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Early Response of Ponderosa Pine to Spacing and Brush: Observations on a 12-year-old Plantation

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Ponderosa pine (*Pinus ponderosa* Laws.) was planted at five different spacings, from 6 by 6 to 18 by 18 feet, on a productive site in northern California. Spacing and brush effects on tree growth were evaluated both on plots where brush was allowed to develop and on plots kept free of brush. Competition between trees in brush-free plots began during the 8th year for trees spaced 6 by 6 feet and during the 10th year for trees spaced 9 by 9 feet. On several plots brush competition reduced tree diameters by the equivalent of nearly 3 years growth. These early results forecast the strong influence of spacing and brush on tree growth.

Retrieval Terms: Pinus ponderosa, tree growth, diameter increment, plantation spacing, ground cover, plant competition, brush, northern California.

The best spacing of ponderosa pine (*Pinus ponderosa* Laws.) for producing usable wood depends upon the forest manager's market objective and cultural investment plans. Today's sawlog economy and a desire to cut precommercial thinning costs often have dictated initial spacings of 10 feet (3 m) or wider. A variety of roundwood markets and a continuing decline in minimum sawlog size are predicted. Future initial spacings should be tailored to fit these changing markets.

Complicating this cultural-marketing relationship is brush, a common and aggressive competitor in most ponderosa pine plantations. Wide spacings are known to produce faster growing trees than narrow spacings, but brush can cancel this advantage by capturing much of the site's resources before tree crowns close. Conversely, narrowly spaced trees often prevent severe brush competition at the expense of slow tree growth caused by intertree competition.

The experiment reported here was devised to explore the effect of tree spacing, brush competition, and the interaction of these two factors on growth and development of a ponderosa pine plantation in northern California. Results, emerging 12 years after planting, merit immediate attention specifically because tree spacing and brush competition were determined to exert strong influence on stem and crown size of ponderosa pine. Subsequent reports will include stand volume and basal area growth.

STUDY ENVIRONMENT

Trees were planted within a 15-acre (6-ha) clearcut on the Challenge Experimental Forest, 1 mile (0.6 km) south of Challenge, Yuba County, California. The area lies at 2650 feet (808 m) elevation, near the lower elevational boundary of the mixed-conifer forest type, on the west slope of the northern Sierra Nevada. Slopes range from 2 to 10 percent, are south and southeast facing, and flat in profile.

Summers are hot and dry and winters are cool and wet at this elevation. Average annual temperature is 58°F (14°C). July and August are the hottest months with a daily average of 75°F (24°C). Minimum temperatures are reached in December when the daily average is 43°F (6°C). About 200 days are without frost. Annual precipitation, measured at Challenge since 1937, averages 68 inches (173 cm), about 98 percent of which falls between October and May.

High temperatures and abundant precipitation have created a deeply weathered Xeric Haplohumult soil tentatively classified as Challenge Series.[1] The profile is more than 5 feet (1.5 m) deep, overlaying weathered Mesozoic metavolcanic rocks commonly known as greenstone. Challenge Series is similar to Sites, an established series found extensively throughout the Coast Range and foothills of the Sierra Nevada and Cascade Ranges of California and western Oregon. Site Index is estimated to be 110 feet (34 m) at 50 years.[2]

In fall 1965, a few months before planting, 15 acres of 90-year-old ponderosa pine as well as smaller amounts of the other mixed-conifer species were clearcut. All unmerchantable material and logging slash were pushed into piles bordering the area with care to avoid removing topsoil. Finally, rough spots were smoothed.

FIELD DESIGN AND ESTABLISHMENT

In March 1966, 1-0 ponderosa pine from the appropriate seed zone was hand planted at staked locations in two randomized blocks. These blocks, each containing five rectangular plots, were planted with trees at five different spacings:

Feet	*Meters*
6 by 6	1.8 by 1.8
9 by 9	2.7 by 2.7
12 by 12	3.7 by 3.7
15 by 15	4.6 by 4.6
18 by 18	5.5 by 5.5

The effect of brush on tree growth at these spacings was tested by splitting each plot in half. On one half, chosen randomly, brush was allowed to develop naturally. The other half was kept brush-free. Each divided plot contained 12 trees to be measured surrounded by a buffer of at least 24 feet (7.3 m) minimally containing two rows of trees. Therefore, split plots with buffer varied in area from 0.107 acre (0.043 ha) for 6-foot spacings to 0.364 acre (0.147 ha) for 18-foot spacings. The entire experiment covered 4.308 acres (1.745 ha).

In brush-free plots, woody vegetation was killed by 2,4,5-T herbicide applied by hand sprayer in the second and fourth years after planting. Newly germinated brush seedlings were grubbed out by hand. The influence of forbs and bracken fern (*Pteridium aquilinum* [L.] Kuhn var. *lanuginosum* [Bong.] Fern.), which occupied the understory in the absence of brush, was not evaluated in this study.

Mortality has been light and has had little apparent effect on results. In the first year, 23 trees, or 1.5 percent of all trees planted in the experiment, died. They were replaced by surplus stock planted adjacent to the experiment when the study was established. Replacement trees were selected based on similarity in height to the mean height of all trees in the plot. Mortality replacements were similarly made for trees which died over the next 2 years. Later mortality was not replaced because stock had become too large to transplant and compete successfully with established trees. After 12 years, six trees to be measured were dead, five of which were in plots with trees spaced 6 by 6 feet.

MEASUREMENTS AND ANALYSES

The 12 trees to be measured in each split plot were tagged. Following the 5th through 10th and the 12th growing seasons, measurements were recorded of stem diameter at breast height, total height, crown width estimated by measuring two branches at right angles in the whorl of longest branches, height to the base of the first all-living branch whorl, and average diameter of the whorl of branches at or just above breast height.

In 1976, 10 years after planting, brush was sampled in plots where it was allowed to develop. Circular 0.0025-acre (0.001-ha) plots were established at random locations within the area containing trees to be measured. Because 25 percent of each area containing trees to be measured was sampled, number of brush sample plots varied with tree plot size. All brush species were identified and their crown volumes were determined from two measurements of mean maximum crown diameter taken at right angles and one measurement of mean maximum crown height.

Subsequent analyses revealed that correlations of brush crown volume to tree growth were higher if only dominant brush species were included.

These species, which comprised 88 percent of all woody vegetation on the plots, were whiteleaf manzanita (*Arctostaphylos viscida* Parry), Indian manzanita (*A. mewukka* Merriam), deerbrush (*Ceanothus integerrimus* H. and A.), small numbers of Sierra gooseberry (*Ribes roezlii* Regel.), and sprouts of California black oak (*Quercus kelloggii* Newb.) and tanoak (*Lithocarpus densiflora* [H. and A.] Rehd.). Although deerbrush is known to fix nitrogen, root nodules are rare on productive sites, and none was found in this plantation.

Spacing effects could be tested statistically by analysis of variance, since mortality has been light. A split-plot analysis of variance with five spacings, with and without brush, and four ages (6, 8, 10, and 12 years from planting), was calculated for the entire experiment.[3] The relation of tree size to brush quantities was tested by regression techniques.

RESULTS AND DISCUSSION

Spacing and brush competition strongly influenced stem diameter at breast height, crown width, live crown ratio, and average branch diameter 12 years after planting (*fig. 1, table 1*). Total height was not significantly affected by spacing ($P > 0.05$), although 12-year-old trees at 6-foot spacings without brush were 3.6 feet (1.1 m) shorter than heights of wider spaced trees. Within a specific spacing, trees in plots with brush tended to be smaller and more variable in size than trees in brush-free plots.

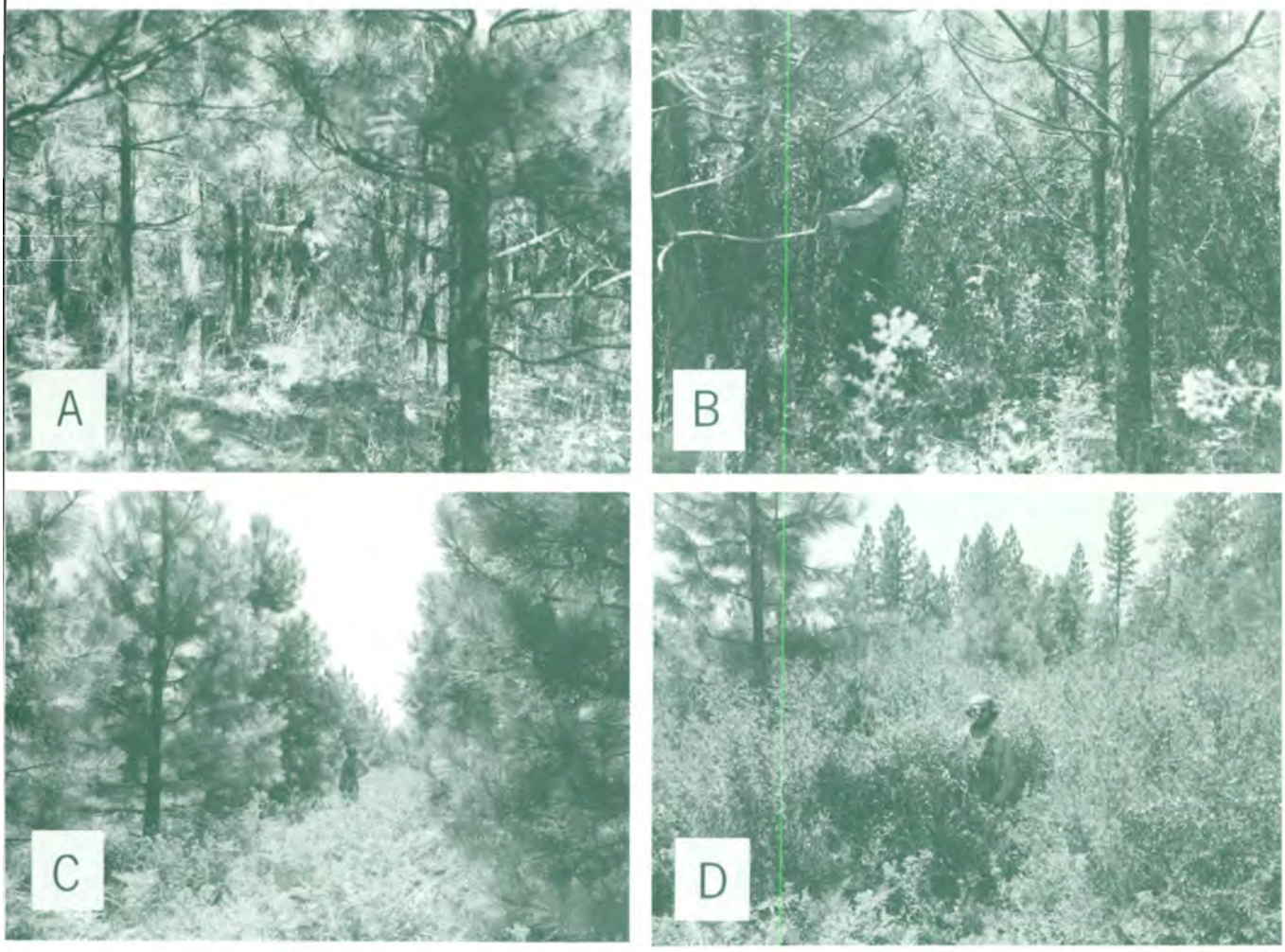

Figure 1—In this 12-year-old ponderosa pine plantation, size differences between trees growing with and without brush were small at narrow spacings and large at wide spacings: (A) 6-foot spacing without brush, (B) 6-foot spacing with brush, (C) 18-foot spacing without brush, (D) 18-foot spacing with brush.

Spacing

Six years after planting, dimensions of trees in brush-free plots were:

D.b.h.	1.0 inch (2.5 cm)
Height	5.8 feet (1.8 m)
Live crown ratio	80 percent
Crown width	3.6 feet (1.1 m)
Branch diameter	0.3 inch (0.8 cm)

Tree size differences among spacings were not significant statistically. Although stem and branch diameters of trees spaced 6 by 6 feet often were smaller than those dimensions for trees spaced wider (*fig. 2A, 2B*), no trend to wider crown based on wider spacing was apparent.

When the trees were 8 years old, differences in stem and crown dimensions between spacings remained nonsignificant. Growth of trees planted at 6-foot spacings, however, began to slow noticeably. Trees spaced 6 feet apart had grown 1.0 inch (2.5 cm) in diameter, 1.2 feet (0.4 m) in crown width, and 0.4 inch (1.0 cm) in branch diameter, whereas, mean growth of trees at the four wider spacings during the same period was 1.5 inch (3.8 cm), 2.4 feet (0.7 m), and 0.5 inch (1.3 cm), respectively (*fig. 2*).

Apparently, trees spaced 6 feet apart began to compete for soil moisture during the eighth growing season.[4] Predawn plant moisture stress, measured by a pressure chamber, was significantly higher in trees at 6-foot spacings than in trees at wider spacings. Furthermore, trees spaced 6 feet apart retained needles for less than 2 years on the average; more widely spaced trees usually retained their needles longer than 2 years.

Table 1—*Stem and crown dimensions of ponderosa pine 12 years after planting to five spacings with and without brush*

Square spacing	Stem		Crown		
	D.b.h.	Height	Width	Ratio	Branch diameter
Feet	*Inches*	*Feet*	*Feet*	*Percent*	*Inches*
	Without brush				
6	3.5 [1]	14.4	5.6	68	0.9
9	4.7	17.1	8.7	78	1.2
12	5.4	18.4	9.7	83	1.4
15	5.5	17.4	9.6	86	1.5
18	6.2	18.9	10.8	86	1.6
	With brush				
6	2.9	13.1	5.2	59	0.7
9	4.2	14.9	7.2	68	1.0
12	3.9	13.1	7.4	65	1.0
15	3.4	13.1	6.3	64	0.9
18	4.4	16.2	7.9	64	1.1

[1] Means not significantly different ($P > 0.05$) are bracketed.

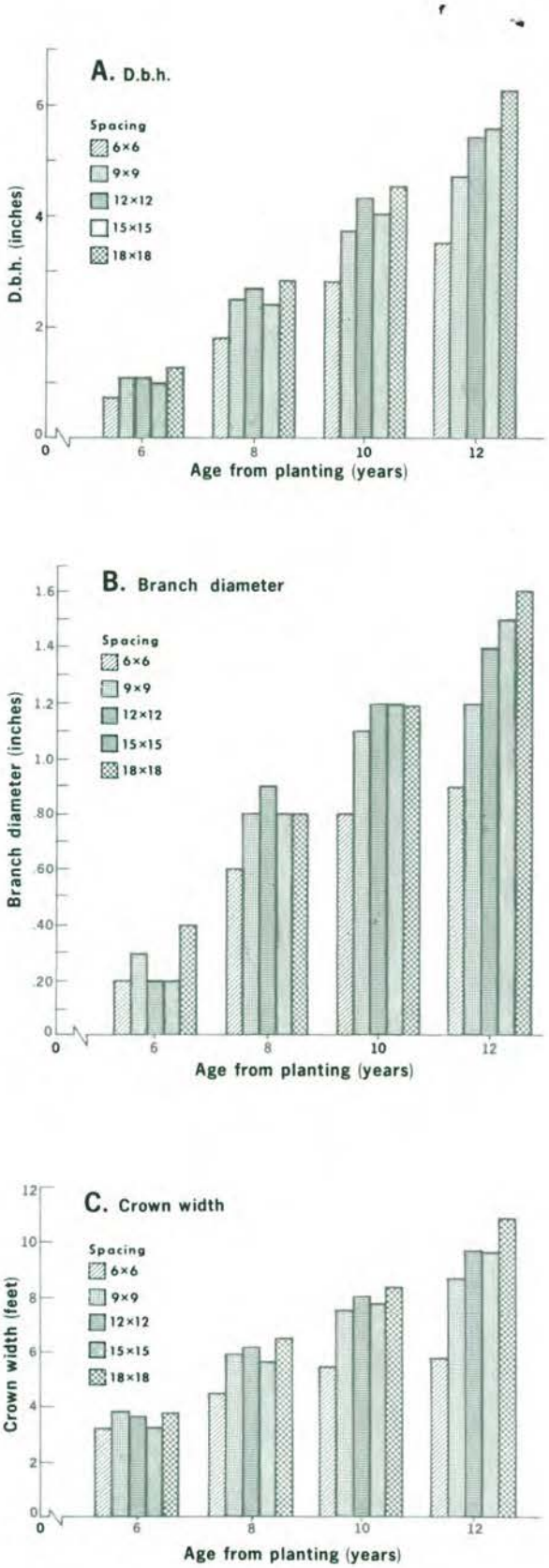

Figure 2—With brush absent, tree spacing exerted an increasing influence on (A) d.b.h., (B) crown width, and (C) live crown ratio, between the sixth and twelfth years in a ponderosa pine plantation on a productive site.

As competition intensified in the 10th year among trees spaced 6 by 6 feet, size differences between them and trees spaced 12 by 12 feet and wider reached statistical significance ($P \leqslant 0.05$) in stem and branch diameters and crown width. Size differences between trees at 6- and 9-foot spacings did not differ significantly. The 10th year, however, did signal the onset of intertree competition at the 9-foot spacing, marked by slackening growth of all stem and crown characteristics.

Size differences and related statistical significances had increased by the 12th year. Trees spaced 12 feet apart and wider continued to grow free of intertree competition.

Brush

Brush seeds germinated abundantly and seedlings grew rapidly on plots where they were allowed to develop. But few ponderosa pines were overtopped by brush owing to the rapid growth in height of the pines, and the complete site preparation which eliminated all existing brush and nearly all hardwood sprouts. Brush averaged 4.6 feet (1.4 m) tall after 8 years. Brush plant numbers varied widely among plots, ranging from 800 to 8700 dominants per acre (2000 to 21,500/ha). Brush crowns covered 75 percent of each plot, on the average, ranging from 30 percent to 124 percent on plots in which brush crowns overlapped. Stand density expressed as crown volume per acre averaged 201,000 cubic feet (14,100 m^3/ha). Volumes on individual plots ranged from 46,000 to 362,000 cubic feet (3200 to 25,300 m^3/ha).

Trees competing with brush grew more slowly than trees free of brush. After 12 years, the increasing disparity in size reached statistical significance for all dimensions (*table 1*). The highly significant years by brush treatment interaction for all dimensions indicates that this increasing disparity is real, not chance. For example, 6 years after planting, trees in brush plots had mean stem diameters which were 93 percent of those found in brush-free plots. Another 6 years later, however, diameters of tree stems in brush were only 76 percent of those found in brush-free plots.

Brush tended to obscure differences in tree size among spacings both by reducing mean differences and increasing variation. After 12 years without brush competition, stem, crown, and branch diameters averaged 83 percent larger for trees spaced 18 by 18 feet than these dimensions for trees spaced 6 by 6 feet; whereas, in plots with brush, these same dimensions averaged only 53 percent larger (*table 1*). Within-plot coefficients of stem diameter variation were compared between plots with and without brush. Plots with brush showed greater variation in tree size. The within-plot coefficient of variation was 28 percent for the average brush plot and 22 percent for the average brush-free plot.

Tree crown characteristics, especially live crown ratio, were more sensitive to brush competition than stem characteristics. At spacings 12 by 12 feet and wider in which no intertree competition was noted, differences in crown ratios between trees in brush and brush-free plots were significant by the 8th year. Crown width and branch diameter differences were significant by the 10th year. But stem diameters differed significantly in the 12th year only for trees spaced 15 by 15 feet and 18 by 18 feet. Height differences were significant only in the 12-foot spacing in the 12th year.

Early results have not revealed if trees at closer spacings have begun to suppress the brush. Brush crown volumes and percent cover tend to be smaller in plots containing trees spaced 9 by 9 feet and closer than in plots containing trees at wider spacings. But neither this trend nor the interaction between spacing and brush are statistically significant.

Quantity of brush, expressed as crown cover percent, was correlated significantly with stem diameter. When differences in mean diameter between plots with and without brush were expressed in years of growth foregone by neglecting brush control, the impact of brush competition became more striking. Years of diameter growth loss for trees in each spacing plot were obtained as follows:

$$Y = (D_{012} - D_{B12}) \,/\, \frac{D_{012} - D_{06}}{6}$$

in which

Y = years of d.b.h. growth loss
D_{012} = mean d.b.h. of trees in a brush-free plot at age 12
D_{B12} = mean d.b.h. of trees in a brush plot at age 12
D_{06} = mean d.b.h. of trees in a brush-free plot at age 6

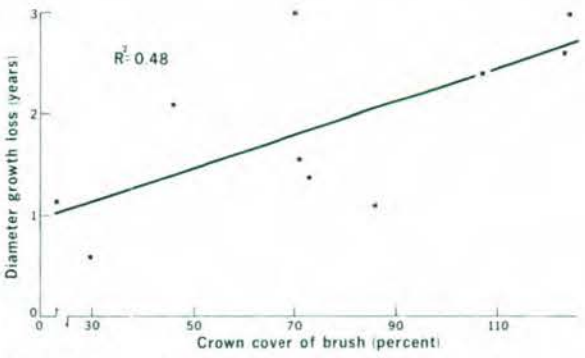

Figure 3—In 12-year-old ponderosa pine planted on a productive site, as many as 3 years of stem diameter growth were lost depending upon quantity of competing brush.

In the 12-year-old plantation discussed here, plots with a light brush cover of 30 percent had lost the equivalent of 1.1 years of diameter growth (*fig. 3*). Plots completely covered by brush, of which some crowns were overlapping (120 percent cover), lost the equivalent of 2.6 years of diameter growth. Nearly one fourth the growth potential was lost in these brush-choked plots, despite a productive site cleared and groomed before planting, and rapid height growth which kept tree crowns above the brush. The relation of diameter growth loss to brush crown cover can be expressed by the following equation fitted by least squares:

$$Y = 0.629 + 0.0166X$$

in which

Y = diameter growth loss in years
X = crown cover of brush in percent.

Brush crown cover explained a significant proportion (48 percent) of the variation in diameter growth loss within the range of data presented. But extending the equation especially to brush coverages less than 30 percent may give erroneous results.

Let us assume that brush continues to suppress diameter growth by the same proportion for the next 10 to 15 years and that the 12-foot spacing will support a commercial thinning when mean stand diameter reaches 12 inches (30.5 cm). Then, the plantation might be commercially thinned at age 25, if trees are free of brush; however, brush competition could delay commercial thinning for another 6 years or until age 31.

The impact of brush competition on the Challenge plots was found to be minimal compared with most plantations which are on less productive sites and prepared with less care. For example, in a similar spacing study on a site of low productivity in central Oregon, growth of naturally established ponderosa pines were compared in plots with and without understory vegetation.[5,6] Brush species were mostly bitterbrush (*Purshia tridentata* [Pursh] DC.) and snowbrush (*Ceanothus velutinus* Dougl. ex Hook.). After 12 years, trees in plots with a 30 percent brush crown cover lost the equivalent of 2.4 years of diameter growth—over twice that found in this study. The impact on growth was greater, in part, because Barrett removed all competing vegetation including grasses. Nevertheless, that the total difference in growth loss could be attributed to grass competition is unlikely. In California, on another site of low productivity, brush crown volumes exceeding 10,000 cubic feet per acre (700 m^3/ha) had reduced mean height of ponderosa pine 5 years after planting.[7] Trees competing with mostly greenleaf manzanita (*Arctostaphylos patula* Greene) and snowbrush with crown volumes of 30,000 cubic feet per acre (2100 m^3/ha) (lowest volumes found in this study) were only 69 percent of the height of trees growing brush-free. More information spanning the range of site productivities is being gathered now to assess fully the impact of brush competition on ponderosa pine growth.[8]

CONCLUSIONS

Tree spacing and presence and quantity of brush were strong influences on stem diameter and crown size of ponderosa pines 12 years after planting. The increasing influence of tree spacing and brush suggest that this study will provide a wide range of information for managing ponderosa pine plantations on sites of similar productivity. For example, we should learn when and by how much tree stem and crown characteristics are reduced by intertree competition over the entire range of tree spacings. As trees become larger, influence of tree spacing and brush on stand basal area and volume can be evaluated. Also, the ability of trees at different spacings to dominate brush by capturing site resources may become apparent. These expected results will aid in devising optimum tree densities and brush control strategies for production of wood for single or multiple markets.

Also important are the effects of tree spacing and brush control on soil moisture and mineralization rates of nitrogen on similar soils—areas of investigation which this study is well-suited to answer.

NOTES

[1]Herbert, Fred W., Jr., and Eugene L. Begg. 1969. *Soils of the Yuba area, California.* 170 p., 41 maps. Dep. Soils and Plant Nutrition, Univ. Calif., Davis.

[2]Powers, Robert F., and William W. Oliver. 1978. *Site classification of ponderosa pine stands under stocking control in California.* USDA Forest Serv. Res. Paper PSW-128, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

[3]Steel, Robert G., and James H. Torrie. 1960. *Principles and procedures in statistics.* McGraw-Hill, New York. 481 p.

[4]Oliver, William W. 1974. *Moisture stress related to spacing and brush competition in a ponderosa pine plantation. In* Proc., 3d North American Forest Biology Workshop, p. 378-379. Sept. 9-12, 1974. Fort Collins, Colo. (abstr.)

[5]Barrett, James W. 1970. *Ponderosa pine saplings respond to control of spacing and understory vegetation.* USDA Forest Serv. Res. Paper PNW-106, 16 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

[6]Barrett, James W. 1973. *Latest results from the Pringle Falls ponderosa pine spacing study.* USDA Forest Serv. Res. Note PNW-209, 22 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

[7]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.

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[8]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.

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