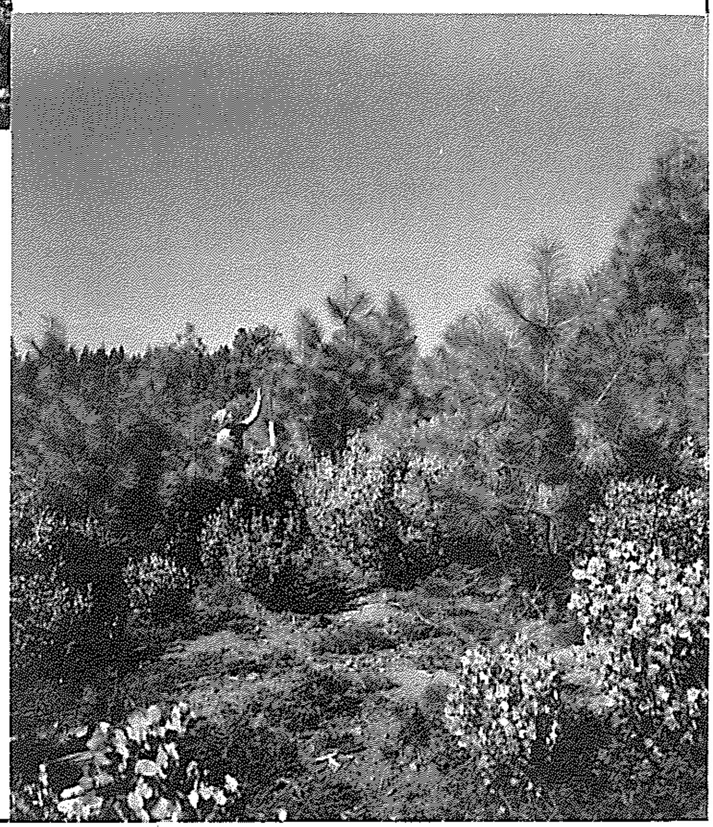
PACIFIC SOUTHWEST Forest and Range Experiment Station

FOREST SERVICE
U.S.DEPARTMENT OF AGRICULTURE

PONDEROSA PINE RESPONSE TO FERTILIZATION:

influence of brush removal and soil type

Robert F. Powers Grant D. Jackson



RESEARCH PAPER PSW-132

The Authors

ROBERT F. POWERS, a research forester, is conducting silvicultural studies in the Sierra Nevada forest types, with headquarters in Redding, California. He earned a bachelor's degree in forestry (1966) at Humboldt State University. He joined the Station's research staff in 1966. **GRANT D. JACKSON** was, at the time of the study reported here, on the staff of the Shasta-Trinity National Forest. He is now cropping systems specialist with the Montana Cooperative Extension Service, Bozeman. He received a bachelor's degree in agronomy (Panhandle State University, 1968), and a master's degree and doctorate in soil science (Montana State University, 1970, 1974).

ACKNOWLEDGMENT

We are grateful to E. I. (Bud) Veirs and Duane Nebeker, who were stationed on the Eldorado National Forest at the start of this study, for their help in installing plots and treatments at Balderston Plantation.

Cover: Ponderosa pine growing with and without a brush understory at Balderston plantation. Manzanita biomass averaged nearly 30 tons per hectare (*lower right*).

PONDEROSA PINE RESPONSE TO FERTILIZATION: influence of brush removal and soil type

Robert F. Powers

Grant D. Jackson

CONTENTS

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701
1978

IN BRIEF...

Powers, Robert F., and Grant D. Jackson
1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: 174.7 *Pinus ponderosa:* 237.4:232.211 [–176.1 *Arctostaphylos* spp.]
Retrieval Terms: Pinus ponderosa; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

Growth of forest stands is limited by the availability of moisture, nutrients, and light. These controlling factors are particularly evident in young plantations. There, fertility often is depressed if topsoil has been removed during site preparation. Frequently, trees in young plantations must compete for scarce site resources with invading brush species that aggressively colonize sites of recent disturbance. These conditions are favored by California's Mediterranean climate and by droughty, immature soils. Where such conditions occur, trees often are stunted. This paper describes an experiment aimed at improving growth of young, planted ponderosa pine through nitrogen fertilization and brush control on two soils of contrasting fertility.

In late 1975, study plots were established in the western foothills of the Sierra Nevada on two soil series—a fertile Cohasset, and a less fertile Mariposa—each supporting 9-year-old plantations of ponderosa pine and dense understories of whiteleaf manzanita. Brush was removed completely from half of the plots and plots were fertilized with urea at rates equivalent to 0, 224, or 448 kg N/ha.

Measurements and chemical analyses made after the next growing season showed that trees on the Mariposa soil were initially deficient in nitrogen, but that fertilization was not effective if brush remained in place. Where brush was removed, fertilization produced a doubling in height growth and a major increase in foliar nitrogen content. Needles formed in 1976 were nearly twice as heavy on Mariposa plots free of brush as they were where brush remained. Fertilized trees on plots free of brush seemed to retain needles better. Results suggest that trees on the Mariposa soil made major gains in crown biomass.

Trees on the fertile Cohasset soil seemed to dominate the brushy understory, and height growth of pine was not improved significantly by any treatment. Foliar N concentrations generally increased with fertilization rate, whether brush was present or not. Foliar analyses of untreated trees indicated, however, that the supply of soil nitrogen was adequate for rapid growth, even without fertilization. Needles formed following treatment were about 40 percent heavier for trees on Cohasset plots free of brush than on plots where brush remained.

On the Mariposa soil, tree growth was limited severely by the scarcity of moisture and nitrogen, and to some degree, by reduced amounts of light. Brush removal, coupled with fertilization, caused major growth gains in the first year following treatment. Improvements in foliar biomass and nutrient content were noted for trees on the Mariposa soil—and to a lesser degree, for trees on the Cohasset soil as well. Resulting increases in photosynthetic area suggest that rapid growth rates will continue for treated trees.

Western forest managers are turning to intensive silvicultural practices in coaxing greater wood yield from a diminishing forest base. Generally, commercial yields can be improved through better stocking. But on many sites stocked adequately with trees, growth rates may be depressed because of poor soil fertility or competition from invading vegetation. Foresters need to recognize growth problems before they become severe, understand the conditions causing the problems, and choose appropriate treatments to correct them.

Competing vegetation often reduces growth in young stands of ponderosa pine, as demonstrated in various studies. Pole-sized trees on a dry site in northeastern California showed small but significant increases in 5-year basal area growth following removal of perennial grasses (Gordon 1962). Removing a brushy understory from a thinned stand of pine saplings on a dry, central Oregon site resulted in 4-year growth improvements of nearly 40 percent in diameter and 60 percent in height (Barrett 1965). Bentley and others (1971), studying a 5-year-old plantation near Mount Shasta, found trees growing free of brush to be about twice as tall as trees competing with manzanita (*Arctostaphylos* sp. Adan.) and ceanothus (*Ceanothus* sp. L.). Fago (1972) found that saplings and poles on Site I land of California's interior Coast Range had diameter increases 40 percent greater than controls in the 5-year period following removal of a dense manzanita understory. A similar study on Site II land in the California Cascades[1] reported height growth increases between 46 and 124 percent in the decade following release.

Information is emerging on nutritional characteristics of California forest soils (Jackson 1977, Powers 1977). Sites where surface soil has been removed during site preparation have the greatest potential for nutrient deficiencies. On poor sites, the top 10 cm (4 in) may contain as much as one-third of the total soil reservoir of nitrogen, with the relative proportion decreasing as site quality improves (Powers 1976). Thus, scalping the surface soil to eradicate roots and seeds of weed species during type conversion may reduce nutrient availability and depress soil fertility, particularly on poor sites. As recently as 1959, the standard prescription for preparing certain brush sites for conifer regeneration was to bulldoze 45 to 60 cm (18 to 24 in) of surface soil from the regeneration site into windrows or terraces (Buck 1959). As a consequence, many young stands in California now show evidence of nutrient deficiencies because of past cultural practices.

Waring and Youngberg (1972) and Powers (1974[1]) believe that nutrient deficiencies, fertilizer response, and site productivity pivot on interacting site factors of temperature, moisture supply, and nutrient availability, and that these key factors should be measurable. To develop the theory further, the Pacific Southwest Forest and Range Experiment Station and Region 5 of the Forest Service began in 1975 a 10-year cooperative program in forest nutrition research (Jackson 1977). Using one of our first field installations, we were able to study the interaction of fertilization with brush competition in a plantation on contrasting soils. We sought answers to these questions:

- How severely are young trees influenced by brush competition?
- Will nitrogen fertilization affect growth rates?
- How do trees react to the interaction of brush removal and fertilization?
- Do these effects vary with soil type?

This report documents early growth response of planted ponderosa pine (*Pinus ponderosa* Laws.) to brush removal and nitrogen fertilization on contrasting soils in the western Sierra Nevada. Results should help forest managers to prescribe silvicultural treatments in young stands.

---

[1] Powers, Robert F. *Determining site quality in California.* (Manuscript in preparation.)

THE STUDY PLANTATION

Balderston Plantation covers 32 ha (80 acres) and is located at 975 m (3200 ft) on the Georgetown Ranger District of the Eldorado National Forest in California. Relief is gentle, with a slight southern exposure. The climate is typically Mediterranean. Precipitation begins in late fall and averages 135 cm (53 in) annually, of which slightly more than half is snow. July and August are the driest months. Annually, an average of 48 days reach or exceed a temperature of 32° C (90° F). The mean number of days with temperature minima above freezing is 189.

Before 1966 the area was dominated by whiteleaf manzanita (*A. viscida* Parry) resulting from a 1947 burn. In 1966, brush was bulldozed into windrows spaced about 20 m (66 ft) apart. Notes were not taken at the time, but soil remaining in the windrows today suggests that only a few centimeters of topsoil were scalped from the planting surface. In spring 1967, ponderosa pine were planted at 2.4-m (8-ft) spacings and the area was sprayed the following year with 2,4,5-T to control reinvasion by brush. The herbicide treatment was ineffective, and by 1975 *A. viscida* again dominated much of the area.

Examination of the site in spring 1975 showed that the plantation overlapped two contrasting major soil series. One, the Mariposa, derived from metamorphosed Paleozoic marine sediments, is a fine-loamy, mixed, mesic, ruptic-lithic-xerochreptic Haploxerult. It is less than 1 m deep over fractured schist. The Mariposa series is moderately acid, has gravelly silt-loam textures and is rated relatively low in timber productivity. The second soil, the Cohasset, derived from Pleistocene basic volcanics, is a fine-loamy, mixed, mesic, ultic Haploxeralf. It averages more than 1 m deep. The Cohasset series has loam/clay loam textures, is moderately acid, and is rated high in timber productivity. These series are similar in total amounts of nitrogen stored in their profiles; each averages slightly more than 5000 kg N/ha (4460 lb N/acre). They rank centrally in the array reported for California soils (Zinke and Stangenberger 1975). Total nitrogen storage is misleading, however, because nearly all the stored nitrogen is in the organic form, unavailable to higher plants. Of greater importance are differences between the series in rate of mineralization of organic nitrogen.[2]

The tallest planted trees on the Mariposa soil extended only half a meter above the brush, but on Cohasset the tallest trees overtopped the brush by more than a meter *(fig. 1)*. Matured needles formed the previous season were sampled from dominant trees and analyzed for total N concentration by micro-Kjeldahl (Jackson 1958). Needles of trees on the Mariposa series tested 0.8 percent N on a dry-weight basis, and needles of trees on Cohasset tested 1.1 percent. Spring is a poor time for foliar sampling (Powers 1974). Nevertheless, we felt results suggested a nitrogen deficiency on the Mariposa soil (<1.0 percent) but no apparent deficiency on the Cohasset.

METHODS

Plot Installation

In July 1975, National Forest personnel established eighteen 0.04-ha (0.1-acre) plots on each soil series in a randomized block design, with three blocks of six treatment plots each. (One block was later omitted from data analysis because it had been inadvertently installed on a contact zone between the two soils.) Treatments were assigned as factorial combinations of dry, agricultural grade urea (46 percent N) at 0, 224, and 448 kg N/ha (0, 200, and 400 lb N/acre) and removal or nonremoval of competing brush. Hand tools were used the following month to remove brush from nine plots on each soil series *(fig. 2)*. We established measurement plots of 0.01 ha (0.03 acres) within the boundaries of the 0.04 ha plots. Trees in the measurement plots were separated from the outer plot boundaries by a 1- to 2-tree-wide buffer strip. Measurement plots contained an average of 16 trees.

In November 1975, following several weeks of scattered showers, urea was applied by hand to each plot. Temperatures were cool during fertilization and the warmest temperature in the 2 weeks that followed was 20° C (68° F). Precipitation continued intermittently for the next several weeks, with a total of 14 cm (5.5 in) in December.

[2] Powers, R. F. Unpublished data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, California.

Figure 1—Manzanita competes strongly with trees for site resources at Balderston plantation. *Above,* planted trees are slightly taller than brush on the Mariposa soil series. *Below,* planted trees reach well above the brush on the Cohasset series.

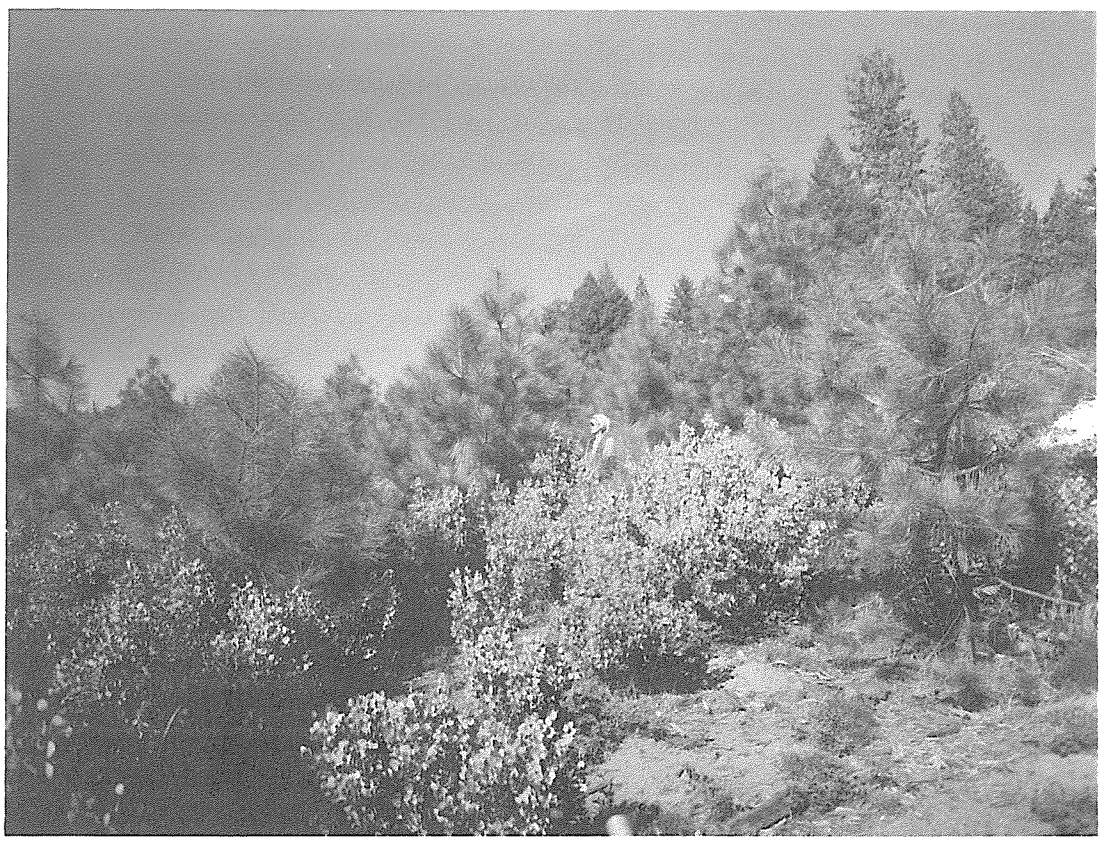


Figure 2—Brush has been removed on the Mariposa series plot (*above*) and on the Cohasset series plot (*below*).

Data Collection

Following fertilization, all measurement plot trees were measured for total height to the nearest 3 cm (0.1 ft) and diameter at 30 cm (12 in) to the nearest 2.5 mm (0.1 in). Brush density was estimated by dropping a metal pin at systematic intervals along two line transects across each plot. The product of the proportion of "hits" to "misses," and the mean of vegetation heights at each point of pin contact, gave a cubic measure known from a previous study to correlate well with standing biomass of brush.[2]

In August 1976, at the end of the first growing season following treatment, composite samples were drawn from fully matured needles in the upper third of the crowns from three to five of the tallest trees in each plot. Needles formed during the current and previous year were sampled separately. Samples were refrigerated for laboratory analysis of total nitrogen by micro-Kjeldahl. The plots were revisited in September and the 10 tallest trees per measurement plot were selected for measurement of 1976 height increment and current diameter at 30 cm. The tallest trees were chosen for sampling because they generate the crown classes that produce future crop trees (Oliver and Powers 1971). Needle fascicles were removed from the central part of the main leader of each measurement tree and stored on ice for determination of fascicle lengths to the nearest millimeter (0.04 in) and dry weights to the nearest milligram. Additionally, in each plot, one branch was taken from the second-year whorl of a single tree that seemed representative of the measurement trees. Live needle fascicles remaining from the current and previous year were counted separately.

Table 1—*Initial condition of vegetation on ponderosa pine plantation study plots, Eldorado National Forest, fall 1975*

Soil series[1]	Trees		Brush[2]		
	Total height	Diameter at 30 cm	Coverage	Height	Biomass
	Cm.		*Pct.*	*Cm.*	*Tons/ha*
Mariposa:					
Mean	113	3.5	56	54	19.5
S.D.	19.1	.65	10.9	4.1	3.94
Cohasset:					
Mean	191	5.4	58	75	28.0
S.D.	32.7	1.23	16.1	10.1	8.83

[1] Data cover 18 Mariposa plots and 12 Cohasset plots.
[2] Cover percentage (C) and height (H) were determined by point density estimates; biomass (tons/ha) = 0.581 + 0.0062CH.

Data Analysis

The heights and diameters of plot trees in 1975, before treatment, were analyzed for variance. The analysis revealed highly significant differences between trees on the two soil series ($\alpha = 0.01$). Trees on the Mariposa series were less than two-thirds the size of trees on Cohasset nine growing seasons after planting. Variation in tree size on Mariposa was about half that on the Cohasset, although coefficients of variation for height were 17 percent on both soils. Whereas brush coverage was similar on each soil, manzanita was 39 percent taller on the Cohasset series, and standing biomass there was 44 percent greater (*table 1).*

Differences between blocks on the Mariposa soil series were not significant statistically. Block differences were highly significant on the Cohasset series when all three blocks were included in the analysis, but not when the block installed on a contact zone was omitted. Data from this block are not reflected in analyses of results.

Main effects for all categories of data gathered in August 1976, after treatment, received preliminary screening by random block factorial analysis of variance. Where treatment effects were found significant at $\alpha = 0.10$ or less, treatments were tested orthogonally according to specific comparisons planned *a priori.* This is a sensitive test for describing general response surfaces through a limited number of comparisons. Further, it provides an effective test of treatment effects if response differences are small. Additionally, all treatment means were compared at $\alpha = 0.05$, using Duncan's New Multiple Range Test, allowing each treatment to be compared with every other.

RESULTS

Tree response to brush removal and fertilization was tempered by the soil series on which trees grew. Certain treatment combinations produced striking results on the Mariposa series, but changes on the Cohasset series were more subtle. Results can be separated into categories of stem growth and foliar traits.

Stem Growth

Separately, neither brush removal nor fertilization significantly affected height growth on Mariposa soil. But combining these treatments produced growth responses nearly double those on plots where either treatment had been applied (*table 2).* A strong quadratic component was found through orthogonal contrasts for height response to fertilizer rate on Mariposa soil, indicating that the major response was to 224 kg N/ha, and that the highest rate of fertilization had no further effect on growth. Height growth was unaffected by treatment on the Cohasset series.

Fertilized trees on Mariposa soil from which brush had been removed had diameters significantly larger (α = 0.05) than those where brush remained. Again, significant changes in diameter were only apparent when treatments were combined. Tree diameters on Cohasset soil were unaffected by treatment.

Foliar Traits

Fertilization had no significant effect on foliar N concentration for trees on the Mariposa series if brush remained on plots. Where brush had been removed, foliar N concentration increased linearly with fertilization rate in both current and older needles. Orthogonal tests of results on the Cohasset series showed that nitrogen concentration in 1-year-old needles increased significantly with fertilization rate (α = 0.01), particularly where brush had been removed. But for current year's foliage, concentration increases were not quite significant at α = 0.10—probably because losing one treatment block decreased the sensitivity of the test. Removing brush from Cohasset series plots caused no significant change in the nitrogen concentration of current needles.

Brush removal on the Mariposa soil, separately or combined with fertilization, produced striking increases in needle length, averaging 47 percent for

Table 2—*Chemical and physical properties*[1] *of trees on the Mariposa and Cohasset soil series on ponderosa pine plantation plots at Eldorado National Forest, the first growing season after brush removal and fertilization, August 1976*

Treatment	Foliar nitrogen		Height increment	Diameter (30 cm)	Current needle fascicles		Needle fascicles per branch	
	Current	1 yr old			Length	Weight	Current	1 yr old
	Pct			*Cm*		*Mg*		
				Mariposa series				
Brush present:								
0 kg N/ha	0.82a	0.80a	12.5a	4.5a	14.0a	140a	82a	91a
224	.82ab	.90ab	15.7a	5.0a	14.9a	168a	115ab	93a
448	.90ab	.91ab	14.7a	4.7a	14.5a	163a	58c	69a
Brush absent:								
0	.77ab	.70c	16.5a	4.9ab	21.2b	251b	86a	55a
224	.98b	1.03bd	29.8b	6.8c	24.0c	321c	160d	139a
448	1.22c	1.24d	28.1b	6.2bc	24.7c	356c	138bd	111a
				Cohasset series				
Brush present:								
0	.92a	.91a	41.1a	8.5a	20.8a	262a	174a	154a
224	1.14a	.95a	51.1a	9.2a	20.4a	250a	174a	158a
448	1.22a	1.30b	42.0a	9.1a	21.3a	242a	222a	142a
Brush absent:								
0	.90a	.87a	45.5a	9.3a	22.8a	326b	164a	184a
224	1.16a	1.30b	52.0a	9.6a	25.5a	377b	190a	151a
448	1.24a	1.22b	43.2a	7.9a	24.0a	356b	171a	168a

[1] For each soil series, within-column values not designated by the same letter are significantly different at α = 0.05 by Duncan's New Multiple Range Test.

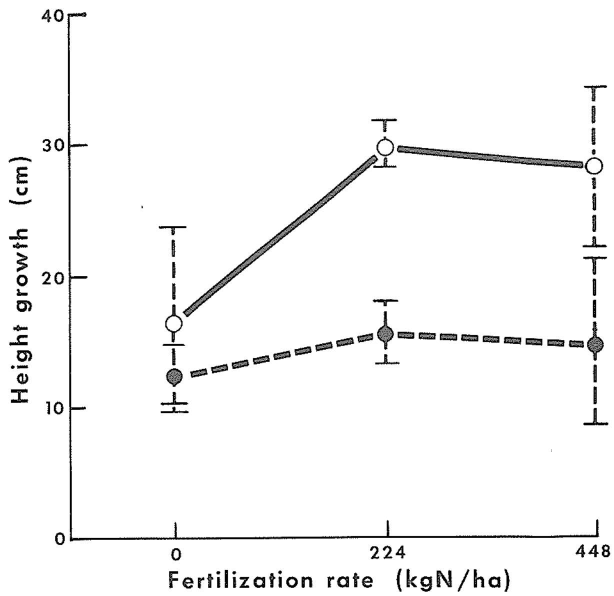


Figure 3—Height growth increased sharply for nitrogen fertilized trees on Mariposa soil series plots from which brush had been removed (solid line). Height growth varied little with fertilization rate on plots where brush remained (broken line). Vertical bars bracket 95-percent confidence intervals for treatment means (open and solid circles).

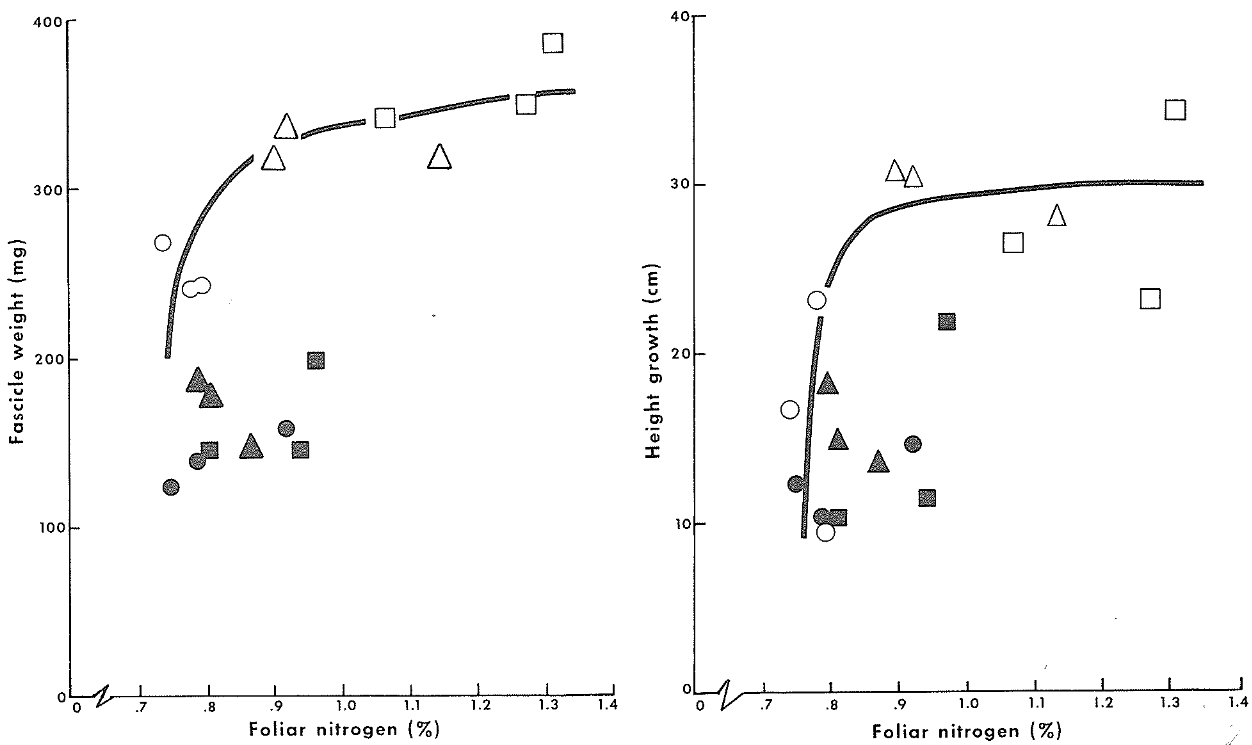


Figure 4—Growth increased sharply with foliar nitrogen content of trees on Mariposa soil series plots where brush had been removed (open symbols). Where brush remained (solid symbols), foliar nitrogen varied little and growth remained poor. Fertilizer rates were 0 (circles), 224 (triangles), and 448 (squares) kgN/ha. Trend curves are shown for brush-free plots.

brush removal alone, and 68 percent when combined with fertilization *(table 2).* No significant differences were detectable between the rate effects of 224 and 448 kg N/ha. Though needles of Cohasset trees were longer on plots from which brush had been removed, differences were small and not statistically significant.

Dry weights of 1976 needle fascicles were increased for trees on both soils following brush removal. Weight gains averaged 60 percent on the Mariposa series and 40 percent on Cohasset. Combining brush removal with fertilization on the Mariposa soil increased fascicle dry weight by nearly 120 percent. No difference was apparent between fertilization rates—224 kg N/ha was as effective as 448 kg N/ha, and neither were effective where brush remained. Fascicle weights for trees on the Cohasset series were not affected significantly by fertilization.

Treatments had no discernible effect on the retention of needle fascicles formed the current year on the Cohasset soil, or the previous year on either series. Our sampling intensity (one branch per plot) was insufficient for the variation we found. However, combining brush removal with fertilization on the Mariposa soil resulted in significant gains in current-year fascicles remaining in September. Where brush remained, the heaviest fertilization rate seemed to decrease fascicle numbers.

DISCUSSION AND CONCLUSIONS

Climatic conditions affecting the 1976 growing season provided a strong test of brush competition for soil moisture at Balderston. Weather records at the Georgetown Ranger Station 4.8 km (3 miles) to the west of the study site show that the 1975-76 hydrologic year was the driest in over 20 years, with precipitation only 46 percent of normal. Statewide averages for the two soils (Zinke and Stangenberger 1975) show that the Cohasset series has the potential for holding 40 percent more plant-available moisture, and four times the exchangeable cations than has the Mariposa series. Undoubtedly, nutrient and moisture availability—and probably the shade cast by manzanita—affected tree growth on the Mariposa series more severely than on the Cohasset.

First-year results at Balderston plantation show that brush had suppressed the growth of pine seedlings severely on the Mariposa soil series. Though trees there clearly were deficient in nitrogen, brush competition circumvented growth response to fertilization. Where brush was removed, height growth increased, peaking on plots receiving 224 kg N/ha *(fig. 3).* Similar fertilizer rates have produced good growth response in a variety of species (Powers 1974). Combining fertilization with brush removal raised foliar N concentration above the critical level for ponderosa pine – 0.85 percent N,[3] and contributed to a doubling of both height growth and needle weight *(fig. 4).* Gains in foliar biomass and nutrient content of trees on Mariposa series plots indicate that improved growth rates will continue.

Growth on the Cohasset series was not limited by nitrogen availability, for unfertilized trees contained foliar N concentrations greater than critical level (*table 2*). But whereas trees on Cohasset plots clearly dominated the manzanita understory, growth was limited to some extent by moisture supply. Although heights and diameters were not influenced by brush removal, needle weights were increased 40 percent by this treatment. Gains in foliar biomass on brush-free Cohasset plots suggest that improved growth rates will follow.

On both soil series, removing brush on unfertilized plots resulted in small decreases in the concentration of foliar N in current and older needles (*table 2*). This can be explained by the "dilution effect" (Ulrich 1948) resulting from major changes in the biomass of current needles and little or no change in their nutrient supply. Differences great enough to be significant statistically were found only for older foliage on the Mariposa series. Coupled with brush removal, fertilization increased greatly the quantity of nitrogen stored in the standing biomass of trees on both soil series. Luxury amounts of nitrogen contained currently in widely spaced trees will supplement demands made on soil nitrogen once crowns close. Thus, high growth rates will continue even if soil nitrogen availability should diminish.

The key to increasing forest yields is our ability to identify the primary factors limiting growth. Coordinated research in forest nutrition is providing a framework for recognizing the controlling factors of temperature, moisture and nutrient supply, and linking them with silvicultural prescriptions for sustaining or enhancing forest growth.

---

[3] Powers, R. F. Unpublished data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, California.

LITERATURE CITED

Barrett, James W.
1965. **Spacing and understory vegetation affect growth of ponderosa pine saplings.** USDA Forest Serv. Res. Note PNW-27, 8 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Bentley, Jay R., Stanley B. Carpenter, and David A. Blakeman.
1971. **Early brush control promotes growth of ponderosa pine planted on bulldozed site.** USDA Forest Serv. Res. Note. PSW-238, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Buck, John M.
1959. **Site preparation for forest regeneration in California.** USDA Forest Serv. Calif. Region, 26 p., illus. San Francisco, Calif.

Fago, Clifford.
1972. **Ponderosa pine growth response on a California Division of Forestry fuelbreak.** Calif. Div. For. State Forest Note 49, 2 p., illus. State of Calif., Resour. Agency, Dep. Conserv. Sacramento.

Gordon, Donald T.
1962. **Growth response of east side pine poles to removal of low vegetation.** USDA Forest Serv. Res. Note 209, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Jackson, Grant D.
1977. **Region 5 forest soil fertility program.** 1976 Proc. Fifth Calif. Forest Soil Fertility Conf., p. 33-43. Soil Improvement Comm., Calif. Fertilizer Assoc., Sacramento, Calif.

Jackson, M. L.
1958. **Soil chemical analysis.** 498 p. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Oliver, William W., and Robert F. Powers.
1971. **Early growth of ponderosa pine forecasts dominance in plantations.** USDA Forest Serv. Res. Note PSW-250, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Powers, Robert F.
1974. **Evaluating fertilizer programs using soil analysis, foliar analysis, and bioassay methods.** Proc. Servicewide Silvic. Work Conf. 1974, p. 124-162. USDA Forest Serv., Washington, D. C.

Powers, Robert F.
1976. **Principles and concepts of forest soil fertility.** Proc. 1976 1st. Ann. Earth Sci. Symp. 33 p. USDA Forest Serv., San Francisco, Calif.

Powers, Robert F.
1977. **Research in forest nutrition at the Pacific Southwest Forest and Range Experiment Station, Redding, California.** 1976 Proc. Fifth Calif. Forest Soil Fertility Conf., p. 44-48. Soil Improvement Comm., Calif. Fertilizer Assoc., Sacramento.

Ulrich, Albert.
1948. **Plant analysis–methods and interpretation of results.** *In* Diagnostic techniques for soils and crops. H. B. Kitchen (ed.), p. 157-198. Amer. Potash Inst., Washington, D.C.

Waring, R. H., and C. T. Youngberg.
1972. **Evaluating forest sites for potential growth response of trees to fertilizer.** Northwest Sci. 46(1):67-75.

Zinke, P., and A. Stangenberger.
1975. **Soil-vegetation survey soil moisture storage, nutrient storage, meter depth summary.** Agric. Exp. Stn. Proj. 1762, 2595, 2937. 10 cards, microfiche. Univ. Calif., Berkeley.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Powers, Robert F., and Grant D. Jackson.
1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

First-year results of fertilization in a young ponderosa pine plantation on two contrasting soils were analyzed. Trees testing low in foliar nitrogen responded strongly to fertilization where brush had been removed, but failed to respond if brush remained. Height growth was doubled by certain treatment combinations on the less fertile Mariposa soil, but was not influenced by treatment on the more fertile Cohasset. Brush removal increased needle weight for trees on both soils. Increases in foliar biomass and nitrogen content of trees on treated plots suggest that rapid growth rates will continue.

Oxford: 174.7 *Pinus ponderosa:*237.4:232.211 [–176.1 *Arctostaphylos* spp.]
Retrieval Terms: Pinus ponderosa; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

Powers, Robert F., and Grant D. Jackson.
1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

First-year results of fertilization in a young ponderosa pine plantation on two contrasting soils were analyzed. Trees testing low in foliar nitrogen responded strongly to fertilization where brush had been removed, but failed to respond if brush remained. Height growth was doubled by certain treatment combinations on the less fertile Mariposa soil, but was not influenced by treatment on the more fertile Cohasset. Brush removal increased needle weight for trees on both soils. Increases in foliar biomass and nitrogen content of trees on treated plots suggest that rapid growth rates will continue.

Oxford: 174.7 *Pinus ponderosa:*237.4:232.211 [–176.1 *Arctostaphylos* spp.]
Retrieval Terms: Pinus ponderosa; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

Powers, Robert F., and Grant D. Jackson.
1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

First-year results of fertilization in a young ponderosa pine plantation on two contrasting soils were analyzed. Trees testing low in foliar nitrogen responded strongly to fertilization where brush had been removed, but failed to respond if brush remained. Height growth was doubled by certain treatment combinations on the less fertile Mariposa soil, but was not influenced by treatment on the more fertile Cohasset. Brush removal increased needle weight for trees on both soils. Increases in foliar biomass and nitrogen content of trees on treated plots suggest that rapid growth rates will continue.

Oxford: 174.7 *Pinus ponderosa:*237.4:232.211 [–176.1 *Arctostaphylos* spp.]
Retrieval Terms: Pinus ponderosa; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

Powers, Robert F., and Grant D. Jackson.
1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

First-year results of fertilization in a young ponderosa pine plantation on two contrasting soils were analyzed. Trees testing low in foliar nitrogen responded strongly to fertilization where brush had been removed, but failed to respond if brush remained. Height growth was doubled by certain treatment combinations on the less fertile Mariposa soil, but was not influenced by treatment on the more fertile Cohasset. Brush removal increased needle weight for trees on both soils. Increases in foliar biomass and nitrogen content of trees on treated plots suggest that rapid growth rates will continue.

Oxford: 174.7 *Pinus ponderosa:*237.4:232.211 [–176.1 *Arctostaphylos* spp.]
Retrieval Terms: Pinus ponderosa; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.