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Response of Douglas-Fir Seedlings to Nitrogen, Sulfur, and Phosphorus Fertilizers

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Abstract

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Effects of nitrogen, sulfur, and phosphorus fertilizers on growth and nutrient content of Douglas-fir seedlings potted in Grove and Bunker forest soils were determined. Growth was primarily stimulated with nitrogen in the Grove soil and with phosphorus in the Bunker soil. Fertilization influenced nutrient levels in the seedlings. Growth results agree with observed response of Douglas-fir to fertilization in the field where the soils were collected. Data also suggest that low phosphorus and/or high nitrogen may be responsible for lack of positive growth response of Douglas-fir to nitrogen fertilizer on some sites.

Keywords: Fertilizer response, nutrient elements (plant), plant-soil relations, seedling growth, Douglas-fir.

Summary

Two experiments were conducted to determine effects of N, S, and P fertilizers on growth and nutrient content of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) seedlings grown in two different forest soils in a lathhouse. In both experiments, soils of the Grove and Bunker series were used. The Grove soil was obtained from a fertilizer-test installation where Douglas-fir had shown good growth response to N fertilizer; the Bunker soil was collected from another field installation that did not show significant response. One-year-old seedlings from a low-elevation seed source were used, and each study was run for 2 years. In experiment 1, fertilizers were: (1) urea [U]; (2) U + powdered S [U + S]; (3) U + $CaSO_4$ [U + CS]; (4) $(NH_4)_2$ SO_4 [AS]; and (5) sulfur-coated urea [SCU]. In experiment 2, fertilizers were: (1) U; (2) triple superphosphate [TP]; (3) U + TP; (4) TP + CS; and (5) U + TP + CS. Fertilization was carried out in early spring (that is, April-May). In both experiments seedling growth was primarily stimulated with N in the Grove soil and with the P fertilizer in the Bunker soil; S, with N or P, did not affect growth in either soil. In addition, seedling growth in Bunker soil was consistently less with than without U or U + S, although not significantly so. Nutrient concentrations of the untreated seedlings varied between the shoots and roots, and reflected the status of nutrients in the two soils! Fertilization influenced nutrient concentrations, and trends varied by nutrient and between shoots and roots. Amounts of nutrients were significantly increased in both the shoots and roots by U fertilizer in the grove soil and by the P fertilizer in the Bunker soil, reflecting significant enhancement of seedling growth and nutrient uptake and utilization. Results agree with response-to-N observations obtained in the field where the test soils were collected and confirm earlier reports that positive response of Douglas-fir to application of N fertilizer is not always possible. Overall, the data also suggest that low supplies of P and/or high soil N, and not S, may be responsible for lack of positive response of Douglas-fir to N fertilizer.

Contents

Introduction

In the Pacific Northwest, intensive management of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) forests currently includes application of synthetic fertilizer to commercial forests. The practice started some 20 years ago, and by 1979 approximately 500,000 ha, mostly in Douglas-fir, had been operationally fertilized with nitrogen (N) (Bengtson 1979).

Although growth response of Douglas-fir to N fertilizer is generally good, about 30 percent of the unthinned stands do not respond positively to treatment (University of Washington 1975). The exact causes of this lack of response are unknown. Several reasons have been postulated, but supplies of sulfur (S) and/or phosphorus (P) seem to be among the most likely factors affecting response. This assessment is based upon investigations that have shown: (1) depletion of SO_4-S reserves in Douglas-fir foliage by N fertilizer (Humphreys and others 1975, Turner and Lambert 1978); (2) decrease in mineralization of soil S by N fertilizer (Kowalenko and Lowe 1975,1978); (3) requirement of adequate supplies of foliar SO_4-S for positive growth response of Douglas-fir to N fertilizer (Turner and others 1977,1979); (4) association of low soil P with lack of positive growth response of Douglas-fir to N fertilizer on some sites in western Washington;[1/] and (5) substantial increase in growth of potted Douglas-fir seedlings by application of P fertilizer (Heilman and Ekuan 1980, Strand and Austin 1966).

This study, therefore, was designed to study effects of N, S, and P additions on growth and nutrient content of Douglas-fir seedlings grown in two forest soils in a lathhouse. We are aware of the limitations of pot tests in providing prescriptions that can be directly applied to field situations. However, the very limited information about Douglas-fir nutrition now available and the high cost of establishing field tests strongly justify preliminary experimentation with seedlings.

Materials and Methods

The study consisted of two separate experiments. Both experiments utilized seedlings from the same seed source and the same two different soils. Each experiment included six treatments and was run for 2 years. Experiment 1 (1980 to 1982) compared N fertilizer alone, N plus different sources of S, and untreated controls. In experiment 2 (1981 to 1983), comparisons were between controls and treatments with N, P, N + P, P + S, and N + P + S.

Test Soils

Soils of the Grove and Bunker series were selected for study; these soils differ greatly in many of their properties and they are known to support Douglas-fir growth in many areas in the Pacific Northwest. The soils were obtained from the control plots of two low-elevation, Douglas-fir fertilizer-test installations located in western Washington. The Grove-soil installation, maintained by the University of Washington Regional Forest Nutrition Research Project, showed good positive growth response to N fertilizer. The Bunker-soil installation, administered by the Washington State Department of Natural Resources, did not show significant response.

[1/] Unpublished data on file, Forestry Sciences Laboratory, 3625 93d Ave. S.W., Olympia, WA 98502.

At each installation, the forest floor was removed, and the top 20-cm layer of mineral soil was dug up and transported to the lathhouse in Olympia. The soil samples were passed through a 0.6-cm sieve to remove large rocks and debris, mixed thoroughly, and placed in 7.6-1 plastic pots. Each pot, with a top area of about 3 x $10^{'6}$ ha, contained approximately 6 kg of soil, on an air-dry basis.

A representative sample of each soil was passed through a 2-mm sieve, and sieved subsamples were used for determination of selected chemical characteristics as shown below.

Test Seedlings

Uniform, bare-root, 1-year-old Douglas-fir seedlings grown from a low-elevation seed source at Washington State Department of Natural Resources Webster Forest Tree Nursery were used. In early spring 1980 and 1981, seedlings were individually planted in the plastic pots containing the two different soils. A three-seedling group served as the basic experimental unit. There were three three-seedling groups (three replications and nine seedlings) for each soil-fertilizer treatment. Seedlings were placed, as groups of three, at random on benches in a roofed lathhouse.

Treatments

In experiment 1, treatments were: (1) untreated control (C); (2) urea (U); (3) U + powdered S (U + S); (4) U + $CaSO_4$ (U + CS); (5) $(NH_4)_2$ SO_4 (AS); and (6) sulfur-coated urea (SCU). All fertilizers were applied at a rate equivalent to 150 kg N/ha. It was not possible to apply S at the same rate for all S treatments while maintaining the same rate of N application (that is, 150 kg/ha) and using different S sources. Application rates of S, in kilogram per hectare, were: 0 for treatments 1 and 2; 171 for treatments 3, 4, and 5; and 62 for treatment 6. Fertilizers were applied to the seedlings in 1980 and again in 1981.

In experiment 2, treatments were: (1) untreated control (C); (2) U; (3) triple superphosphate (TP); (4) U + TP; (5) TP + CS; and (6) U + TP + CS. Rates of application were 150 kg N/ha, 171 kg S/ha, and 500 kg P/ha. N was applied in 1981 and again in 1982, but S and P were applied only once, in 1981.

In both experiments, fertilizers were applied in early spring (that is, April-May), and first-year treatments were assigned to the seedling groups at random. Fertilizers were mixed with the top 2-cm layer of soil, and the pots were watered the same day. Periodically, the seedlings were watered with deionized water as needed, and watering was done carefully without wetting the foliage or leaching soil solution. Seedlings were grown under natural temperature and light conditions in the lathhouse, and the pots were wrapped with glass wool insulation during the winter to reduce the likelihood of freezing injury to the roots.

Growth Measurements

Height and diameter of test seedlings were measured prior to treatment and at the end of each experiment 2 years later. At harvest, shoots and roots were separated by clipping at the root collar. Roots were washed free of soil, and excess moisture was removed with blotting towels. Roots and shoots were cut up and dried to constant weight at 65 °C. Height and diameter growth, and dry weight of shoots and roots of individual seedlings and averages for the different three-seedling groups (replications), as well as grand averages per treatment (three replications) were calculated.

Processing of Seedling Shoots and Roots

Ovendry tissues, separated by plant part, replication, soil, and treatment were individu--ally ground to 40 mesh in a Wiley mill. Samples were stored in plastic containers at -15 °C until analyzed.

Chemical Analyses

Soils were characterized by determination of pH on a 1:1 mixtures with water by glass electrode, total N by semimicro-Kjeldahl method (Bremner and Mulvaney 1982), total S by turbidimetric method (Butters and Chenery 1959), Bray 2-extractable P according to Bray and Kurtz (1945), cation exchange capacity by $NH_4$0Ac extraction (Chapman and Pratt 1961), and exchangeable K, Ca, and Mg (NH_4OAc extraction) by atomic absorption (Anonymous 1976). At harvest, some soil samples were taken at different depths from the pots receiving the P fertilizer, and extractable P was estimated in order to determine P movement in the soil.

Plant shoots and roots were analyzed for N by Kjeldahl procedure, S by turbidimetric method (Butters and Chenery 1959), P by molybdenum blue technique (Chapman and Pratt 1961), and K, Ca, and Mg by atomic absorption (Anonymous 1976). Contents of selected nutrients in seedling shoots and roots were calculated from tissue dry weights and nutrient concentrations.

Statistical Analysis

For the different variables measured in each experiment, data were treated by analysis of variance to assess effects of soils and treatments; means within soils were separated by Tukey's test as required (Snedecor 1961). Differences were considered significant at $p<0.05$.

Results and Discussion

Study Soils

The Grove and Bunker soil samples used in this study differed in many of their characteristics (table 1). Parent material was glacial for Grove and basalt for Bunker. The Bunker sample was particularly higher in N, S, cation exchange capacity, and exchangeable Mg, and lower in extractable P than was the Grove soil. There were only small differences between the two soils in pH, exchangeable K, and exchangeable Ca.

Table 1—Selected characteristics of study soils

	Soils series	
Item	Grove	Bunker
Soil parent material	Glacial	Basalt
pH	5.55	5.20
Kjeldahl N (%)	.20	.30
Total S (%)	.02	.05
Bray 2-extractable P (ppm)	65.0	5.2
Cation exchange capacity (me/100g)	23.7	37.2
Exchangeable (NH_4OAc) K (me/100g)	.4	.5
Exchangeable (NH_4OAc) Ca (me/100g)	2.0	2.2
Exchangeable (NH_4OAc) Mg (me/100g)	.3	.6

Seedling Growth

The three-seedling-group arrangement allowed ample space for individual seedlings to grow for 2 years in large, but manageable pots. This, we believe, provided for more trustworthy results than if seedlings had been crowded into smaller pots.

In both experiments, seedlings roots were mycorrhizal. There was no evidence of disease or insect damage on seedling roots or shoots.

Experiment 1.—Without fertilization, there were only small differences in growth of seedlings in the two soils (table 2). Fertilization had, however, a significant effect on growth in the Grove and not in the Bunker soil. Although differences between the controls and the fertilized trees in the Bunker soil were never significant, all fertilizers appeared to depress growth. This is an indication of the negative effects of N fertilizer, which have been observed in the field with Douglas-fir and other conifer species. In the Grove soil, all fertilizers significantly increased diameter growth as well as root and shoot dry weights; only height growth was not significantly affected by treatment. Also, in that soil, fertilizers were equally effective except for the U + CS mixture which produced larger, but mostly insignificant, increases in diameter, height, and root and shoot dry weights more than any other fertilization treatment. This effect was probably not caused by the presence of S. More likely, the increased response was caused by the calcium sulfate, which can reduce the rise in soil pH by urea, and/or by the growth-stimulating effect of Ca as reported by Heilman and Ekuan (1973).

Table 2—Effect of fertilization over a 2-year period on growth of Douglas-fir seedlings in 2 forest soils[1/]

Treatment	Diameter growth		Height growth		Root dry weight		Shoot dry weight	
	Grove	Bunker	Grove	Bunker	Grove	Bunker	Grove	Bunker
	Millimeters		Centimeters		Grams			
			EXPERIMENT 1 (1980-1982)					
C	7.0a	6.2a	40a	34a	17.2a	15.7a	22.2a	20.0a
U	10.2b	5.5a	45a	28a	33.1b	11.4a	43.2b	17.9a
U + S	10.7bc	5.2a	46a	27a	31.7b	10.2a	46.3bc	16.2a
U + CS	11.7c	5.2a	51a	26a	36.9b	10.4a	56.6c	15.9a
AS	11.1bc	5.6a	48a	26a	27.8b	13.6a	46.8bc	19.9a
SCU	9.9b	5.7a	48a	27a	28.9b	12.2a	41.6b	18.5a
			EXPERIMENT 2 (1981-1983)					
C	3.6a	4.9a	19a	26a	7.6a	9.9a	7.7a	14.4a
U	10.1b	4.3a	55b	21a	30.8b	6.2a	44.0b	10.9a
TP	4.6a	8.7b	24a	54b	9.9a	18.6b	11.0a	38.8b
U + TP	12.9c	9.7bc	65b	52b	37.6b	23.2b	72.6c	44.2b
TP + CS	4.9a	9.1bc	26a	54b	9.5a	21.3b	12.6a	41.7b
U + TP + CS	13.4c	10.5c	62b	56b	36.6b	25.6b	62.4c	45.2b

1/ C = Untreated control, U = urea, S = powdered sulfur, CS = calcium sulfate, AS = ammonium sulfate, SCU = sulfur-coated urea, TP = triple superphosphate. Values are averages of 3 replications each. Within each experiment, averages in the same column followed by different letters are significantly different at $p < 0.05$.

In this experiment seedlings responded positively to added N only in the low-N Grove soil; average seedling responses were 52 percent in diameter and 102 percent in total dry weight. Added S, in whatever form it was used, did not affect seedling growth response to N application in either soil. This indicates that S was not limiting even in the Grove soil, which was much lower in S content than was the Bunker soil (table 1).

Experiment 2.—For both soils, the unfertilized seedlings were generally smaller in this than in the previous experiment (table 2). Unlike the first experiment, however, fertilizers affected growth in both soils and effects varied by soil and fertilizer.

As in experiment 1, seedling growth in the Grove soil was significantly increased by N application. N alone increased diameter growth by 180 percent, height growth by 190 percent, and seedling dry weight by 390 percent. When added with urea, P increased diameter growth and shoot dry weight further, but P alone or with S, and S when added with U and P had no affect.

Growth in the Bunker soil was consistently less with than without urea alone or urea with S, although not significantly so. During cold weather, some seedlings had purple needles, typical of P deficiency in other plants, that were apparently induced by the N fertilizer. In that soil, significant growth response to fertilizer was obtained primarily with P; only diameter growth was significantly increased further by addition of N or N and S to the P fertilizer. Averaged over all P treatments, growth responses in diameter, height, and total dry weight were, respectively, 96 percent, 107 percent, and 170 percent. Similar results, with P fertilizer have been reported for Douglas-fir seedlings grown in coastal soils from Oregon and Washington (Heilman and Ekuan 1980, Strand and Austin 1966).

Results from both experiments show positive response to N fertilizer only in the Grove soil, which is low in N and high in P content. This is in agreement with results of the field fertilizer-test installations where the study soils were collected. The data also indicate that although N is considered to be the primary growth-limiting nutrient in forests of the Pacific Northwest, Douglas-fir growing on soils of low-P status may benefit only from additions of P.

Nutrient Concentrations of Seedling Shoots and Roots

Experiment 1.—Nutrient concentrations in the untreated seedlings appeared to vary by plant part (that is, shoot or root) and by soil (table 3). In both soils, concentrations were generally higher in the shoots than in the roots. In addition, seedlings grown in Bunker soil were mostly higher in N, S, and K, and lower in P, reflecting the status of nutrients in the two soils.

Nutrient concentrations in the shoots of the unfertilized seedlings are comparable with values in the literature (Krueger 1967, Radwan and others 1974).

Fertilization affected nutrient concentrations, and trends appeared to vary mostly by nutrient and by plant part. The N-containing fertilizers increased N and decreased P concentrations in seedling shoots and roots in both soils. The N increase reflects uptake of fertilizer N by the seedlings. Depression of P by N fertilizer has been observed before with foliage of Douglas-fir (Heilman and Gessel 1963, Radwan and others 1984b) and other conifers (Radwan and others 1984a); Tamm (1956) attributed such reductions in P to stimulation of P-consuming soil organisms by the N fertilizer.

The U + CS treatment increased Ca concentration in seedling shoots and roots in both soils, reflecting increased Ca uptake from the added calcium sulfate. Surprisingly, however, calcium sulfate and other sulfur-containing fertilizers did not increase S concentration in the shoots or roots in either soil. Apparently, any increased uptake of S was offset by the dilution effect resulting from increased growth in Grove soil. Similar results with S in foliage of western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) have been recently reported (Radwan and others 1984a).

With some exceptions, especially with Mg in seedling shoots from Grove soil, concentration of K and Mg were affected little by fertilizer. This is in agreement with results obtained recently with foliage of Douglas-fir saplings (Radwan and others 1984b).

Table 3—Effect of fertilization (in percent of dry weight) on nutrient concentrations in seedling shoots and roots (experiment 1, 1980-82)[1/]

Soil and treatment	Nutrient					
	N	P	S	Ca	Mg	K
			Shoots			
Grove soil:						
C	0.69a	0.14a	0.09a	0.33ab	0.12a	0.45a
U	1.37b	.08b	.07b	.30ab	.08b	.31a
U + S	1.14b	.07b	.09a	.28b	.08b	.32a
U + CS	1.01ab	.07b	.11a	.41c	.08b	.30a
AS	1.36b	.07b	.10a	.29ab	.09b	.29a
SCU	1.21b	.09b	.09a	.34a	.10ab	.36a
Bunker soil:						
C	1.23a	.10a	.14a	.26a	.11a	.61a
U	2.30a	.04b	.09c	.28a	.11a	.56ab
U + S	2.31b	.05b	.10bc	.25a	.11a	.59ab
U + CS	2.41b	.05b	.12ab	.34b	.11a	.58ab
AS	2.43b	.05b	.12ab	.27a	.09a	.45b
SCU	2.34b	.05b	.12ab	.25a	.10a	.50ab
			Roots			
Grove soil:						
C	.56a	.11a	.07ab	.17a	.10a	.26a
U	.78bc	.10ab	.06b	.22a	.11a	.28a
U + S	.74abc	.10ab	.08a	.19a	.10a	.25a
U + CS	.64ab	.09b	.08a	.29b	.10a	.19a
AS	.71abc	.09b	.09a	.19a	.09a	.25a
SCU	.84c	.10ab	.07ab	.19a	.08a	.24a
Bunker soil:						
C	.78a	.09a	.11a	.20a	.13a	.42a
U	1.14b	.06b	.08b	.21ab	.10ab	.45a
U + S	1.24b	.06b	.09ab	.23ab	.11ab	.49a
U + CS	1.22b	.06b	.10a	.27b	.10ab	.50a
AS	1.13b	.07b	.11a	.20a	.10ab	.49a
SCU	1.17b	.07b	.09ab	.22ab	.09b	.44a

1/ C = untreated control, U = urea, S = powdered sulfur, CS = calcium sulfate, AS = ammonium sulfate, SCU = sulfur-coated urea. Values are averages of 3 replications each. Within each soil of each seedling part, averages in the same column followed by different letters are significantly different at $p < 0.05$.

Experiment 2.—As expected, added P did not move much in the soil profile. In both soils, fertilizer P remained within the top 5 cm, and there was no detectable increase in native P beyond the 5-cm depth at the end of the experiment. Added P was clearly available, however, for uptake by the seedlings as many roots were in the surface soil layer in direct contact with the P supply.

With few exceptions, nutrient concentrations of the unfertilized seedlings of this experiment (table 4) were similar to those of experiment 1. Also, as in experiment 1, fertilizers influenced nutrient concentrations of the seedlings. For example, urea generally increased N and depressed S and P concentrations of the shoots and roots in both soils. Triple superphosphate, on the other hand, had little effect on nutrient concentrations of the Grove plants, but reduced N, S, and K contents in the Bunker seedlings. In addition, calcium sulfate, in mixture with TP or U + TP, increased Ca and reduced S concentrations in shoots and roots of the Bunker seedlings, and increased Ca content in roots of the Grove plants.

Increased nutrient concentrations, such as those of N and Ca, were probably caused by greater uptake of the elements, with or without increased growth, depending upon the soil and fertilizer used. In contrast, nutrient depressions, such as those observed in the Bunker seedlings, were mostly a result of dilution by growth as the seedlings of this low-P soil grew significantly better with than without P fertilizer.

Table 4—Effect of fertilization (in percent of dry weight) on nutrient concentrations in seedling shoots and roots (experiment 2, 1981-83)[1/]

Soil and treatment	N	P	S	Ca	Mg	K
			Shoots			
Grove soil:						
C	0.80a	0.28a	0.13a	0.37a	0.15a	0.69a
U	1.17b	.07c	.06c	.30b	.09b	.29b
TP	.67a	.28a	.13a	.35ab	.15a	.64a
U + TP	.77a	.08c	.08bc	.31ab	.10b	.23b
TP + CS	.66a	.24b	.13a	.37a	.14a	.67a
U + TP + CS	.84a	.08c	.09b	.34ab	.10b	.26b
Bunker soil:						
C	1.70a	.10ab	.15a	.24a	.09ab	.48a
U	2.46b	.04c	.10bc	.22a	.09ab	.60b
TP	.88d	.12a	.12b	.25ab	.11c	.35c
U + TP	1.17c	.06bc	.09c	.27abc	.08a	.31c
U + CS	.84d	.11a	.12b	.30bc	.10bc	.32c
U + TP + CS	1.11cd	.07bc	.09c	.31c	.08a	.33c
			Roots			
Grove soil:						
C	.58a	.13a	.08a	.20a	.12ab	.29a
U	.71b	.09c	.06b	.25ab	.10ab	.20b
TP	.59a	.16b	.08a	.29b	.14a	.28a
U + TP	.65ab	.09c	.06b	.25ab	.09b	.18b
TP + CS	.56a	.14a	.08a	.28ab	.10ab	.29a
U + TP + CS	.66ab	.10c	.08a	.32b	.11ab	.20b
Bunker soil:						
C	.86b	.09ab	.14a	.16a	.09a	.32a
U	1.20a	.05d	.09cd	.25b	.09a	.38a
TP	.68d	.10a	.10bc	.17a	.09a	.18b
U + TP	.80bc	.07c	.08d	.21ab	.06a	.21b
TP + CS	.75cd	.10a	.12b	.25b	.09a	.19b
U + TP + CS	.81bc	.08bc	.08d	.25b	.08a	.22b

1/ C = untreated control, U = urea, TP = triple superphosphate, CS = calcium sulfate. Values are averages of 3 replications each. Within each soil of each seedling part, averages in the same column followed by different letters are significantly different at $p < 0.05$.

Nutrient Weights of Seedling Shoots and Roots

Nitrogen, P, Ca, and S were the nutrients most affected by fertilizer application. Weights of these nutrients per seedling are shown in figures 1 and 2. Unlike concentrations, weights more accurately reflect changes in seedling biomass and the simultaneous uptake of different nutrients and their allocation among the shoots and roots.

Experiment 1.—Within soils and for almost all treatments, shoots contained more nutrients than the roots, reflecting the greater biomass and/or higher nutrient concentrations of the shoot. Fertilization increased nutrient weights in the shoots and roots of the Grove seedlings. These gains most probably resulted from parallel increases in dry matter production (table 2) and nutrient uptake and utilization. This did not occur in the Bunker soil. In that soil, most N fertilizers significantly increased amounts of N in the shoots but not in the roots; this was probably due to luxury consumption, as treatments did not increase biomass (table 2). In the same soil, fertilization also reduced amounts of P in the shoots. These reductions must have resulted mostly from decreased P uptake effected by additions of N, because both shoot weight and P concentrations were lower with than without fertilizer (tables 2 and 3).

Experiment 2.—As in the first experiment, more dry matter was allocated to the shoots than to the roots in each of the two study soils. In the Grove soil, amounts of nutrients were significantly increased over the controls by treatments containing N and not by the P- or (P + S) - fertilizers; growth of seedlings in this low-N soil was stimulated only by N treatments (table 2).

Trends in nutrient accumulation in seedlings grown in the Bunker soil were different from those observed in the Grove soil. Bunker soil is low in native P, and only treatments containing P significantly increased weights of nutrients in both the shoots and roots. The greater nutrient content was clearly the result of significant enhancement of seedling growth (table 2) and nutrient uptake and utilization with than without P fertilizer. Conversely, use of urea alone resulted in reductions in almost all nutrients in both the shoots, and roots of Bunker seedlings. These reductions resulted from decreases in both seedling weights and nutrient concentrations (tables 2 and 4).

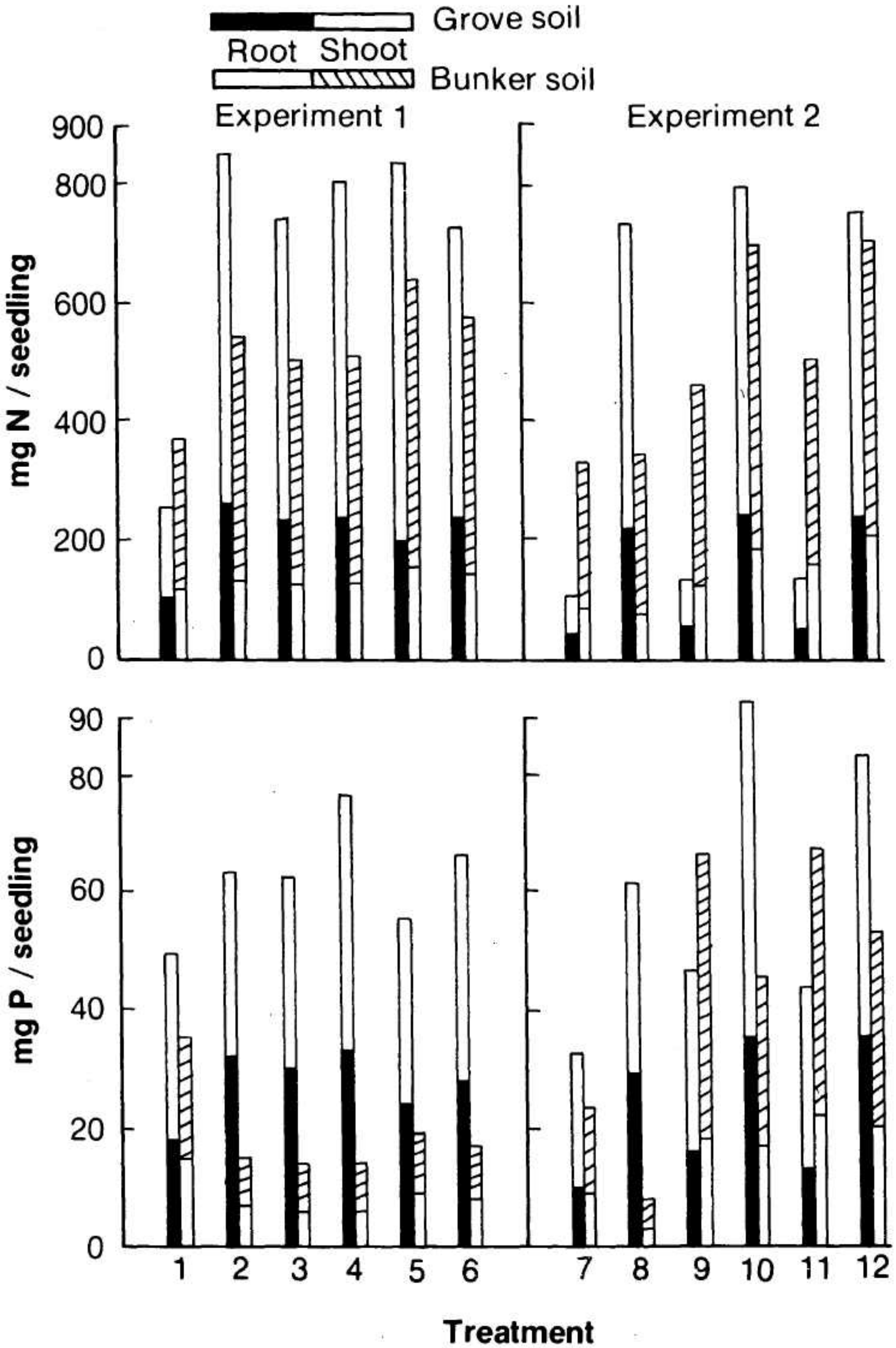

Figure 1.—Effect of fertilization on nitrogen and phosphorus contents of Douglas-fir seedling shoots and roots. (Treatments: 1 = untreated control (C), experiment 1; 2 = urea (U); 3 = U + powdered S; 4 = U + calcium sulfate(CS); 5 = ammonium sulfate; 6 = S - coated urea; 7 = C, experiment 2; 8 = U; 9 = triple superphosphate (TP); 10 = U + TP; 11 = TP + CS; 12 = U + TP + CS.)

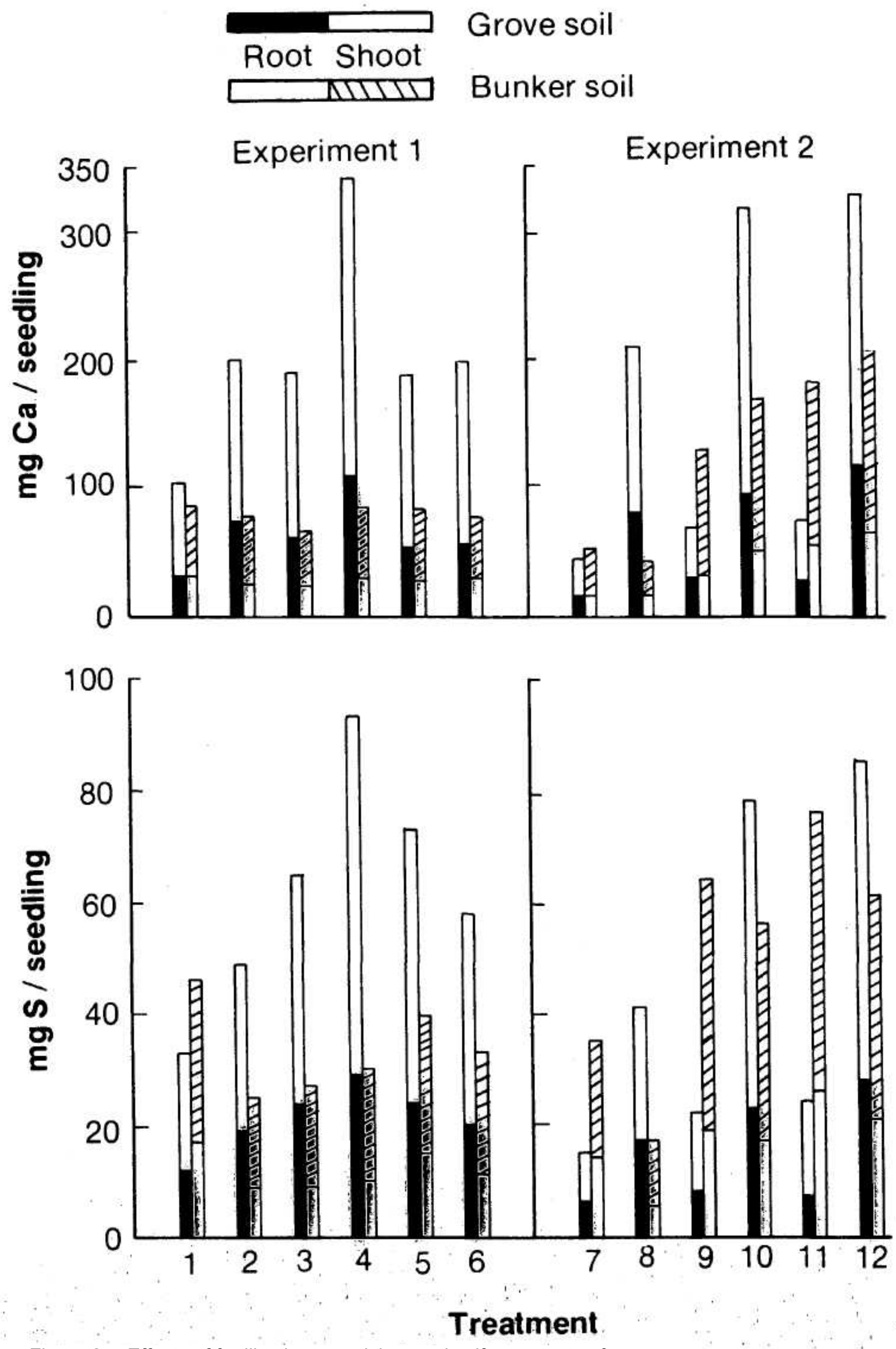

Figure 2.—Effects of fertilization on calcium and sulfur contents of Douglas-fir seedling shoots and roots. (Treatments: 1 = untreated control (C), experiment 1; 2 = urea (U); 3 = U + powdered S; 4 = U + calcium sulfate (CS); 5 = ammonium sulfate; 6 = S – coated urea; 7 = C, experiment 2; 8 = U; 9 = triple superphosphate (TP); 10 = U + TP; 11 = TP + CS; 12 = U + TP + CS.)

Conclusions

Results of the two experiments reported here confirm earlier observations that positive growth response of Douglas-fir to application of N fertilizer is not always possible. Overall, the data also suggests that: (1) Soil analysis for important nutrients may be helpful in diagnosing inadequate nutrient supplies and selecting effective fertilizer prescriptions. (2) N fertilizer may be effective only when soil supplies of native N are low and levels of other nutrients, especially P, are adequate. (3) Low supplies of extractable P and/or high soil N may be responsible for lack of positive growth response of Douglas-fir to urea-N fertilizer, especially along the coast where low P-high N soils are prevalent. (4) S fertilizers do not appear useful for stimulating growth of Douglas-fir in some soils such as those used in the present study. Such soils apparently have adequate S supplies. (5) Analysis for plant nutrients may be important for understanding the growth-nutrition relationships. It must be noted, however, that amounts and not concentrations of nutrients accurately reflect the true effect(s) of fertilization treatments on the uptake of nutrients. (6) Pot tests may be useful in assessing different fertilizer on Douglas-fir, and results may agree with those from field tests. It is prudent, nevertheless, to supplement greenhouse work with field experiments in order to develop reliable prescriptions for fertilization.

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English Equivalents

1 hectare (ha) = 2.47 acres
1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 liter (l) = 1.06 quarts
1 gram (g) = 0.03527 ounce
1 kilogram (kg) = 2.2046 pounds
°C = (°F -32)/1.8

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Effects of nitrogen, sulfur, and phosphorus fertilizers on growth and nutrient content of Douglas-fir seedlings potted in Grove and Bunker forest soils were determined. Growth was primarily stimulated with nitrogen in the Grove soil and with phosphorus in the Bunker soil. Fertilization influenced nutrient levels in the seedlings. Growth results agree with observed response of Douglas-fir to fertilization in the field where the soils were collected. Data also suggest that low phosphorus and/or high nitrogen may be responsible for lack of positive growth response of Douglas-fir to nitrogen fertilizer on some sites.

Keywords: Fertilizer response, nutrient elements (plant), plant-soil relations, seedling growth, Douglas-fir.

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