Atkinson

Regional Forest Nutrition Research Program

ANNUAL REPORT 1971·72

INSTITUTE OF FOREST PRODUCTS
COLLEGE OF FOREST RESOURCES
UNIVERSITY OF WASHINGTON

PARTICIPATING MEMBERS

1971 - 1972

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Borden Chemical, Division of Borden, Inc.

Broughton Lumber Company

Bureau of Land Management

Chevron Chemical Company

Collier Carbon and Chemical Corporation

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FOREWORD

This report marks the successful conclusion of four years' plot establishment activity for the Regional Forest Nutrition Research Project. For thoroughness, consistency, and magnitude of effort, these field trials are unmatched in the Pacific Northwest. Now the concerns will be to protect and monitor the plots and interpret the results which are already beginning to accumulate.

Data of the nature being provided by this program are essential to the decision-making process involved in the management of forest ecosystems. The implications of intensive management are often viewed with a skeptical eye by company stockholders, directors, foresters, governmental authorities and the general public. Without hard data, and a thorough understanding of the factors, processes and relationships involved, arguments for intensive forest management sound hollow and pretentious.

The regional fertilization project is contributing timely inputs to man's knowledge of forest behavior under management. It will be a success, however, only if its results are presented in a comprehensible manner, widely circulated and effectively understood by those for whom they are intended.

James S. Bethel, Dean
College of Forest Resources
University of Washington

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RESEARCH

OBJECTIVES

The Regional Forest Nutrition Research Project was initiated in 1969 with the primary objective of providing resource managers with more accurate data on the effects of fertilizing and thinning on young-growth Douglas-fir and western hemlock forests. Project development and methodology were described at length in the 1969-70 and 1970-71 Annual Reports.

Based on the needs for additional information which previous forest fertilization research in the Pacific Northwest had brought to light, the Northwest Forest Soils Council determined that an intensive field program with regional focus should incorporate the following goals:

1. to establish and maintain a series of fertilizing and thinning field trials on participants' lands in western Washington and western Oregon under various conditions of soils, climate, age, and site index;

2. to collect and analyze response data from these plots over a 6-year period and report results to subscribers;

3. to conduct supplemental research in related areas such as diagnosis of elemental deficiencies, analysis of the effects of fertilizer application on total ecosystems, effects on wood quality, economics and logistics of fertilization and thinning, mensurational aspects, etc.;

4. to report findings regularly to subscribers, to advise them on fertilization problems and practices, and to offer additional seminars, discussions and short courses; and

5. to cooperate with other programs and research designed to intensify forest management and increase wood production.

Because of the scope of this program, a cooperative funding approach was used to enlist a broad base of support from regional timber companies, fertilizer manufacturers, and governmental agencies involved with resource management. The College of Forest Resources of the University of Washington administers the project under the direction of Dr. Stanley P. Gessel.

ANNUAL FIELD PROGRESS REPORT

Crewmen Bill Bizak and Bob Gonyea have been with the Project since its inception, enabling maintenance of high work quality and standardized procedures. The experienced field crew is also necessary to physically keep track of 160 separate research areas spread between the Canadian and Californian borders. With the exception of few notable instances, Bill and Bob can drive unerringly to any of the installations.

Phase I

The period from mid-October 1971 until mid-January 1972 was spent remeasuring diameters on first-year Phase I installations (two growing seasons after fertilization). Generally, the plots were found to be in excellent condition. Installation 12 was destroyed by ice and wind in the first winter after establishment and has been dropped from the study. Three plots of Installation 40 (east of Seaside, Oregon) were severely damaged by wind. Fortunately, the three undamaged plots constitute one complete series of treatments. Windfall or other damage on the remaining installations was rare.

Occasionally tags and nails are missing, sometimes on entire plots. In these cases, it has been possible to positively identify and retag each tree and locate the original nail hole so that accuracy was not jeopardized.

Emphasis in the remeasurement job has been on quality work and not speed. Occasional errors in original diameter measurements are being corrected in the field using an increment hammer. Plot boundary lines are also repainted and location maps updated.

In the office the new data are entered onto office copies of field sheets from which they can be keypunched and eventually stored on tape. Corrections in first measurement data are also made on the tapes. Information on 2-year basal area increment is summarized later in this report.

Remaining Phase I installations are being measured this winter (1972-1973). Again, the areas have, for the most part, come through the first 2 years without serious damage. It is anticipated that 2-year growth response data for the entire set of Phase I installations will be available by spring, 1973.

Phase II

The Phase II (thinning-nitrogen interaction) research plots are now in place, the summers of 1971 and 1972 having been devoted to this effort. Sixteen installations were located, surveyed, and marked for thinning in 1971, and another 27 installations were completed in 1972, making a total of 43 as required by the sampling design. Plot locations by province and owner are as follows:

Province I	
Dept. of Natural Resources	2
St. Regis	1
Pope & Talbot	2
Seattle Water Department	1
Weyerhaeuser	1
	7

Province II	
U.S. Forest Service	5
Univ. of Washington (Pack)	1
St. Regis	1
	7

Province III	
St. Regis	2
U.S. Plywood	1
Scott Paper	1
	4

Province IV	
Simpson	1
Longview Fibre	1
Dept. of Natural Resources	1
Oregon State Bd. of Forestry	2
U.S. Forest Service	2
	7

Province V	
ITT-Rayonier	1
Boise-Cascade	1
	2

Province VI	
Willamette Industries	2
Timber Service Co.	1
U.S. Forest Service	2
	5

Province VII	
Fruit Growers Supply	1
Bureau of Land Management	1
	2

Province VIII	
Georgia Pacific	2
Bureau of Land Management	2
U.S. Forest Service	1
Willamette Industries	2
	7

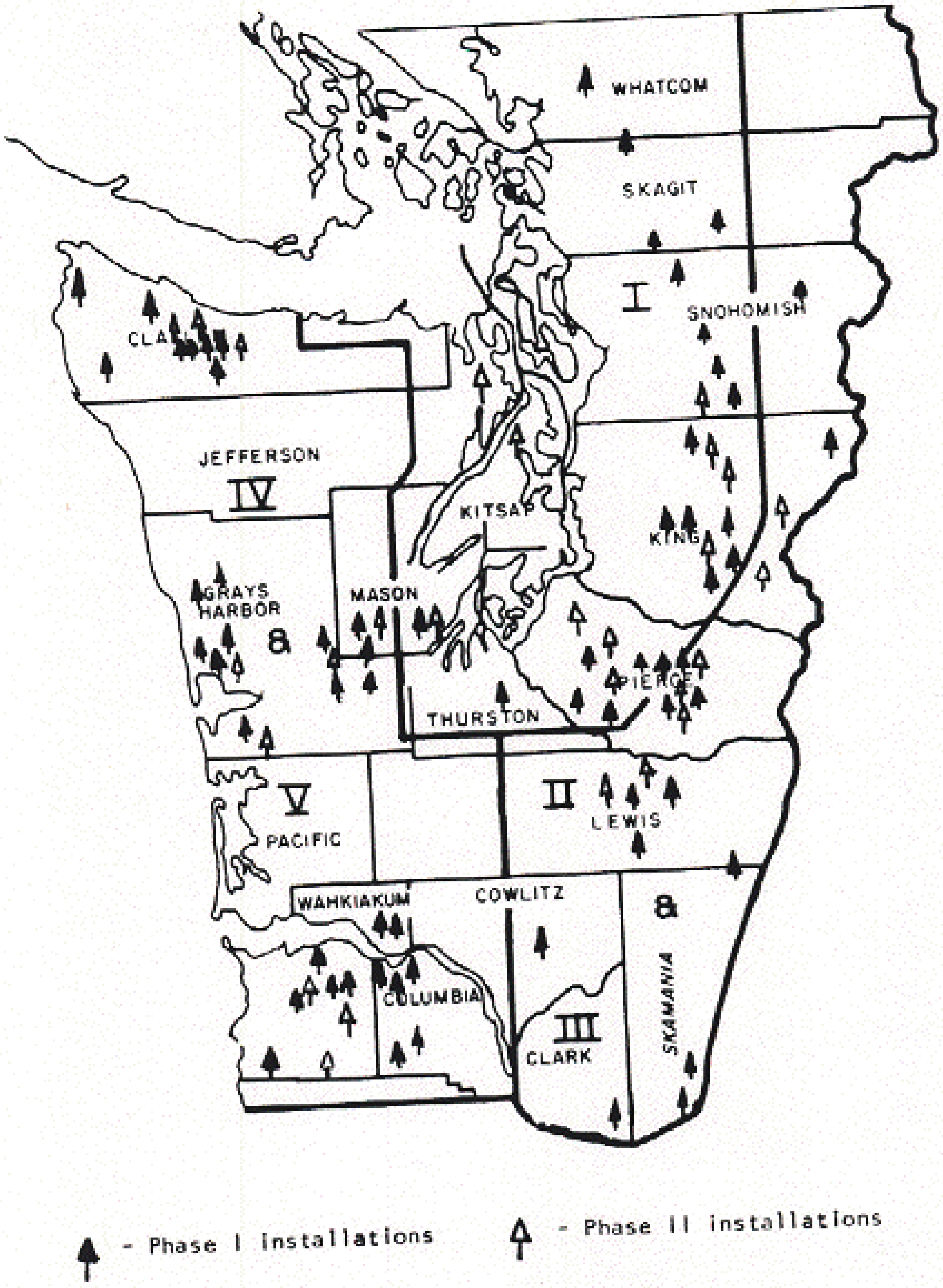
Province IX	
Boise Cascade	1
Publishers Paper	1
	2

Each Phase II installation consists of ten plots: two thinned with no fertilizer, two thinned with 200 pounds of nitrogen per acre, two thinned with 400 pounds of nitrogen per acre, two unthinned with a "complete" fertilizer treatment, and two unthinned with no fertilizer. In addition, every fourth Phase II installation contains two unthinned "bridge" plots with 200 pounds of nitrogen per acre, so named because they provide a bridge between Phase II and Phase I treatments by enabling some comparison of the effects of yearly weather variations. This would not have been necessary had it been possible to establish the thinning plots in the same years as the nonthinned plots.

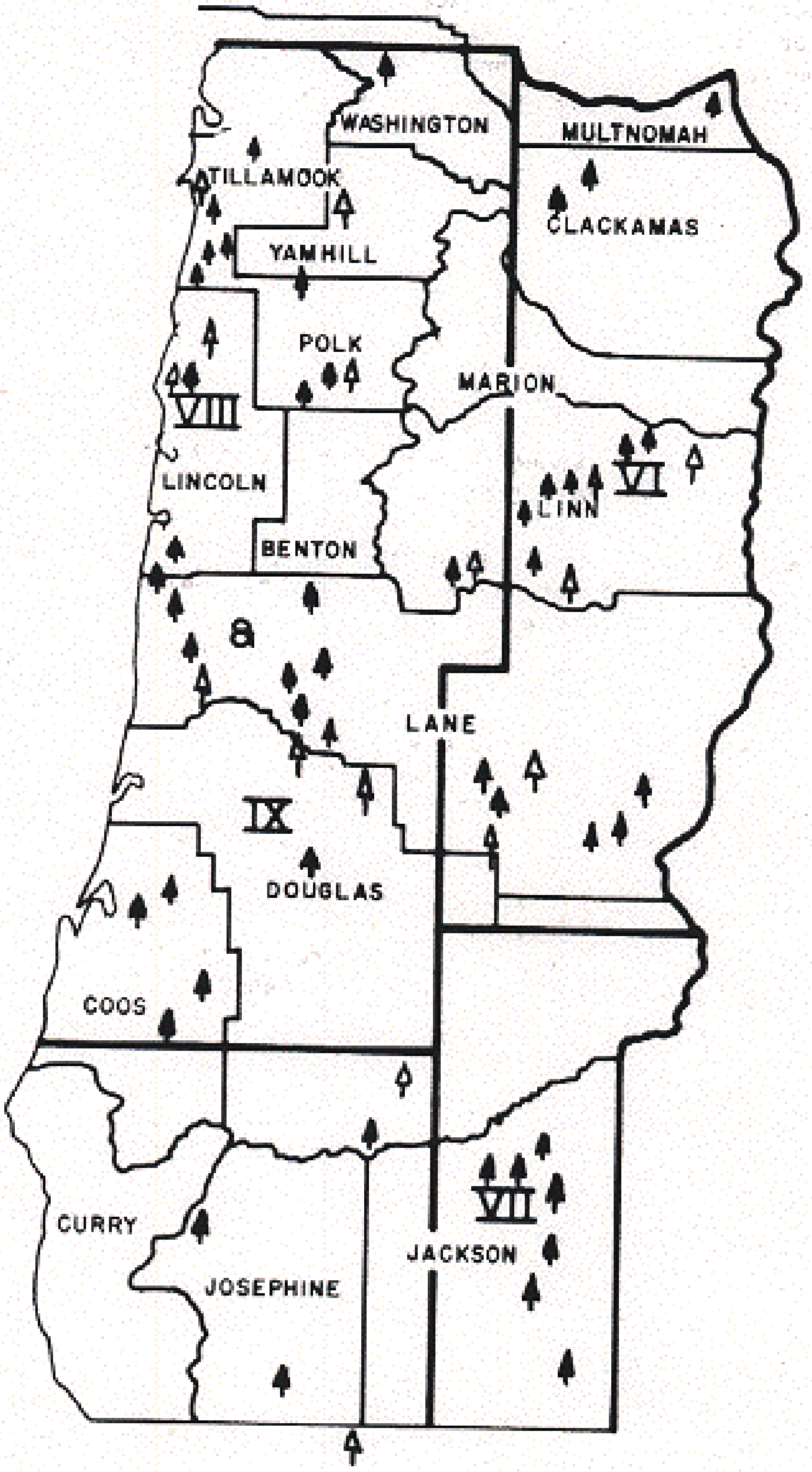
The "complete" fertilizer treatment that is being applied as part of Phase II consists of the following materials:

Element	Rate per acre (pounds)	Material
Nitrogen	400	Urea
Phosphorus	100	Treble-super-phosphate
Potassium	100	Potassium chloride
Calcium	164	Treble-super-phosphate and dolomite
Magnesium	50	Dolomite
Iron	50	Ferrous sulfate
Manganese	15	Manganese sulfate
Zinc	15	Zinc sulfate
Copper	8	Copper sulfate
Molybdenum	0.5	Sodium molybdate
Boron	1	Borax
Sulfur	54	Above products

WASHINGTON PROVINCES



OREGON PROVINCES



▲ - Phase I installations   △ - Phase II installations

(SCHEDULE OF MEASUREMENTS CONTINUED)

Winter 1973-1974	Remeasure Diameters and Heights[*]		Remeasure Diameters	
Winter 1974-1975		Remeasure Diameters and Heights[*]		Remeasure Diameters
Winter 1975-1976			Remeasure Diameters and Heights[*]	
Winter 1976-1977				Remeasure Diameters and Heights[*]

[*] Final measurements are taken after four growing seasons under current scheduling.

Several points should be borne in mind when examining the tree growth response data:

(1) Growth is presented only in terms of basal area. Volume increment will be available in 1974, after height measurements are taken.

(2) These are <u>raw</u> data. No attempt has yet been made to extract mensurational variation caused by initial stocking differences and prefertilization growth patterns.

(3) Two years is a very brief time in which to assess response to fertilization. Data presented here should be regarded as preliminary and used cautiously. Their primary value is to indicate response trends.

(4) Both gross and net growth data are presented. The former measures actual growth that occurred on all trees which were alive both at the beginning and at the end of the remeasurement period. The latter recognizes mortality (i.e., net growth = gross growth minus mortality). Comparison of fertilization treatments can best be accomplished using gross growth data because the extraneous influence of mortality, most of which is apparently due to non-fertilization causes, is eliminated. Net growth data, on the other hand, indicates true forest performance and hence becomes a guide to realistic growth projections.

TABLE 1. BASAL AREA GROWTH RESPONSE BY PROVINCE

Spp.	Prov.[1]	# of Installations[2]	Treatment (lbs of N per Acre)	GROSS GROWTH Annual Basal Area Growth (sq.ft.)[3]	GROSS GROWTH % Increase in Growth over control	GROSS GROWTH Range in Response % Low	GROSS GROWTH Range in Response % High	GROSS GROWTH # of Installations in which Response is 10% or greater	NET GROWTH Annual Basal Area Growth (sq.ft.)[3]	NET GROWTH % Increase in Growth over control
DF	I	8	0	5.82	--	--	--	--	4.54	--
			200	6.68	+15	-9	+30	5	5.37	+18
			400	6.91	+19	-7	+55	6	5.36	+18
DF	II	7	0	6.44	--	--	--	--	3.84	--
			200	8.88	+38	+15	+67	7	5.23	+36
			400	8.57	+33	+16	+49	7	6.12	+59
DF	IV	10	0	6.52	--	--	--	--	4.48	--
			200	7.70	+18	-12	+47	9	5.24	+17
			400	7.63	+17	-2	+51	5	4.51	+1
DF	VI	7	0	6.58	--	--	--	--	5.78	--
			200	8.54	+30	+10	+90	7	7.04	+22
			400	8.13	+24	-4	+75	6	6.89	+19
DF	VII	2	0	7.03	--	--	--	--	4.71	--
			200	7.68	+12	-2	+27	1	4.74	+1
			400	8.42	+27	-4	+58	1	6.06	+29
DF	VIII	7	0	7.46	--	--	--	--	5.61	--
			200	9.00	+21	+6	+30	6	7.38	+32
			400	9.43	+26	+5	+52	5	7.03	+25
DF	Average of 41 Installations		0	6.56	--	--	--	--	4.80	--
			200	8.07	+23	--	--	--	5.91	+23
			400	8.08	+23	--	--	--	5.86	+22
WH	III	5	0	10.37	--	--	--	--	9.01	--
			200	10.54	+2	-16	+28	3	9.41	+4
			400	11.35	+9	-12	+45	3	10.45	+16
WH	V	9	0	7.73	--	--	--	--	4.32	--
			200	8.14	+5	-9	+22	3	4.63	+7
			400	8.09	+5	-11	+34	3	3.17	-27
WH	IX	2	0	8.57	--	--	--	--	5.86	--
			200	7.85	-8	-15	-1	0	6.05	+3
			400	8.05	-6	-10	-2	0	6.76	+15
WH	Average of 16 Installations		0	8.66	--	--	--	--	5.98	--
			200	8.85	+2	--	--	--	6.30	+5
			400	9.10	+5	--	--	--	5.89	-2

[1] See Province Maps.

[2] Each Installation contains 6 plots.

[3] Periodic annual growth, 1970 and 1971.

TABLE 2. BASAL AREA GROWTH RESPONSE BY AGE

				GROSS GROWTH					NET GROWTH	
Spp.	Age Class (years)	# of Installations	Treatment (lbs of N per acre)	Annual Basal Area Growth (sq.ft.)	% Increase in Growth over control	Range in Response % Low	Range in Response % High	# of Installations in which Response is 10% or greater	Annual Basal Area Growth (sq.ft.)	% Increase in Growth over control
DF	15-30	6	0	8.24	--	--	--	--	6.84	--
			200	10.87	+32	+17	+90	6	9.02	+31
			400	11.05	+34	+5	+75	5	9.19	+34
DF	31-45	24	0	6.46	--	--	--	--	4.39	--
			200	7.83	+21	-2	+67	21	5.52	+25
			400	7.68	+19	-7	+52	17	5.28	+20
DF	46-60	11	0	5.88	--	--	--	--	4.60	--
			200	7.06	+20	-12	+62	8	4.88	+6
			400	7.34	+25	-6	+58	8	5.30	+15
	TOTAL	41								
WH	15-30	3	0	15.81	--	--	--	--	14.45	--
			200	15.55	-2	-14	+12	1	13.98	-3
			400	15.77	0	-8	+18	1	13.34	-8
WH	31-45	10	0	7.37	--	--	--	--	4.47	--
			200	7.60	+3	-16	+27	4	4.52	+1
			400	7.85	+7	-12	+45	3	5.02	+12
WH	46-60	3	0	5.87	--	--	--	--	2.52	--
			200	6.23	+6	-2	+28	1	4.59	+82
			400	6.62	+13	+2	+23	2	1.35	-46
	TOTAL	16								

TABLE 3. BASAL AREA GROWTH RESPONSE BY SITE

Spp.	50-year site class	# of installations	Treatment (lbs of N per acre)	GROSS GROWTH					NET GROWTH	
				Annual Basal Area Growth (sq.ft.)	% Increase in Growth over control	Range in Response % Low	Range in Response % High	# of installations in which Response is 10% or greater	Annual Basal Area Growth (sq.ft.)	% Increase in Growth over control
DF	1	8	0	6.08	--	--	--	--	3.24	--
			200	7.51	+24	-12	+67	7	4.35	+34
			400	6.72	+11	-2	+48	3	3.94	+21
DF	2	21	0	6.87	--	--	--	--	5.35	--
			200	8.45	+23	-9	+90	17	6.35	+18
			400	8.66	+26	-6	+75	19	6.59	+23
DF	3	8	0	6.13	--	--	--	--	4.64	--
			200	7.34	+20	-2	+47	7	5.87	+27
			400	7.23	+18	-4	+52	5	5.72	+23
DF	4	4	0	6.82	--	--	--	--	5.63	--
			200	8.64	+27	+25	+30	4	5.88	+4
			400	9.49	+39	-7	+58	3	6.52	+15
	TOTAL	41								
WH	2	8	0	6.87	--	--	--	--	3.72	--
			200	6.92	+1	-16	+27	2	4.13	+11
			400	7.32	+7	-12	+45	2	4.13	+11
WH	3	8	0	10.44	--	--	--	--	8.23	--
			200	10.79	+3	-14	+28	4	8.45	+3
			400	10.89	+4	-11	+34	4	7.65	-7
	TOTAL	16								

Some General Impressions of Response Data

(1) Douglas-fir response to nitrogen seems to be general throughout the study area. Thirty-five out of forty-one installations increased annual basal area growth by 10 percent or more when fertilized. Average annual response for all 41 installations was 23 percent.

(2) No clear trends are apparent in western hemlock. Response to fertilization is not as impressive nor as consistent as with Douglas-fir, at least not after the initial 2-year period.

(3) No consistent differences have shown up between applications of 200 and 400 pounds of nitrogen per acre. The heavier application may ultimately extend the duration of response, but that will not be clear until future measurements are made.

(4) Differences between gross and net growth indicate high mortality losses, which point toward the desirability of stocking control and salvage programs. Further light in this area will be shed by Phase II (nitrogen-thinning interaction) installations.

(5) All three age classes in Douglas-fir are responding to nitrogen. From an economic standpoint, the response of 46-60 year old stands is especially interesting. It would be valuable to have experimental plots in stands older than 60 years but there are none in the Regional Project.

(6) High sites are responding in about the same manner as low sites. This result is contrary to most published data, which indicate higher percent response on low sites.

PROJECT COMMITTEES

The cooperators' Liaison Committee met for its annual meeting on January 28, 1972. At this meeting, the following reports were presented:

Field Progress and Work Plan for 1972
Statistical Analysis Procedures
Soil Field Work and Analysis Studies in Foliar Nutrient Status
Graduate Student Research Projects

The next meeting is scheduled for January 26, 1973. The Liaison Committee members and their respective organizations are:

Name	Organization
E. C. Scheider	Boise Cascade Corporation
Jerry P. Re	Borden Chemical
Karl E. Karlsson	Broughton Lumber Company
Charles Thomas	Bureau of Land Management
H. W. Hawkinson	Chevron Chemical Company
W. E. Duggins	Collier Carbon & Chemical Corp.
M. E. Switzer	Cominco American, Inc.
G. H. Schroeder	Crown Zellerbach Corp.
D. R. Hopkins	Dept. of Natural Resources
M. E. Barron	Fruit Growers' Supply Company
R. V. Dickhaus	Georgia Pacific Corp., Bellingham Division
Philip Hahn	Georgia Pacific Corp., Springfield Division
David Mote	International Paper Company
J. P. Hendrickson	ITT Rayonier, Inc.
R. K. Stryker	Longview Fibre Company
William Lansing	Menasha Corp.
N. L. Case	Phillips Petroleum Company
T. J. Driscoll	Pope & Talbot, Inc.
R. W. Holmes	Publishers Paper Company
Kurt Munnich	Scott Paper Company
J. E. Monahan	Seattle Water Department
R. E. Wickman	Shell Chemical Company
A. O. Petzold	Simpson Timber Company
E. S. Sedlacek	St. Regis Paper Company
J. D. Beaton	The Sulphur Institute
G. M. Bowe	Timber Service Company
R. E. Miller	U.S.D.A. Forest Service
Robert Kline	U.S. Plywood Champion Papers, Inc.
E. C. Steinbrenner	Weyerhaeuser Company
M. H. Bergman	Willamette Industries, Inc.
G. C. Griffith	Willamina Lumber Company

The College Advisory Committee consists of:

Dean	James S. Bethel
IFP Director	David P. Thomas
Associate Dean	Stanley P. Gessel
Project Supervisor	William A. Atkinson
Research Associate Professor	Ian G. Morison
Forest Biometrist	Kenneth J. Turnbull
Forest Pathologist	Charles H. Driver
Wood Scientist	Harvey D. Erickson
Wood Scientist	Lawrence Leney
Staff Forester	Steven G. Archie

The Technical Advisory Committee met three times during the past year to discuss project matters and provide operational and research recommendations to principal investigator Dr. Stanley P. Gessel. Members of the Committee include:

Mr. George R. Staebler	Weyerhaeuser Research Center
Dr. Robert Strand	Crown Zellerbach Corporation
Dr. Richard E. Miller	PNW For. & Rge. Expt. Sta.
Dr. Paul Heilman	Washington State University
Dr. Eugene C. Steinbrenner	Weyerhaeuser Research Center
Dr. Dennis P. Lavender	Oregon State University
Dr. Donald B. Malmberg	Crown Zellerbach Corporation
Mr. Harry Anderson	Wash. Dept. of Natural Resources
Dr. Byron Thomas	Bureau of Land Management
Dr. Chet T. Youngberg	Oregon State University
Dr. James E. King	Weyerhaeuser Research Center

The principal subject deliberated this year was the foliar-diagnostic program outlined in the 1970-1971 Annual Report. The use of foliar nutrient status as a tool for detecting nutrient deficiencies, for predicting response, and for determining frequency and rate of application has been studied for a wide range of species around the world. Preliminary work indicates high potential for its use in the Douglas-fir region.

The Northwest Forest Soils Council with Drs. Miller and Heilman, T.A.C. members, organized a 2-day foliar analysis workshop in April, at the Forest Science Laboratory in Olympia. Researchers from British Columbia, Idaho, Washington, Oregon, and New Zealand participated. The purposes of the workshop were to examine what was known of the use of foliar nutrient status, to assess its potential use for Douglas-fir and western hemlock, and to define areas of investigation where more work is required.

Two divergent viewpoints on the ultimate value of foliar analysis emerged during the course of the meeting. One group suggested that foliar analysis is an imprecise tool because of the complexity of factors which affect a plant's nutrient status. It may be useful, together with soil analysis, to show which elements are in deficient supply, but it is not likely by itself to indicate how much of a certain element or combination of elements should be applied.

The other viewpoint proposes that through refinement of sampling procedures, it should be possible to use foliar analysis more precisely for diagnosing nutrient status of plants and determining subsequent fertilizer applications. The differrence is one of degree of belief in the ability to quantify the relationship of nutrient concentration and growth.

Definitions and methods varied according to the speaker's adherence to either of these philolophies. Dr. Heilman suggested that a reasonable guide might be to develop values on "critical ranges" of various elements so that probability levels of response could be summarized. These would show, for example, the range of inherent nutrient values for which response could be obtained 80 percent of the time, the range for which response could be obtained 30 percent of the time, etc. The questions of why and how much response would require greater refinement and correlation with individual genetic traits, stand structure, soil type, interactions of various elements, moisture supply, and other environmental factors. Whether these values should be determined by greenhouse trials, field plots, or some combination is also a question.

Dr. Dennis Lavender, T.A.C. member and tree physiologist at Oregon State University, is researching the regional range and variability of nutrient levels for Douglas-fir. Expanding on previous work by Dr. Ian Morison at Sumas, Washington, Dr. Lavender has obtained soil and foliage samples from eleven Oregon installations of the R.F.N.R.P. His work, funded by the Oregon State Board of Forestry, includes greenhouse bioassays of seedlings grown on restructured installation soils, laboratory soil analysis, field sampling of foliage from project plots and analysis thereof, and comparisons between these values and preliminary response data summarized previously in this annual report. Dr. Lavender's final conclusions await the result of further refinement of the statistical growth data.

There still remain many questions with respect to the type of sampling for foliar analysis appropriate to various objectives. The desire to achieve maximum accuracy may have to be compromised in the practical world by the seasonal availability of sample-gathering personnel and the physical difficulties of obtaining samples from high above the ground. Which crown class trees should be sampled? What parts of the crown should be sampled? What age (ages) branch foliage? What is the effect of tree age? What are the effects of sampling at various times of the year . . . during different moisture conditions . . . at various times in the diurnal fluctuations of trees? What is the influence of year-to-year climatic variation? What is the importance of dilution effects . . . of basic ecosite differences? How are these determined? Which are best?

These are complex questions, but very basic and not answerable at present. A concerted and well-designed investigation is required to begin to answer some of these questions, and a subcommittee of the Technical Advisory Committee is currently formulating an expanded effort as part of the R.F.N.R.P.

BUDGET REPORT

Project Year 03 (April 1, 1971 - June 30, 1972)

Year 03 was made a 15-month period so that the original Phase I budget would coincide with the newer Phase II account and so that both would correspond to the University's fiscal year.

A total of $138,500 was contributed to the support of Phase I and II during this period, as prorated for the 15 months. The actual field expenditures during this time were:

Salaries and wages	$48,918
Employee benefits	5,100
Supplies, equipment and services	7,000
Travel	17,795
Indirect costs	10,518
	$89,331

Year 02 had suffered a paper deficit of $9,834. This amount, together with $25,297 spent in support of graduate student basic research projects in year 03, for the first time left black ink at the bottom of the ledger in the amount of $14,038.

Since the initiation of the project in April, 1969, $236,322 has been spent on the field component and $45,140 on the basic research component, for a grand total of $281,462. The present state of fiscal solvency will insure the active development of further related research activities and the full potential of the field plot data.

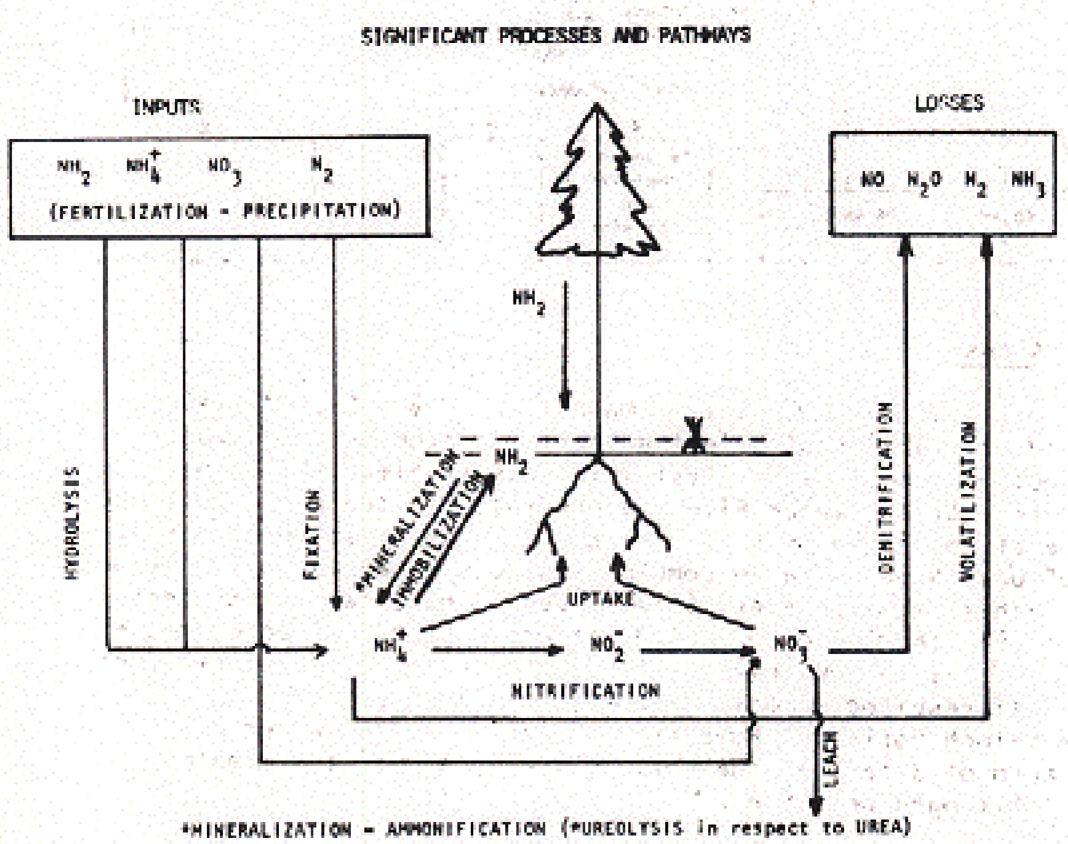
SOIL/FERTILIZER CHEMISTRY AND ENVIRONMENTAL RESEARCH

The 3-year study directed by Dr. Dale W. Cole in the area of soil/fertilizer chemistry and environmental aspects of forest fertilization was completed in May, 1972. A doctoral dissertation covering the work was submitted to the University by W. J. B. Crane entitled "Urea-nitrogen transformations, soil reactions, and elemental movement via leaching and volatilization in a coniferous forest ecosystem following fertilization."

The original research proposal called for an environmental assessment of nitrogen fertilization practices in the Douglas-fir region of the Pacific Northwest. However, the nature of the question involved a broad examination of soil chemistry, so that the study has opened several new avenues of research which may lead to methods for improved growth responses. The experimental approach used was that of lysimetry, and both soil-water tension lysimeters and gas lysimetry enabled the compilation of a comprehensive model of nitrogen movement and soil chemistry following urea-N fertilization. Figures 1 and 2 illustrate the complexity and interrelationships involved.

Figure 1 depicts the major pathways of nitrogen cycling in a coniferous forest ecosystem.

FIGURE 1: NITROGEN CYCLE

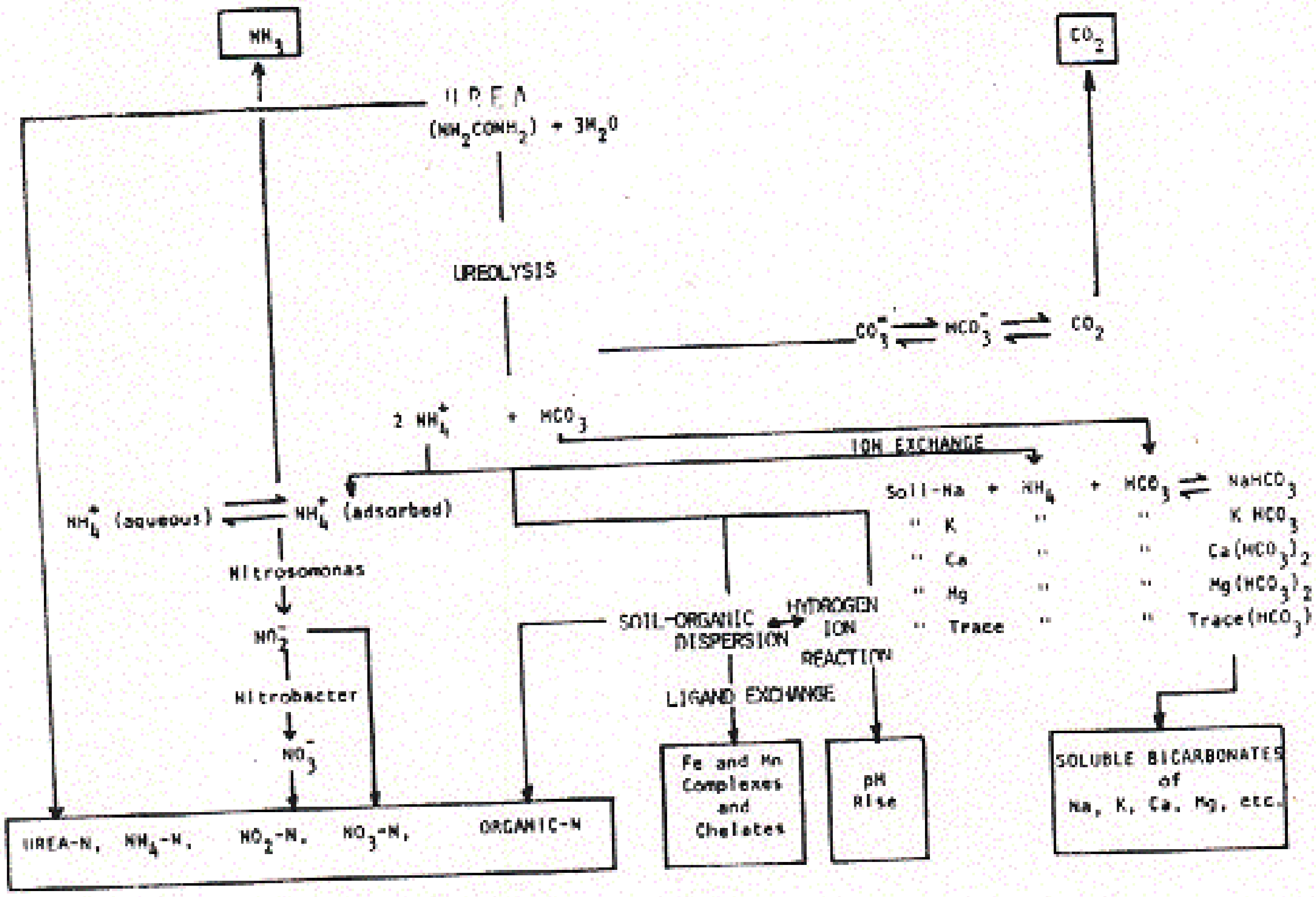


*MINERALIZATION - AMMONIFICATION (*UREOLYSIS in respect to UREA)

The specific chemistry and behavior of urea is depicted in Figure 2. In this figure, mineralization is specifically the ureolysis reaction. Nitrogen transformations, soil reactions, and elemental movement following urea fertilization of a coniferous forest ecosystem are shown.

FIGURE 2: UREA-N TRANSFORMATION, SOIL-REACTIONS, AND ELEMENTAL MOVEMENT

IN CONIFEROUS FOREST SOILS



Environmental Conclusions

The model has confirmed previous conclusions made by Cole and Gessel (1965)[*] in which they found an insignificant effect of fertilization on groundwater leached below the rooting zone in the forest which was studied (the Alan E. Thompson Research Forest at the Cedar River Watershed). In the current studies, which were also done at the Thompson Forest, the single application of approximately 200 pounds of urea N per acre in combination with a regular application of approximately 1 inch irrigation every 6 days (beginning 3 days after fertilization) resulted in the leaching of only 0.3 percent of the applied nitrogen through a depth of 6 inches in the soil profile. Heavier application rates of fertilizer and rainfall resulted in only slightly greater quantities of nitrogen leached through the 6-inch horizon. However, no nitrogen was leached below the rooting zone at a depth of 3 feet in the soil following any of the treatments (up to 400 pounds of nitrogen per acre).

A significant aspect of nitrogen movement was the almost total absence of nitrification. This is significant because of the fact that nitrate is relatively mobile in soil systems.

[*] Cole, D. W. and S. P. Gessel, 1965. "Movement of elements through a forest soil as influenced by tree removal and fertilizer additions." IN: C. T. Youngberg (ed.) Forest-soil Relationships in North America. Oregon State University Press. p. 95-104.

The causal factors of this phenomenon were not specifically identified, but it appeared that one contributing factor was the inhibition of nitrification by components of the soil organic complex. The results generally lend weight to a growing body of evidence that nitrification is not a major component of the mineralization step of nitrogen cycling in many closed canopy coniferous forests. Further research is required to determine the validity and extent of this hypothesis within the Douglas-fir soils in the Pacific Northwest.

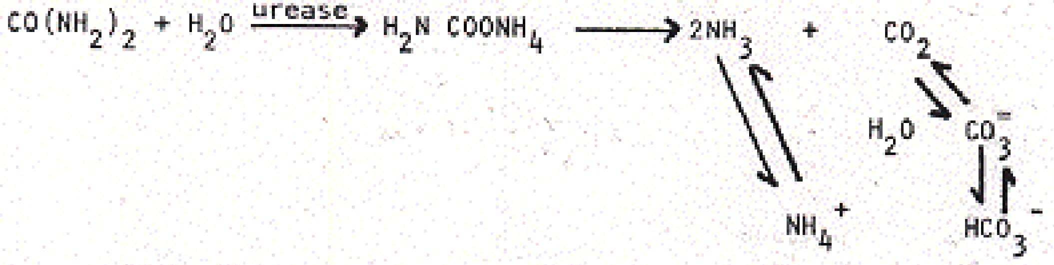
As the research concerned only one forest and soil type, any blanket conclusions from an environmental standpoint require qualification. In order to allow a generalized statement, it is necessary to compare the forests which comprise the range on which operational forest fertilization is at present a management tool with the Alan E. Thompson Research Forest.

The soil and site properties which determine the depth of leaching and stabilization of fertilizer-N in a forest soil profile involve many complex factors. In the short-term period following fertilization, it is mainly soil properties which determine nitrogen movement. Porosity and cation exchange capacity are two major soil variables affecting nitrogen movement. The Everett-type soil which was specifically studied is derived from a relatively coarse glacial outwash, and the soil profile developed under Douglas-fir since glaciation is relatively "immature." By comparison to the majority of Douglas-fir soil types in the Pacific Northwest, this soil has a high porosity and low total cation exchange capacity and would thus be considered as comparatively low in potential to retain nitrogen in urea and ammonium forms. The fact that this soil nonetheless produced these results allows for a broader generalization and extrapolation in the Pacific Northwest.

Nutritional Conclusions

Rainfall was the major variable which was found to influence the total chemistry and behavior of nitrogen in the soil. Rainfall had a diminishing total effect with time after fertilization, but rainfall occurring during the period immediately after fertilization (a period in which urea decomposes to inorganic ammonium form) can influence substantially the distribution of fertilizer-N in the soil profile. This is because urea is more mobile in the soil system than ammonium forms. Hence, rainfall occurring while fertilizer still remains mainly as urea results in deeper leaching of fertilizer-N in the soil profile.

The transformation by which urea is decomposed to ammonium carbonates is a hydrolytic reaction known as ureolysis.



$$CO(NH_2)_2 + H_2O \xrightarrow{urease} H_2N\ COONH_4 \longrightarrow 2NH_3 + CO_2$$

The reaction is biologically mediated by the specific enzyme, urease, which is associated with nonspecific microorganisms in natural soil systems.

The time period following fertilization in which urea decomposes to ammonium form (i.e., the rate of hydrolysis) is itself a function of rainfall and fertilizer distribution. It is also a function of specific soil and climatic factors, particularly urease enzyme status and temperature. The period can range from 2-20 days or more following fertilization.

The following table shows the effect of rainfall occurring after fertilization with 224 Kg urea-N/ha. The figures do not total to 224 because additional nitrogen was inherently present in the system and not all was retrievable by the methods used; however, the trend is evident.

Distribution of Fertilizer-N (kg/ha) in Forest Soil Profile Three Months After Fertilization.

	Depth 0-2 cm	Depth 2-5 cm	Depth 5-15 cm	Depth 15-30 cm	Depth 30+ cm
First rain at time of fertilization	37	55	37	89	9
First rain 3 days after fertilization	42	60	93	23	0
First rain 12 days after fertilization	87	90	20	12	0

It was also found that rainfall immediately or soon after fertilization could markedly reduce potential losses of fertilizer by volatilization. The magnitude of volatilization loss is dependent upon a number of climatic variables for a specific forest and fertilization treatment. If temperature, wind, and moisture conditions are such that they result in evaporative conditions at the soil surface, then fertilizer-N can be lost as volatile ammonia. However, wind conditions at the forest floor are often minimal, particularly if an understory is present, and temperatures in the spring and autumn months (normal fertilization period) in the Pacific Northwest are usually moderate. It was concluded that losses of 12 percent or more can occur if fertilizer-N remains unleached in the forest floor for extended periods following fertilization. However, it was also concluded that if rainfall occurred within 3-4 days following fertilization, then volatilization losses would rarely exceed 5 percent.

Rainfall occurring soon after fertilization would presumably have some significance in terms of nutritional efficiency due to the saving of nitrogen otherwise lost by volatilization. However, follow-up research is required to determine the nutritional significance of nitrogen distribution within the soil as affected by rainfall or irrigation. A pilot trial designed to determine if a relationship exists between growth response and different fertilizer-N profiles in the soil was established as part of this research in 1971. No data are yet available, however.

The occurrence of early rainfall following fertilization was also found to have a considerable effect on the nature and magnitude of reactions in the surface soil horizons. These reactions included a dissolution of fulvic acid and the displacement of potassium into soil-water solution. The former reaction involved a mobilization of iron and manganese as organic/metallic complexes in the soil. The pH of the soil and soil-water was also found to increase following the mineralization of urea to ammonium form. Follow-up research will be necessary to determine the nutritional significance of these secondary reactions.

Summary of Conclusions

1. Following fertilization with levels of 100-400 pounds of urea N per acre, there is no apparent loss of nitrogen via leaching through the soil.

2. Conversion of urea-nitrogen to either nitrate or nitrite in the Douglas-fir forest environment studied is negligible. There appears to be little danger of damaging water quality if nitrification of applied fertilizer and leaching movement remain at negligible levels.

3. Rate of hydrolysis and depth of fertilizer penetration into the soil profile are dependent upon wetness of the soil and rainfall patterns after application. From the point of view of most effective use of nitrogen, it is best to have solution and movement into the soil as quickly as possible. Therefore, application of urea to dry soil followed by protracted dry periods is not a good practice.

4. If precipitation occurs 3-4 days after application, then volatilization is less than 5 percent of the applied nitrogen. However, losses of over 12 percent can occur if the urea remains on the forest floor for 2 weeks or more after application.

FOREST FERTILIZATION AND FOREST DISEASE

In the summer of 1970, a 2-year study concerning nitrogen fertilization and forest disease was initiated by Master's student B. D. Nelson and pathologist Dr. Charles H. Driver. The purposes of the study were to (1) begin monitoring disease conditions in certain installations of the regional project and (2) conduct research on the effect of nitrogen fertilization on forest root rot diseases. Methods were explained in last year's annual report. In June, 1972, the study was concluded.

I. Disease Monitoring of Field Plots

During the summers of 1970 and 1971, 47 Phase I installations were surveyed to evaluate disease conditions in and around the plots; 40 installations were Douglas-fir and seven were western hemlock.

Most of the Douglas-fir installations were free of serious disease problems. Only six were located in stands having a high incidence of root rot disease caused by Poria weirii. Although some bark beetle activity was found associated with root rot centers, no activity was noticed in stands free of disease. There was only minor occurrence of root rot caused by Armillaria mellea. Mistletoe did not appear to be a problem in the Douglas-fir installations.

In the western hemlock installations, the percentage infection of the stand by Fomes annosus ranged from a low of 13 percent to a high of 50 percent. Occurrence of other root rot diseases was minor. Although mistletoe was commonly present in western hemlock installations, it did not appear to be serious. No unusual insect activity was observed in these installations.

Considering the common regional occurrence of Poria weirii in Douglas-fir stands and the apparent moderate to high frequency of Fomes annosus infections in western hemlock stands, the field crew can be commended for laying out installations in areas generally free of disease problems.

Information collected by the disease survey will benefit the project in two ways. First, it can be used to help explain the anomalies which might occur in growth response data from the plots surveyed. Secondly, now that the disease conditions have been benchmarked in the 47 installations, it is possible to monitor changes in disease occurrence which may be associated with a particular plot treatment.

II. Research on the Effects of Nitrogen Fertilization on Forest Root Rot Disease

There were two basic goals to this research: (a) to compare the effects on artificially established host-pathogen associations between urea-fertilized soils and unfertilized soils (referred to as the seedling experiment) and (b) to compare the decay resistance of wood from roots of urea fertilized and unfertilized Douglas-fir and western hemlock trees (referred to as the decay experiment). In both experiments there were three host-pathogen associations studied. The following is a description of the results of the research on each association.

Douglas-fir and *Poria weirii* association. In the seedling experiment, urea nitrogen fertilization did not increase the activity of *Poria weirii* in the soil or increase the susceptibility of the seedling roots to infection by the pathogen. In fact, there was evidence that the opposite may have occurred. Survival of wound inoculated seedlings was greater in the fertilized treatments. This would suggest that either the fertilized soil environment reduced the activity of the pathogen or the resistance of the seedlings to infection was increased by fertilization. Survival of the pathogen after nine months in the soil was unaffected by the fertilizer application. In the decay experiment, rootwood from urea fertilized Douglas-fir trees was found to be more resistant to decay by *Poria weirii* than rootwood from unfertilized trees. The increased decay resistance of the fertilized tree rootwood is apparently due to a greater amount of fungal inhibitory compounds in the wood.

Douglas-fir and *Fomes annosus* association. In the seedling experiment, urea fertilizer had no effect on this host-pathogen association. *Fomes annosus* was found to be very virulent on Douglas-fir seedlings in both treatments. Survival of the pathogen was high in both fertilized and unfertilized soil. The results of the decay experiment showed that rootwood from fertilized Douglas-fir trees was more resistant to decay by *Fomes annosus* than the unfertilized tree rootwood. This agrees with the results obtained in the decay experiment on the Douglas-fir and *Poria weirii* association.

Western hemlock and *Fomes annosus* association. Western hemlock seedlings were found to be very susceptible to fertilizer toxicity damage. Approximately 97 percent of the fertilized seedlings died during the early months of the experiment and most of mortality was due to the fertilizer application. Because of the high mortality in the fertilized treatment, the results from the seedling experiment are inconclusive regarding the effects of urea fertilizer on this host-pathogen association. In the decay experiment, no difference in the resistance to decay by *Fomes annosus* could be found between rootwood from fertilized and unfertilized western hemlock trees.

Based on the results of the seedling-greenhouse and laboratory tests, the following statements can be made:

1. Forest fertilization with urea will probably not increase *Poria weirii* root rot problems in Douglas-fir stands.
2. Similarly, urea fertilization will probably not of itself increase *Fomes annosus* root rot problems in unthinned stands of Douglas-fir. However, there is evidence to indicate that the pathogen may become a serious problem in any stand under intensive management when thinning is conducted.
3. Roots of Douglas-fir trees may be more resistant to decay by *Poria weirii* and *Fomes annosus* after urea fertilization.
4. Young western hemlock stands may suffer some root damage from the fertilizer applications. If so, they could be predisposed to attack by root rot pathogens.

TREE FERTILIZATION AND WOOD QUALITY

Once growth response is known, the next logical question relevant to an economic evaluation of forest fertilization concerns wood quality. In an attempt to provide information on this subject, the R.F.N.R.P. has undertaken a major new research effort under Drs. Harvey D. Erickson and Lawrence Leney of the College of Forest Resources.

The primary objective of this study is to determine the effect of accelerated growth caused by fertilization and thinning upon the more important anatomical characteristics and physical properties of Douglas-fir. Effects of site differences and geographic location will also be considered.

The implications of intensive cultural practices for producing a greater wood supply are now well known and much research has been done throughout the world to measure growth responses. Relatively less effort has been expended to determine the relationship of wood quality to increased growth rate, but the amount of work done in this area in the last 15 years is still impressive.

Although broad generalizations can be made on causes of wood quality changes, there are often great differences in quantitative responses by various species and the relative importance of any given factor. There is adequate evidence that studies are needed on important species in a variety of locations, sites, and forest treatments if practical decisions are to be made on how to manipulate a forest in order to obtain the optimum quantity of useful wood. Extensive and intensive research on the southern pines in recent years exemplifies this point of view.

A brief summary of existing information on general anatomical and physical characteristics is presented here. In the years up to 1960, certain conclusions had been reached. Age, especially in the first two decades of a tree's life, was found to have a definite effect on tracheid length. Tracheid length increases from the pith outward. Generally growth rate decreases from the pith, but with no uniform pattern. Percent summerwood tends to increase for two or three decades as does specific gravity.

However, there are conflicting reports on the effect of faster growth on specific gravity. Paul (1963) has reviewed the silvicultural aspects of controlling specific gravity. He concludes that a growth objective for average density of coastal Douglas-fir be set at 6 to 10 rings per inch. Drow (1957) found that percent summerwood of Douglas-fir tends to increase with a decrease in growth rate (in wood less than 20 rings per inch) but specific gravity is higher in slowly grown wood at a given percentage of summerwood. Wellwood and Smith (1962) compared the long and short radius of the same tree to arrive at their conclusion that the faster growth caused some increase in specific gravity. In another location, however, specific gravity decreased as site index and growth rate increased. Knigge (1962) reported that several growth effects accounted for only one-third of the density variation but ring width and age were clearly important.

Duffield (1964) found very diverse patterns of tracheid length relative to rings from the pith. Similar patterns were often found in trees of close proximity. Harrison (1963) found a very good correlation of tracheid length with the logarithm of age and only a slight change after 20 years.

The first study on wood from fertilized Douglas-fir was by Erickson and Lambert (1958) who reported faster growth but reduced specific gravity in young trees on thinned and fertilized stands on high Site V. Growth rate and volume increment, however, more than compensated for the density loss. Fertilization and thinning of the trees starting at age 20 caused very little difference in chemical analysis of the major constituents but any change was toward slightly lower cellulose after fertilization. Kennedy and Jaworsky (1960) found rate of growth (not due to fertilization) had little influence on cellulose content.

Sastry (1967) found a general decrease in specific gravity, percent summerwood and mean tracheid length in wood of three trees after fertilization. Siddiqui, et al. (1972), reported a 74 percent increase in volume, a 10 percent decrease in specific gravity, and a small decrease in extractive content in six trees thinned and/or fertilized. Megraw and Nearn (1972) said that fertilizing and/or thinning (two trees per treatment) of stock initially 8 to 10 years old caused more intermediate-density fiber to be formed. This was due to a lower latewood density and an increased earlywood density, but the overall wood density was not affected.

The reports do not agree on the effect of growth rate of specific gravity. The problem is too complex for a simple answer. Reasons for differences probably include different tree populations and genetic characteristics, different growing conditions (site and even microsite), very small number of samples in some cases, errors from too small core samples and uneven loss of springwood from small cores, and difficulty of accounting for the effects, in some cases, of juvenile wood, and where or when juvenile wood ceases and mature wood begins.

Using fertilized and thinned plots which were treated ten or more years ago by researchers at the College of Forest Resources and cooperating organizations, the research intends to examine the following wood quality characteristics:

1. Specific gravity before and after treatment and on control trees over the same periods. Specific gravity (density) is the best single criterion in which to judge wood quality. At an April meeting of a subcommittee of the Regional Level of Growing Stock Committee, density and growth rate were chosen to have priority in wood quality studies. Density gives a measure of production and of wood quality. It indicates fiber wall thickness to a fair degree and also mechanical strength for structural purposes.

2. Growth rate--ring widths. Growth rate together with density indicates amount of fiber production. A small decrease in density may well be more than compensated by greatly increased growth rate.

3. Percent summerwood and springwood. These are relatively easily measured and make the interpretation of density and growth rate more meaningful. Generally, the percentage of summerwood should not drop substantially for use as structural material. Percent summerwood can be used as a visual indication of wood density.

4. Tracheid length of summerwood tissue. This characteristic is associated with wood strength and some paper properties. Generally, the tracheid length should be near normal for the species to maintain the species properties.

5. Fibril angle of summerwood tracheids on selected groups of trees showing large differences in growth rate and specific gravity. A large fibril angle is undesirable for most solid wood uses because it causes higher longitudinal shrinkage and warping. Pulp properties are affected to a lesser degree and there is more averaging of fiber properties in the pulp mass.

6. Lignin analysis and extractives analysis on a reduced and selective basis. In the initial phases of this project, a total chemical analysis of extractives, lignin, holocellulose, and alpha cellulose would entail more laboratory time than is available. Extraction must be done first to get an accurate lignin determination. The lignin content is the ingredient least desired and the amount and how it changes is of importance from the standpoint of many aspects of utilization, especially pulp products.

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