RESPONSE OF NORTHWEST FORESTS TO ELEMENTS OTHER THAN NITROGEN

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ABSTRACT

This paper reviews the development of forest tree nutrition research in the Northwest. Field observations, foliar analysis, and greenhouse cultures using both solution and forest soil as media established deficiency symptoms and levels for major and minor elements. Field experimentation with the entire range of essential elements has failed to demonstrate widespread deficiencies of elements other than nitrogen. Certain test areas have shown somewhat better response to combinations of elements; but because of the limitations of experimental design and field variation, the response does not generally have a high statistical significance. In some cases of apparent response, application of fertilizer materials other than nitrogen does not appear to be economic. There is sufficient evidence of response to other elememts to suggest that much work needs to be done. Increased utilization of forest materials, shorter rotation, and greater yields with nitrogen fertilization all point to the fact that many of the Northwest forest areas could have future elemental deficiencies, other than nitrogen.

INTRODUCTION

Forest fertilization research and practice has been addressed in various sessions of this symposium. The discussions have concentrated on nitrogen. This may lead to the impression that laboratory and field research on other elements, e.g., phosphorus, potassium, sulfur, has been totally neglected in the Northwest. However, this is not true as this review will show. Specific interactions of N and S are addressed in a separate paper of this symposium.

Table 1. Yield and elemental composition of western redcedar in tank cultures.

Treatment	Dry Wt. GMS	N	P	K	Foliage Content % CA	MG
Complete	90.5	2.64	0.406	1.80	1.04	0.232
- B	79.8	2.65	0.419	1.74	0.94	0.249
- FE	67.6	2.73	0.432	2.28	0.94	0.238
LOW N	22.6	1.54	0.267	2.39	1.44	0.306
LOW P	44.0	2.67	0.112	1.70	1.04	0.204
LOW K	54.8	3.07	0.452	0.36	1.24	0.331
LOW CA	51.0	3.18	0.475	2.30	0.19	0.457
LOW MG	80.0	2.68	0.436	1.89	1.05	0.159
LOW S	66.1	2.76	0.403	1.75	0.98	0.167

Plants started in tanks April 20, 1952
Plants harvested November 24, 1952
Yield is total WT. of 22 plants

BACKGROUND

The early work of Gessel and Walker (1950) and Walker, Gessel, and Haddock (1955) on mineral nutrition of Northwest forest species involved a series of greenhouse experiments using sand, solution, or soil culture techniques. The need for all essential elements by Northwest species was quickly demonstrated in solution cultures. These experiments established the effect of extreme, as well as low level deficiency. Methodology and typical results are shown in Tables 1 and 2 and Figures 1 and 2.

The next step was to explore nutrient status of local forest soils and effect of elemental additions by using a standard test plant (Romaine lettuce) as well as forest tree seedlings. These experiments demonstrated that (1) nutrient demands of forest tree species on a soil system are different than Romaine lettuce, and (2) availability of elements in a soil system is different for forest trees than for the standard test plants. The role of mycorrhizal relationships in modifying nutrient uptake by forest trees thus became apparent as a result of these experiments and is receiving much research effort at the University of Washington.

A common result from such experiments (Figure 3, Table 2) was that Romaine lettuce would die without P addition or, in some cases, lime. Yet, forest seedlings in most forest soils were relatively unaffected by additional P. These experiments also suggested that in some soils Mg or K were sufficiently low

Table 2. Yield of Romaine lettuce grown on low and medium site soils from Pack Forest, La Grande, Washington, with and without the addition of fertilizers.

Treatment	Soil #74 Ave. Dry Wt. gms.	Soil #74 Percent of $N_2P_6K_1C_a$	Soil #84 Av. Dry Wt. gms.	Soil #84 Percent of $N_2P_6K_1C_a$
Ca (Lime)[a]	0.13	4	0.10	4
$N_2P_6K_1Ca$[a]	3.59	100	2.35	100
$N_0P_6K_1Ca$	1.29	36	2.79	119
$N_2P_0K_1Ca$	0.10	3	0.10	4
$N_2P_6K_0Ca$	3.87	108	2.78	118
$N_2P_6K_1CaMg$	3.05	85	2.70	115
$N_2P_6K_1CaS$	2.79	78	2.64	112
$N_2P_6K_1CaB$	3.93	109	2.96	126
$N_1P_2K_1Ca$	3.93	109	3.74	159

[a]Subscripts refer to elemental application levels in hundreds of pounds per acre.

to reduce growth of both Romaine lettuce and tree seedlings in the greenhouse.

These greenhouse experiments were supplemented by field observations and by collection and analysis of foliage to establish both visual symptoms and actual elemental levels at which deficiency exists in conifers. Results from some of this work are shown in Table 3.

Recent greenhouse pot tests by Anderson (1979) on two soils from the Quinault Indian Reservation demonstrated a response by western hemlock and Sitka spruce to P as well as lime. These soils have developed under high rainfall in the western Olympic Mountain area, are quite acid, and have high Al contents. Heilman and Ekuan (1980) have also shown a P response in greenhouse pot tests with Douglas-fir using a Washington coastal soil.

Figure 1. Douglas-fir seedlings growing in nutrient solutions to demonstrate nutrient deficiencies.

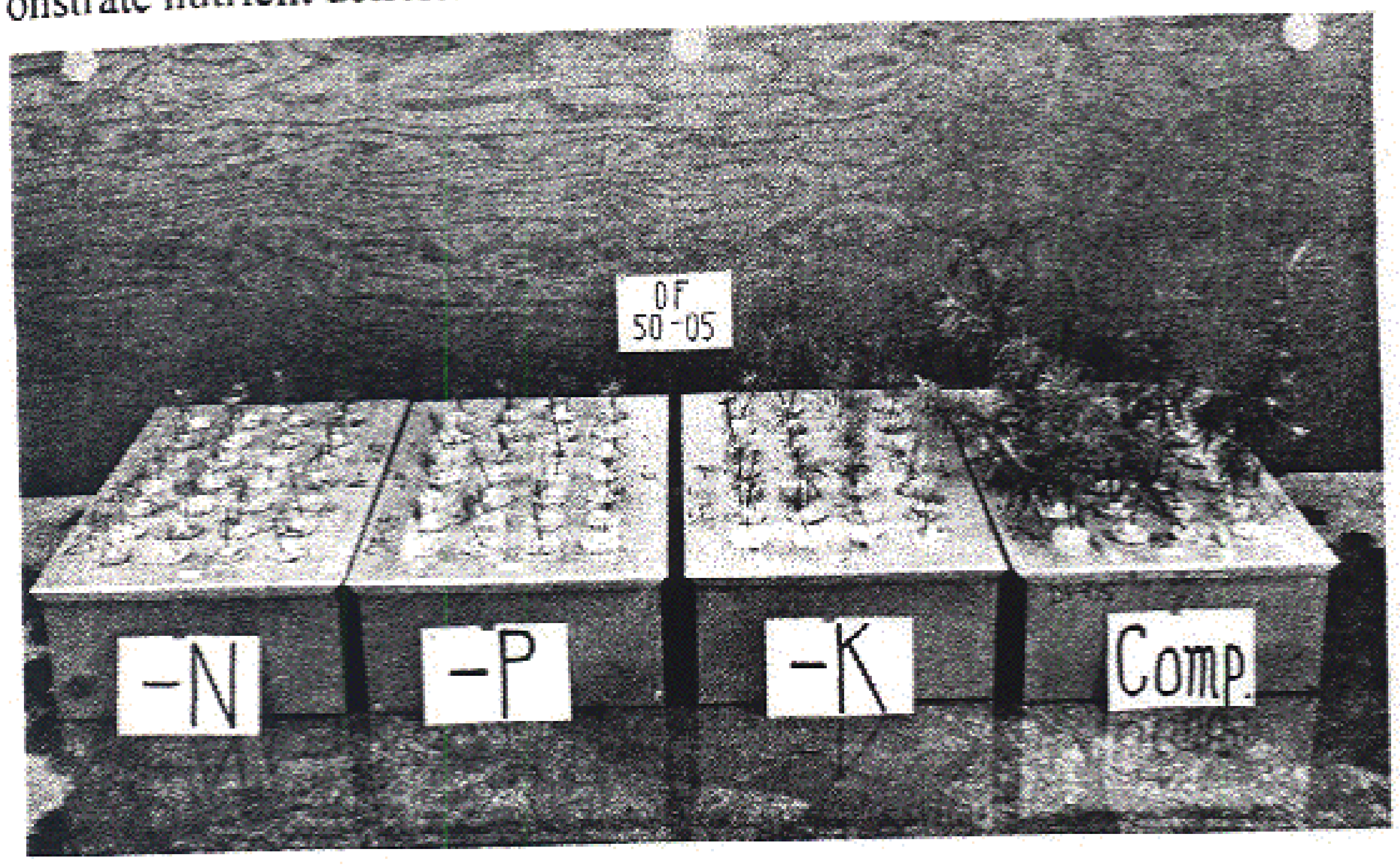
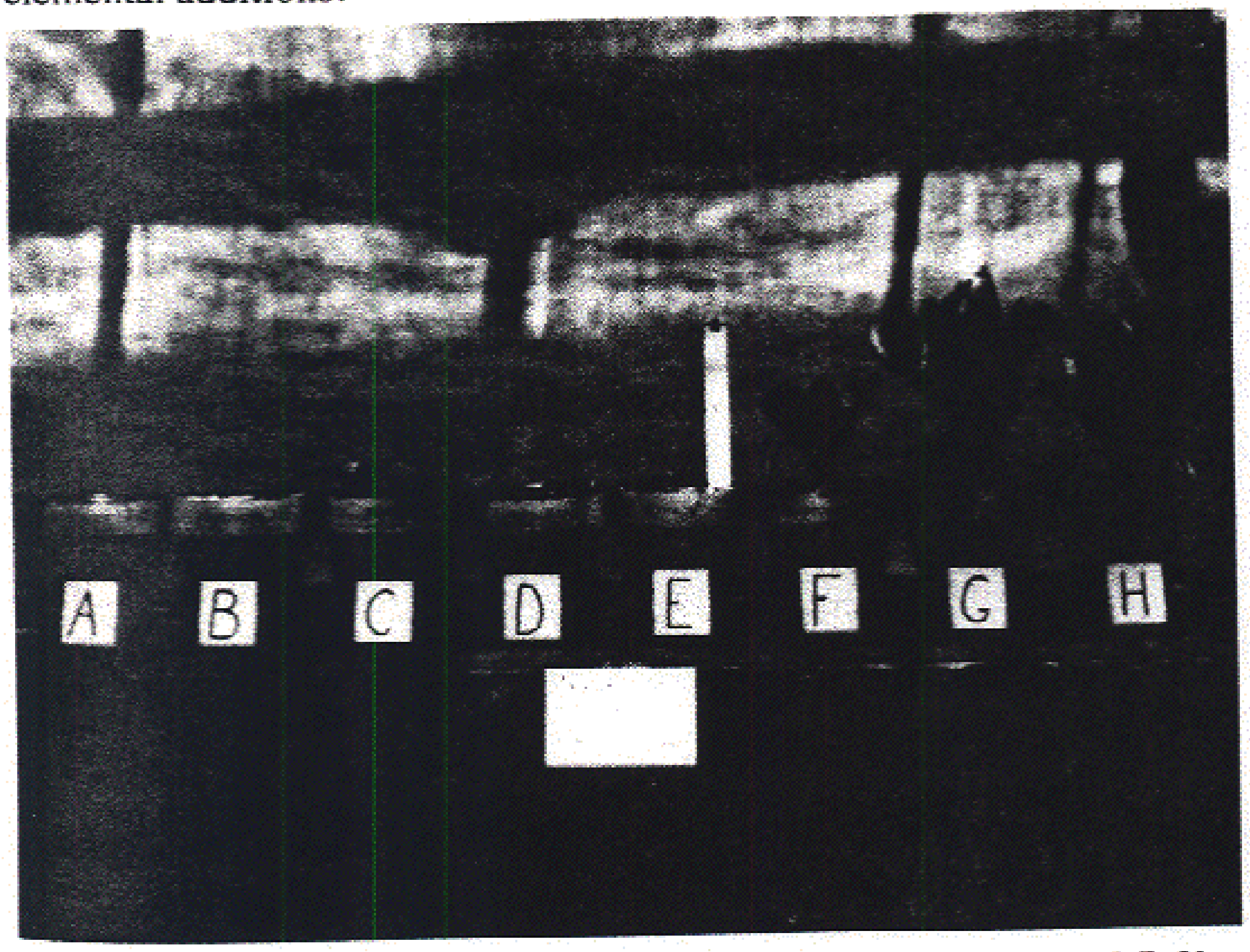


Figure 3. Romaine lettuce growing in a forest soil with and without elemental additions.



A—No fertilizer; B—$N_3P_4K_1$; C—N_0P_{41}; D—$N_3P_0K_1$; E—$N_3P_4K_0$; F—$N_3P_{10}K_1$; G—$N_3P_{20}K_1$; H—$N_3P_{20}K_1$Lime (2t/acre)/L (subscripts refer to hundreds of pounds per acre)

Early greenhouse tests with soils indicated that available N supply was deficient in many forest soils and that response to N application in the forest could be expected in western Washington (Table 4, Figure 4). As a result, a number of field trials

Figure 2. Douglas-fir seedlings after growth in nutrient solutions pictured in Figure 1.

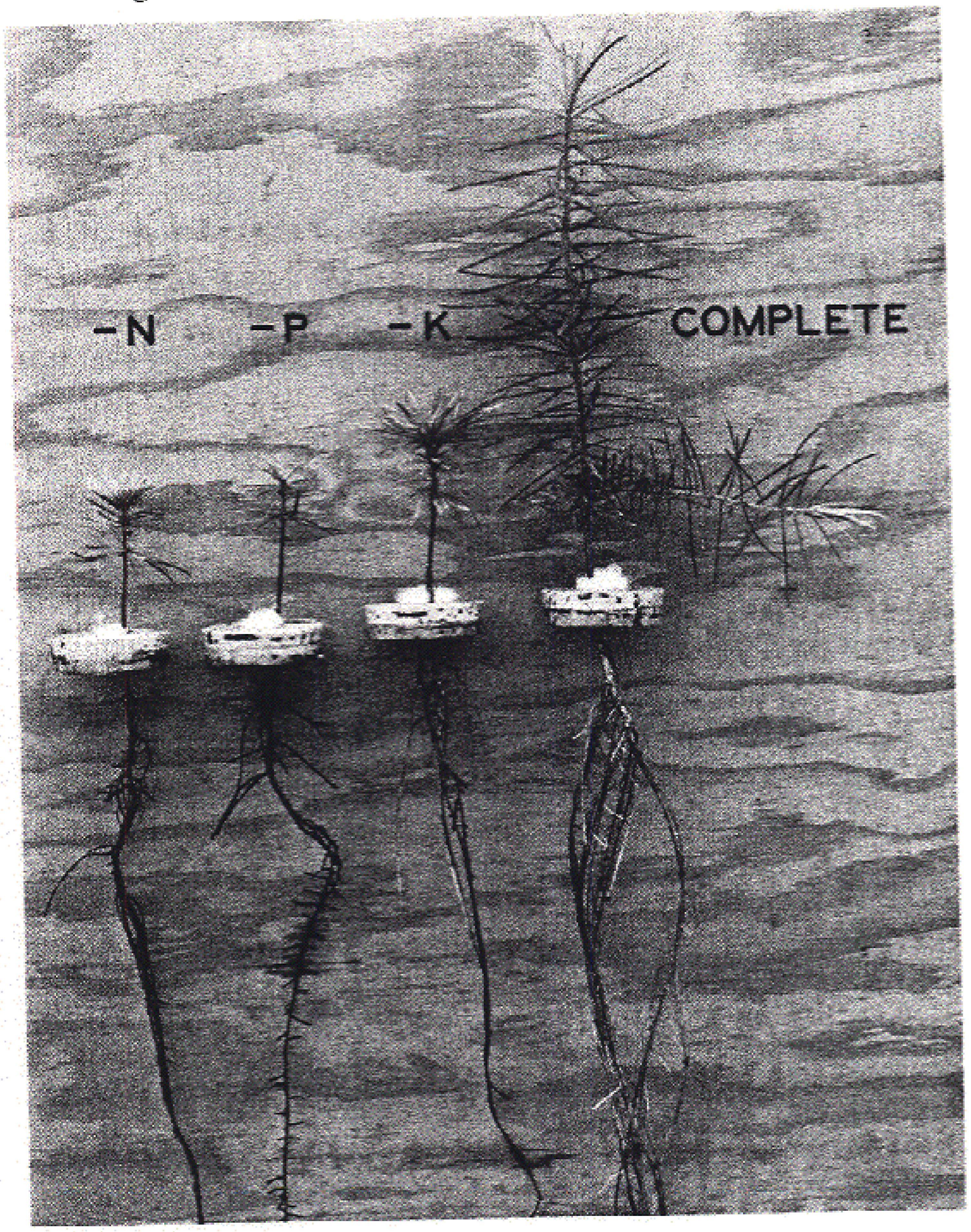


Figure 4. Radiata pine in forest soil with nitrogen and Boron additions.

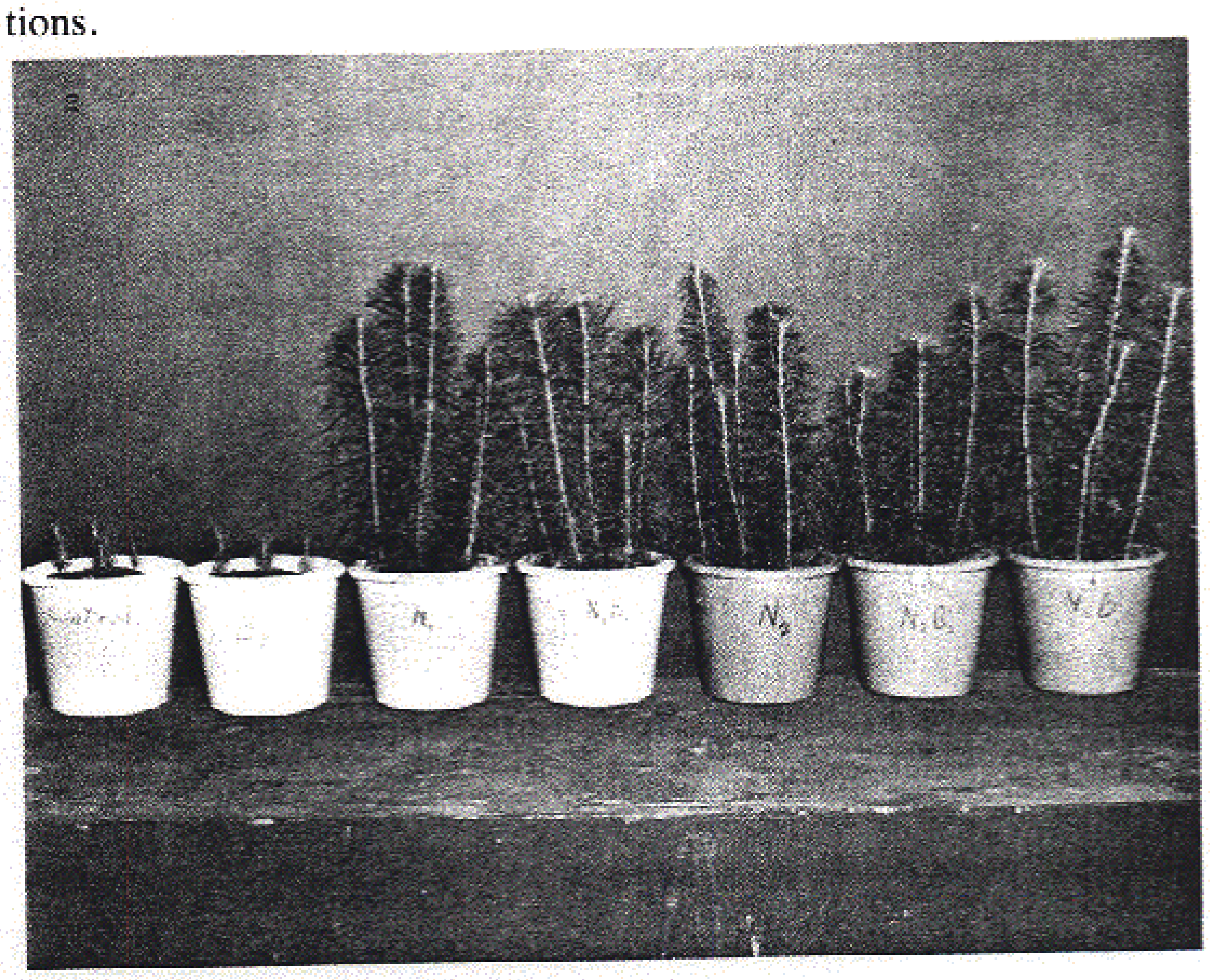


Table 3. Results of tissue analysis of Douglas-fir and western redcedar.[a]

			(A) Douglas-fir					
Vey gravelly loam	Chlorotic	1949	10	0.39	0.84	0.89	0.18	0.91
		1948		0.78	0.63	0.79	0.31	0.85
Shallow loam	Chlorotic	1949	10	0.28	0.86	0.05	0.082	1.17
		1948		0.58	0.86	0.58	0.10	1.24
		1947		0.80	0.81	0.53	0.069	0.97
Gravelly loam	Green	1949	11	0.32	0.16	0.64	0.16	0.95
		1948		0.44	0.13	0.73	0.29	1.07
		1947		0.58	0.15	1.04	0.28	1.06
Loam	Green	1949		0.28	0.17	1.21	0.78	1.59
		1948		0.38	0.14	0.92	0.070	----
		1947		0.47	0.14	0.75	0.067	1.42
Deep loam	Green		4	0.35	0.73	0.90	0.24	2.10
			(B) Western Redcedar					
Cravelly loam			100	1.10	1.14	0.66	0.063	1.24
			11	1.78	0.70	0.52	0.059	1.27
Loam			100	1.57	0.77	0.39	0.092	0.70
			100	1.31	0.94	0.55	0.090	1.44

deficiencies in Douglas-fir and western redcedar.

Table 4. Western redcedar--pot test soil 87--Pack Forest.

Treatment	Dry Wt. GM/S Pl	N Old	N Young	P Old	P Young
		Foliage Content %			
A-Control	3.98	0.55	0.72	0.103	0.112
B-$N_2P_4K_1$	18.56	1.15	1.52	0.104	0.153
C-$N_0P_4K_1$	3.29	0.64	0.94	0.125	0.173
D-$N_2P_0K_1$	18.49	1.03	1.40	0.090	0.141
E-$N_2P_4K_0$	15.54	1.03	1.55	0.098	0.160
G-$N_2P_4K_1$L	18.81	1.06	1.60	0.101	0.168
H-$N_2P_4K_1$B	16.82	1.05	1.33	0.116	0.173

Notes:
Planted May 10, 1951
Harvested September 30, 1953
Nitrogen Addition, May 1953
Lime at rate of 2 tons/a-
B at rate of 3.5 lbs./A

near Darrington beginning in 1948 and continuing over a period of years. These field trials were generally designed to evaluate N at different levels and in different forms, but also other elements. Therefore, the treatments usually included N, P, K, Mg singly and in combinations. An array of trace elements were also applied to many of the plots.

These early tests were followed by a series of more complete experiments to evaluate the relative response of both major and Walker working in conjunction with Dr. T. N. Stoate who joined the fertilizer research work in the Northwest after his pioneering efforts in Australia. Dr. Stoate established many field trials on Vancouver Island while working with MacMillan-Bloedel Ltd. (Crossin, et al. 1966, Handley and Pienaar 1972).

This early research at the University of Washington was supplemented by studies carried out by Dr. Steinbrenner (Weyerhaeuser Company); Dr. Strand (Crown Zellerbach Corporation); Dr. Heilman (Washington State University); and Dr. Miller (U.S. Forest Service). In addition a comprehensive research effort to examine response of Northwest forest trees to application of other elements is included in the Regional Forest Fertilization Study (RFFS). Phase II of the RFFS included a complete treatment with all essential elements. Results from this study are presented later in this report.

This brief history of the research effort about role of elements other than N is given to show that considerable work has established the sufficient and deficient levels in foliage of Douglas-fir, western redcedar, and Sitka spruce under controlled conditions. An example of these levels from the work of Chen (1955) is given in Table 5. A similar table for red alder from research by Hughes (1967) is in Table 6. The level of elements in many of our forest soils associated with the normal and deficient foliage status were also established.

However, it has been much more difficult to demonstrate of any convincing evidence may be partially other than N. The lack rational and design problems of detecting small growth responses. The great variation in stand stocking and factors which affect growth within a series of forest plots generally requires a response level of more than 10% for detection. The general apparent deficiency of N under many forest situations also detracts from response to other elements until the N deficiency is corrected.

The remainder of this paper will summarize results from various field experiments on the application of other elements and attempt to qive some perspective to the direction of future needed work. This summary will exclude the interrelationships of N and S as that is covered in a separate paper of this symposium.

RESULTS FROM FIELD TRIALS

Field trials established at Pack Forest, the Kitsap Peninsula, the Darrington area, and others in western Washington generally showed no marked response to a single application to elements other than N. This was true for both macro and micro elements. When other elements are included in complete treatments with N, there is evidence of some additional growth response. However, this has generally not been established as statistically significant or as an economic response. Most of the field tests were established to screen other elements and not to provide a basis for a thorough statistical examination. Results from several of the test areas will be examined in greater detail.

PACK FOREST

A large number of fertilizer plots were established at the Charles Lathrop Pack Forest of the University of Washington near Eatonville in the 1950's. Treatments included various amounts and forms of N with and without other elements. Total N application has been substantial and has included repeat treatments. We have selected a series of plots from Pack Forest which allows a comparison of growth rates over a 21-yr

Table 5. Mineral deficiency symptoms of Sitka spruce seedlings.[b]

Element	Deficiency level[a]	Deficiency Symptoms
Nitrogen %	1.84%	Foliage exhibited a pale yellow-green color, which later turned to pale light green; roots thin and long; seedlings stunted.
Phosphorus %	0.097	Older foliage reddish, later becoming necrotic and dying; roots short and poor; seedlings stunted.
Calcium %	0.054	Youngest foliage paler, later burning to brown; or browning at the tips of the youngest foliage.
Potassium %	0.27	Older foliage necrotic and dying, or yellowish brown at the tips of some needles depending upon the deficiency condition.
Magnesium %	0.066	Youngest needles yellowish, older foliage entirely necrotic; or necrotic at the tips only, yellowish brown on the middle portion and light green on the lower part. In some seedlings with more serious deficiency symptoms, necrosis covered the whole branch, even the youngest needles. Roots short.
Iron ug/g	104	Youngest foliage chlorotic; older foliage green; roots succulent.
Sulfur %	0.15	Foliage yellowish; roots long and succulent.
Boron ug/g	5.4	Youngest needles curled closely into a "rosette", dark gray green color; roots short, with the branches somewhat bulbous on the ends.

[a]The quantities given were the levels found in the foliage of deficient seedlings. [b]Chen, H. F. Growth and mineral uptake of Sitka spruce in solution cultures. Unpublished thesis. University of Washington, 1955.

period under no fertilizer, two levels of N, and N plus other elements. Original sites for these plots were comparable as shown by the periodic annual increment (p.a.i.) and they were generally a low site IV for Douglas-fir. This selection of plots does show a greater p.a.i. over the 21-yr growth period from addition of a number of other elements. However, the results do not permit examination of the effect of any one element other than N (Table 7).

Table 7. Response to nitrogen and other elements with low site Douglas-fir at Pack Forest.

Plot No.	Treatment Elements lb/acre		21-yr p.a.i. (Gross)
			Ft^3/acre
15	Control		145.1
F-41	Control		132.1
		Ave.	138.6
36	N-366		210.2
40	N-366		267.2
14	N-600		184.7
15	N-600		217.6
		Ave.	219.9
IN	N975, P35, K25, Mg 14, Ca147, S24		271.5
F-42	N746, P420, S924		252.3
F-43	N746, P176, K134, Ca408, B5, S911 (and other trace elements-)		
		Ave.	262.4

COLUMBIA VALLEY

Bloedel Timberlands has supported an investigation of forest tree nutrition on a portion of their land in Columbia Valley, Whatcom County, Washington. This is a glacial outwash soil which exhibited poor growth of coniferous species. Nitrogen applications during 1958–1962 produced response but the

Table 6. Deficiency guidelines for red alder seedlings as observed in a sand medium.

Deficient	Foliar Percentage Corresponding with Deficiency[a]	Effect on Growth	Visual Symptoms of Deficiency
Nitrogen	2.4[b]	Stem height and weight, weight of roots and foliage significantly reduced.	Small, pale green foliage. Stems slender and reddish Roots small and thin.
Phosphorus	0.16	Stem height and weight, weight of roots and foliage significantly reduced.	No specific symptoms.
Potassium	0.4	Stem height and weight, weight of roots and foliage significantly reduced.	Margins of foliage chlorotic, later turning bright orange-"scorched." Older foliage affected first.
Calcium	0.08	Stem height growth reduced.	No specific symptoms.
Magnesium	0.11	Weight of foliage significantly reduced because of abscissed foliage.	Gray or brown spotting along leaf margins, spreading inward through intervenal areas. Abscission typically occurring while areas adjacent to veins still green. Older foliage affected first. Large amounts of abscissed foliage.

[a]Approximate guideline values. [b]Below this value nitrogen deficiency is very likely. Strong nitrogen deficiency was found at 2.7% however, so nitrogen deficiencies above 2.7% are probable in some instances.

results were variable and generally not up to expectations. Dr. Stoate established an array of other elemental applications in these stands in addition to N. Results from these plots give us the opportunity to examine the effect of N alone or with combinations of N, P, K, and S.

However, S application on the plots chosen for this review is small. Two site qualities are included, a lower site at Heady Road and a higher site at Helicopter Road. A portion of both areas received an initial N application of 200 lb/acre in 1962. In 1970 both areas received a moderate commereial thinning. Plots were established at that time to test N along with P, K, and S. In the case of the Helicopter Road area, plots were also thinned and fertilized in a previously unfertilized strip. These are the C-Series. Periodic annual increment for the period 1970–1975 for all plots is given in Table 8. The increments are adjusted for differences in initial stocking. There is some evidence of additional response from P but the results are not statistically significant.

PROJECT 13

One of the more extensive tests of the effect of elements in addition to N was established in 1958 on Simpson Timber Company lands near Shelton, Washington. This is referred to as the Project 13 experiment because of the geographical location. This discussion will not detail the history of the study but will examine those aspects related to other elements. The treatments and the growth summary through 1975 are given in Table 9. Results represent two plots for each treatment. The experiment included stocking control by commercial thinning and up to 1975 only the initial fertilizer treatment.

As in other experiments, there appears to be evidence of a slightly better response when P is included in the treatment. The gain is somewhat better in the thinned stand. The duration of response seems to be slightly better with additional elements (Table 9). Because of plot-to-plot variations, the response to additional elements is not statistically significant. However the apparent increase in growth with the addition K in the thinned plots should be studied.

REGIONAL FERTILIZER PROGRAM

As a component of Phase II of this program, a series of 1/40-acre plots were established in the proximity of Phase I and II installations. These plots received the entire range of macro

Table 8. Comparison of growth response from nitrogen and other elements for two sites in Columbia Valley, WA.

Treatment lb/acre 1962 F	1970 C	N	S	P	K	Adjusted Net p.a.i. 1970–75 ft³/acre/yr Heady Rd. F Series	C Series[b]	Helicopter Rd F Series
200	0	0	0	0	0	151.0	236.7	191.7
200	0	270	0	0	0	272.0	307.9	231.9
200	0	216	8	0	0	277.8	216.6	227.4
200	0	216		96		217.6	308.2	263.8
200	0	128		128	128	153.1	389.7	285.4

[a]F. Series - 200 lb/N/acre in 1962 plus 1970 treatment. [b]C-Series - Only 1970 treatment.

Table 9. Comparison of growth response from nitrogen and other elements for thinned and unthinned stands at the Project 13 area, Shelton, WA.

Treatment Lb/acre	Thinned p.a.i. Ft³/acre/yr 1958–1965	Thinned p.a.i. Ft³/acre/yr 1965–1975	Unthinned p.a.i. Ft³/acre/yr 1958–1965	Unthinned p.a.i. Ft³/acre/yr 1965–1975
Control	269.2	265.0	319.6	237.6
P-88, K-87, Ca-204	237.0	238.4	345.8	264.5
S-119	310.3	271.5	344.4	264.8
N-300	361.0	300.8	339.7	265.1
N-300, K-87	333.6	290.6	388.9	303.2
N-300, P-88, S-154	381.4	304.4	367.9	277.2
N-300, P-88, K-87, S-154				
W/O nitrogen	253.1	251.6	339.2	255.5
W/ Nitrogen	346.4	290.5	360.2	277.6
W/Nitrogen and other elements	358.6	298.6	365.5	281.8

and micro elements (Table 10). They covered a wide range of stand, site, age class, and soil conditions. Growth in basal area was determined after 6 yr and compared to growth on control plots and on plots that received 200 and 400 lb N/acre. The analysis is complicated by the differences in plot size and the fact that the 1/40-acre plots are generally better stocked and more uniform than the 1/10-acre plots. Therefore, the relative average response was calculated for each treatment based on untreated plots of the same size (Table 11). The result is an increase of about 25% in the basal area growth due to 400 lb/acre of N and an average increase of 29% in the basal area growth due to the complete treatment.

This would indicate some marginal benefit from the complete treatment but it does not appear to be worth the additional expense of the additional 557 lb of fertilizer and the application cost. However, there is some evidence that response of basal area growth to N may decline at very high initial basal areas. Since the 1/40-acre plots are much higher in basal area, the estimate of 29% response may be underestimating gain by a complete treatment in stands of lower to initial basal area (i.e., 200 f^2/acre rather than 250 ft^2/acre).

Dr. Rustagi (1979) of the College of Forest Resources faculty did a separate statistical analysis of the regional fertilizer complete treatment plots and concluded, "It would be difficult to draw any definite conclusion about basal area growth response in complete treatment plots over 400-N plots because of the limited range of the data and differences in size and character of the plots."

USDA FOREST SERVICE TRIALS

An objective of these field trials was to detect the effect of nutrient elements other than N on tree growth. It was suspected that deficiencies in one or more nutrients existed or could develop after N deficiencies were corrected. Attaining this objective, however, was secondary to that of quantifying the effects of various N fertilizers and dosages on growth of Douglas-fir stands.

To minimize costs of this secondary effort, the general research strategy was to proceed in two phases: (1) Compare effects of N versus N + other elements on growth of individual trees. Presumably, the need for—and therefore the response to—other elements would be increased by the accompanying N dosage. If the complete treatment, e.g., NPKS, was clearly more stimulating of diameter and/or height growth, then, (2) start new trials to determine which element(s) was responsible. Thus in Phase I, fertilizers containing NPKS were applied within a 44–87 ft^2 area around dominant or codominant

Table 10. Fertilizer applied to Regional Fertilizer Program plots for complete treatment.

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	Mangenese sulfate
Zinc	15	Zinc sulfate
Copper	8	Copper sulfate
Molybdenum	0.5	Sodium molybdate
Boron	1	Borax
Sulfur	54	Above products
Total	957	

Table 11. Comparison of gross basal area growth (ft^2/acre) with nitrogen and nitrogen plus complete fertilizer unthinned regional plots for 4 yr.

Phase	No of Plots	Size	Treat	B_o	B_4	ΔB	ΔB diff	Relative Response %
1	135	1/10	ON	201.2	227.0	25.8		
1	135	1/10	4N	204.2	236.5	32.3	6.5	25%
2	65	1/40	ON	*245.7	279.0	33.8		
2	65	1/40	Complete	*249.9	293.6	43.7	9.9	29%

trees and the subsequent growth of these center or subject trees was compared to that of similar trees treated with only N at the same N dosage. Through this procedure, it was frequently possible to gain six or more replications of each treatment at a given location and thus have a more statistically sensitive test of N versus N + other elements. Such tests of other elements were made at nine locations in western Washington and Oregon (Table 12).

At three of the nine locations, the addition of other elements stimulated growth of Douglas-fir. Differences among treatments were statistically significant (P = 0.10). Thus, at locations 2 and 3, growth of trees fertilized with NPKS grew 27% to 62% more than did trees fertilized only with the same N dosage of 300 lb/acre. Surprisingly, at both locations, the 300-N dosage in these overstocked stands failed to stimulate growth, but a 600-N dosage almost doubled growth. At location 4, potassium sulfate was 13% more effective than ammonium sulfate when both were sprayed on Douglas-fir saplings. Yet, the same potassium sulfate treatment failed to stimulate growth of nearby saplings in the same stand that had been fertilized with 800 lb N/acre. These results were contrary to expectations, because it had been previously determined that heavy N dosages greatly reduced the concentrations of sulfate-S in the foliage. Therefore, it was assumed that additions of K and S to N-fertilized trees would be stimulating because preceding dosage of 800 lb N/acre would have created a deficiency of S, and possibly K.

At the remaining six locations, other elements applied with

Table 12. Response of individual Douglas-fir trees to nitrogen and other nutrients in western Washington and Oregon, U.S. Forest Service Trials.

Location	Trial	Parent material	Age	Site	Stand Thinned	Fertilized	Treatment and Response 1/ N	N + others	Others	Response Variable	Period	Reference
			Years								Years	
Quilcene, WA	1	glacial drift	28	V	Yes	No	400 158	NPKS 2/ 132		Vol	10	3/
	2	glacial till	40	IV	no	No	300 87	NPKS 2/ 114		Vol	10	3/
	3	glacio-lacustrine	80	IV	No	No	300 98	NPKS 2/ 160		Vol	10	3/
Sequim, WA	4	glacial till	8	V	No	No Yes 4/		35N, 40S 101	98K, 40S 114 102	ht ht	4 4	3/ 3/
McCleary, WA	5	glacial till/ basalt	75	II	Yes	No	300 131	NPKS 2/ 136		b.a.	5	5/
Carson, WA	6	ash/pumice	20	V	Yes	No	300 191 222	NPKS 2/ 182 220		d.b.h. ht	5 5	6/ 6/
Roseburg, OR	7	sandstone	15	V IV	No	No	200 150 113	NPKS 2/ 135 114		Vol	8	3/
	8	tuff/breccia	60	IV	No	No	150 123	NPKS 7/ 137		Vol	6	3/
	9	tuff/breccia	72	IV	Yes	No	300 91	NPKS 2/ 86		b.a.	10	3/

1/ Treatment in pounds element per acre and response as percent of unfertilized control.

2/ Equal N dosage + 15P + 100K + 50S pounds per acre.

3/ Unpublished data on file at Forestry Sciences Laboratory, Olympia, WA.

4/ Trees fertilized with 800 pounds N per acre in 1970, then refertilized with K and S in 1972.

5/ Miller, R. E., and D. L. Reukema. 1974. Seventy-five-year-old Douglas-fir on high quality site respond to nitrogen fertilizer. USDA For. Serv. Res. Note PNW-237, 8 p. Pac. NW For. & Range Exp. Stn., Portland, OR.

6/ Miller, R. E., and D. L. Reukema. 1977. Urea fertilizer increases growth of 20-year-old, thinned Douglas-fir on a poor quality site. USDA For. Serv. Res. Note PNW-291, 8 p. Pac. NW For. & Range Exp. Stn., Portland, OR.

7/ Equal N dosage + 80P + 140S.

N failed to stimulate growth of Douglas-fir more than did the N-only treatment; none of the differences were statistically significant at P = 0.10.

The results from these Forest Service trials indicate the need for continued screening of locations for response to elements other than N. Many extensive soil and climatic strata remain untested. Initial results suggest that the additional gains in tree growth from elements other than N are marginal—relative to the additional costs of fertilizers and application.

WEYERHAEUSER COMPANY TRIALS

Weyerhaeuser Company has extensive field tests of N alone and N in combination with other elements. One of these experiments, which was a single tree treatment with a factorial design, showed significant reduction of growth when other elements, especially K, was applied without N.

A long term fertilization experiment near Yacolt, Washington, originally established for seed production purposes, has involved periodic additions of both N and P. Results on this relatively high quality site show a significant response to N, but no response to P; however, P was not tested as a separate treatment. Figure 5 shows the volume response for the initial (1955–1959) and a later (1964–1969) period of fertilizer applications. The total weight of each nutrient applied during the 5-yr period is depicted on the volume response bar. The 1960–1964 and 1970–1974 periods are not shown as only N was applied in the former and no fertilizer was applied in the later. The influence of P application was statistically nonsignificant in both periods shown.

OTHER RESEARCH

This paper has not attempted an exhaustive examination of all forest fertilization research in the Pacific Northwest with respect to elements other than N. However, we have tried to review results from a variety of sources and also elicit information by personal contact, especially regarding positive response.

An important contribution is the work of Bartlett (1977) who has made a thorough study of the many plots established on Vancouver Island by the late Dr. T. N. Stoate. Bartlett summarizes the examination in the following words:

"Response to NS, NP8, and NPK was common to most experiments and was often greater than N alone, especially NS and NPS."

He suggested that NPKS together gave poor results, possibly because of ion antagonism. He believes that a fertilizer of NPS at the rates of 287, 161, 92 lb/acre gave the best response.

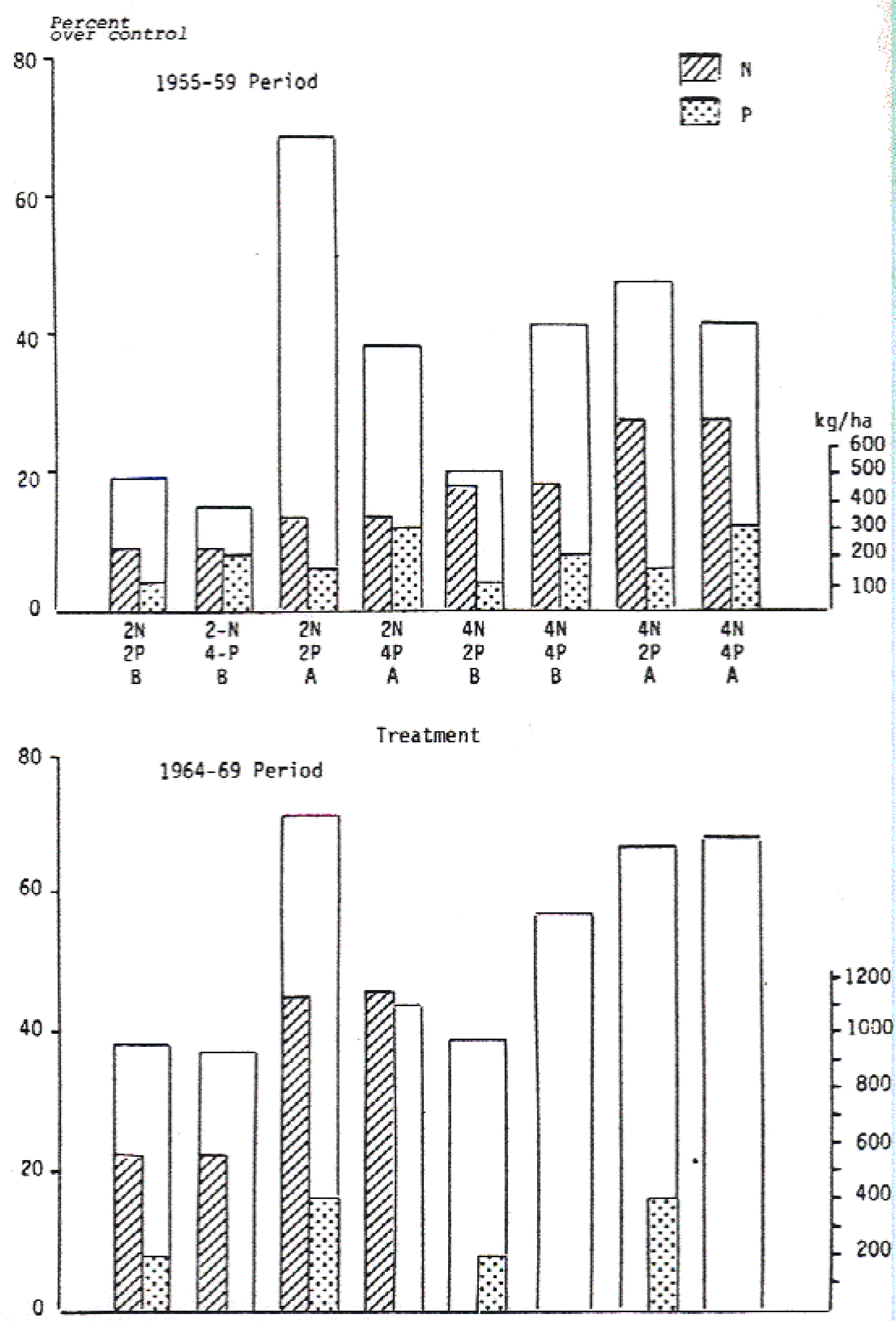
Heilman (1973) reported a response by hemlock and Douglas-fir saplings to lime in greenhouse tests, using Olympic Peninsula soils. In a field experiment with Douglas-fir in southwestern Washington, Heilman (1971) concluded there was no response to P, K, S, or B. For coastal soils, Heilman (1980) and Anderson (1979) have both demonstrated response to P under greenhouse conditions.

SUMMARY AND CONCLUSIONS

Laboratory and greenhouse experiments have demonstrated that Northwest forest tree species require the same essential elements as agricultural plants. Foliar analysis of field-grown trees shows a great range in concentration of elemsnts. Soil analysis also shows a wide range of elsmental supply in many forsst soils, and apparent near deficient levels in foliar concentrations leads to the expectation of a growth response when these elements are added to a N fertilizer.

A considerable number of fertilizer experiments have been established to investigate this expectation. A review of results from these experiments shows occasional evidence of a growth response, but it is quite variable from experiment to experi-

Figure 5. Influence of nitrogen and phosphorus on volume response of young Douglas-fir on Yacolt plots.



ment. At present there is little evidence that an economical response has resulted from additional elements. In other words, the extra growth would not pay for the fertilizer and the application cost.

We do not believe that this means research on the role of elements other than N in the nutrition of Northwest trees should cease. On the contrary, we believe that it should increase and be more innovative. Most of the research has been what may be called a screening effort. Other elements have been applied with the hope that a "sore thumb" effect would develop as in the case of certain elements applied to forests in Australia. The experimental design and mensurational techniques have not been sufficient to detect less pronounced response. The great variability encountered in plots within natural forests, complexes all the field experiments and calls for better design. Further, the experience of agriculture would suggest that deficiencies of the other elements might develop after further rotations and harvests.

We also believe, and find some experimental evidence to support our belief, that response to othsr elements will be more soil specific than response to N. Nitrogen response appears to have no highly significant relationship to soil series but this question is being closely examined at the present time. Response to other elements should receive more research effort directed toward soil series relationships. We also believe that a combination of field tests and tests under the more controlled conditions of a greenhouse or growth chamber must be used.

Finally, evidence that forest trees will respond to a combination of elements better than N alone is developing from the various sewage sludge research and forest land applications. More careful analysis of these may help to eventually develop the fertilization recommendation which will produce the most economical wood supply for each forest owner.

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