationships in Douglas-fir in western Washington"); results of her research project are summarized in this report. John Blake is putting the final touches on his Ph.D. thesis, entitled "Characterization of soil nitrogen and sulfur availability in relation to volume response of Douglas-fir in western Oregon and Washington."

Hans Porada is pursuing a Ph.D. degree under the direction of Dr. Robert Zasoski; his research project examines comparative growth and nutrition of Douglas-fir and western hemlock seedlings in coastal Washington. Hans will also be continuing Phil Ryan's work on acidity and aluminum concentration effects on conifer growth.

Tom Gower, Ph.D. student, and Rachel Friedman-Thomas, M.S. student, are working with Dr. Charles Grier on projects examining above- and belowground carbon allocation in Douglas-fir stands as influenced by mineral nutrition. Rachel is particularly interested in mycorrhizal development following urea fertilization.

Linda Heath and Dan Opalach, Ph.D. students supervised by Dr. Bruce Bare, are deeply involved in RFNRP data management and statistical analyses. Their research projects will center on analyses of the Project database, such as current efforts relating stand structure development, fertilizer applications, and growth response.

THE ROLE OF ACID AND ALUMINUM-RICH MEDIA IN THE GROWTH AND NUTRITION OF PACIFIC NORTHWEST CONIFERS

Philip Joseph Ryan

Forest soils of coastal Washington and Oregon tend to be very acidic with large accumulations of organic matter. Yet the productivity of forest species on these sites can attain record levels. The effect of acid and aluminum-rich media on the growth and nutrition of Pacific Northwest conifer species was investigated for western hemlock, Douglas-fir, western redcedar, and Sitka spruce. The four different types of growth media utilized were solution cultures, sand cultures, mineral soils, and forest floor organic matter. Hydroponic nutrient solutions and sand cultures were used in experiments designed to differentiate the effect of aluminum ions from the hydrogen ions generated by

hydrolysis of Al^{3+}. Relative to agronomic plants, all the conifers were found tolerant of the acid solutions and high levels of aluminum. Species differed in their relative tolerance to H^+ and Al^{3+} ions. Western hemlock was most tolerant of acid followed by western redcedar, Sitka spruce, and Douglas-fir. In contrast to the other species, western hemlock survived and thrived in acid solution of pH3 while the presence of Al in acid solution adversely affected seedling root growth and tissue divalent cation concentrations, especially calcium and magnesium.

Western hemlock seedling growth was superior to Douglas-fir in the acidified soils and forest floor media, while $Ca(OH)_2$ amendment favored Douglas-fir. The marginal increase in western hemlock growth in N+P treated soils was highest in acidified soils.

Western hemlock exhibited an ability to absorb nutrients in the presence of excess solution H^+ ions, maintain growth with low tissue requirements of Ca and Mg, and accumulate high levels of aluminum in its roots and foliage without major adverse effect. These attributes are considered to make western hemlock the most acid and Al-tolerant of the four Pacific Northwest forest species studied. Western redcedar was second in acid tolerance to western hemlock. This species' ability to accumulate Ca minimized Al absorption and H^+ damage to its roots.

RFNRP PERSONNEL

Dr. Stanley P. Gessel, Principal Investigator
Dr. Nick Chappell, Associate Director
Mr. Robert W. Gonyea, Program Manager
Mr. Charles Peterson, Mensuration Director
Mr. Rick Ells, Database Manager
Mr. Michael Rinehart, Field Supervisor
Mr. Michael Johnson, Field Technician

A number of changes in Project staff occurred during 1982-84. Mike Rinehart joined the staff in July 1982, with responsibilities for fieldwork supervision; he also participates in analysis and interpretation of Project studies. Dr. Nick Chappell was appointed Associate Director in August 1983, with initial assignments of strengthening liaison with cooperators and coordinating planning for the next 5-year phase of the RFNRP. Al Becker, RFNRP Database Manager for 9 years, left in September 1983 to take a position with Georgia-Pacific in Portland; Al maintains active contact and serves on the TAC. Rick Ells joined the RFNRP staff in October 1983 assuming responsibilities in data management and analysis. Dr. Stan Gessel retired at the end of 1983 from the College of Forest Resources faculty, although he continues to actively participate in RFNRP efforts.

Faculty participation has increased in the past two years. Drs. Bruce Bare, Dale Cole, Robert Edmonds, Charles Grier, Chadwick Oliver, and Robert Zasoski have devoted considerable time to the Project, and their continuing interest and participation demonstrate the College's commitment to the RFNRP. Graduate students supervised by these faculty provide for research projects beyond the scope of the core RFNRP effort.

Fieldwork in the past two years has been accomplished with the able assistance of Messrs. Pete Hasselberg, Paul Hook, Ron Kent, Larry Maechler, and Dave Marrett. The RFNRP is indebted to Mrs. Kathi Grier for her supervision of Project secretarial and publication tasks. Special recognition is due Mrs. Dolores Batayola and Ms. Margaret Lahde for their secretarial and word processing efforts.

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RFNRP PUBLICATIONS, REPORTS, AND PRESENTATIONS 1982-1984

Included in this list are publications, reports, and presentations by Project personnel, and those which are results of research using the Project database.

1982 Cole, D. and S.P. Gessel. Effects of forest harvesting on soil nutrients. Paper presented at Western Forestry and Conservation Association meeting, Portland, OR.

1982 Gertner, G. Application of a Bayesian technique for increasing the precision of growth projection estimates. In: Proc. Forest Growth Modelling and Simulation Meeting. Mitteilungen der Forstlichen Bundesuersuchsanstalt, Vienna, Austria.

1982 Gertner, G. Estimating the precision of a growth projection system. Presented at the Midwestern Mensuration Meeting, Madison, Wisconsin, Sept. 7-9, 1982.

1982 Gessel, S.P. Acid rain and forest productivity. In Symposium/Workshop Proceedings Acid Forming Emissions in Alberta and Their Ecological Effects. Alberta Department of the Environment. Edmonton, Alberta.

1982 Gill, R. Nutrition of western hemlock (A survey of existing knowledge). Unpublished report to RFNRP. 26 p.

1982 Radwan, M.A. and J.S. Shumway. Soil nitrogen, sulfur and phosphorus in relation to growth response of western hemlock to nitrogen fertilizer. Forest Sci. 29:469-477.

1982 Ryan, P.J., S.P. Gessel, and R.J. Zasoski. The effect of aluminum concentration and solution acidity on the growth and nutrition of three Northwest conifers. Agron. Abstr. 1982:271.

1982 Zasoski, R.J. and S.P. Gessel. Response of western hemlock seedlings to N, P, and S fertilization in a coastal Washington soil. Agron. Abstr. 1982:273.

1983 ________ Regional Forest Nutrition Research Project (pamphlet) 6p.

1983 Archibald, R.M. Effect of nitrogen fertilizer on allometric relationships in Douglas-fir in western Washington. M.S. thesis. College of Forest Resources, University of Washington. 65 p.

1983 Archibald, R.M. and C.C. Grier. Allometric relations in Douglas-fir. Northwest Sci. Assoc. Abst. 1983:73.

1983 Gertner, G. A feedback mechanism for improving forest simulation estimates. In: Proc. of 6th Annual Workshop of the Biological System Simulation Group, Champaign, IL. (Abstract)

1983 Gertner, G. and L. Heath. 1983. Automatic adjustment of growth projection estimates to silvicultural response. In: International Conference on Renewable Resource Inventories and Remote Sensing Working Groups, FAO-UN, USDA. Oregon State University, Corvallis, Oregon.

1983 Heath, L.S. Evaluating a sequential Bayesian procedure to modify forest growth models for silvicultural treatments and unknown disturbances. M.S. thesis, Department of Forestry, University of Illinois. 104pp.

1983 Little, S.N. Weibull diameter distributions for mixed stands of western conifers. Can. J. of Forest Res. 13:85-88.

1983 Peterson, C., J. Bethel, R. Pezeshki, S.Gessel, and R. Zasoski. Impact of Mt. St. Helen's ash on growth of Douglas-fir. Northwest Sci. Assoc. Abstr. 1983:60.

1983 Peterson, C.E. and S.P. Gessel. Forest fertilization in the Pacific Northwest: Results of the Regional Forest Nutrition Research Project. p. 365-369 In: R. Ballard and S.P. Gessel, eds. IUFRO Sympos. on Forest Site and Continuous Productivity. Gen. Tech. Rep. PNW-163. Portland OR: USDA For. Serv., Pacific Northwest Forest and Range Experiment Station.

1983 Ryan P.J. The role of acid and aluminum-rich media in the growth and nutrition of Pacific Northwest Conifers. Ph.D. diss. College of Forest Resources, University of Washington. 336 pp.

1984 Bare, B. B. and R. Loveless. An overview of the Regional Forest Nutrition Research Project. Presented at Research Evaluation Workshop, N. Central For. Exp. Sta., St. Paul, MN. August 20-21, 1984.

1984 Chappell, H.N. and D. Opalach. Forest fertilization and stand management in western Oregon and Washington: Status and prospect. Unpublished, RFNRP Report 1. 23 pp.

1984 Ells, R. The Regional Forest Nutrition Research Project information management system. Unpublished, RFNRP Report 3. 45 p.

1984 Gessel, S.P. Position paper: site productivity. p. 433-439 In: D.C. Grey et al., eds. Proc. IUFRO. Sympos. on Site and Productivity of Fast Growing Plantations, April 30-May 11, Pretoria and Pietermaritzburg, South Africa.

1984 Gessel, S.P. and W.A. Atkinson. Use of fertilizers in sustained productivity of Douglas-fir forests. p. 67-87 In: E.L. Stone, ed. Forest Soils and Treatment Impacts. Proc. Sixth N. Am. Forest Soils Conf., Knoxville, Tenn.

1984 Grier, C.C., K.M. Lee, and R.M. Archibald. Effect of urea fertilization on allometric relations in young Douglas-fir. Can. J. Forest Res. (in press).

1984 Hazard, J.W. and C.E. Peterson. Objectives and analytical methods of the Regional Forest Nutrition Research Project. Institute of Forest Resources, Contrib. 53, University of Washington, Seattle, WA. 23 pp.

1984 Peterson, C.E. Fertilization of Douglas-fir plantations in the Pacific Northwest RFNRP cooperative. p. 637-645 In: D.C. Grey et al., eds. Proc. IUFRO Sympos. on Site and Productivity of Fast Growing Plantations. April 30-May 11, Pretoria and Pietermarizburg, South Africa.

1984 Peterson, C.E., P.J. Ryan, and S.P. Gessel. Response of northwest Douglas-fir stands to urea: Correlations with forest soil properties. Soil Sci. Soc. of Am. J., 48:162-169. (Also presented at 1982 American Society of Agronomy meetings, Anaheim, Ca.; Agron. Abstr. 1982:264).

1984 Radwan, M.A., D.S. DeBell, S.R. Webster, and S.P. Gessel. Different nitrogen sources for fertilizing western hemlock in western Washington. Can. J. For. Res. 14:155-162. (Also presented at 1982 American Society of Agronomy meetings, Anaheim, Ca.; Agron. Abstr. 1982:263).

1984 Radwan, M.A. and J.S. Shumway. Site index and selected soil properties in relation to response of Douglas-fir and western hemlock to nitrogen fertilizer. p. 89-104. In: E.L. Stone, ed. Forest Soils and Treatment Impacts. Proc. Sixth N. Am. Forest Soils Conf., Knoxville, Tenn.

1984 Shumway, J.S. Mineralizable nitrogen as a guide to fertilizing Douglas-fir stands. Agron. Abstr. 1984:265.

1984 Strand, R.F., compiler. Nitrogen assessment workshop, May 19-20, 1982. Unpublished, RFRNP Report 2. 84 pp.

1984 Walker, R.B., S.P. Gessel, and R.E. Miller. Greenhouse/laboratory evaluation of three "problem" soils from Rogue River forest sites. Northwest Sci. Assoc. Abstr. 1984:202.