AN ABSTRACT OF THE THESIS OF

Diane Elise White for the degree of Doctor of Philosophy in
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Title: Competitive Interactions between Douglas-fir or Ponderosa Pine and Whiteleaf Manzanita

Signature redacted for privacy.

Abstract approved: ______________________
Dr. Michael Newton

Juvenile Douglas-fir, ponderosa pine, and whiteleaf manzanita growth in southwest Oregon varied with density of co-developing manzanita and presence of herbaceous cover. Plant xylem pressure potential and stomatal conductance of each species was responsive to competition-induced depletion of soil water. Rates varied among species. The best correlations with growth usually accompanied a two-year lag between stress and observed response. The densities of manzanita observed ranged from 0 to 27000 seedlings per hectare.

Intra-specific competition between individual manzanita seedlings began at age three and became more accentuated, reducing growth by age five. The competitive indices used were basal diameter, canopy volume, above-ground biomass, and leaf area. Growth was always least when herbaceous plants were present. Soil moisture depletion was negatively correlated to amount of seedling growth. The community parameters leaf area index, stand biomass, and stand basal area, increased most rapidly at the highest densities, suggesting full site occupancy did not occur by age five.

Six levels of manzanita density were provided by thinning and

planting to manipulate biomass, leaf area index, and canopy cover. These parameters were used as inter-specific indices of competition for Douglas-fir and ponderosa pine. Competitive influence of shrubs on conifers was slight at age three, and increased progressively through the fifth year. Stem volume in 1985 was most highly correlated with manzanita canopy cover in 1983. Conifers grownng with both manzanita and herbaceous competition had the smallest stem volumes, and those kept herb-free during the first and second years of the study had smaller stem volumes than those that were herb-free during the entire three years.

Species showed different strategies in water use. Manzanita maintained high levels of xylem pressure potential with high levels of stomatal conductance. Douglas-fir had intermediate level of xylem pressure potential, and pine was lowest. Douglas-fir and pine had similar stomatal conductance. This suggests the pine had access to soil water that the Douglas-fir and manzanita could not exploit.

Competitive Interactions between Douglas-fir or Ponderosa Pine and Whiteleaf Manzanita

By

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COMPETITIVE INTERACTIONS BETWEEN DOUGLAS-FIR OR PONDEROSA PINE AND WHITELEAF MANZANITA

INTRODUCTION

Southwest Oregon and northern California include thousands of hectares of potential conifer sites which are now occupied by sclerophyll hardwoods and shrubs. The Mediterranean climate of this region dictates that reforestation efforts be accomplished under the influence of hot, dry summers. Reforestation is further complicated by shallow, rocky soils, transpirational water losses through seedling or sprouting brush, and by herbaceous vegetation. The interior foothill region has the greatest extremes of temperature and lowest summer rainfall. Large areas of this region have not been in conifer production for well over 50 years, the result of wildfires and recolonization by shrubs and herbaceous vegetation. Reforestation of these areas would enhance the local economies by enlarging the timber base.

Water is the most limiting resource for conifers in the interior foothill region of the Siskiyou Mountains. Without the possibility of irrigation, removal of non-coniferous vegetation is the best approach to soil water conservation.

Economics dictates that removal of non-coniferous vegetation in site preparation or release operations may occur only once or twice during a conifer rotation. This constraint makes it important to find the optimum time for conifer release and also to be able to predict levels of release of uncontrolled vegetation compatible with conifer growth. Information on growth and site occupancy rates of both conifers and competitors will help to identify economic thresholds and improve yield projections.

Another important factor to be considered in reforestation is the relative competitive abilities of conifers and non-conifers in obtaining site resources, in this case, soil moisture. The plant that is able to continue to utilize water under high levels of stress has a "water-user" strategy. When "water-users" grow among "water-conservers," the former are able to preempt more of the resource, giving them a competitive advantage.

The final factor that must be considered is the performance of the conifers. In the interior foothill region both Douglas-fir and ponderosa pine have been planted. Each species' ability to compete with non-conifers and produce wood products will determine its silvicultural success on a particular site or competitor community. Also, the conifer's ability to preempt site resources will determine its dominance potential on the site, and the benefit, in terms of enhanced conifer growth, of a conifer release treatment.

Scientists working under the auspices of the Forestry Intensified Research (FIR) program have conducted reforestation research in southwest Oregon since 1978. A major focus of this research has been the ecology of major shrub species and its effect on conifer growth. This dissertation describes a portion of this research which focuses on the ecology of whiteleaf manzanita, and its competitive properties in particular.

The general object of this research is to quantify the rate of site occupancy by whiteleaf manzanita, to examine the water use strategies of whiteleaf manzanita, Douglas-fir, and ponderosa pine growing on the same site, and to quantify the inhibition of conifer growth by herbaceous vegetation and various densities of manzanita.

The specific objectives were:

1. To evaluate growth rates of manzanita shrubs in response to density (intraspecific competition).

2. To evaluate site occupancy by stands of manzanita seedlings at a wide range of densities in terms of basal area, leaf area index, and biomass.

3. To evaluate the effect of herbaceous vegetation on growth of manzanita and conifers.

4. To describe soil moisture depletion patterns under influences of variable shrub/herb coverage.

5. To compare diurnal and seasonal patterns of plant xylem pressure potential and stomatal conductance of manzanita, Douglas-fir, and ponderosa pine seedlings under variable competitive influences.

6. To evaluate the impacts of manzanita growing at several densities and herbaceous vegetation on growth of Douglas-fir and ponderosa pine.

The research is summarized as three chapters. The first evaluates the effects of the initial treatments on individual and stand manzanita growth parameters and encompasses objectives 1 through 4. The second chapter examines the water use strategies of Douglas-fir, ponderosa pine, and whiteleaf manzanita and examines objective 5. The last chapter shows the relationships between different levels of manzanita and herb competition and conifer growth, and also the relationships between water resource levels and conifer growth and satisfies objectives 3, 4, and 6.

CHAPTER 1

Effects of Intra-Specific and Herbaceous Competition on Growth of Whiteleaf Manzanita

Introduction

Whiteleaf manzanita (Arctostaphylos viscida Parry) occurs from the Siskiyou Mountains of southern Oregon south through the Sierra Nevadas (Latt 1984). It is often a component of the transition zone between commercial conifer sites and foothill chaparral and digger pine or oak types throughout its range. It is characteristic of some of the driest sites of the Siskiyou Mountains and can form nearly continuous stands, sometimes to the exclusion of conifers (Whittaker 1960, Gratkowski 1961, Waring 1969, Badura and Jahn 1977).

The success of regenerating conifer stands, especially on hot, dry sites, is inversely related to the site occupancy by shrub competitors (Gratkowski 1961). Knowledge of the growth and developmental patterns of whiteleaf manzanita, coupled with information on shrub community soil moisture depletion, would allow foresters to predict site occupancy by this species. Information concerning the interactions of various manzanita densities with herbaceous vegetation is also needed to provide a more complete picture of competitive relationships.

This is a study of competition and growth within the whiteleaf manzanita community. Specific objectives of this study were to: 1) examine growth responses of whiteleaf manzanita seedlings to density, 2) evaluate the impact of native herbaceous cover on manzanita growth, 3) determine effects of operationally planted conifers on manzanita growth, and 4) determine the moisture resource limitation and its effects with respect to several growth indices.

Materials and Methods

Study sites. Three study sites were selected near Ruch, Oregon, about 35 km west of Medford. The sites were selected because of recent disturbances and suitability for studying manzanita. The sites were designated Big Humbug (T38S. R4W. Sec. 12), Little Humbug (T38S. R4W. Sec. 12 and 13), and China Gulch (T38S. R3W. Sec. 21). The sites were located on southeast to southwest slopes with about 20 percent gradient. The soils were moderately deep (60-90 cm) clay loams of the Vannoy soil type (Stearns-Smith and Hann 1986). They were classified as mixed, mesic, Typic Haploxeralfs. Estimated timber growth capacity was Site V or poorer for Douglas-fir [Pseudotsuga menziesii (Mirbel) Franco] and Site IV for ponderosa pine (Pinus ponderosa Dougl. ex Loud) (McArdle et al. 1949, Meyer 1938). The major shrubs and hardwoods on the site were whiteleaf manzanita, Pacific madrone

(*Arbutus menziesii* Pursh.), wedgeleaf ceanothus [*Ceanothus cuneatus* (Hook.) Nutt.], and poison oak (*Rhus diversiloba* T. and G.). Herbaceous plants formed 100 percent cover and were primarily downy brome (*Bromus tectorum* L.), bedstraw (*Galium aparine* L.), hedge parsley (*Caucalis microcarpa* L.), tarweed (*Madia* sp.), and willowweed [*Epilobium minutum* (Lindl. ex. Hook.)].

Site history. Vegetation on the sites has been influenced strongly by wildfire, the last ones occurring 40 to 50 years ago. The sites were cleared for reforestation in 1980 with crawler tractors equipped with brush blades. The brush was piled in windrows and burned. As a result of scarification, manzanita seed germinated in large numbers and produced up to 500,000 seedlings per hectare in patchy distribution. Shrub seedlings were mostly absent from the burned windrows, presumably because the intense heat destroyed the seeds. These areas were not used in the study. After brush removal, the soil was ripped with a crawler tractor along the contour at 2 m intervals to a depth of about 45 cm and planted (2.5 m x 2.5 m spacing) in spring, 1981, with a mixture of 2-0 bareroot Douglas-fir and ponderosa pine seedlings. On the Humbug sites, a 0.9 m square paper mulch (Kraft 2-ply) was placed around each tree to reduce herbaceous competition and surface evaporation. This was effective during 1981 and 1982. The China Gulch site received a glyphosate spray treatment in spring, 1981, and a hexazinone spray treatment in spring, 1982. Each reduced herbaceous competition for one year. The spray treatments had negligible direct toxic effect on the manzanita seedlings, and the stand appeared quite vigorous compared to other stands in the region.

Study installation. In spring, 1983, the treatments (different densities of manzanita and presence or absence of herbs) were established by chemical thinning or interplanting natural seedlings. Manzanita densities ranged from 0 to 27,000 shrubs per hectare and were established on a square grid within 22 m square plots (0.0484 ha). Treatments were: 27000C, 13500CH, 13500C, 13500, 6720C, 3360C, 1700C, 0C, and 0; where the number is manzanita density, in shrubs/ha, C indicates conifers were present, and H indicates herbs were present. Treatment plots were installed within the plantation where 2-year-old conifers were growing. Conifer density ranged from 1760 to about 1050 seedlings per hectare, depending on the amount of mortality before the study was initiated. Nine treatments were established in each of the replications (sites). The study was a randomized complete block design with the blocks = sites.

Chemical thinning and herbaceous weed control were accomplished by covering the desired manzanita and conifer seedlings, then broadcast spraying with a mixture of 3.3 kg/ha simazine, 2.8 kg/ha glyphosate, and 3.8 kg/ha 2,4-D. The total volume of spray was 121 l/ha. Herbaceous weed control was maintained in 1984 by a broadcast spray of 4.4 kg/ha of simazine in January. By 1985, the use of herbicides on local federal forest land was enjoined. Three times during the spring of 1985, a 1.3 m radius circle around three conifers of each species in each treatment (except 13500CH) was handhoed, removing all herbaceous plants. The remaining area of the treatment plots experienced varying levels of herb reinvasion. In treatment 13500CH, the herb community was left intact and shrubs were removed to treatment specifications by handpulling or chopping.

Soil moisture. Soil moisture was measured monthly during the spring and summer of 1983 and 1985 using a neutron moisture meter (Troxler Model 3225A). In each plot five aluminum access tubes were installed systematically, with one in each quadrant of the plot (allowing for a buffer) and one in the center. Tube depth ranged down to at least 60 cm, and readings were made at 30 cm and 60 cm. The values from these depths were added to give an estimate of total soil moisture in the soil zone measured.

Field capacity readings were made three days after full recharge in April, and cumulative mm of water used near each tube was calculated by subtracting mm of water present each month from mm of water present at field capacity. From this value, the mean mm of water used in treatment 0 (no vegetation) was subtracted to account for evaporation and subsurface movement.

A complete set of soil moisture measurements was made in 1983 and 1985 in treatments 13500C, 13500CH, 2700C, and 0, on the two Humbug sites. Measurements in 1984 were not complete because of equipment breakdown. These observations were graphed showing soil moisture change from April through September. A seasonal index of soil moisture depletion was calculated. The soil moisture depletion, after accounting for evaporation and subsurface movement, was graphed for May through September for each treatment and unit where measurements were made. The highest level of depletion for each treatment-unit combination was noted. The area under the curve between the line of highest level of depletion and the graphed seasonal depletion was calculated and defined as Soil Moisture Deficit (SMD).

Plant xylem pressure potential. Plant xylem pressure potential, measured as xylem sap tension, was recorded in 1983 and 1984, using a pressure chamber apparatus (Waring and Cleary 1967, Ritchie and Hinckley 1975). Readings were taken before dawn, and at 900, 1300, and 1500 PDT hours on treatments 13500C, 13500CH, and 27000C. Readings were made in June, July, August, and September using three individual shrubs from each plot.

A seasonal index of plant moisture stress was calculated. Diurnal curves were drawn for each treatment. An upper-stress threshold level of -2 MPa was chosen, above which photosynthesis was assumed to be limited or negligible (Newton and Preest, in press). The area between the threshold level and the diurnal curve was measured and designated the Moisture Stress Relief (MSR). The values for each of the four months were multiplied by the number of days in that month, then added together to get seasonal MSR.

Shrub measurements. At the end of each growing season, manzanita height, basal diameter, and crown width were measured. Crown cover was calculated using the formula for the area of a circle. Manzanita biomass, leaf area, leaf area index, and basal area values were calculated from basal diameter using regression equations (Hughes et al., in press; Latt 1984):

Individual shrub leaf area (cm^2)

Log leaf area = 2.4839 + 1.9034 * log (basal diameter, cm) (1)

Leaf area index (m^2/m^2):

LAI = Leaf area x 10^{-4} * Density, seedlings/ha x 10^{-4} (2)

Individual shrub biomass (g):

Log biomass = 1.8042 + 2.3486 * log (basal diameter, cm) (3)

Stand biomass (g/m^2):

SB = Biomass * Density, seedlings/ha x 10^{-4} (4)

Stand basal area (m^2/ha) = π (basal radius, cm)^2 x 10^{-4} * Density (5)

Statistical methods. The impacts of manzanita density, conifers, and herbaceous vegetation on manzanita growth parameters were analyzed using 1983, 1984, and 1985 data each in a one-way analysis of variance. (Neter and Wasserman 1974). When treatments were significantly different, the means were separated using Tukeys HSD test (Snedecor and Cochran 1980).

The effects of soil moisture depletion and moisture stress relief were analyzed with regression, using manzanita basal diameter, height, or basal area as the dependent variable.

Results

Intra-specific competition, individual shrubs. The relationships of manzanita density and individual shrub basal diameter, canopy volume, leaf area, and biomass over the three years of the study are shown in Figures 1-1 through 1-4. None of the parameters were significantly responsive to treatment after the first year. In 1983, diameters of shrubs grown at the highest density were 11.2 mm whereas those at the lowest density were 15.5 mm. By 1985, the diameter values diverged showing a 10 mm difference between shrubs grown at the highest density, compared to those growing at the lowest density.

Canopy volumes and shrub biomass showed no differences between densities until the third year, at which time reduction in individual shrub size occurred in the highest densities (Figures 1-2, 1-4).

Shrub leaf area showed density effects after the second year, and by the third year the two lowest density treatments showed higher leaf area per shrub, 8300 to 9600 cm^2, than the highest density treatment, 4700 cm^2 (Figure 1-3).

Inter-specific competition, individual shrub. The treatment that included herbaceous vegetation resulted in reduced manzanita basal diameter, canopy volume, leaf area, and biomass (Figures 1-1 through 1-4). In 1985, shrubs in the herb treatment (13500CH) had smaller basal diameters (18.5 mm) and leaf areas (3070 cm^2 shrub) than shrubs with no herbs, at 26 mm and 6200 cm^2/shrub, respectively.

Comparison of treatments 13500 and 13500C shows no difference between any of the growth parameters during any of the years. This shows that during the measurement period, conifers did not affect manzanita growth.

Intra-specific competition, stand growth. The stand growth parameters LAI, stand biomass, and stand basal area are all increasing each year (Figures 1-5 through 1-7). The treatments with the highest densities appear to be increasing most rapidly, suggesting that at the densities and ages in this study, the manzanita did not completely occupy the site.

Inter-specific competition, stand growth. Comparison of treatments 13500, 13500C, and 13500CH show that stand biomass is reduced by about 60 percent by the third year when herbs are included in the stand (Figure 1-8). LAI and basal area values for the 13500CH treatment are about the same as the manzanita stand with half the number of plants, treatment 6720C (Figure 1-5 and 1-7, respectively). Comparison of treatments 13500 and 13500C show no significant differences, indicating conifers had negligible impact on the manzanita stand by year 3 in this study.

Soil moisture and plant xylem pressure potential. Significant relationships were found between soil moisture and plant xylem pressure potential values, and manzanita height, diameter, and stand basal area (Table 1-1). The regressions of SMD and June (early season) soil moisture values on height and diameter were all significant; however, more of the variation in height was explained (R^2=0.6 and R^2=0.73) than variation in diameter (R^2=.56

and R^2=.68). The coefficient of determination for basal area was 0.71. Regressions using 1985 SMD as the independent variable were not significant.

Regressions of height on MSR were not significant, but diameter and basal area on MSR were, explaining 44 to 49 percent of the variation, respectively. Midday June plant xylem pressure potentials were highly significant, explaining 55 percent of the variation in diameter and 71 percent of the variation in height.

Discussion

Intraspecific competition, individual shrubs. Basal diameter appeared to be the most density-sensitive growth index of the four response variables examined. The variance around the mean was much smaller than that of the other growth parameters. In conifer responses to competition treatments, diameter is also often the most sensitive index. Canopy volume was the least sensitive method of assessing shrub growth, perhaps because the irregular canopy dimensions are not characterized well by the equation for the area of a circle. Several authors have reported on the adaptation of branch die-off during periods of drought stress, which may cause irregular canopies (Davis 1973, Parsons et al. 1981). Branch die-off was observed in the present study.

Intraspecific competition stand growth. The increasing trend in LAI through age 4 has been shown in previous work (Latt 1984, Hughes et al. in press). Latt's study showed a maximum LAI of about 3.6 at age 4 while the current study reported maximum LAI values of 1.4 at age 5. This may be accounted for by the lower density of shrubs regulated in the present study. Trends in LAI suggest that it will continue to increase at the densities present in this study. LAI is regarded as an ecologically important index because it is a measure of the transpiring and photosynthesizing area of a plant community (Hughes et al. in press). Based on growth of individual manzanita shrubs, one may postulate that maximum competitive influence may not be reached until LAI reaches a maximum. The rate of individual shrub leaf area accumulation will continue to increase until maximum LAI for the community is reached.

Trends in stand biomass show that it is strongly dependent on density. At the highest densities in this study biomass increased rapidly. Other studies show that biomass continues to increase through age 15 (Hughes et al. in press); in this study it has increased through age 5, the time since plants were established. Values are about one-third less than those predicted by regression equations of Hughes et al. (in press), even at the highest density, which falls within the range they studied. This may be the result of site differences; this study was conducted at lower elevations and in drier conditions. On the other hand, my values are in agreement with those of Latt (1984).

The biomass values for whiteleaf manzanita at age 5 appear to be much lower than the 2055 g/m^2 observed for five-year-old <u>Ceanothus</u> <u>megacarpus</u> Nutt., another evergreen sclerophyllous shrub (Schlesinger and Gill 1980). They are also lower than the values predicted for five-year-old deerbrush, [Ceanothus integerrimus (H. and A.)] and one population of Ceanothus velutinus (Dougl.) (Hughes et al. in press).

Trends in community basal area again show the most rapid increase in the highest density treatment, reaching a basal area of about 11 m^2/ha at 5 years, with no suggestion of approaching an upper limit. This appears to fall within the range observed by Hughes et al. for this species (in press).

Interspecific competition. More common forestry research examines the effects of shrubs on conifers (Cole and Newton 1987, Oliver 1984), rather than the effects of conifers on shrubs in young plantations. My study shows no early effect of conifers on shrubs at shrub densities of 13500 seedlings per hectare. Shainsky (1986) showed reduction in greenleaf manzanita [Arctostaphylos patula (Greene)] yield when manzanita were present at a density of 42000 stems/ha and pines at 3200 stems/ha at age 5 on a good site. This is approximately twice the conifer density and more than twice the conifer biomass of my study. As the study matures and the trees become dominant, manzanita is expected to become less vigorous in the understory unless it can prevent canopy closure in the pine, a pattern conceivable in view of Roy's (1981) finding in the Shasta Brushfields.

Shrub growth inhibition by herbaceous competition has been well documented in the horticultural literature (Fales and Wakefield 1981), but not as well for native shrubs. Blaisdell (1949) demonstrated competition between sagebrush seedlings and related native grasses. Our study showed important reductions in manzanita shrub and community growth indices as a result of exotic herb competition. This was associated with reduced soil moisture when herbs were present. Newton and Preest (in press) demonstrated lower soil moisture in plots with herbs in the Oregon Coast Range. Herbs appeared to extract moisture readily from soil depths to 0.9 m depths, suggesting they have deep root systems. Herbs may also have a large LAI because many small leaves provide a high ratio of surface to biomass, hence a substantial transpiring surface. Herb LAI was not measured in this study.

Soil moisture and plant xylem pressure potential. The significant relationship between SMD and manzanita growth parameters suggest that water is an important limiting resource (Hobbs and Wearstler 1985). The higher coefficient of determination for the June soil moisture value, as compared to the SMD, is logical in that the SMD is a seasonal value, utilizing information including August and September when the shrubs are not actively growing. In June, growth rates are high and a deficiency in water would then reduce growth. It is notable that measurements of the soil water resource at age three can be used to predict manzanita height and diameter at age five. This, combined with the other data presented in this paper, implies that the trends toward site occupancy may be predicted early in the age of the community.

The most significant regressions for predicting manzanita height and diameter were those using June midday plant xylem pressure potential as the independent variable. Again, the high coefficient of determination suggests that plant water status is also very important in determining future growth. Several authors have documented reduced net assimilation with high levels of moisture stress in trees (Havranek and Benecke 1978, Hinckley et al. 1978, Brix 1979, Benecke 1980) and presumably this is true for shrubs. It appears that in my study, increased levels of moisture stress at age three set manzanita seedling growth at different trajectories, which, within the time frame of this study, continue to diverge. Maximum impact is not yet determined.

Conclusion

Intra-specific competition in manzanita is occurring by age five throughout the density range of 1700 to 27000 seedlings per hectare. Early competition reduces growth of individual plants when growth trajectories are diverging. Community growth indices, LAI, biomass, and basal area, show that full site occupancy has not occurred, even at the highest shrub densities at age 5. Herbaceous vegetation has significant negative impacts on manzanita growth, particularly on basal diameter. Conifers did not affect manzanita growth. Growth appears to be well correlated with early season moisture available on the site at age three, and this appears to be a major factor in determining individual shrub growth.

Table 1-1. The relationship of 1983 soil moisture deficit (SMD) and plant moisture stress relief (MSR) on height, diameter, and stand basal area of whiteleaf manzanita in 1985.

Independent Variable	Equation with Dependent Variable	n	R^2
SMD	56.04 + 0.019 basal diameter	6	0.56*[1]
	15.51 + 0.012 height	6	0.60*
	1.41 + 0.069 basal area	6	0.71*
June soil moisture[2]	25.51 + 0.069 basal diameter	6	0.68*
	69.41 + 0.137 height	6	0.73*
MSR83	11.84 + 0.044 basal diameter	9	0.44*
	47.17 + 0.074 height	9	0.32
	-1.73 + 0.038 basal area	9	0.49*
MSR84	7.71 + 0.114 basal diameter	9	0.44*
	42.13 + 0.176 height	9	0.28
	-5.12 + 0.096 basal area	9	0.48*
June, 1983 midday[3]	48.08 - 1.409 basal diameter	9	0.55***
	121.34 - 3.121 height	9	0.71***

[1] *P=0.05, **P=0.01, ***P=0.001

[2] Millimeters of water depleted between field capacity and the end of June, 1983.

[3] Midday value of plant xylem pressure potential in June, 1983.

Figure 1-1. Mean basal diameter of manzanita seedlings growing at several densities and with and without native herb competition or conifers in treatment 13500 (p=.0282). Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

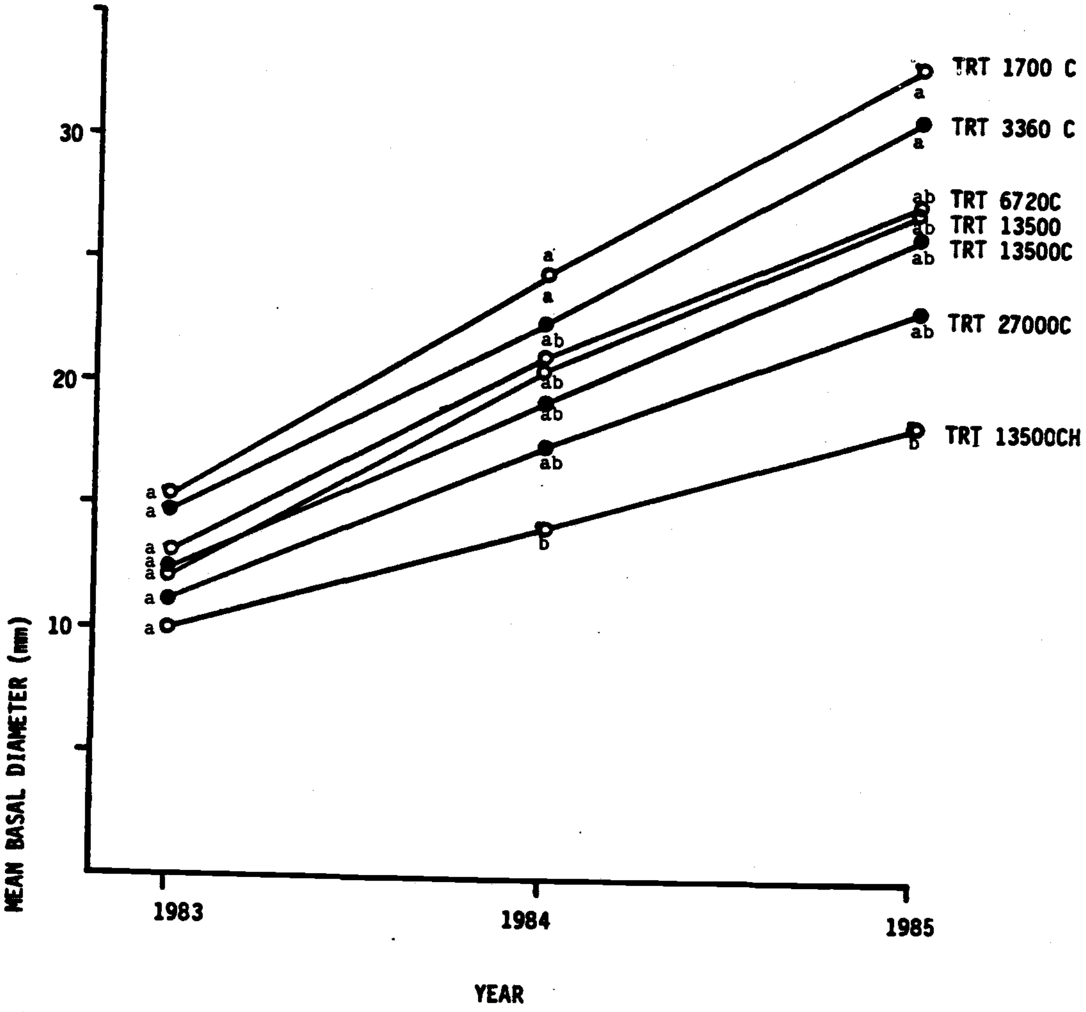


Figure 1-2. Mean manzanita canopy volume of seedlings growing at several densities and with and without native herb competition and conifer in treatment 13500 (p=.0282). Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

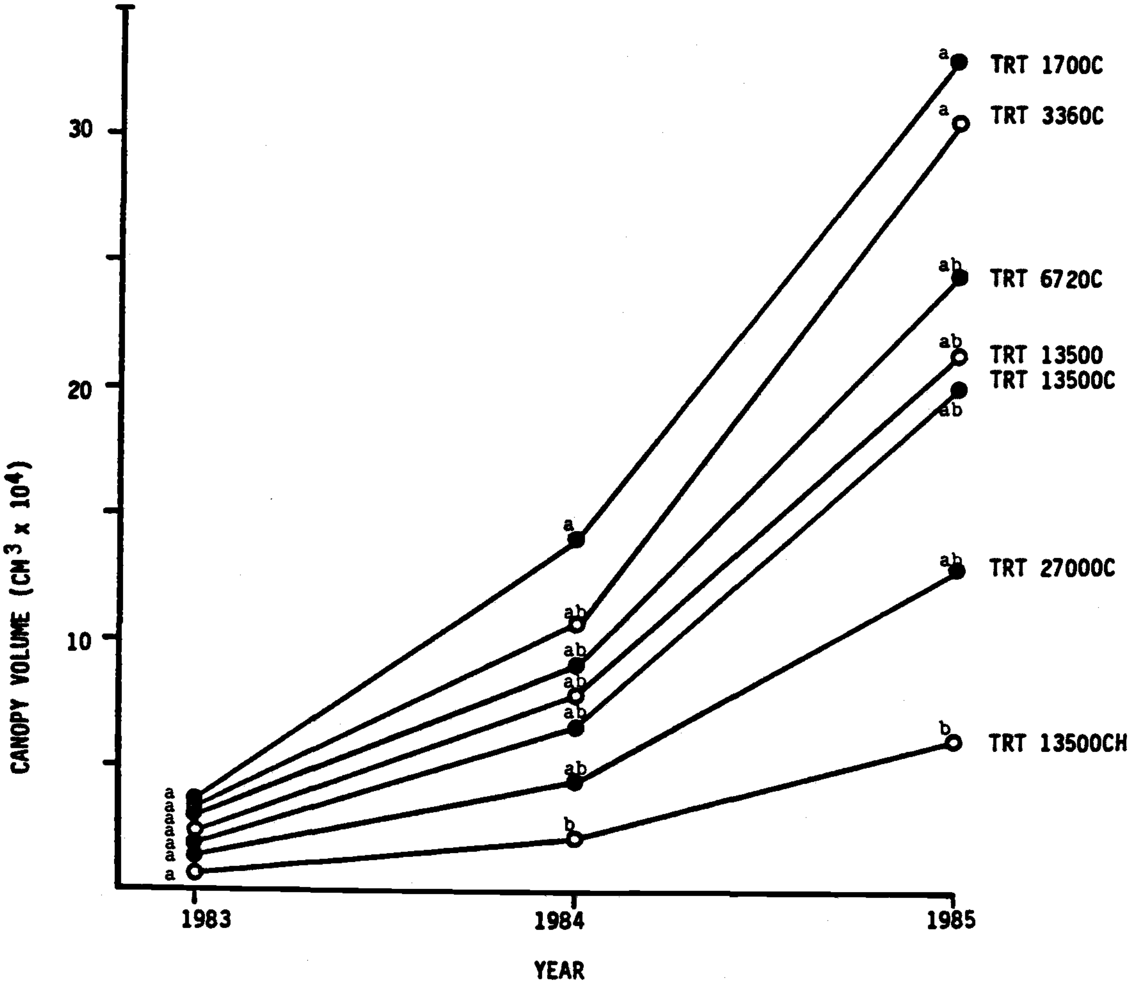


Figure 1-3. Mean individual shrub leaf area of manzanita seedling growing at several densities; and with and without native herb competition or conifers in treatment 13500. Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

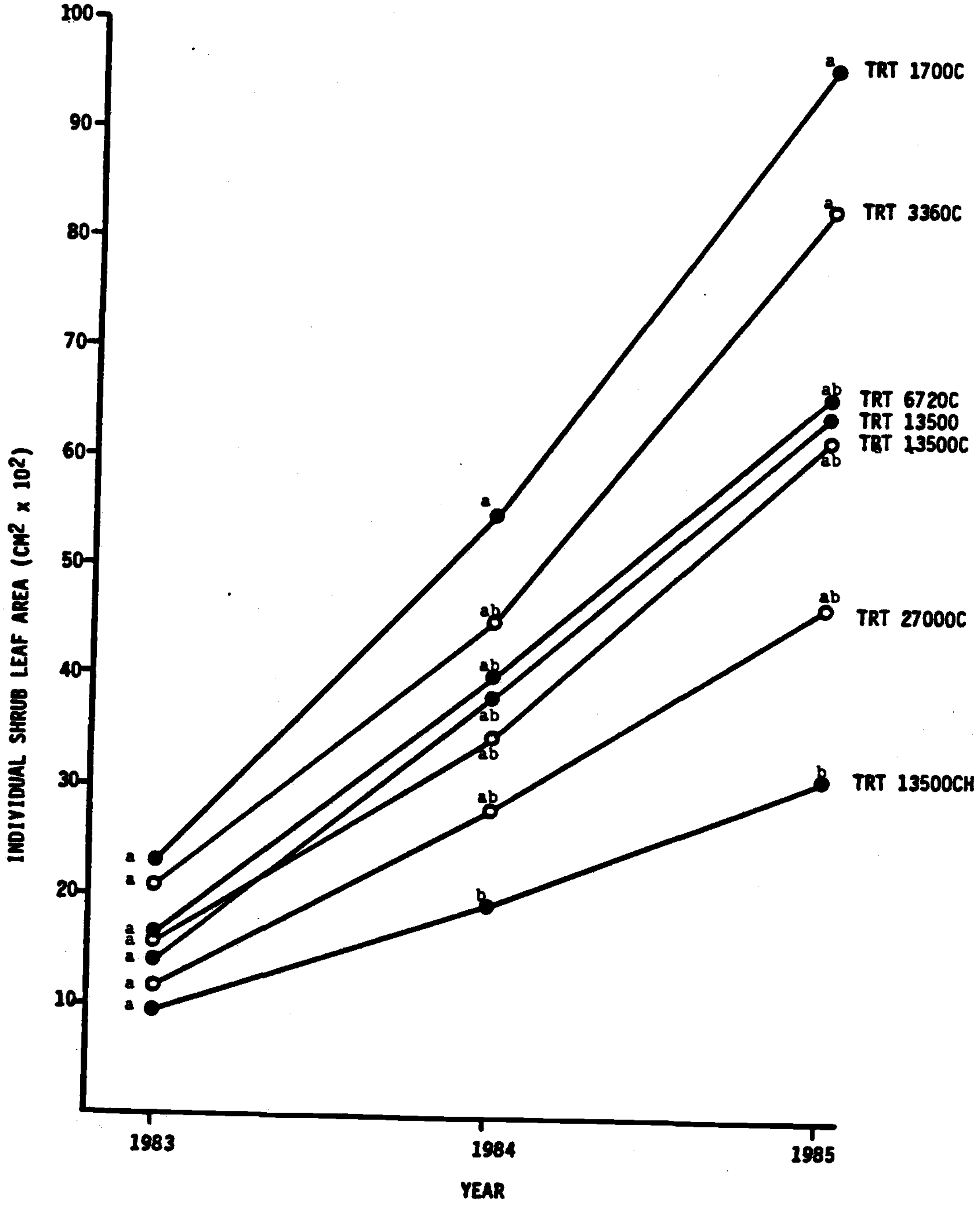


Figure 1-4. Mean individual shrub biomass of manzanita seedlings growing at several densities, and with and without native herb competition or conifers in treatment 13500. Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

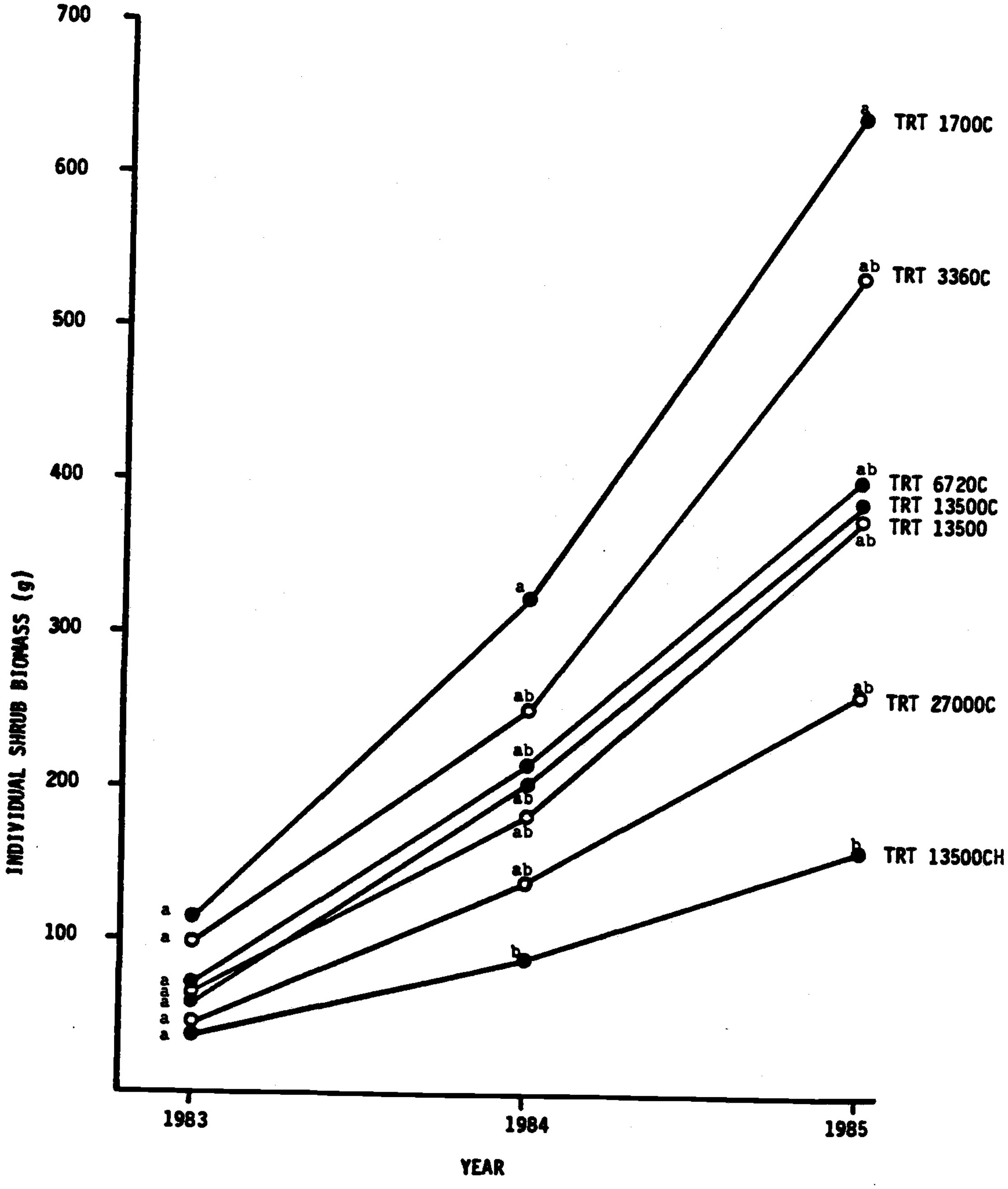


Figure 1-5. Mean shrub community leaf area index (LAI) at several densities and with and without native herb competition or conifers in treatment 13500. Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD:

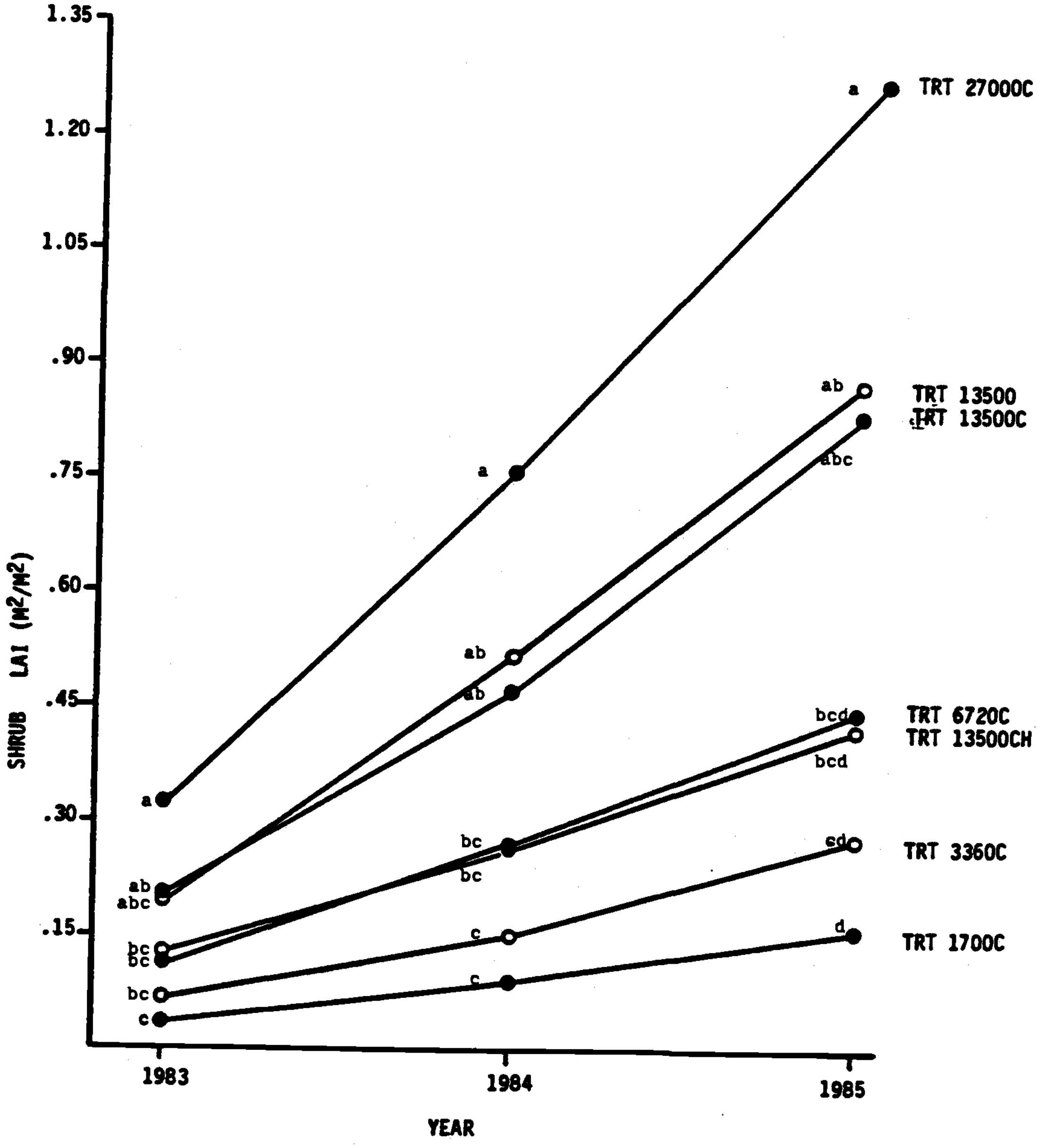


Figure 1-6. Mean shrub community biomass at several densities of manzanita, and with and without native herb competition or conifers in treatment 13500. Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

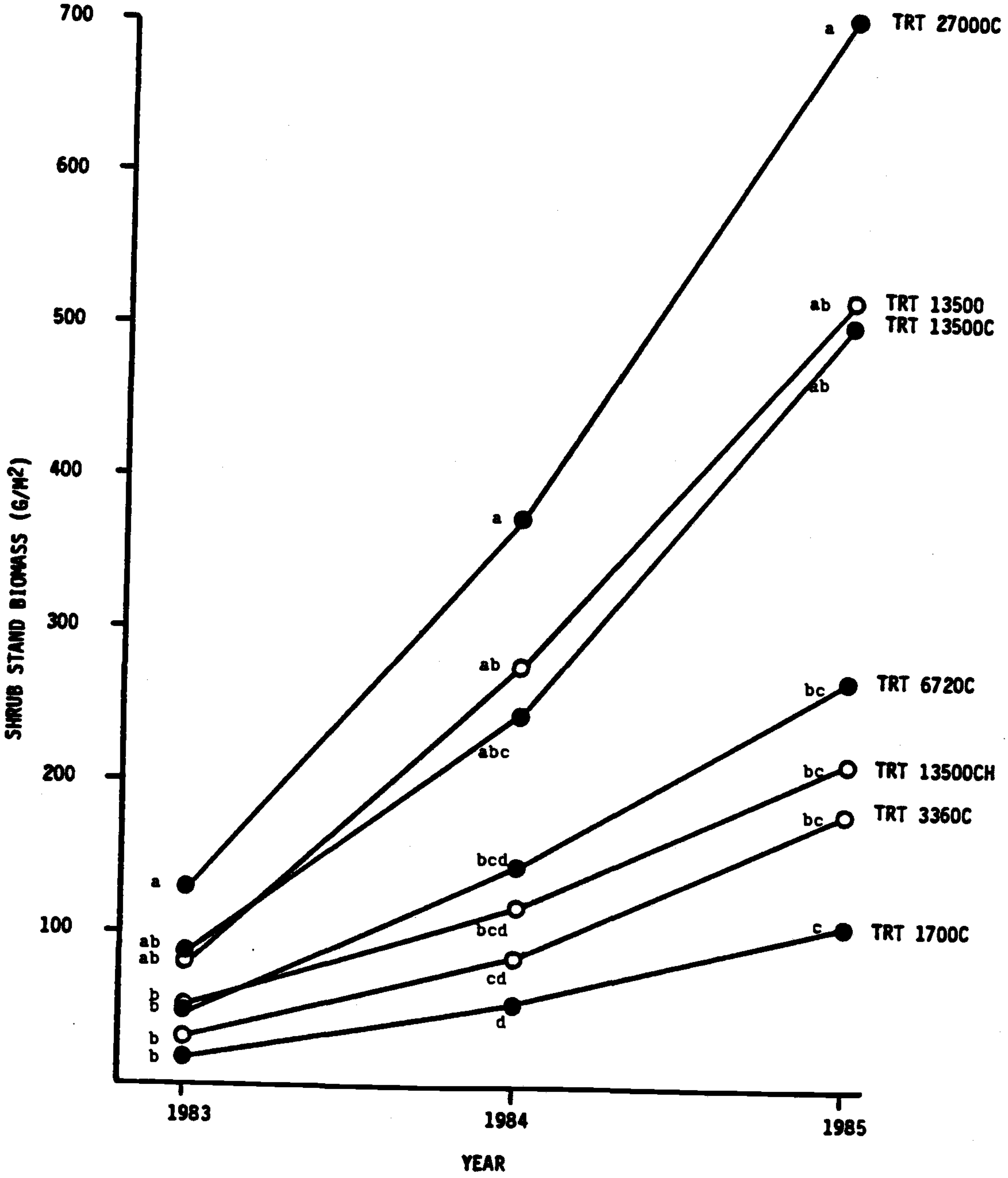


Figure 1-7. Mean shrub community basal area at several densities of manzanita, and with and without native herb competition or conifers in treatment 13500. Within each year, treatments followed by the same letter are not significantly different according to Tukey's HSD.

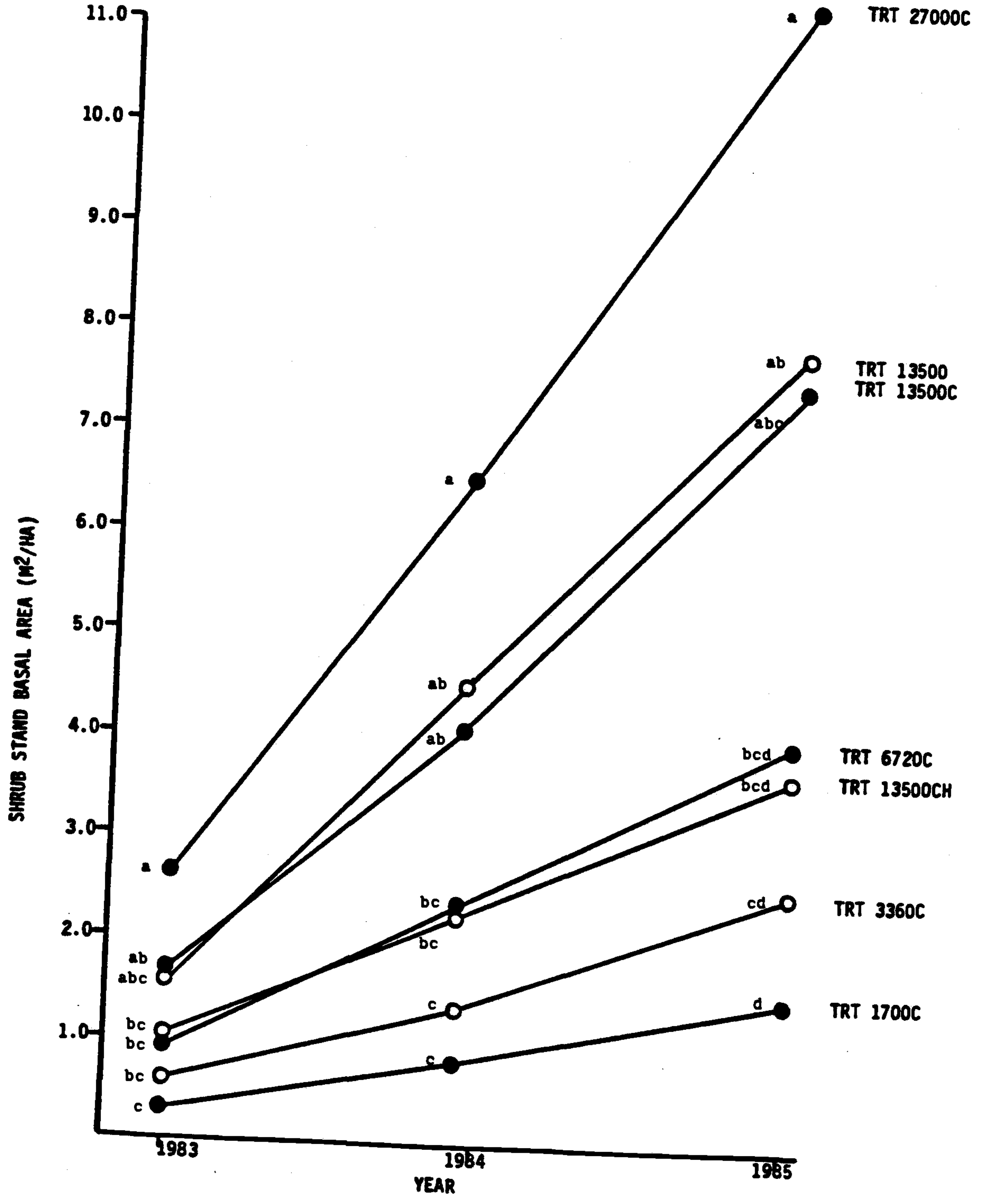
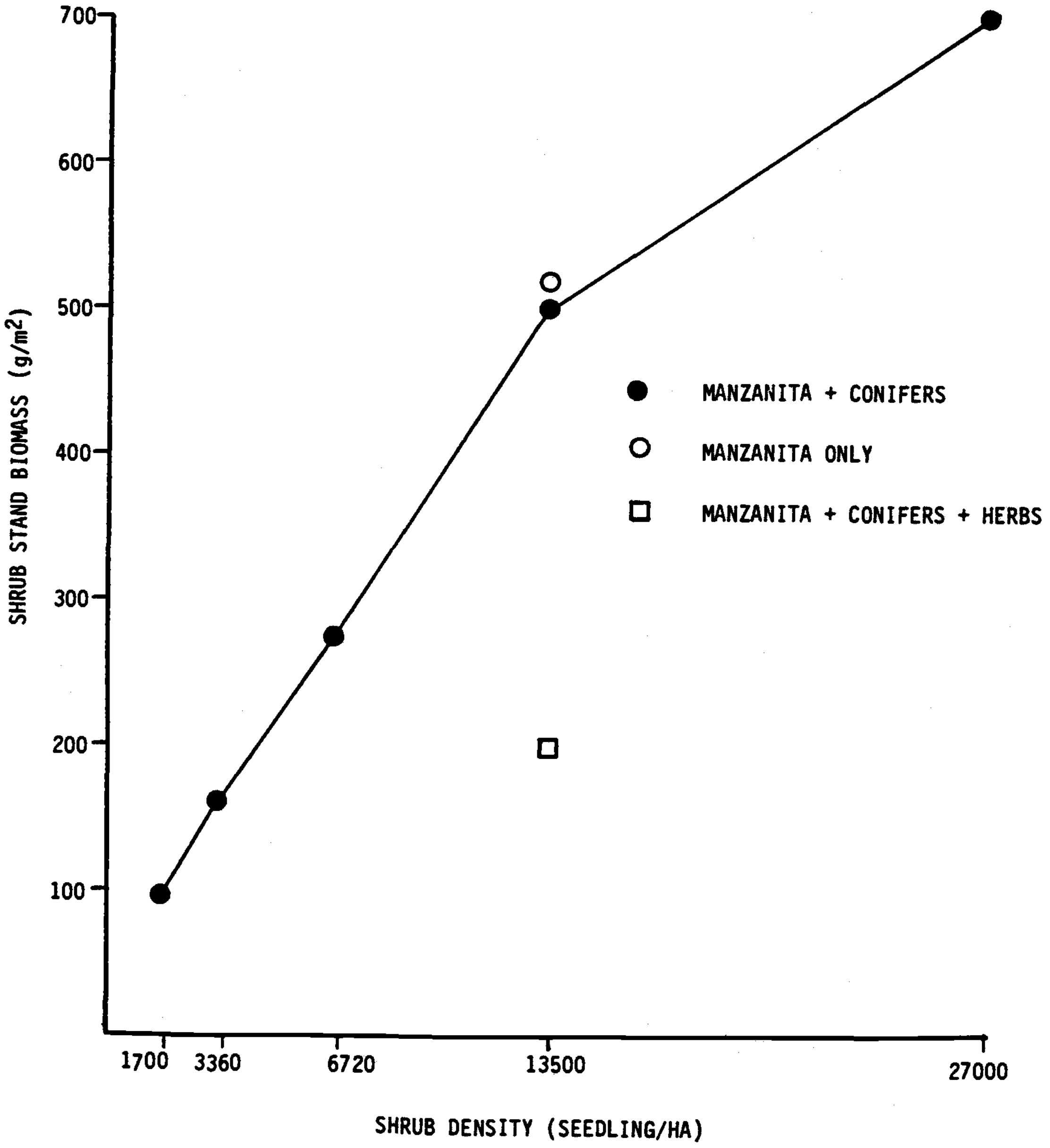


Figure 1-8. Relationship of shrub density to stand biomass after three years.



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CHAPTER 2

Water Relations of Douglas-fir, Ponderosa Pine, Whiteleaf Manzanita Seedlings in Southwest Oregon

Introduction

Conifer regeneration in southwest Oregon and California is complicated by high temperatures and summer drought, a normal part of the local Mediterranean-type climate. Areas where whiteleaf manzanita (*Arctostaphylos viscida* Parry) grow are some of the most severe for conifer establishment (Waring 1969). Often both ponderosa pine (*Pinus ponderosa* Dougl. ex Loud) and Douglas-fir [*Pseudotsuga menziesii* (Mirbel) Franco] are planted in these areas.

Studies have shown that controlling shrubs results in higher soil moisture levels during periods of low summer rainfall (Tarrant 1957, Petersen 1980, Conard and Radosevich 1982, Hobbs and Wearstler 1985). This in turn raises conifer plant xylem pressure potential and often results in increased growth (Hobbs and Wearstler 1985).

Various species have been shown to exhibit different strategies for obtaining soil moisture (Poole and Miller 1975, Hart and Radosevich 1987), but few studies have compared strategies of conifers and shrubs on the same site (Conard and

Radosevich 1982, Shainsky and Radosevich 1986, Marshall and Waring 1984). The objective of this study was to define water use strategies of Douglas-fir, ponderosa pine, and whiteleaf manzanita grown together under various levels of competition in the interior foothill region of southwest Oregon. The investigation included: (1) comparison of leaf conductance of manzanita and conifers, (2) comparison of soil moisture depletion induced by conifer regeneration, manzanita, and herbaceous vegetation, (3) a description of diurnal and seasonal fluctuations in plant xylem pressure potential (PXPP), and (4) a description of the interactions of soil moisture, PXPP, and leaf conductance in manzanita, Douglas-fir, and ponderosa pine grown under the same conditions.

Materials and Methods

Study sites. Three study sites were selected near Ruch, Oregon, about 35 km west of Medford. The sites were designated Big Humbug (T38S. R4W. Sec. 12), Little Humbug (T38S. R4W. Sec. 12 and 13), and China Gulch (T38S. R2W. Sec. 21). The sites were located on southeast to southwest slopes with about 20 percent gradient. The soils were moderately deep (60 to 90 cm) clay loams of the Vannoy soil series and classified as fine-loamy, mixed, mesic, Typic Haploxeralfs (Stearns-Smith and Hann 1986). Estimated timber growth capacity was Site V or lower for Douglas-fir and Site IV for ponderosa pine (Meyer 1938, McArdle et al. 1949). The major shrubs and hardwoods on the site were whiteleaf manzanita, Pacific madrone (*Arbutus menziesii* Pursh.), wedgeleaf ceanothus [*Ceanothus cuneatus* (Hook.) Nutt.], and poison oak (*Rhus diversiloba* T. and G.). The herbaceous plants on the sites had 100 percent cover and were primarily downy brome (*Bromus tectorum* L.), bedstraw (*Galium aparine* L.), hedge parsley (*Caucalis microcarpa* L.), tarweed (*Madia* sp.), and Willowweed [*Epilobium minutum* (Lindl. ex Hook.)], all introduced species.

Site history. Vegetation development on the sites resulted from wildfire, the last occurring 40 to 50 years ago. Sites were cleared for reforestation in 1980 with crawler tractors equipped with brush blades. The brush was piled in windrows and burned. As a result of scarification, manzanita seed germinated in large numbers and produced up to 500,000 seedlings per hectare with an aggregate distribution. The soil was ripped along the contour at 2 m intervals to a depth of about 45 cm to reduce compaction and planted (2.5 m x 2.5 m spacing) in spring, 1981, with a mixture of 2-0 bareroot Douglas-fir and ponderosa pine seedlings. On the Humbug sites, a 0.9 m square paper mulch (Kraft 2-ply) was placed around each tree to reduce herbaceous competition and surface evaporation. The mulch stayed intact during 1981 and 1982. The China Gulch site received a glyphosate spray treatment in spring, 1981, and a hexazinone spray treatment in spring, 1982. Each reduced herbaceous competition for one year. The spray treatments had negligible direct toxic effect on the manzanita seedlings, the stand appeared quite vigorous as compared to other stands in the area.

Study installation. In spring, 1983, the treatments (different densities of manzanita and presence or absence of herbs) were established by chemical thinning or interplanting natural seedlings. Manzanita were established on a square grid, with 22 m square plots (0.0484 ha), and treatments were: 13500CH, 13500C, 0C, and 0; where the number is manzanita density, in shrubs/ha, C indicates conifers were present, and H indicates herbs were present. Treatment plots were installed within the plantation where 2-year-old conifers were growing. Conifer density ranged from 1760 to about 1050 seedlings per hectare due to mortality before the study was initiated. Four treatments were established in each of three replications (sites). The study was a randomized complete block design with sites used as blocks

Chemical thinning and herbaceous weed control were carried out by covering the desired manzanita and conifer seedlings, then broadcast spraying with a mixture of 3.3 kg/ha simazine, 2.8 kg/ha glyphosate, and 3.8 kg/ha 2.4-D. The total volume per hectare of spray was 121 liters. Herbaceous weed control was maintained in 1984 by a broadcast spray of 4.4 kg/ha of simazine in January. By 1985, the use of herbicides on local federal forest land was enjoined by court order. Three times during the spring of 1985, a 1.3 m radius circle around three conifers of each species in each treatment (except 13500CH) was handhoed, removing all herbaceous plants. The remaining area of the treatment plots experienced varying levels of herb reinvasion. In treatment 13500CH, the herb community was left intact and excess shrubs were removed by handpulling or chopping.

Climate. Mean monthly maximum and minimum air temperatures and monthly precipitation values were recorded at a nearby U.S. Weather Service monitoring site in Ruch, Oregon (Climatological Data of Oregon).

Soil moisture. Soil moisture was measured monthly during the spring and summer of 1983 and 1985 using a neutron moisture meter (Troxler Model 3225A). In each plot five aluminum access tubes were installed, systematically, with one in each quadrant of the plot (allowing for a buffer) and one in the center. Tube depth varied with the depth of the soil and ranged down to 90 cm, although a small sample size at that depth precluded using ANOVA-type statistical analyses on readings. Readings were made at 30 cm and 60 cm on all tubes. Field capacity readings were made three days after full recharge in April; water used during the season or during each sample interval at each tube was calculated by subtracting water present each month, in millimeters, from water present at field capacity or in the previous month. From this value, the water used in the treatment 0 (no vegetation) was subtracted to account for evaporation and subsurface movement. The soil water contents in the 30 cm and 60 cm depths were added to give total soil moisture change within this zone.

A complete set of soil moisture measurements was made in 1983 and 1985, in treatments 13500C, 13500CH, and OC, but because of equipment breakdown only September measurements were made in 1984.

Plant xylem pressure potential. Plant xylem pressure potential, measured as xylem sap tension, was recorded in 1983 and 1984, using a pressure chamber apparatus (Waring and Cleary 1967, Ritchie and Hinckley 1975). Readings were taken before dawn, and at 1300 PDT hours on treatments 13500C, 13500CH, OC, and O. Readings were made in June, July, August, and September on three individuals of each species from each plot.

Stomatal conductance. Stomatal conductance was measured on two blocks (Little Humbug and China Gulch) during 1985 using a null balance porometer (Licor Model 1600). Readings were taken twice during the day, at 900 hours and at 1400 PDT hours on all treatments. Fully expanded current or previous season leaves exposed to full sunlight were used. The sampling unit for manzanita was one leaf; for Douglas-fir, a portion of a twig with several needles; and for pine, the middle portion of a fascicle (the needles were spread to allow air circulation). The same area was sampled throughout the day, then the sample was harvested, placed in a plastic bag in a cooler and returned to the lab for leaf area determination. Leaf areas for manzanita and Douglas-fir were determined using a Licor Leaf Area Meter. For manzanita these values were doubled since stomates occur on both sides of the leaf. The Douglas-fir leaf area values were multiplied by 1.13 (Gholtz. et al. 1976) because the species is hypostomatous

(Unterschuetz et al. 1974). Pine fascicle leaf areas were calculated by measuring the radius and length of the fascicle and calculating and summing the areas of the six inner surfaces and the outer cylinder. Conductance values were adjusted using the true leaf area.

Statistical analysis. Data analysis for soil moisture depletion and conductance was by split-plot analysis of variance where the years or months were subplots. Plant water potential was analyzed as a split-split plot analysis of variance where months were subplots and years sub-sub plots (Little and Hills 1978). When the F-values indicated significant differences, means were separated by Tukey's HSD test.

Split-plot analysis requires a balanced design. Because of this, comparisons between all species could be made only on the treatments where manzanita were present. Two analyses were made: one on conifers only that included all treatments, and the other on conifers, manzanita and herbs restricted to the treatments where all species were present. This procedure was followed for the plant water potential and conductance data.

Results

Climate. Mean monthly maximum and minimum air temperatures and monthly precipitation are shown in Figure 2-1. Summer precipitation consists of infrequent light, sporadic showers. Based on soil type and bulk density, summer rainfall was insufficient to affect soil moisture readings. Maximum temperatures increased through July or August, depending on year. June temperatures were higher in 1985 than during the two previous years. July temperatures were lowest in 1983 and highest in 1985.

Soil moisture depletion. Early season soil moisture depletion in 1983 and 1985 shows that 40 mm of soil water was removed from the 13500CH treatment compared to essentially none from the OC treatment (Table 2-1). In the OC treatment and 13500C treatment more soil moisture was removed in 1985 than in 1983; however, in the 13500CH treatment early season soil water removal was most rapid and was equivalent for the two years.

Late season soil water depletion in the 13500C treatment was equivalent in all three years as was that in the 13500CH treatment (Table 2-1). In the OC treatment more soil water was lost in 1985 than in 1983. In 1983 essentially no water was lost from the OC treatment. In 1983 and 1984, soil water loss tended to increase, though not always significantly, as the manzanita, then herbs, are included. In 1985 late season soil water loss was equal among all the treatments (Table 2-1).

Plant xylem pressure potential. In all analyses of plant xylem pressure potential (PXPP), the species responses were dependent on month and plantation age. The treatment x species x month x year interaction was not significant, so means were averaged over treatments. In 1983 and 1984, no significant differences occurred between species or months, at the predawn measurement time (Figure 2-2, 2-3). In July 1985, pine had higher PXPP (i.e., lower stress) than manzanita, and in August and

September, pine had higher PXPP values than both manzanita and Douglas-fir (Figure 2-4). Pine PXPP within months did not decrease significantly between 1983 and 1985, whereas both manzanita and Douglas-fir showed 100 percent to 400 percent decrease.

Midday, as compared to predawn, PXPP values showed more pronounced differences between the species earlier in the age of the plantation (Figure 2-5, 2-6, 2-7). For example, in June 1983, pine PXPP was -0.53 MPa, while that of manzanita was -1.84 MPa. Douglas-fir was intermediate at -1.59 MPa PXPP. By August and September 1983, all three species had similar PXPPs. In July, August, and September 1984 and 1985, pine had higher PXPP values than manzanita. Douglas-fir was intermediate and significantly lower than pine in August of those years.

Pines showed essentially no monthly change in midday PXPP over the three years of the study, whereas manzanita changed dramatically. For example, manzanita midday PXPP in August 1983 was -2.30 MPa and in August 1985 it was -4.16 MPa.

In the conifers-only analysis the trends are similar to those above except that predawn differences between species occur earlier in the age of the plantation.

Appendix 2 shows: (1) a table of means of predawn and midday plant xylem pressure potential broken down by species, treatment, month, and year (Tables B-1 and B-2); (2) tables of means for the all-species and conifers-only analyses (Table B-5); and (3) ANOVA tables for all analyses (Tables B-3, B-4, and B-6).

Stomatal conductance. Analysis of variance using all species showed that species and treatment responses varied from month to month. Conductance was higher in June in treatment 13500C than with treatment 13500CH (Table 2-2). In July and August the treatment conductances were similar. In June, Douglas-fir conductance was less than half that of manzanita, and pine was also significantly less than manzanita. In July and August there were no significant differences between species. In the conifer-only analysis (not shown) results are similar; there was no significant difference in conductance between treatments 0C and 13500C. Treatment 13500CH conductance was significantly less than the other two treatments. Pine showed generally higher conductance values (0.094 cm sec^{-1}) than Douglas-fir (0.071 cm sec^{-1}) over all treatments.

Relationship of soil moisture, plant water potential, and stomatal conductance. The relationship between soil moisture and midday PXPP for manzanita and Douglas-fir is best described by the equation:

$$\log PXPP = a + b\ (\log \text{soil moisture} + \text{soil moisture})$$

while that of pine fits equally well the above equation or a simple linear equation:

$$PXPP = a + b\ (\text{soil moisture})$$

The greatest portion of variation is explained by using soil moisture at 0.9 m for manzanita and Douglas-fir (R^2=.60 and R^2=.58, respectively).

None of the untransformed soil moisture values at any of the depths explains more than 33 percent of the variation in pine midday PXPP (Table 2-3).

The relationship between midday conductance and midday PXPP for each species is shown in Figures 2-8, 2-9, and 2-10. Conductance appears to decline sharply as Douglas-fir approaches -2.1 to -2.2 MPa. Pine conductance is highly variable until PXPP reaches about -1.8 MPa, then conductance becomes very small. Manzanita appears to maintain high conductance to PXPP values of -3.0 MPa.

Discussion

The treatments established in this study set up high (13500CH), intermediate (13500C), and low levels (0C) of competition for soil moisture. The climatic data show that summer moisture input is very light and sporadic, and the soil moisture present in spring is virtually all that will be available to the trees and shrubs until late September or October when effective rains begin.

Early season soil moisture depletion occurs over a period of about two months. In the 3-year-old plantations (1983) the addition of herbs to the manzanita was important in speeding the depletion process. The partial contribution of manzanita was less than that of herbs. By age 5, early season soil moisture depletion was the same regardless of treatments, indicating that the shrubs had replaced herbs as the dominant depleting entity.

Soil moisture at the end of the summer reflects total cumulative depletion. At age 3 the low competition treatment still had soil moisture available, whereas the high competition treatment had none. By age 5, the vegetation in all treatments was sufficient to deplete fully late season soil moisture. Reduction of shrub canopies has been shown to increase soil moisture (Conard and Radosevich 1982, Lanini and Radosevich 1985). In Australia, Sands and Nambiar (1984) demonstrated reduced soil moisture down to 2 m depth in a radiata pine stand with herbaceous weeds compared to no herbaceous weed competition. The range of densities of manzanita in this study does not extend to the densest encountered in natural situations, and more manzanita on the site would probably cause maximum soil moisture depletion at an earlier age or time in the growing season.

Predawn plant xylem pressure potential is an indicator of soil moisture available to the plant. Comparison of Tables 2-1 and Figures 2-2 to 2-7 shows that predawn PXPP is less sensitive to treatments than is soil moisture depletion. This may be because plants are using moisture from depths not measured with the neutron probe or because of plant water regulation through stomatal closure.

Successful conifer regeneration depends on survival, and on the hot, dry interior foothills of southwest Oregon, survival depends primarily on the availability of soil moisture. Utilization of soil moisture during the day when photosynthesis occurs may be demonstrated by midday plant xylem pressure potential and stomatal conductance responses. Of the three species studied, pine consistently had higher PXPP values, Douglas-fir had intermediate values and manzanita had lowest values. At the same time, the two conifers had equal stomatal conductance, while that of manzanita was higher. These data suggest that pine, with low PXPP but equal conductance, may have access to more soil moisture, possibly through a larger, deeper root system than Douglas-fir. It has been shown that ponderosa pine characteristically develops a prominent tap root, whereas Douglas-fir does not. These data also suggest that manzanita may not have access to the same soil moisture as pine. Regression showed that manzanita and Douglas-fir responded to soil moisture at the 0.9 m depth, while a lack of strong correlation in pine suggests it may be obtaining water from even deeper depths.

The stomatal conductance of manzanita is higher than that of Douglas-fir, and appears to function until midday PXPP is around -3.0 MPa, whereas Douglas-fir stomata close at around -2.3 MPa. This suggests that manzanita has less stomatal sensitivity and exhibits a "water user" strategy. Pine has the most stomatal sensitivity and appears to restrict water vapor exchange at around -1.8 MPa. Previously, other species of manzanita have also been shown to withstand high midday stress levels and maintain high conductance (Conard and Radosevich 1982, Shainsky and Radosevich 1987, Hart and Radosevich 1987).

Treatment differences show that at a density of 13500 manzanita seedlings per hectare, the influence of herbs on PXPP and lower conductance is greater than that of shrubs. This may be the result of higher transpiration rates or higher leaf surface areas in the herbaceous plants, factors which were not measured in this study.

Conductance and PXPP have been correlated in other studies with photosynthetic rates of Douglas-fir, ponderosa pine, and greenleaf manzanita. Assuming whiteleaf manzanita responses are similar to greenleaf manzanita, photosynthetic rates were restricted for all species within the levels of competition present in this study except OC in 1983 and 1984 (Cleary 1970, Helms 1976, Conard and Radosevich 1981).

Conclusion

In a 3-year-old plantation, conifers have a minimal effect on soil moisture depletion. Early season soil moisture depletion shows herbs are a serious competitor at age 3. By age 5, shrubs are equally as competitive as herbs.

Pine PXPP was least effected by soil moisture depletion patterns, followed by Douglas-fir and manzanita in that order. Plants growing with herbs were under higher stress than those growing only with manzanita or no competition. Manzanita exhibited higher conductance than either conifer species. Conifers and shrubs growing with manzanita and herbaceous competition had lower conductance than those growing with only manzanita.

Midday PXPP of manzanita and Douglas-fir was highly correlated with soil moisture at 0.9 m depth. Pine PXPP was not highly correlated with soil moisture at any depth measured. The relationship of midday PXPP and conductance showed that manzanita stomatal closure occurred at lower PXPP values than did conifer stomatal closure. Pine stomatal closure may occur at higher PXPP levels than that of Douglas-fir. Physiological responses to hot, xeric sites appears to favor ponderosa pine, whiteleaf manzanita and Douglas-fir, in decreasing order, once populations are established.

Table 2-1 Early and late season soil moisture lost (-) or gained (+) from measurements in the top 60 cm in the soil. Values are mm of water expressed as the difference between field capacity readings in April, and readings made in June or September.

	Year[1]		
Early season (June)	1983	1984	1985
Treatments			
OC	+8a	m[2]	-26b
13500C	-6a	m	-36b
13500CH	-36b	m	-29b
Late season (September)			
Treatments			
OC	+9a	-14ab	-30bcd
13500C	-17abc	-40bcd	-45cd
13500CH	-39bcd	-50d	-29bcd

[1] Values for each season, between year and treatment, followed by the same letter are not significantly different according to Tukeys HSD .05.

[2] These values were not collected because of equipment breakdown.

Table 2-2 Mean monthly stomatal conductance (cm sec^{-1}) by treatment and species pooled over time. Analysis on all species.

	Treatment[1]		Species[2]		
Month	13500C	13500CH	Douglas-fir	Ponderosa pine	Whiteleaf manzanita
June	.183	.116	.095	.133	.220
July	.085	.071	.055	.079	.101
Aug.	.042	.039	.037	.053	.031

[1] Tukeys HSD .05 = .037
[2] Tukeys HSD .05 = .049

Table 2-3 Regression equations for whiteleaf manzanita, Douglas-fir, and ponderosa pine, showing the relationship between midday plant xylem pressure potential (PXPP) and volumetric soil moisture (SM) at 0.3, 0.6, and 0.9 m depths.

	Depth(m)	n	P	R^2
Manzanita, Log PXPP				
9.39-2.32 (log SM+.05SM)	.3	4	.039	.24
21.31-6.74 (log SM+0.16SM)	.6	44	.000	.32
71.46-29.97 (log SM+0.59SM)	.9	20	.001	.60
Douglas-fir, Log PXPP				
8.12-1.87 (log SM+0.03SM)	.3	44	.000	.50
13.69-3.69 (log SM+0.08SM)	.6	44	.000	.40
51.56-17.87 (log SM+0.43SM)	.9	20	.001	.58
Ponderosa pine, Log PXPP				
-2.65+3.35 (log SM-0.23SM)	.3	44	.001	.29
22.89-3.69 (log SM+0.08SM)	.6	44	.000	.40
51.56-17.87 (log SM+0.43SM)	.9	20	.001	.58
Ponderosa pine, PXPP				
33.96 - 0.83 SM	.3	44	.000	.34
33.10 - 0.56 SM	.6	44	.000	.29
37.31 - 0.58 SM	.9	20	.021	.26

Figure 2-1. Summer rainfall and mean monthly maximum (o) and minimum (●) air temperatures in Ruch, Oregon in 1983, 1984, and 1985.

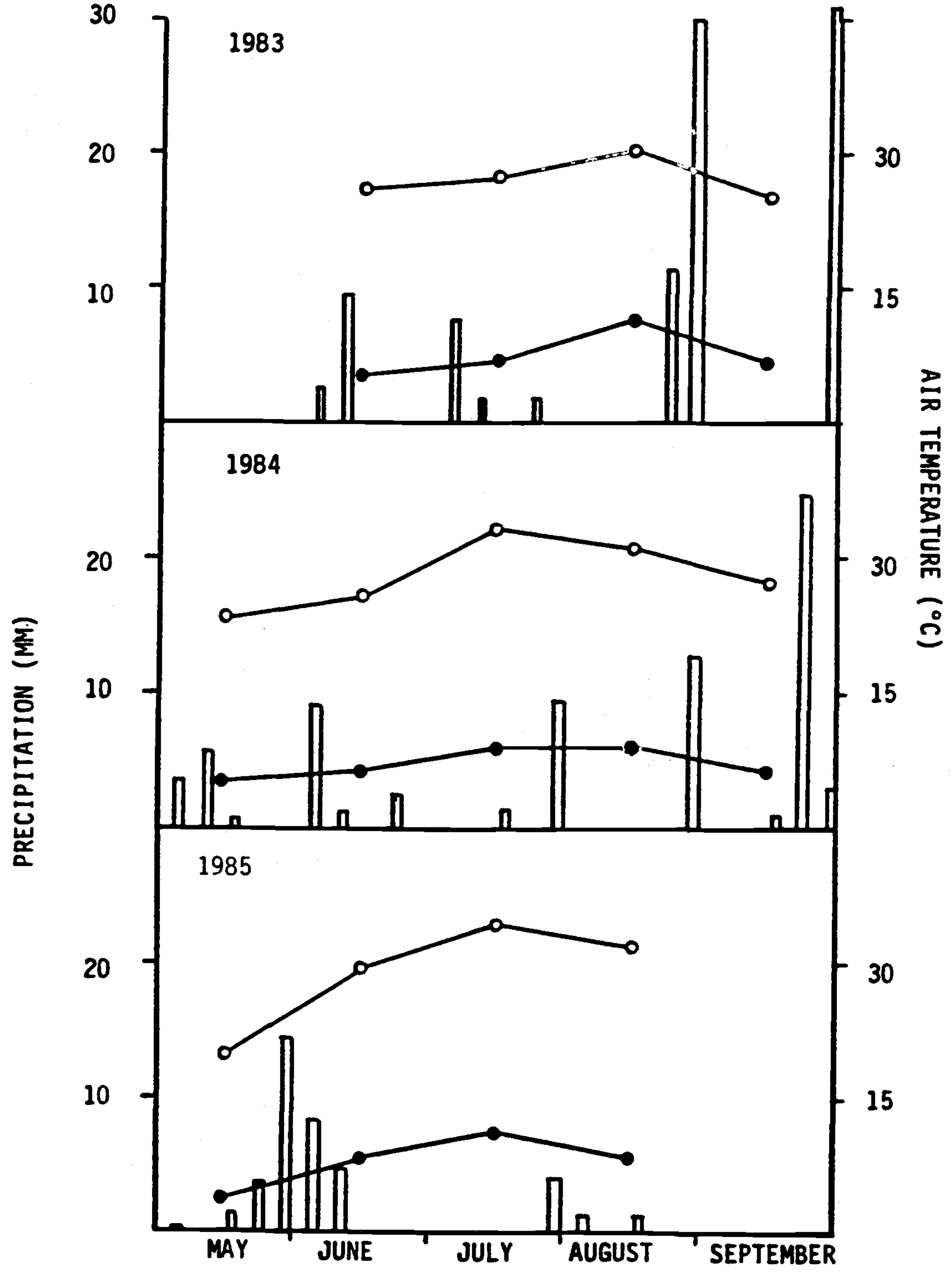


Figure 2-2. Mean seasonal predawn plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine, and Douglas-fir in 1983, averaged over treatments.

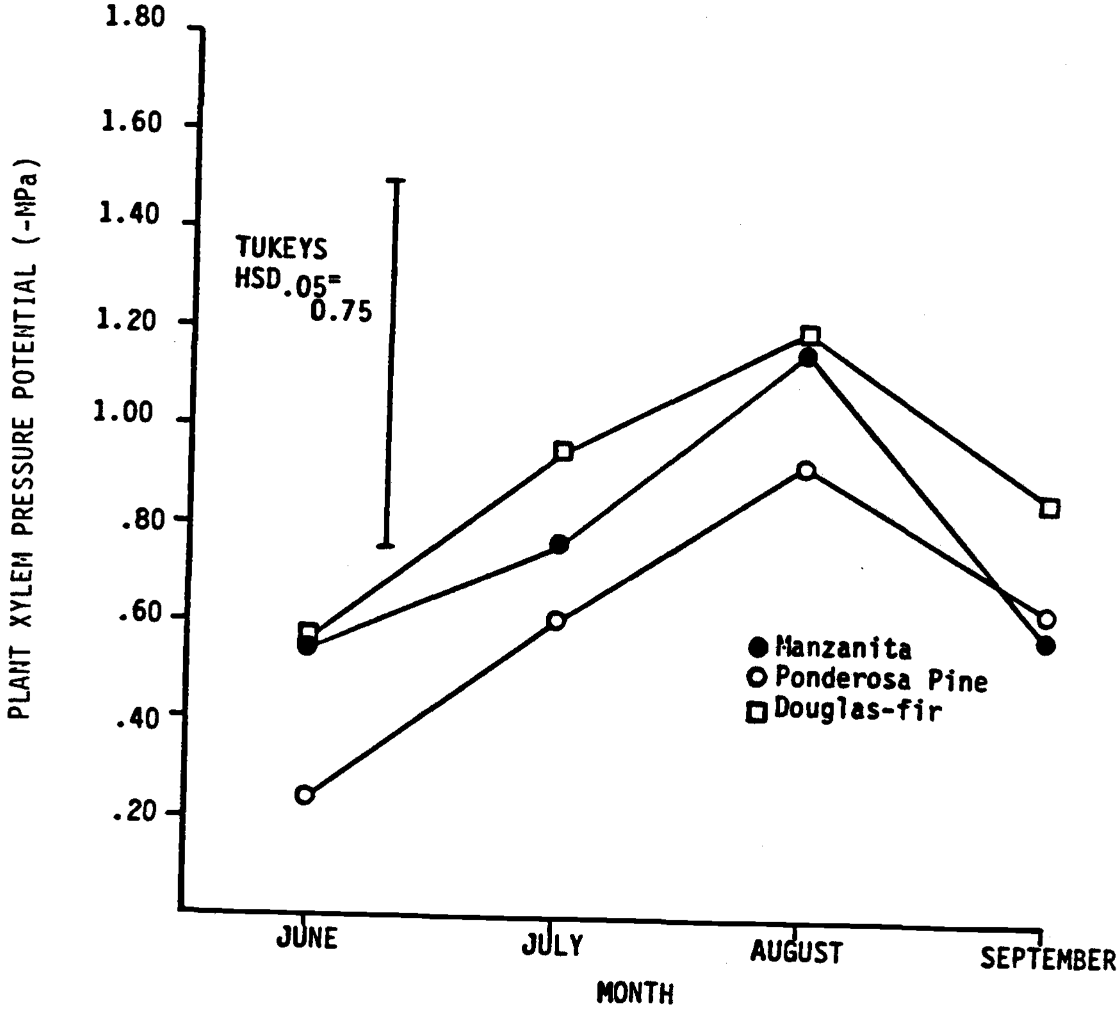


Figure 2-3. Mean seasonalpredawn plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine, and Douglas-fir in 1984, averaged over treatments.

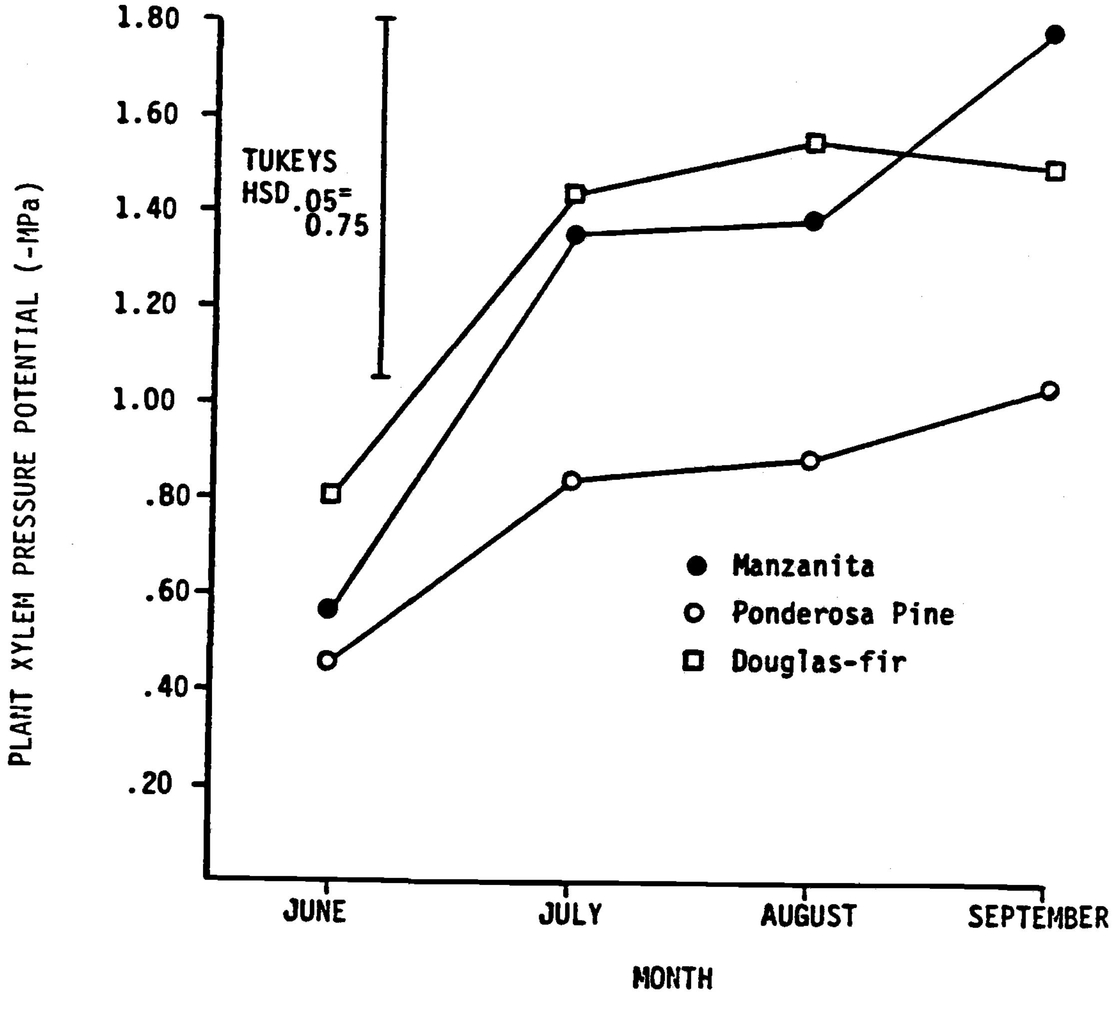


Figure 2-4. Mean seasonal predawn plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine, and Douglas-fir in 1985, averaged over treatments.

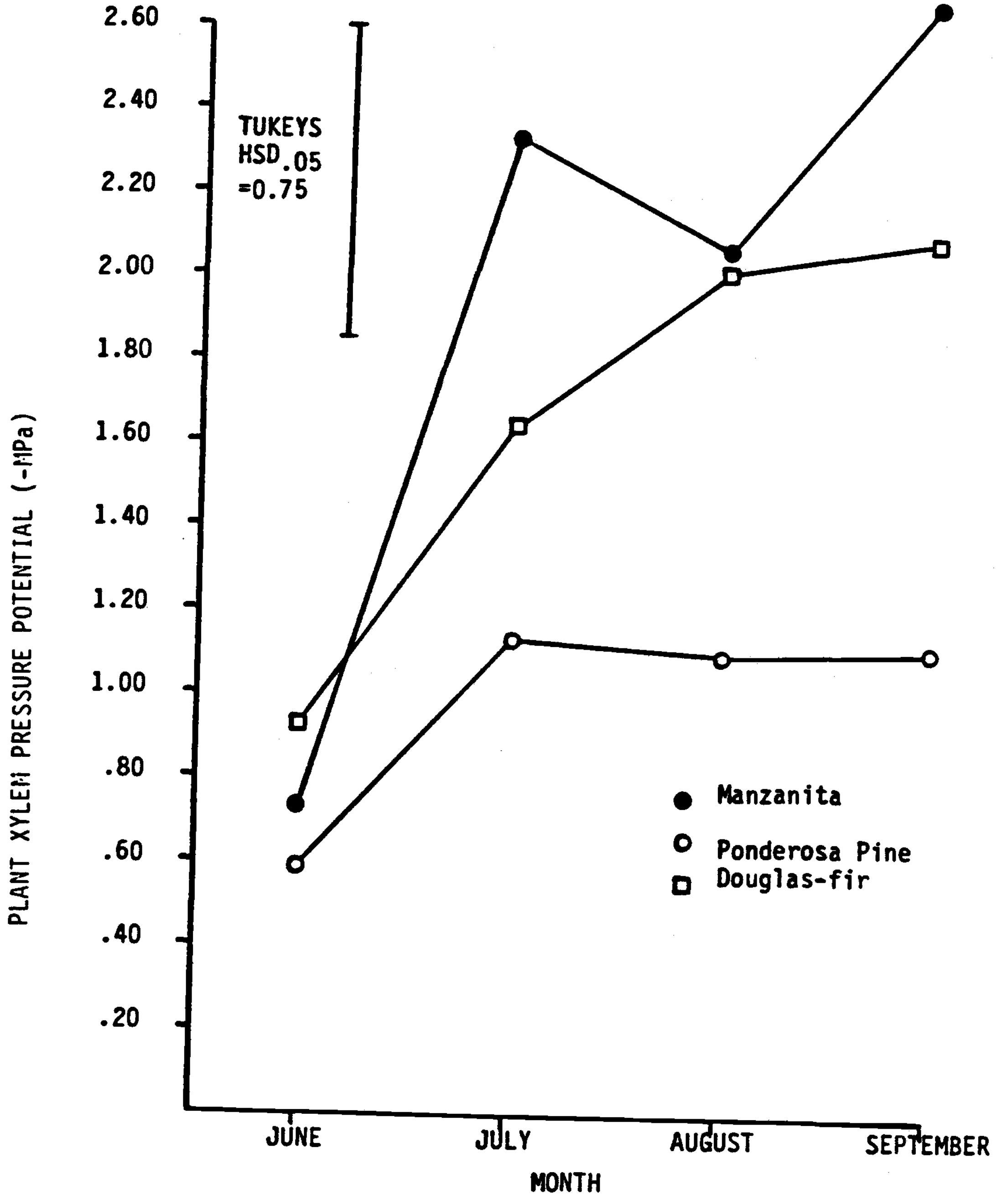


Figure 2-5. Mean seasonal midday plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine, and Douglas-fir in 1983, averaged over treatments.

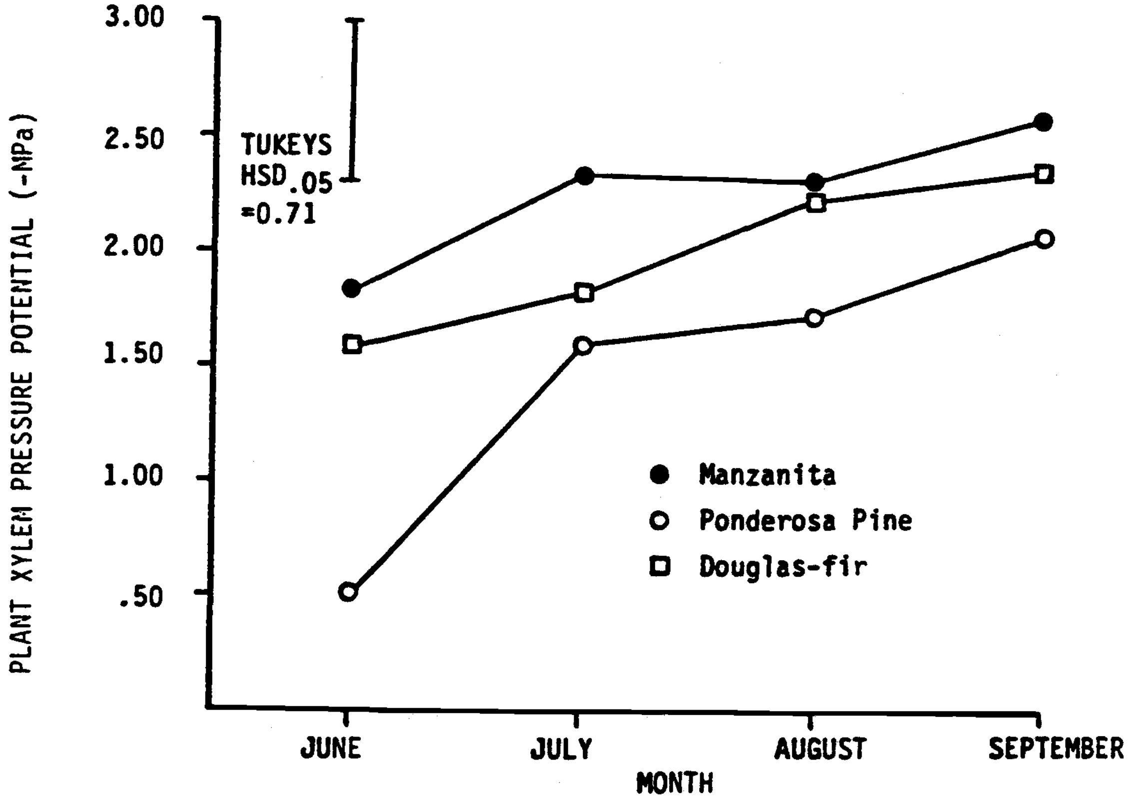


Figure 2-6. Mean seasonal midday plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine and Douglas-fir in 1984, averaged over treatments.

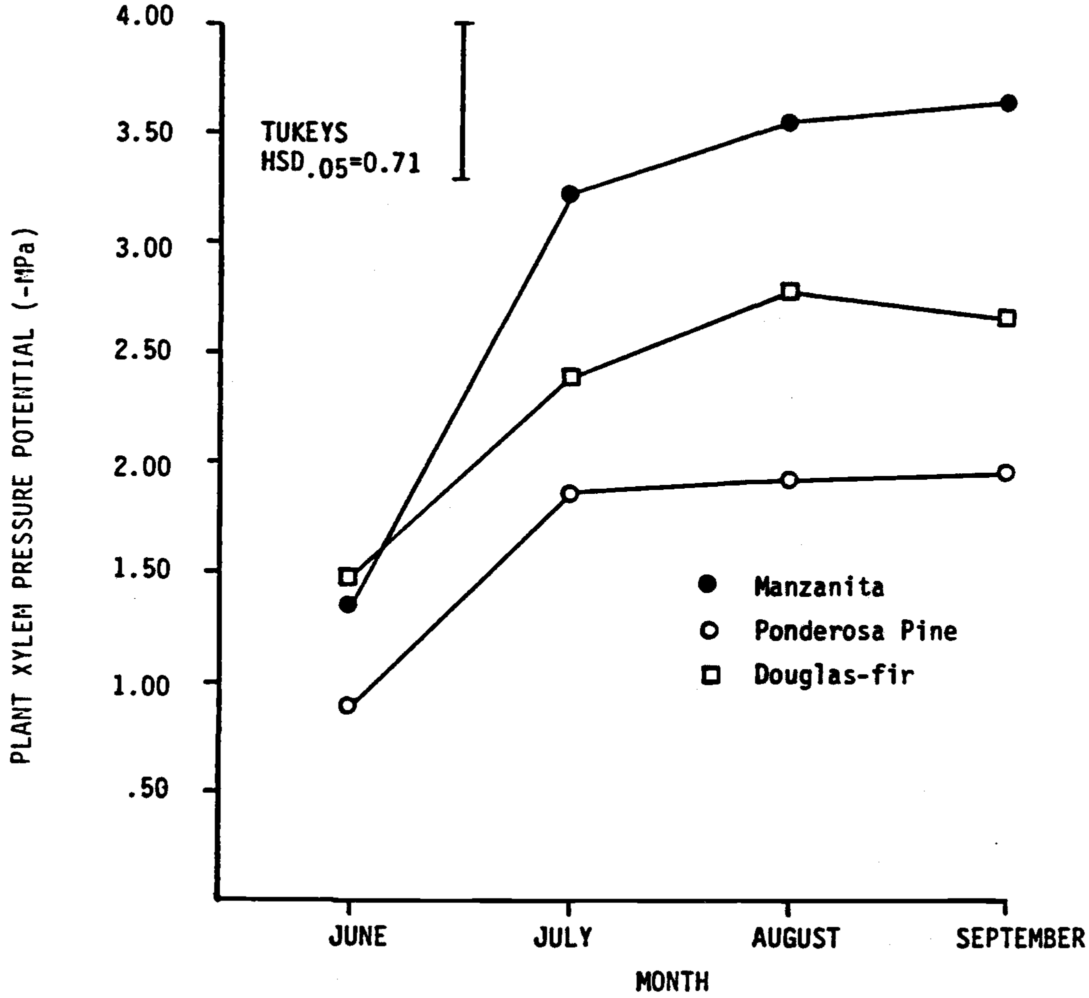


Figure 2-7. Mean seasonal midday plant xylem pressure potential (-MPa) of whiteleaf manzanita, ponderosa pine, and Douglas-fir in 1985, averaged over treatments.

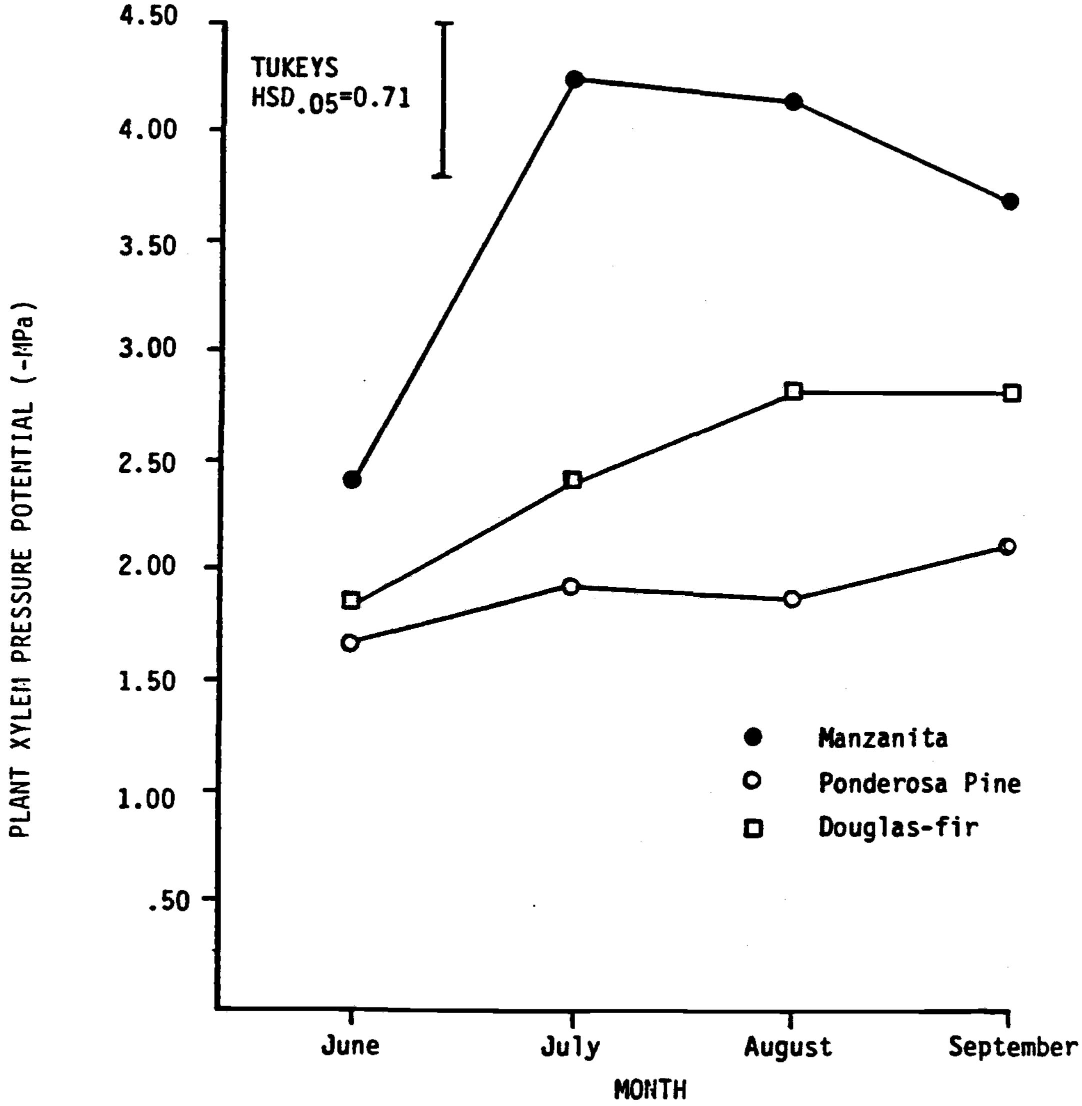


Figure 2-8. The relationship of midday plant water potential and midday stomatal conductance in Douglas-fir

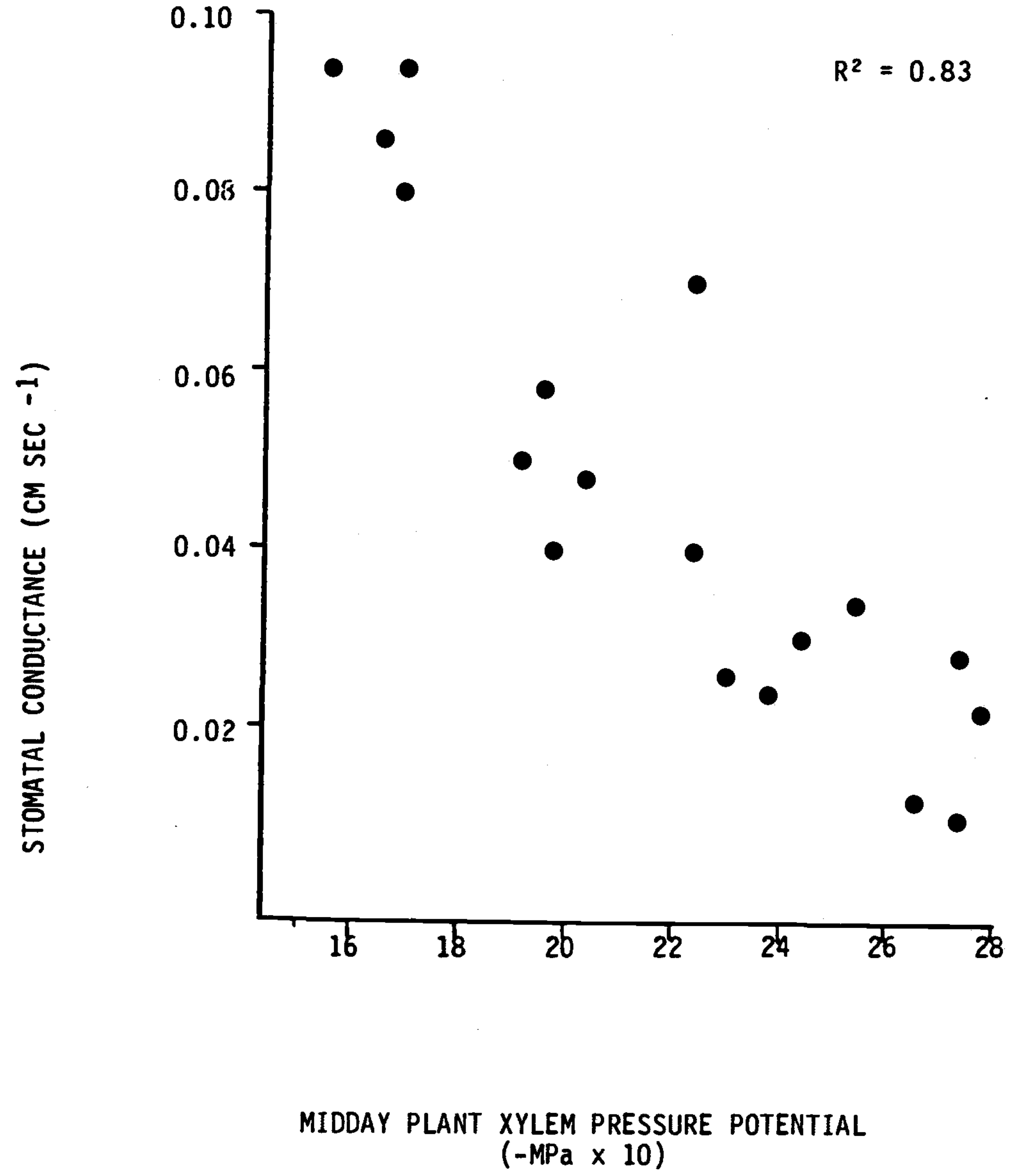


Figure 2-9. The relationship of midday plant water potential and midday stomatal conductance in ponderosa pine.

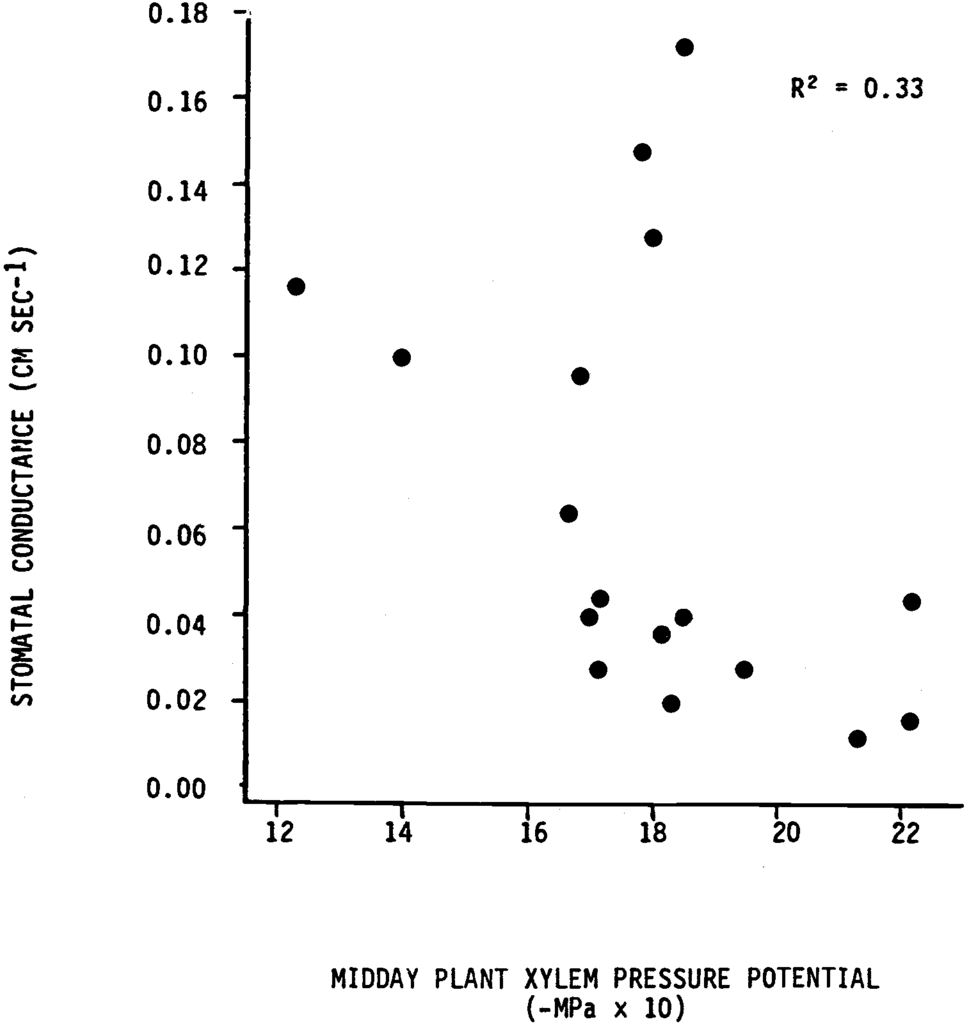
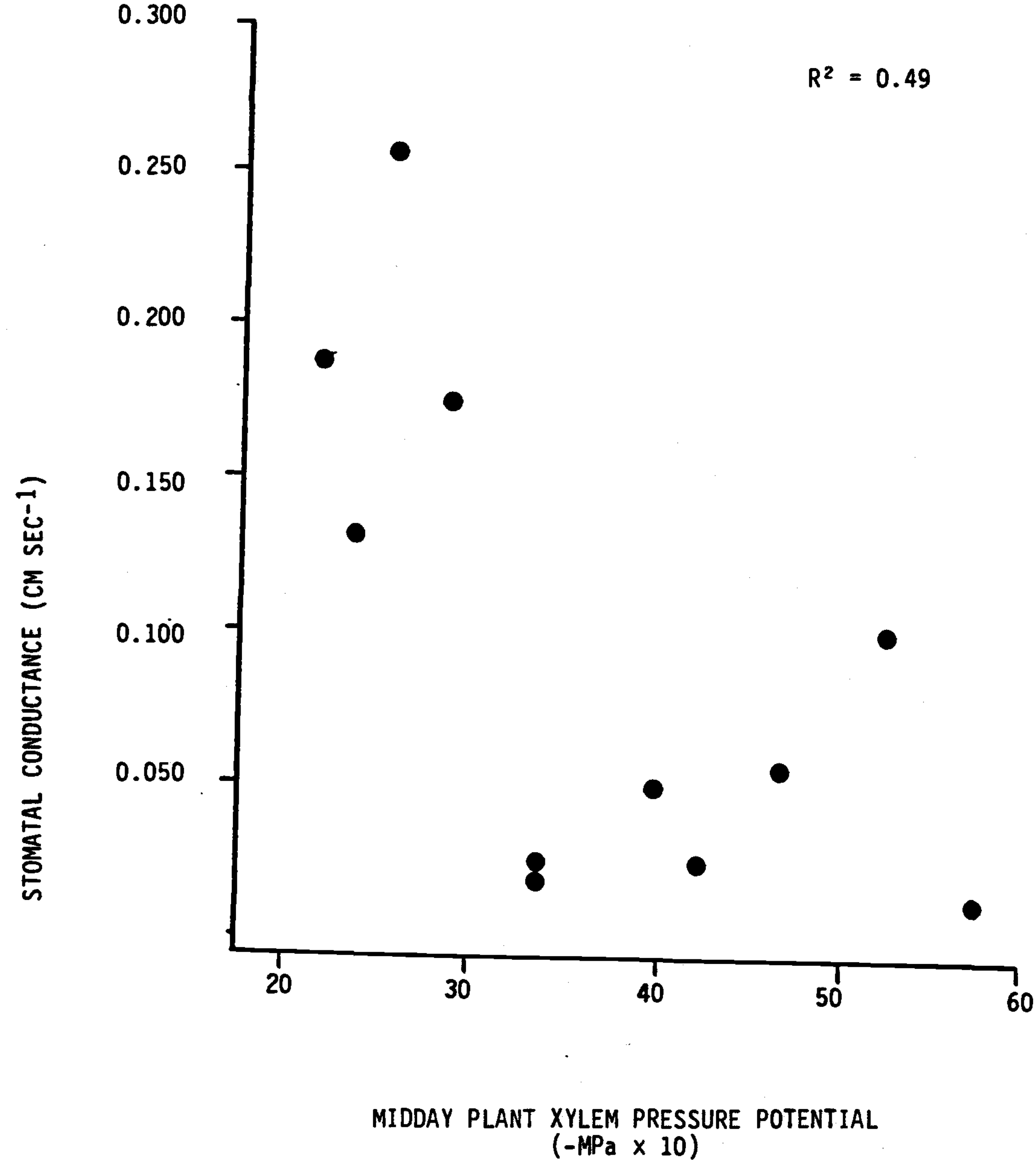


Figure 2-10. The relationship of midday plant water potential and midday stomatal conductance in whiteleaf manzanita.



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CHAPTER 3

Effect of Whiteleaf Manzanita and Herbs on Growth of Juvenile Douglas-fir and Ponderosa Pine

Introduction

Growth of Douglas-fir [Pseudotsuga menziesii (Mirbel) Franco] and ponderosa pine (Pinus ponderosa Dougl. ex Loud) is related to the availability of site resources (Cole and Newton 1987, Oren et al. 1987). Competitors on a site will tie up some of the resources, hence reduction of competitors generally results in increased juvenile conifer growth.

The area under investigation in this study is in the interior foothills of the Siskiyou Mountains. It has been identified by Waring (1969) as a region where water is a primary limiting resource for plant growth. Dominant shrub communities of whiteleaf manzanita are characteristic of this region (Whittaker 1960, Gratkowski 1961).

Researchers in California have done work on the relationships between manzanita and ponderosa pine. Oliver (1979) examined the effects of tree spacing with and without whiteleaf manzanita. He found that brush competition reduced tree diameters up to the equivalent of nearly three years' growth. Bentley et al. (1971) studied the competitive effects of different levels of greenleaf manzanita (Arctostaphylos patula Greene) on pine and found brush control definitely promoted growth of pine seedlings in the first five years after establishment. Powers and Jackson (1978) studied the interaction of whiteleaf manzanita and fertilizer on pine seedling growth. After one growing season, pines growing with brush had equal heights and diameters to those growing without brush. If brush was removed and nitrogen was applied, pine seedlings showed significant increases in height and diameter.

The objectives of this study were to (1) describe the effect of several densities of whiteleaf manzanita on growth of 3- to 5-year-old Douglas-fir and ponderosa pine in southwest Oregon, (2) compare this to conifer growth with no manzanita competition, (3) quantify the impact of the herbaceous plant community on conifer growth, and (4) determine if reinvasion of herbs caused growth reduction in the five-year-old plantations.

Materials and Methods

Study sites. Three study sites were selected near Ruch, Oregon, about 35 km west of Medford. The sites were designated Big Humbug (T38S. R4W. Sec. 12), Little Humbug (T38S. R4W. Sec. 12 and 13), and China Gulch (T38S. R3W. Sec. 21). The sites were located on southeast to southwest slopes with about 20 percent gradient. The soils were moderately deep clay loams of the Vannoy soil series (Stearns-Smith and Hann 1986). They were classified as mixed, mesic, Typic Haploxeralfs. Estimated timber growth capacity was Site V or poorer for Douglas-fir and Site IV for ponderosa pine (Meyer 1938, McArdle et al. 1949). The shrubs and hardwoods on the site were whiteleaf manzanita, Pacific madrone (*Arbutus menziesii* Pursh), wedgeleaf ceanothus [*Ceanothus cuneatus* (Hook.) Nutt.], and poison oak (*Rhus diversiloba* T. and G.). The herbaceous plants on the sites were primarily downy brome (*Bromus tectorum* L.), bedstraw (*Galium aparine* L.), hedge parsley (*Caucalis microcarpa* L.), tarweed [*Madia* sp., and *Epilobium minutum* (Lindl. ex Hook.)], all non-native species.

Site history. Vegetation on the site has been influenced strongly by wildfire, the last one occurring 40 to 50 years ago. The sites were cleared for reforestation in 1980 with crawler tractors equipped with brush blades. The brush was piled in windrows and burned. As a result of scarification, manzanita seed germinated in large numbers and produced up to 500,000 seedlings per hectare in patchy distribution. Shrub seedlings were mostly absent from the burned windrows, presumably because the intense heat destroyed the seeds. These areas were not used in the study. After brush removal, the soil was ripped with a crawler tractor along the contour at 2 m intervals to a depth of about 45 cm and planted (2.5 m x 2.5 m spacing) in spring, 1981, with a mixture of 2-0 bareroot Douglas-fir and ponderosa pine seedlings. On the Humbug sites, a 0.9 m square paper mulch (Kraft 2-ply) was placed around each tree to reduce herbaceous competition and surface evaporation. This was effective during 1981 and 1982. The China Gulch site received a glyphosate spray treatment in spring, 1981, and a hexazinone spray treatment in spring, 1982.

Each reduced herbaceous competition for one year. The spray treatments had negligible direct toxic effect on the manzanita seedlings, and the stand appeared visually quite vigorous compared to other stands in the region.

Study installation. In spring, 1983, the treatments (different densities of manzanita and presence or absence of herbs) were established by chemical thinning or interplanting natural seedlings. Manzanita densities ranged from 0 to 27000 shrubs per hectare and were established on a square grid within 22-m square plots (0.0484 ha). Treatments were: 27000C, 13500CH, 13500C, 6720C, 3360C, 1700C, 0C, and 0; where the number is manzanita density, in shrubs/ha, C indicates conifers were present, and H indicates herbs were present. Treatment plots were installed within the plantation where 2-year-old conifers were growing. Conifer density ranged from 1760 to about 1050 seedlings per hectare because of mortality before the study was initiated. Herbaceous cover was 100 percent. Eight treatments were established in each of the replications (sites). The study was a randomized complete block design with the sites used as blocks.

Chemical thinning and herbaceous weed control were carried out by covering the desired manzanita and conifer seedlings, then broadcast spraying with a mixture of 3.3 kg/ha simazine, 2.8 kg/ha glyphosate, and 3.8 kg/ha 2,4-D. The total volume per hectare of spray was 121 liters. Herbaceous weed control was maintained in 1984 by a broadcast spray of 4.4 kg/ha of simazine in January. By 1985, the use of herbicides on local federal forest land was enjoined by court order. Three times during the spring of 1985, a 1.3 m radius circle around three randomly selected conifers of each species in each treatment was handhoed (except 13500CH), removing all herbaceous plants. The remaining area of the treatment plots experienced varying levels of herb reinvasion. In treatment 13500CH, the herb community was left intact and excess shrubs were removed by handpulling or chopping.

Soil moisture. Soil moisture was measured monthly during the spring and summer of 1983 and 1985 using a neutron moisture meter (Troxler Model 3225A). In each plot, five aluminum access tubes were installed, systematically, with one in each quadrant of the plot (allowing for a buffer) and one in the center. Tube depth varied with the depth of the soil and ranged up to 90 cm, although a small sample size precluded using analysis of variance for statistical analyses on readings at that depth. Readings were made at 30 cm and 60 cm on all tubes. Field capacity readings were made three days after full recharge in April and during each sample interval water used near each tube was calculated by subtracting mm of water present each month from water present at field capacity or the previous month. From this value, the water used in the treatment 0 (no vegetation) was subtracted to account for evaporation and subsurface movement. The values from the 30 cm and 60 cm depths were added to give total soil moisture change within this zone.

A complete set of soil moisture measurements was made in 1983 in treatments 13500C, 13500CH, OC, and 0 on two of the sites (Big and Little Humbug). These observations were graphed showing soil moisture change from April through September. The soil moisture deficit (SMD), defined as the area between the curve of water present and the estimated availability limit (lowest point reached during the season), was calculated for each of the three treatments on two sites.

Plant xylem pressure potential. Plant xylem pressure potential, measured as xylem sap tension, was recorded in 1983 and 1984, using a pressure chamber apparatus (Waring and Cleary 1967, Ritchie and Hinckley 1975). Readings were taken before dawn, and at 900, 1300, and 1500 PDT hours on treatments 13500C, 13500CH, and OC. Readings were made in June, July, August, and September using three individuals of each conifer species from each plot. Missing values were estimated for each treatment by using proportions of values from alternate years.

Diurnal curves were drawn for each treatment at each site. An upper-stress threshold level of -2 MPa was chosen, above which photosynthesis was assumed to be limited or negligible (Newton and Preest, in press). The area between the threshold level and the diurnal curve was measured and designated the moisture stress relief (MSR). The values for each of the four months were multiplied by the number of days in that month, then added together to get seasonal MSR.

Shrub and conifer measurements. At the end of each growing season, manzanita height, basal diameter, and crown width were measured. Crown cover was calculated using the formula for a circle. Manzanita biomass and leaf area index were calculated from basal diameter using regression equations (Hughes et al., in press). Conifer height and diameter were also measured at the end of each growing season. Stem volume index was calculated as $1/3\Pi(\text{basal stem radius})^2$ height, where basal stem radius was measured at 15 cm above ground level.

Statistical analysis. Because of high variation within the plant populations on each treatment plot, plot means were used in the analyses. Manzanita effects on conifer stem volume were analyzed by regression using data from treatments 27000C, 13500C, 6720C, 3360C, 1700C, and 0C. A regression was done for each year and the giant size regression (Neter and Wasserman 1974) technique was used to determine if the slopes of tree size as a function of shrub density were different among years. The manzanita density, 1983 biomass, 1983 LAI, and 1983 canopy cover were independent variables and 1985 conifer stem volume was the dependent variable.

Analysis of herb effects was accomplished by regression using treatments 13500C and 13500CH. Regression equations were developed using conifer stem volume as the dependent variable and year as the independent variable for each treatment. Differences in slope were tested with giant size regression techniques. This and the preceding analysis did not include the conifers that were hoed in 1985.

The effect of hoeing on conifer stem volume in 1985 was analyzed by analysis of variance, with 1984 stem volume as a covariate to equalize pretreatment volumes. Means were separated using Tukey's HSD test (Neter and Wasserman 1974).

Effects of soil moisture depletion and moisture stress relief were analyzed with regression using conifer stem volume as the dependent variable.

Results

Manzanita density effects. Figures 3-1 through 3-4 show the effects of manzanita density, 1983 manzanita biomass, 1983 manzanita LAI, and 1983 manzanita canopy cover on 1983, 1984, and 1985 Douglas-fir stem volume. These figures show that in 1983, manzanita alone had little influence on Douglas-fir stem volume. In 1984, a reduction in stem volume with high levels of manzanita competition began to become apparent, although statistically the slope of volume in response to density was not significantly different from the 1983 curve. By 1985, the slope of the volume curve is statistically different from the 1983 and 1984 slopes for all the independent variables. This indicates an increasing sensitivity to manzanita density as time elapsed and total biomass increased.

Table 3-1 shows that shrub density alone is the poorest indicator of Douglas-fir stem volume, explaining only 22% to 28% of the variation. Manzanita canopy cover was the best indicator, explaining 34% to 44% of the variation. In general, 1983 manzanita biomass, LAI, and cover explained less of the variation in 1983 Douglas-fir stem volume than they did for 1984 or 1985 stem volume.

The manzanita effects on ponderosa pine are similar to those on Douglas-fir (Figures 3-5 through 3-8). After the 1985 growing season, stem volume was about 670 cm^3 at the highest levels of manzanita competition, compared to 1310 cm^3 with no competition.

Table 3-2 shows that shrub density is also the poorest indicator of pine stem volume, explaining 19% to 51% of the variation, and cover is the best indicator, explaining 28 to 60% of the variation. Manzanita biomass, LAI, and cover in 1983 explains more of the variation in 1985 stem volume, than that of 1983 or 1984.

Herb effects. Figures 3-9 and 3-10 show the conifer volumes over the three years in treatments 13500C and 13500CH, which isolate and quantify the herb effect. The slopes of the regression lines of the two treatments are significantly different, with stem volumes in treatment 13500C larger than those in treatment 13500CH. The larger difference in 1985 stem volume of Douglas-fir between treatments suggests that this species is influenced to a greater degree by herbaceous competition than is the pine. The continued divergence of curves suggests that herb effects may be long-term.

Effect of herb reinvasion. Analysis of 1985 conifer volumes between hoed and unhoed trees shows that the hoed trees (those without herb reinvasion) were significantly bigger than the others, p=0.01 (Table 3-3). When volume in 1984 was added to the model as a covariate it was significant, demonstrating that the trees selected for hoeing were significantly larger at that time than the unweeded trees. The hoed trees grew more rapidly than others, even when the initial height differences were accounted for. There was a significant interaction between treatment and hoeing for both conifer species. The general trend is that the higher the manzanita density, the lower the effect of removing herbs by hoeing. For Douglas-fir, the adjusted volume difference in treatment 0C was 106 cm^3 and in treatment 27000C it was 4 cm^3. In pine, the 0C treatment adjusted volume difference was 415 cm^3, while that in the 27000C treatment was only 15 cm^3.

Soil moisture. Figures 3-11 through 3-18 show the effect of the integral of soil moisture depletion in 1983 on conifer stem volumes in 1985. Measurements in 1984 were inadequate to make this analysis, and those in 1985 had much lower coefficients of determination.

Soil moisture depletion during June and July appears to be a good indicator of future conifer volume. Equations including data through June explain 70% and 61% of the variation in stem volume in Douglas-fir and pine, respectively. Total season soil moisture data, through September, explain less of the variation.

Plant xylem pressure potential. For Douglas-fir, moisture stress relief in 1983 and 1984 explained 77% of the variation in

1985 stem volume; ponderosa pine, however, had a coefficient of determination of only 0.55 with MSR (Figure 3-19 and 3-20).

Discussion

Manzanita density effects. The effects of whiteleaf manzanita on Douglas-fir growth have not been previously reported. Cole and Newton (1987) report increased fifth year height growth of Douglas-fir growing with red alder as the spacing between plants increased. In a more general context, control of competing vegetation around young Douglas-fir trees has been shown to enhance growth (Walstad 1981, Stewart et al. 1984, Walstad et al. 1986, Petersen and Newton, 1985).

Oliver (1984) studied the effects of _Arctostaphylos_ _canescens_ and _A_. _roofii_ on ponderosa pine, and found that trees released from about a 30% brush canopy cover showed an immediate increase in diameter growth. After five years, stem volume production was 29 percent higher when all brush was removed and was significantly different from untreated plots. Plots with half brush removal were not different from untreated plots. After 24 years, mean diameter increased 63% to 300%, depending on stocking level, with control of understory vegetation (Oren et al. 1987). A study of greenleaf manzanita (_A_. _patula_) seedlings growing with ponderosa pine showed that the manzanita was a superior competitor (Shainsky and Radosevich 1986). Bentley et al. (1971) looked at pine height five years after establishment and response to varying levels of greenleaf manzanita, snowbrush ceanothus, and Sierra plum. He found the mean height of his 25 tallest trees with little competition to be about 49 inches and those with maximum competition (40000 ft^3/acre brush canopy volume) to be about 26 inches tall. The pines in this study were larger (up to 152 cm tall), possibly because nutrients were not removed from the site by bulldozing. Both studies showed a 100 percent increase in pine size when competition was removed, compared to pines growing at the highest levels of competition. On Powers and Jackson's (1978) poor site, 9-year-old pines growing with dense whiteleaf manzanita (1770.6 g/m^2) averaged only 113 cm tall and on the better site (2542.4 g/m^2 manzanita) the trees averaged 191 cm tall. These trees showed no significant first year response in either height or diameter growth one year after brush removal. The pines in my study were taller after five years than Powers and Jackson's poor site after nine years. This may be accounted for by site differences and also because of the lower amounts of brush biomass on our plots. The failure of Powers and Jackson's trees to respond after one growing season is not surprising; it often takes suppressed trees two or more years to respond to release. Ross (1985) examined growth and survival of ponderosa pine in southcentral Oregon in response to several site preparation methods. He found that 8-year-old trees grew better with site preparation treatments that reduced nonconiferous vegetation, especially when soil disturbance was minimized.

Limited conifer response to manzanita after the first year (1983) may be the result of plant vigor resulting from the amount of carbohydrate stored the previous year (Newton and Preest in press). Another explanation may be a lack of full site occupancy reflected as a lack of competition between manzanita seedlings by the third year within the range of manzanita density in this study. Oliver (1984) did show a first year diameter response in older trees with greater cover of manzanita. Although the curve for the 1984 data are not statistically different from the 1983 data, the trend toward reduced conifer growth with increasing levels of manzanita competition became apparent and was significant by 1985. Increased conifer response over time has been shown by others (Petersen and Newton 1985, Walstad et al. 1986, Newton and Preest, in press).

The management implications of being able to predict fourth and fifth year Douglas-fir growth and fifth year pine growth by measuring parameters of 3-year-old manzanita are noteworthy. Using these data, a forester may estimate the relative need for release from manzanita at the time the stress response is triggered, i.e., one to two years before losses are visible.

Although plant community biomass is an important measure of dominance and productivity, and LAI describes the total transpiring and photosysnthesizing area of the community (Hughes et al. in press), neither these measures nor manzanita density had as high a coefficient of determination with conifer volume as canopy cover. This may be advantageous to the field forester, because estimates of shrub canopy cover are commonly made and can be determined quickly. Canopy cover as an index of competition needs to be examined to determine if specific levels change in competitiveness over different sites.

Herb effects. The conifers growing in the treatment that included herbs over the three years of the study showed lower average stem volumes than those in other treatments. This impact has also been demonstrated by Cole and Newton (1987), Newton and Preest (in press), and Petersen and Newton (1985) for Douglas-fir in western Oregon, and by Elliot and White (1987) for ponderosa pine in Arizona. Often foresters have ignored herbs because of their low stature and considered them insignificant competitors. Unpublished data (Wagner, 1987) has shown that in the Oregon Coast Range, herb competition is just as severe as salmonberry competition. In the present study, Douglas-fir and pine grown without herbs for the duration of the study had volumes 461 percent and 367 percent greater than trees grown with shrub and herb competition. Douglas-fir in a moister climate in western Oregon experienced a 217 percent volume gain when herbs were removed during the first three years after planting (Newton and Preest in press).

Effect of herb reinvasion. Douglas-fir data from Newton and Preest (in press) support results of the present study. They showed significant gains in volume with an additional third year of weed control. This is important because four-year-old Douglas-fir and pine in this study appeared to be well established and presumably dominant over a low-growing herb community. In a management context, herbs appear quickly, hence can reduce conifer growth shortly after colonization. For maximum conifer growth, herbaceous weed control should be maintained until the stand is older and more established.

Soil moisture and plant xylem pressure potential. The significance and moderately high coefficients of determination for soil moisture and plant xylem pressure potential indices suggests that conifer growth in this region is strongly influenced by water deficits. A companion study (White 198X) shows that stomatal conductance of whiteleaf manzanita is significantly greater than that of either conifer species, and that, coupled with the substantially larger numbers of manzanita seedlings compared to conifer seedlings, suggests the water deficits are determined largely by the non-coniferous vegetation. High levels of conductance had also been shown for greenleaf manzanita (_A. patula_), and it has been shown that manzanita is a stronger competitor and more successful at site occupation than ponderosa pine (Conard and Radosevich 1981, Shainsky and Radosevich 1987).

The ability to predict stem volume two years after soil moisture resources are measured suggests that growth trajectories may be established early in the life of the conifer. The predictive ability (one to two years) in advance of visible injury has strong management implications in that it may allow a forester to anticipate losses and avoid them by reducing competition.

Conclusion

As manzanita densities increased from 0 to 27000 seedlings/hectare, conifer volume growth decreased. The effect became more accentuated as the stand reached age 5. The herbaceous vegetation depressed conifer volume more than the high densities of manzanita. An additional third year of herb community removal resulted in increased ponderosa pine volumes, compared to two years of herb removal, and the effect was significant at the lower densities of manzanita. Finally, conifer volume responded linearly to soil moisture deficits created by competing vegetation.

Table 3-1 Douglas-fir stem volume regressed on manzanita density, 1983 biomass(g/m^2), 1983 LAI (m^2/m^2)and 1983 percent shrub canopy cover (n = 18).

		P	R^2
1983 Volume	= 54.74 - 0.0006 density	.05	.23
	= 57.45 - 0.0272 biomass	.01	.33
	= 57.36 - 16.1511 LAI	.01	.33
	= 57.51 - 0.7808 cover	.01	.34
1984 Volume	= 229.26 - 0.0035 density	.02	.28
	= 245.08 - 0.1550 biomass	.00	.43
	= 244.96 - 92.7035 LAI	.00	.43
	= 245.39 - 4.4394 cover	.00	.44
1985 Volume	= 579.84 - 0.0097 density	.03	.26
	= 625.88 - 0.4374 biomass	.01	.40
	= 626.52 - 263.7200 LAI	.00	.41
	= 627.53 - 12.6081 cover	.00	.42

Table 3-2 Ponderosa pine stem volume regressed on manzanita density, 1983 biomass (g/m^2), 1983 LAI (m^2/m^2), and 1983 percent shrub canopy cover (n=18).

		P	R^2
1983 volume	= 96.75 - 0.0012 density	.07	.19
	= 102.17 - 0.0529 biomass	.02	.28
	= 101.17 - 29.7288 LAI	.03	.25
	= 101.98 - 1.4881 cover	.02	.28
1984 volume	= 526.81 - 0.0097 density	.01	.38
	= 552.24 - 0.3707 biomass	.00	.42
	= 551.33 - 220.5500 LAI	.00	.41
	= 552.31 - 10.5571 cover	.00	.43
1985 volume	= 1324.60 - 0.0246 density	.00	.51
	= 1400.00 - 0.9738 biomass	.00	.61
	= 1392.45 - 568.8900 LAI	.00	.58
	= 1396.38 - 27.3676 cover	.00	.60

Table 3-3 Comparison of 1985 conifer stem volumes between treatments that received two years of chemical herbaceous weed control (in 1983 and 1984) and treatments that received two years of chemical herbaceous weed control plus manual weed control (hoeing) during 1985. Means have been adjusted for the covariate 1984 conifer stem volume. Effect of hoeing in 1985 on 1985 conifer stem volume (cm^3)

	Stem Volume (cm^3)			
	Douglas-fir		Ponderosa pine	
Treatment	Hoed	Not Hoed	Hoed	Not hoed
OC	618	512	1608	1193
1700C	555	602	1360	1247
3360C	636	540	1329	1258
6720C	563	541	1236	1152
13500C	552	516	1163	1085
27000C	528	524	1102	1087
Tukeys HSD .05	243		382	

Table 3-4 Influence of soil moisture depletion (SMD) in 1983 and moisture stress relief (MSR) in 1983 and 1984 on conifer volume in 1985[1]

Dependent variable	Independent variable	R^2
Douglas-fir		
Log stem volume	Log SMD through June	.70***
	Log SMD through July	.71**
	Log SMD through August	.67*
	Log SMD through September	.63**
Ponderosa pine		
Log stem volume	Log SMD through June	.61**
	Log SMD through July	.61*
	Log SMD through August	.59*
	Log SMD through September	.57*
Douglas-fir		
Stem volume	Log MSR in 1983	.72**
Log stem volume	Log MSR in 1983	.56*
Log stem volume	Log MSR in 1984	.46
Log stem volume	Log MSR in 1983 + 1984	.52
Ponderosa pine		
Log stem volume	Log MSR in 1983	.37
	Log MSR in 1984	.83**
	Log MSR in 1983 + 1984	.86***

[1] Significance levels *p=0.1, **p=0.05, ***p=0.01

Figure 3-1 . Douglas-fir stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita density. Lines followed by the same letter are not significantly different at the P = 0.05 level.

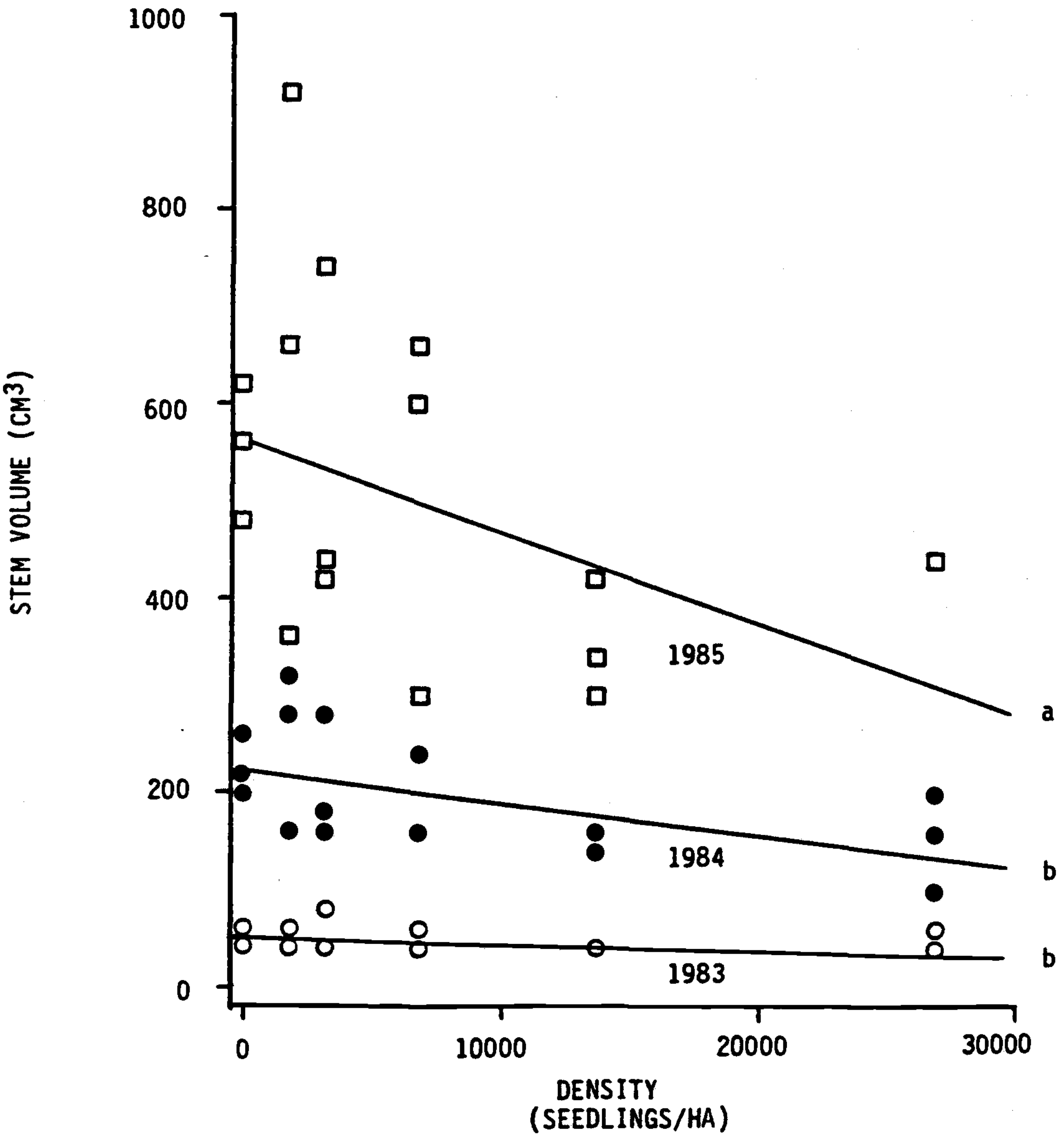


Figure 3-2. Douglas-fir stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita aboveground biomass in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

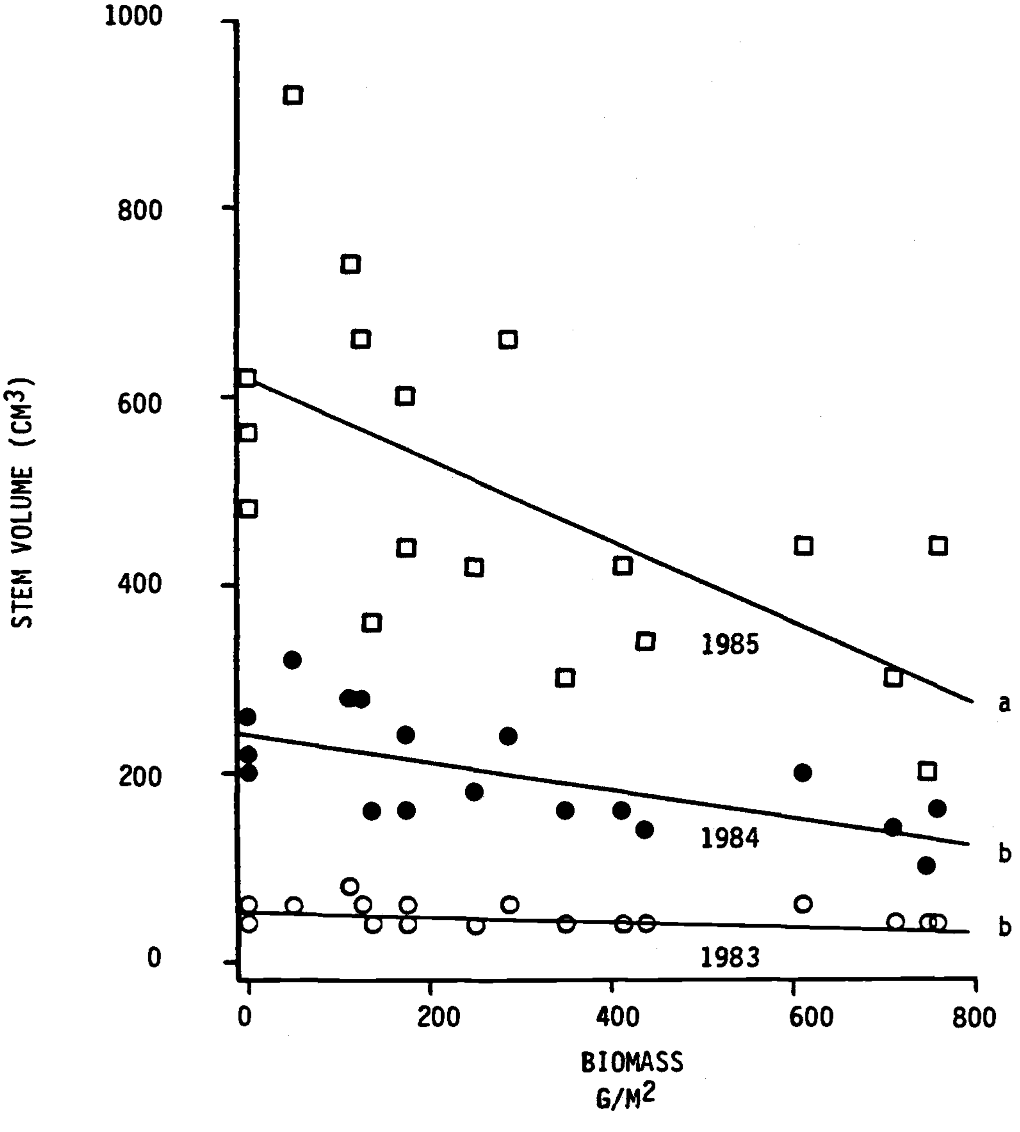


Figure 3-3. Douglas-fir stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita leaf area index in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

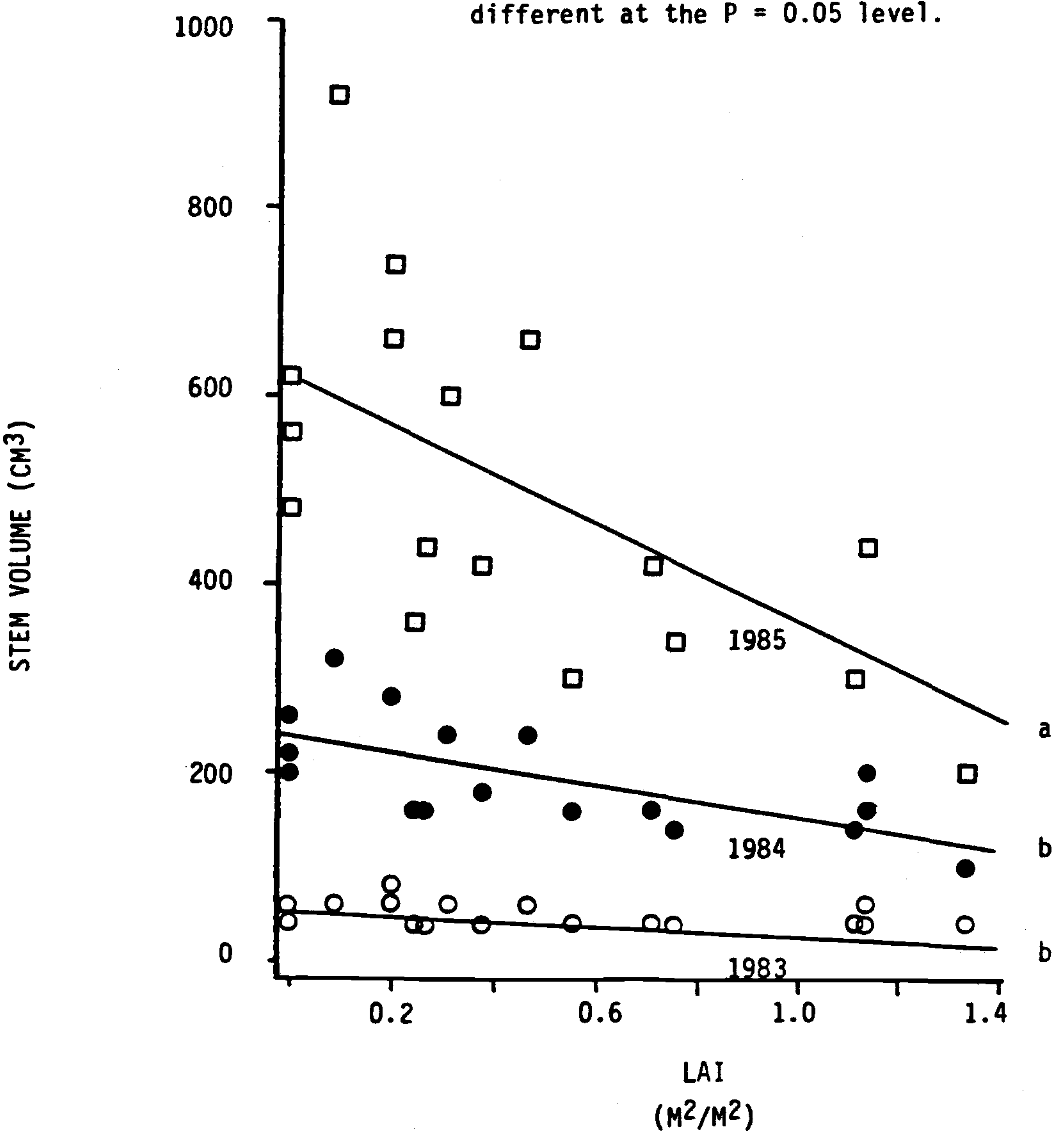


Figure 3-4. Douglas-fir stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita canopy cover in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

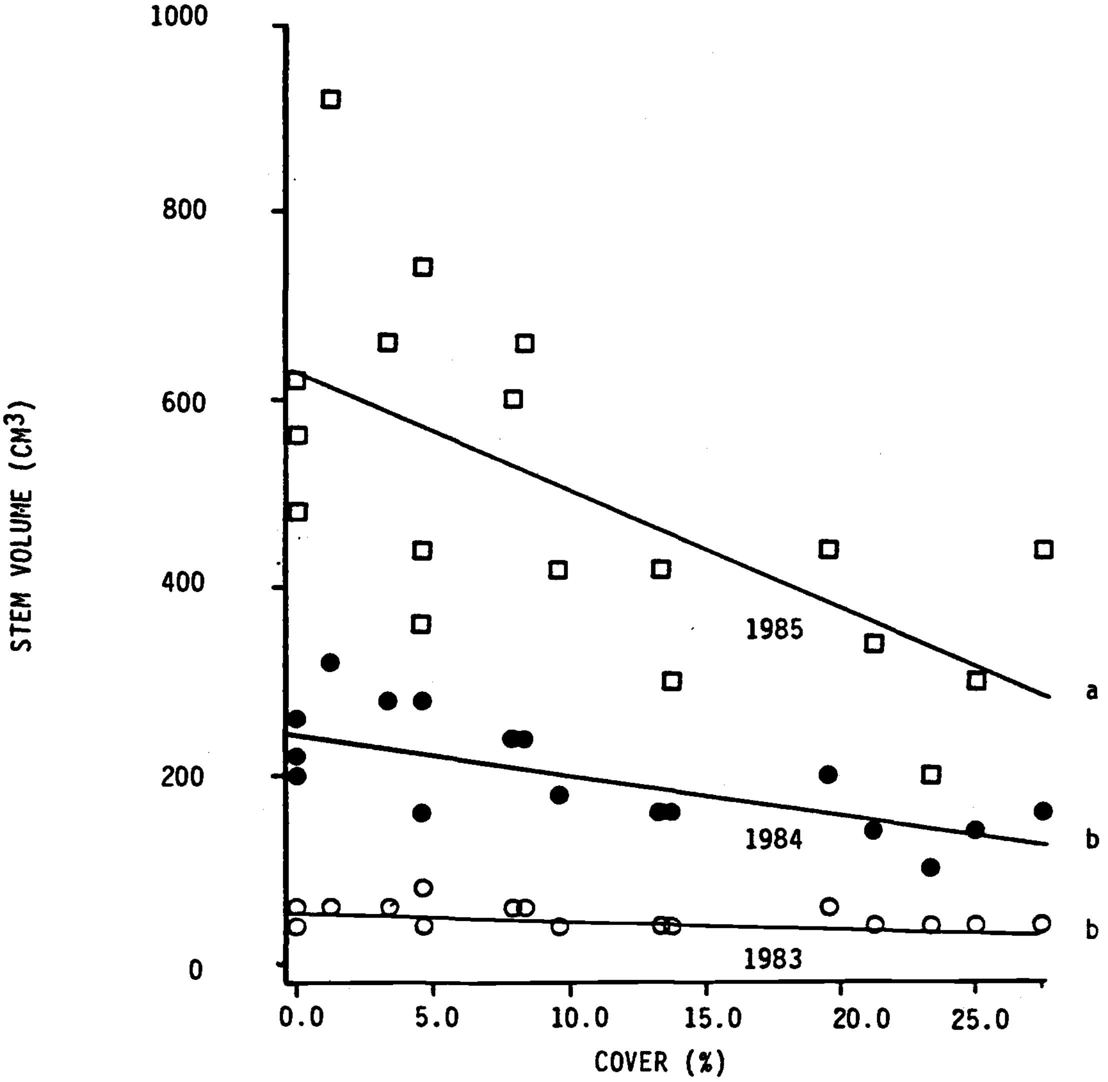


Figure 3-5. Ponderosa pine stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita density. Lines followed by the same letter are not significantly different at the P = 0.05 level.

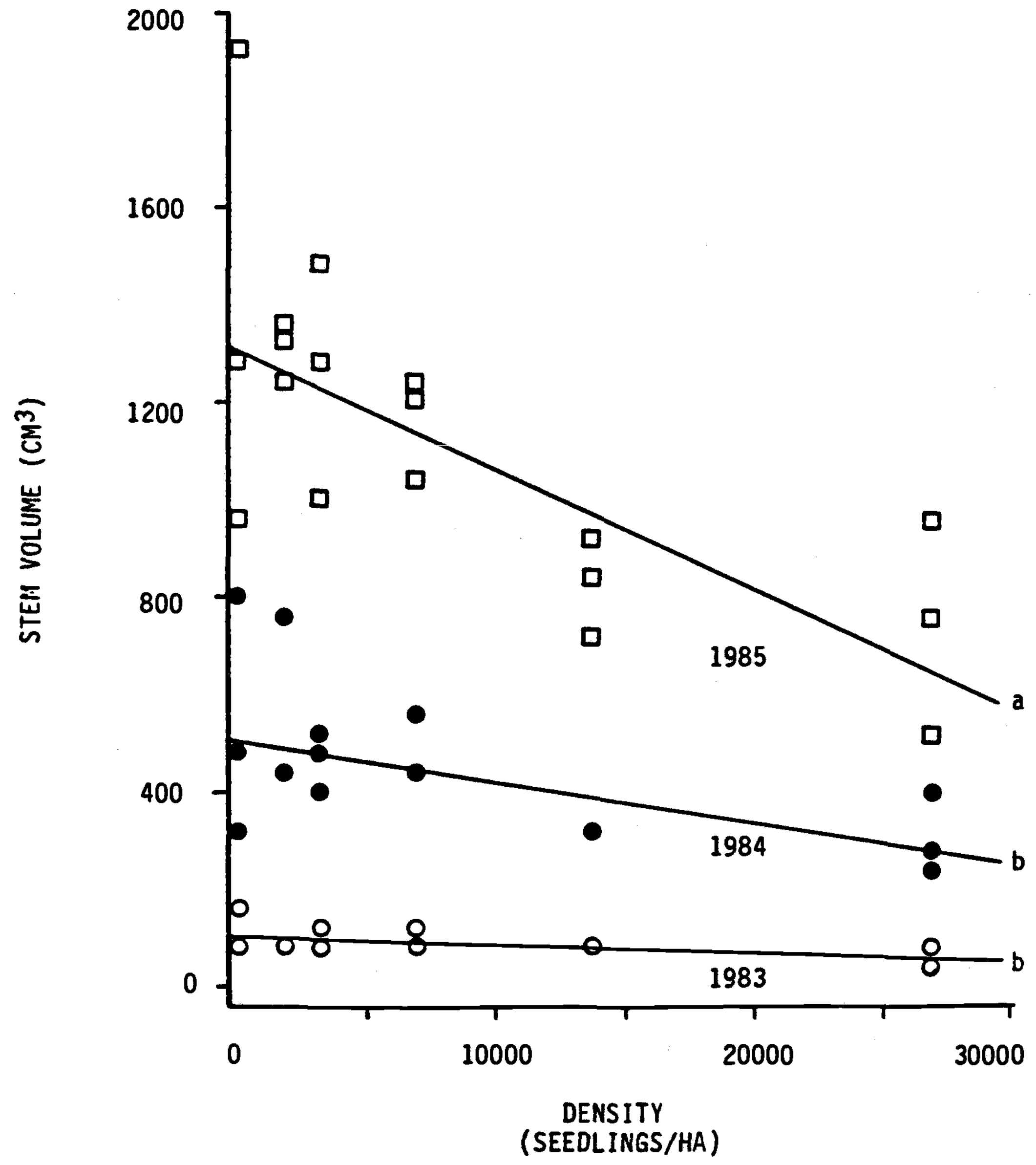


Figure 3-6. Ponderosa pine stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita aboveground biomass in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

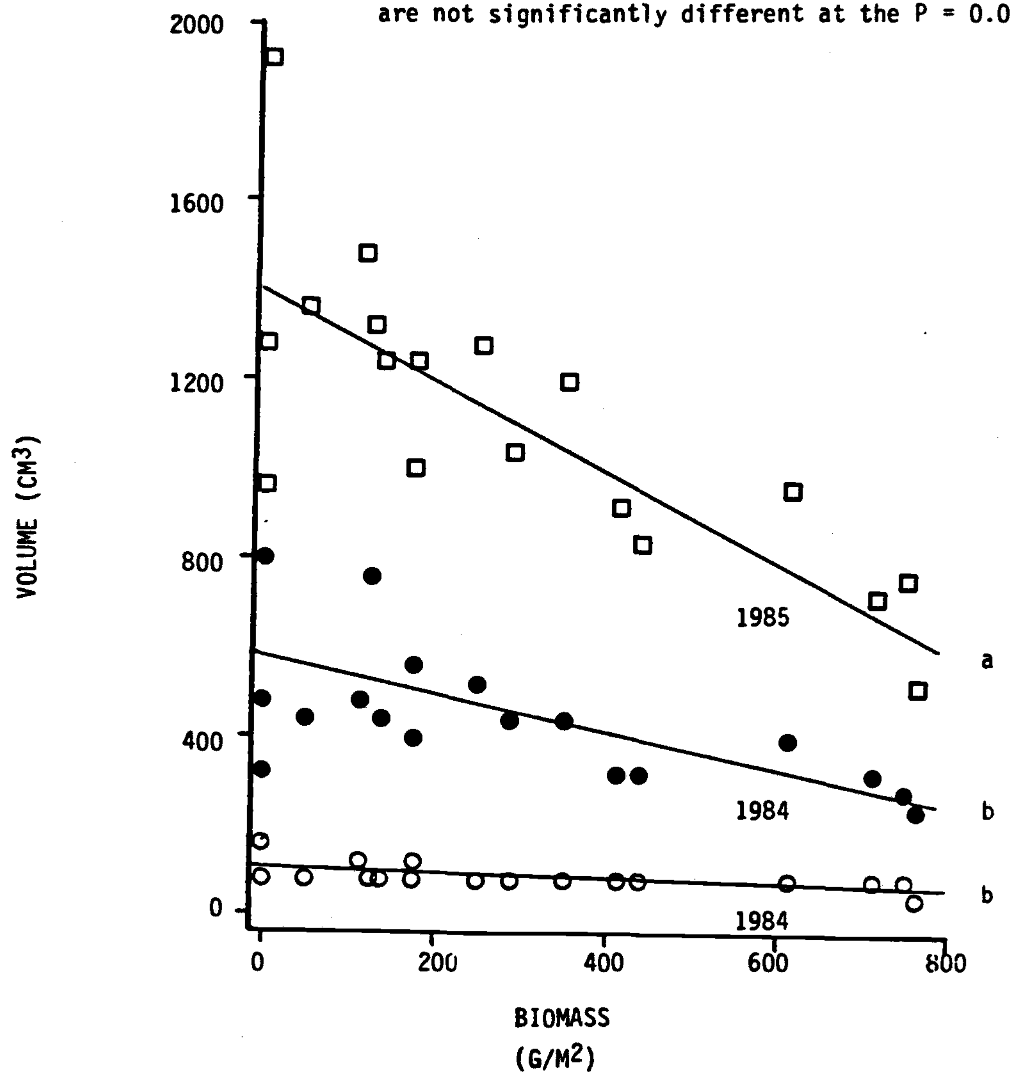


Figure 3-7. Ponderosa pine stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita leaf area index in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

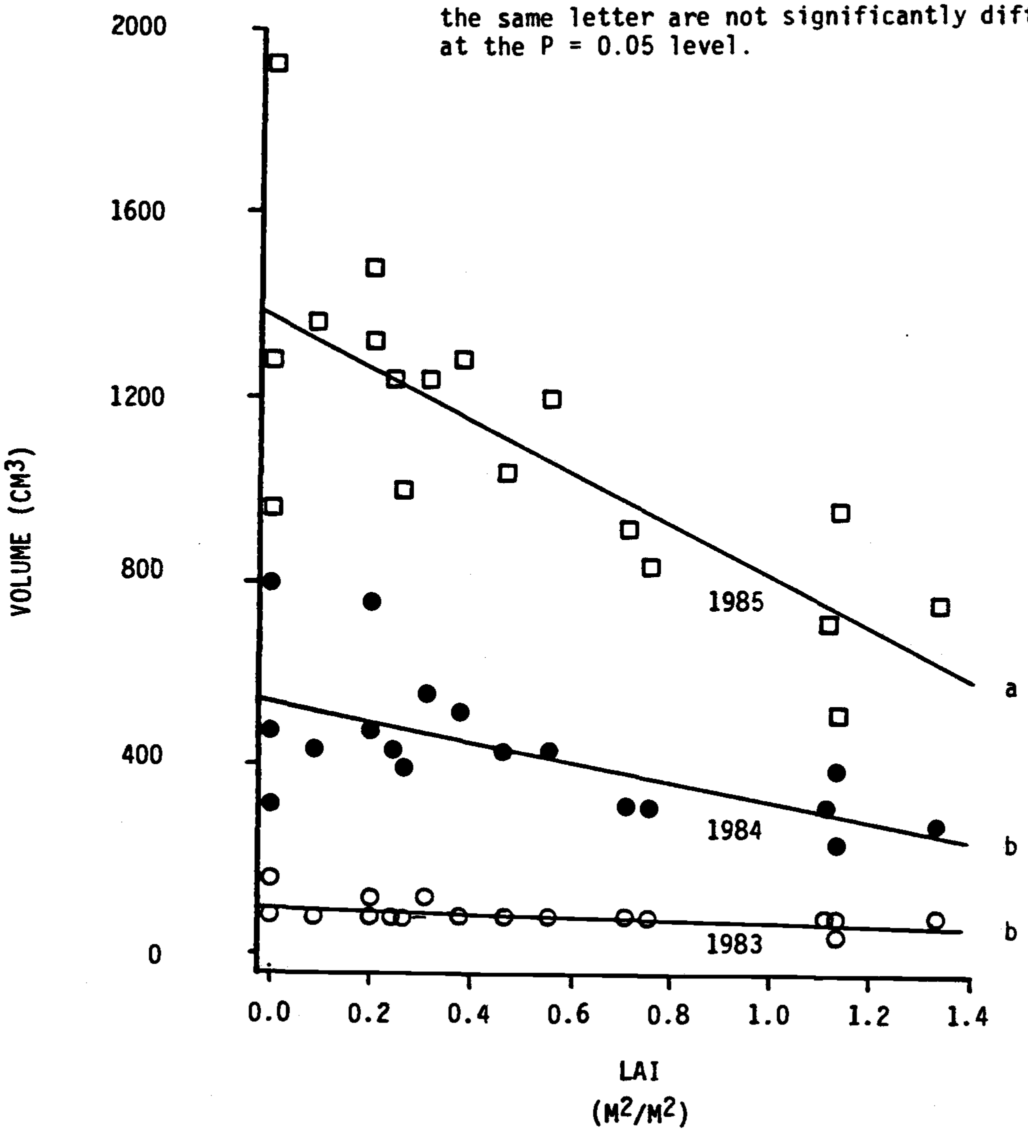


Figure 3-8. Ponderosa pine stem volume in 1983, 1984, and 1985 in response to whiteleaf manzanita canopy cover in 1983. Lines followed by the same letter are not significantly different at the P = 0.05 level.

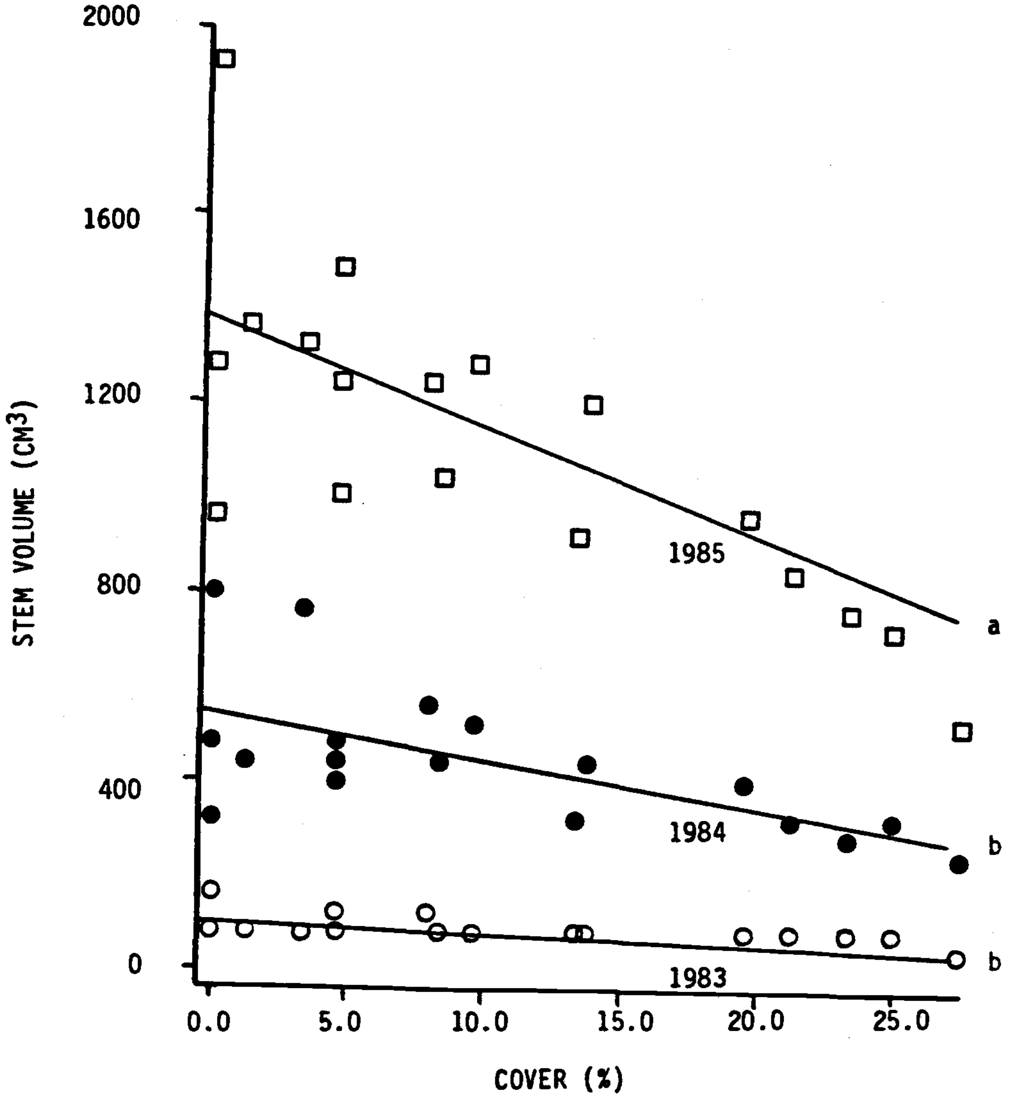


Figure 3-9. Douglas-fir stem volume in treatments 13500C and 13500CH as a function year. Lines followed by the same letter are not significantly different at the P = 0.05 level.

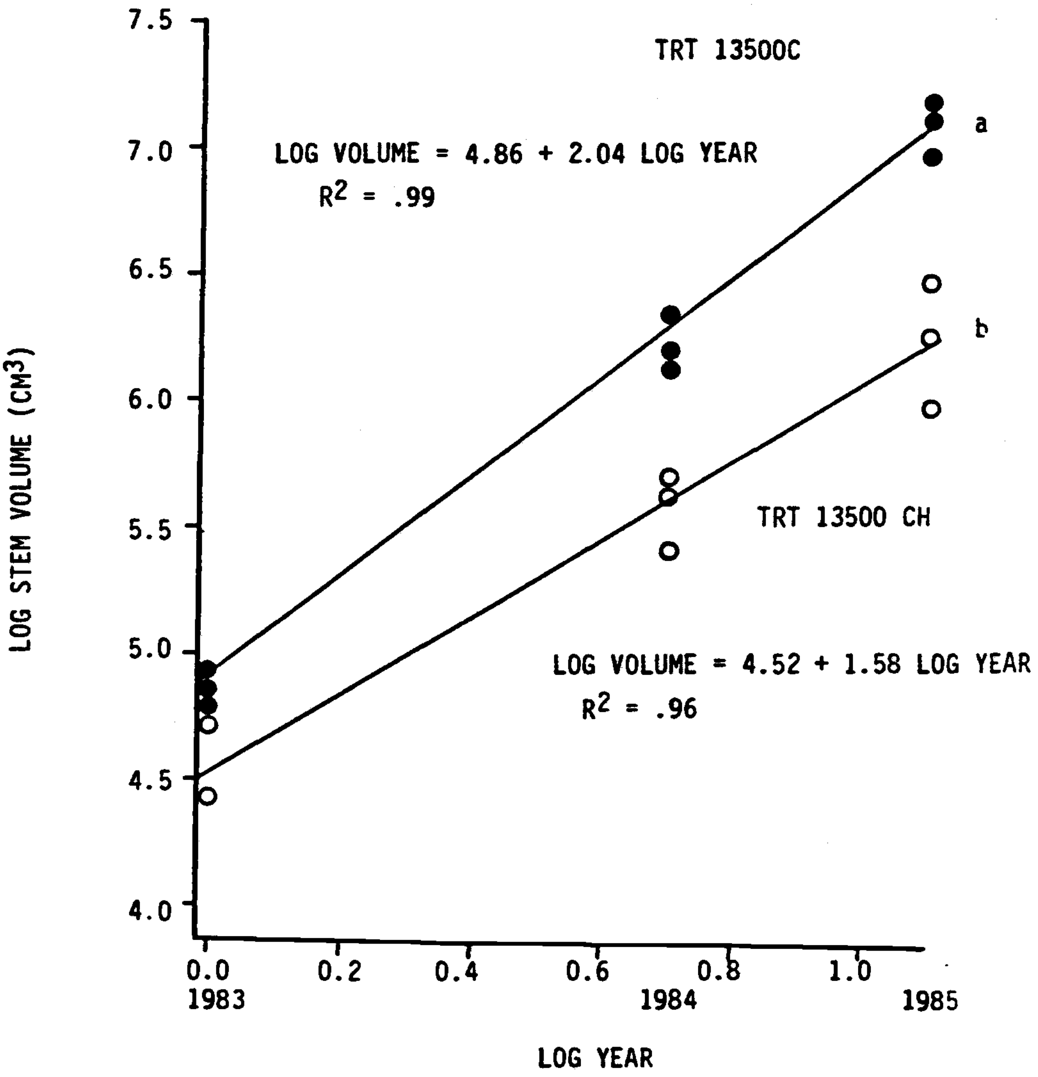


Figure 3-10. Ponderosa pine stem volume in treatments 13500C and 13500CH as a function of year. Lines followed by the same letter are not significantly different at the P = 0.05 level.

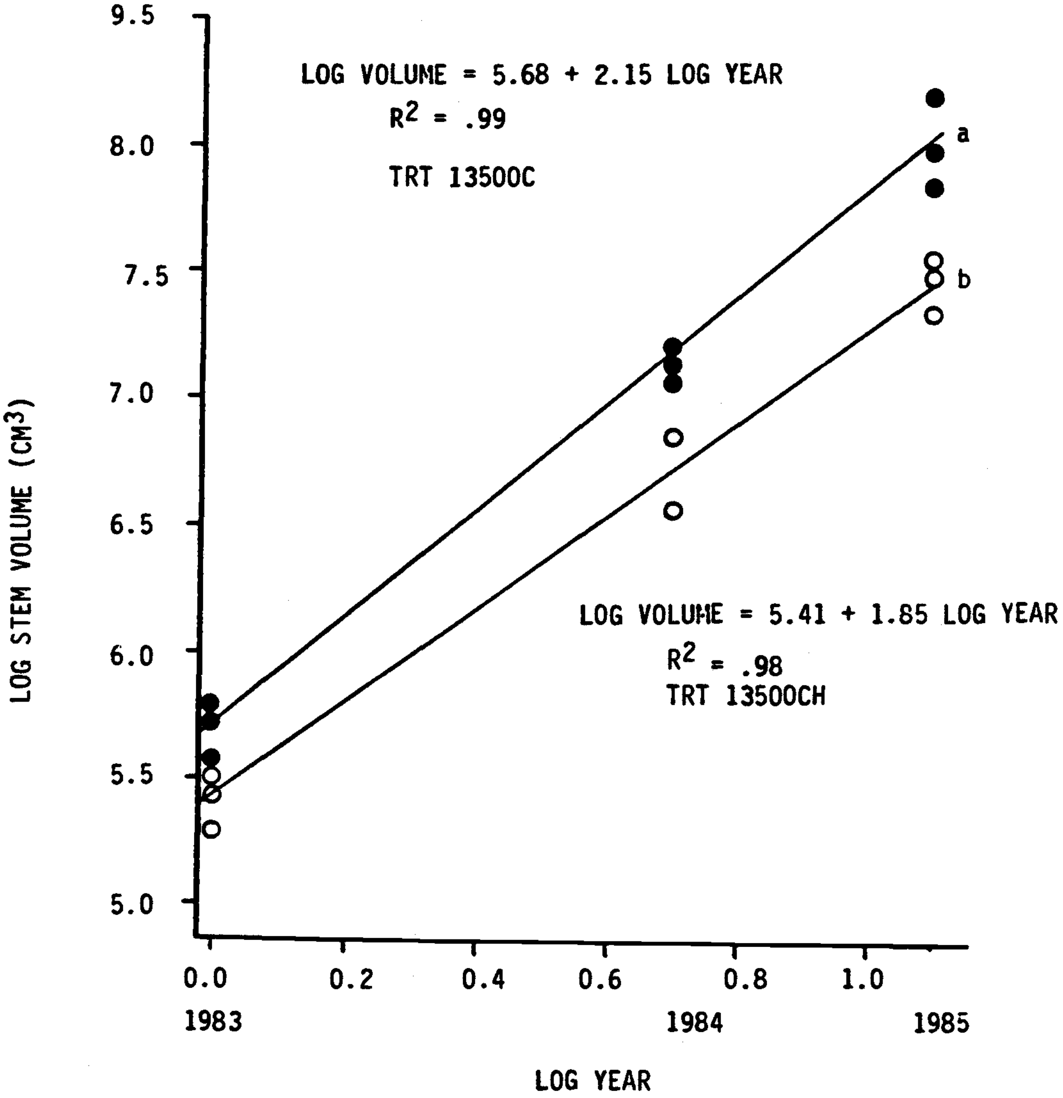


Figure 3-11. Fifth year stem volume of Douglas-fir as a function in variation of soil moisture deficit through June, 1983.

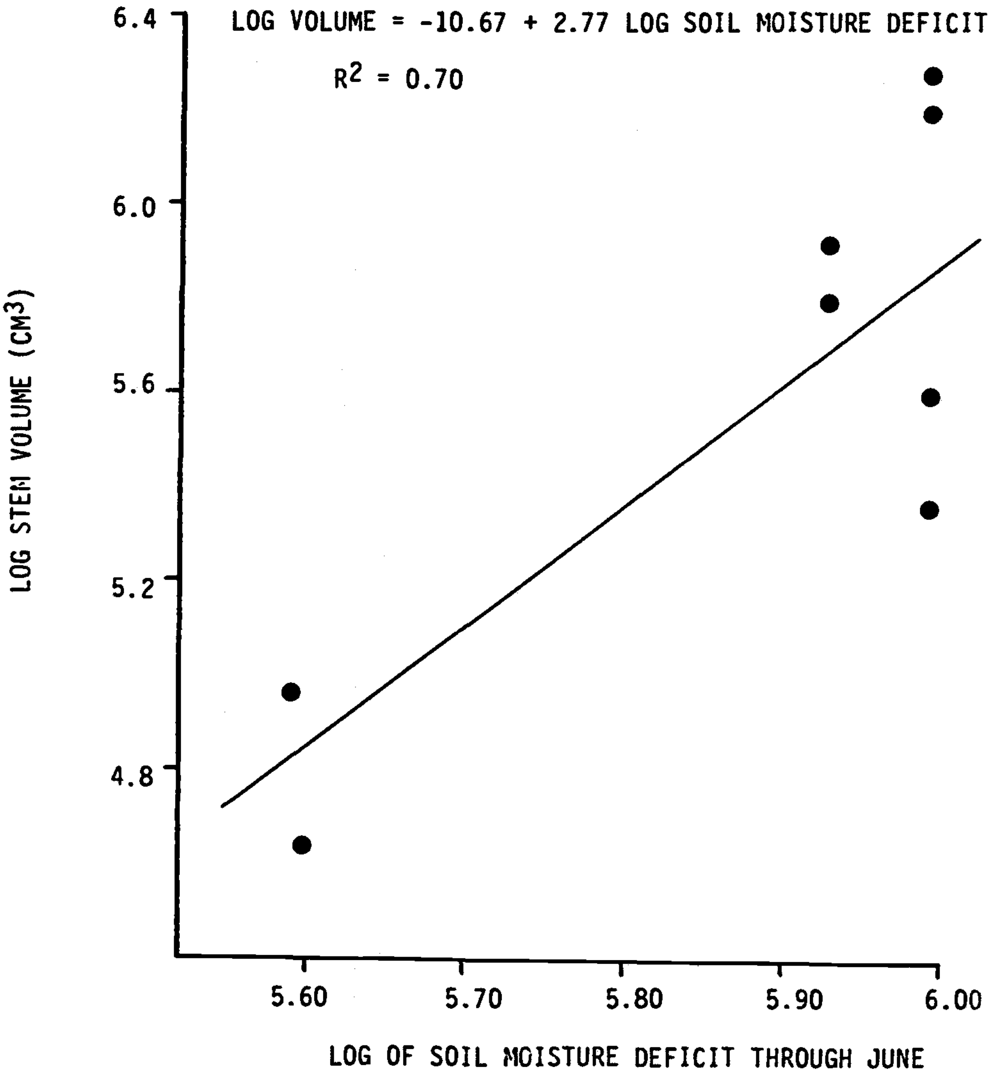


Figure 3-12. Fifth year stem volume of Douglas-fir as a function in variation of soil moisture deficit through July, 1983.

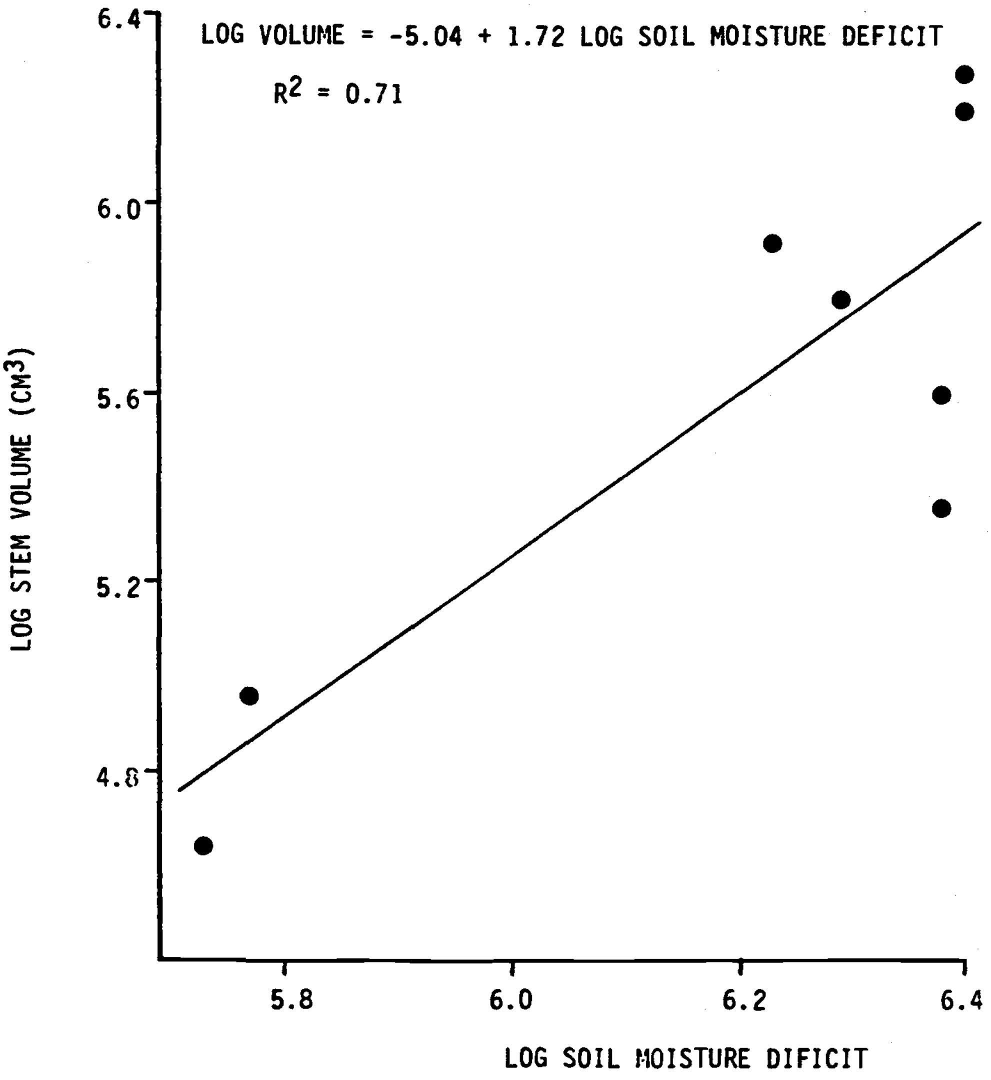


Figure 3-13. Fifth year stem volume of Douglas-fir as a function of variation in soil moisture deficit through August, 1983.

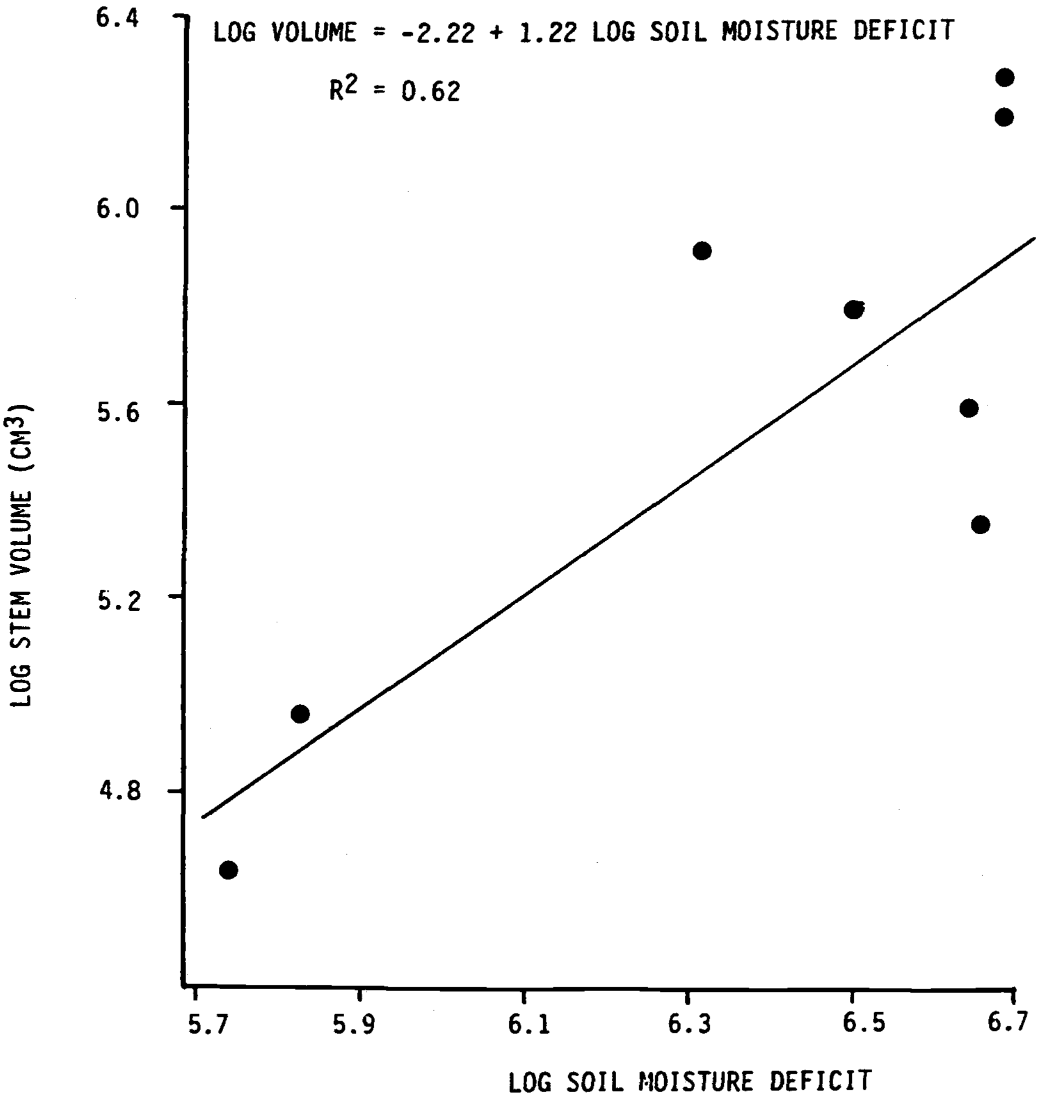


Figure 3-14. Fifth year stem volume of Douglas-fir as a function in variation of soil moisture deficit through September, 1983.

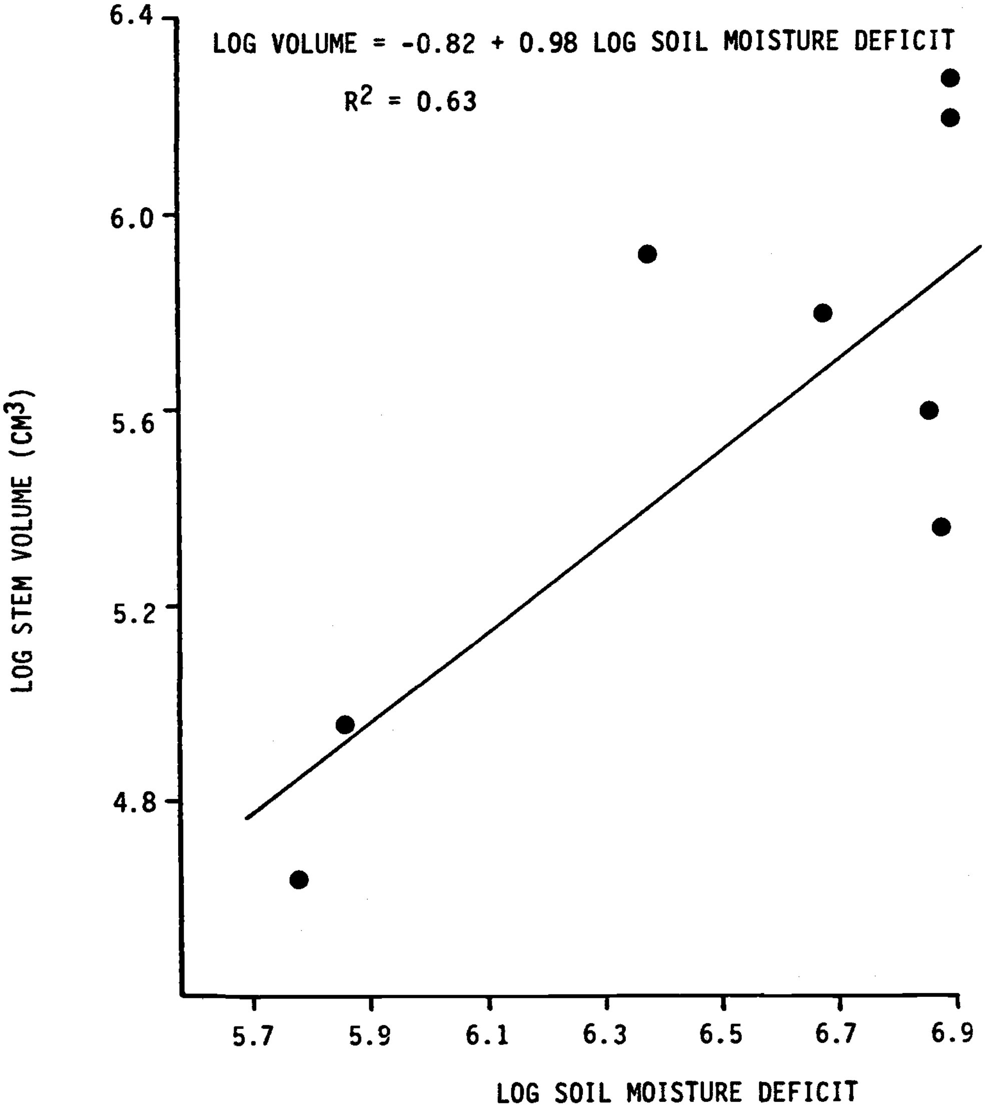


Figure 3-15. Fifth year stem volume of ponderosa pine as a function of variation in soil moisture deficit through June, 1983.

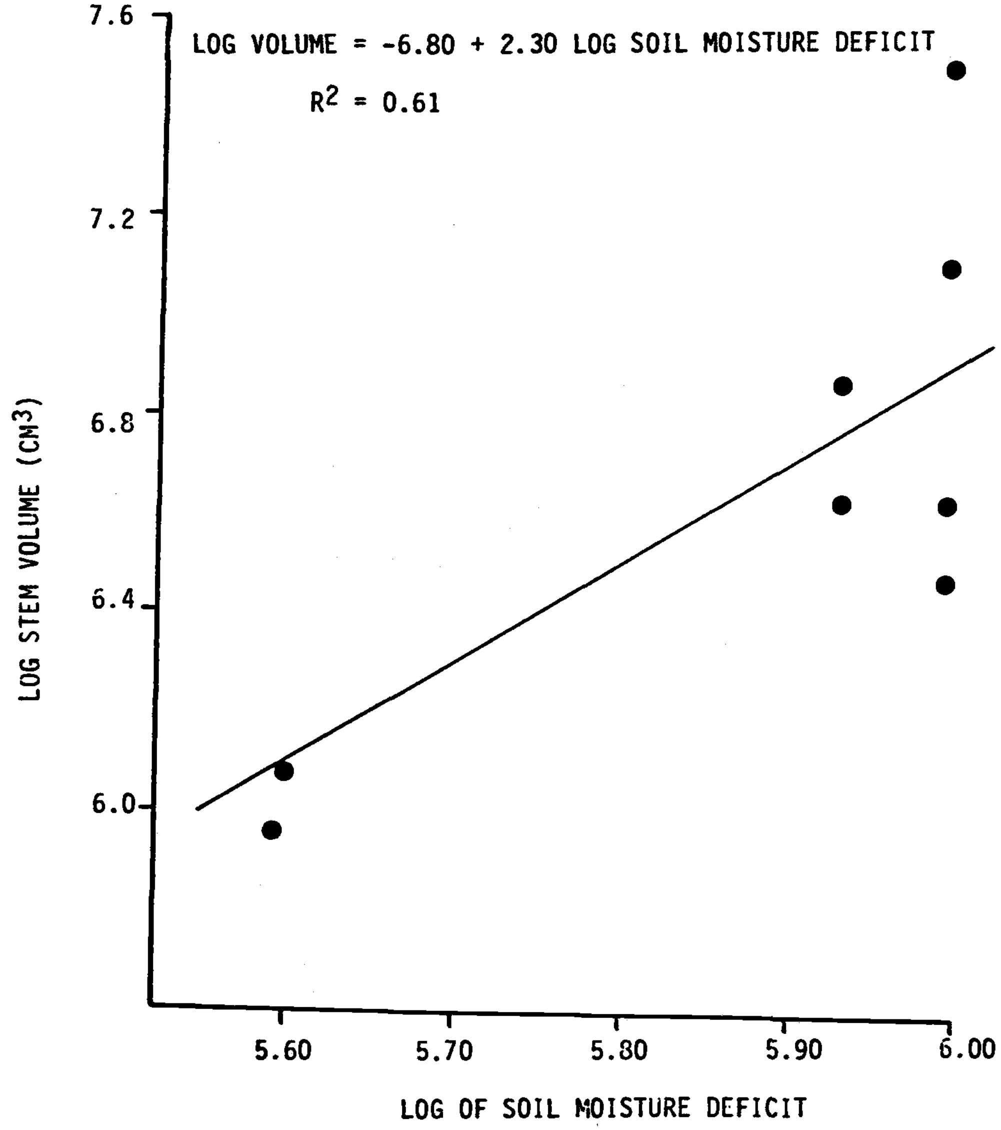


Figure 3-16. Fifth year stem volume of ponderosa pine as a function of variation in soil moisture deficit through July, 1983.

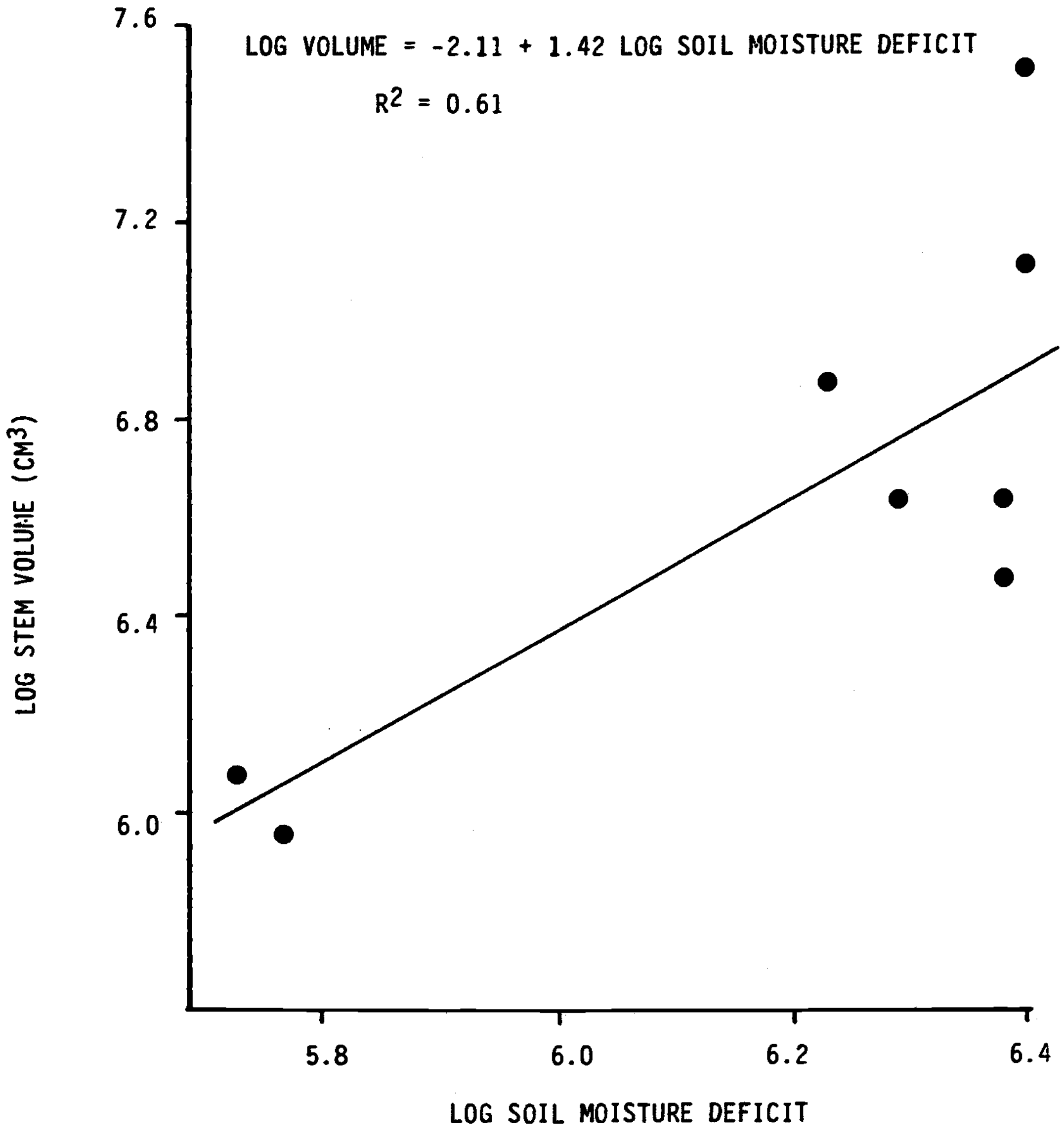


Figure 3-17. Fifth year stem volume of ponderosa pine as a function of variation in soil moisture deficit through August, 1983.

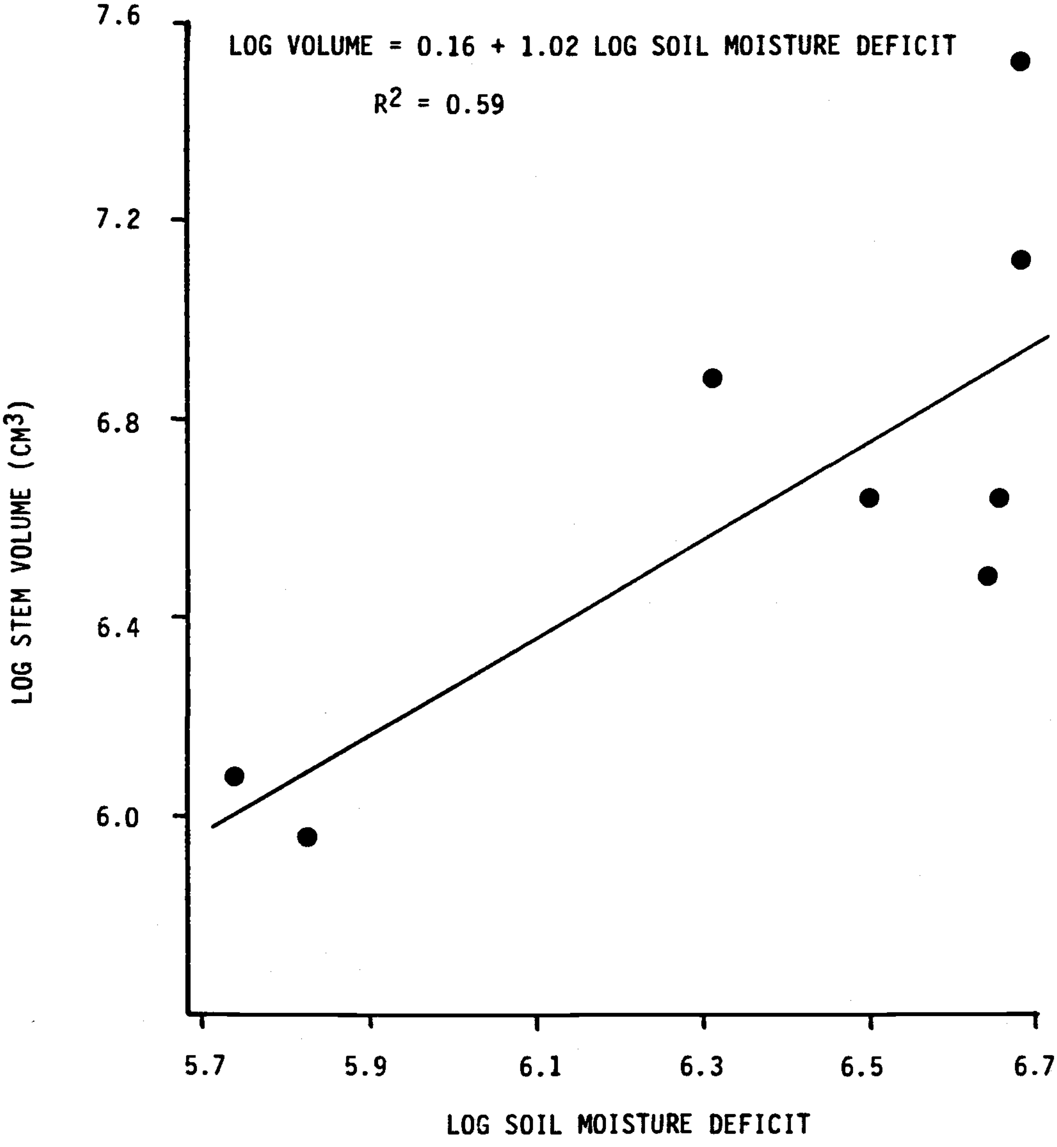


Figure 3-18. Fifth year stem volume of ponderosa pine as a function of variation in soil moisture deficit through September, 1983.

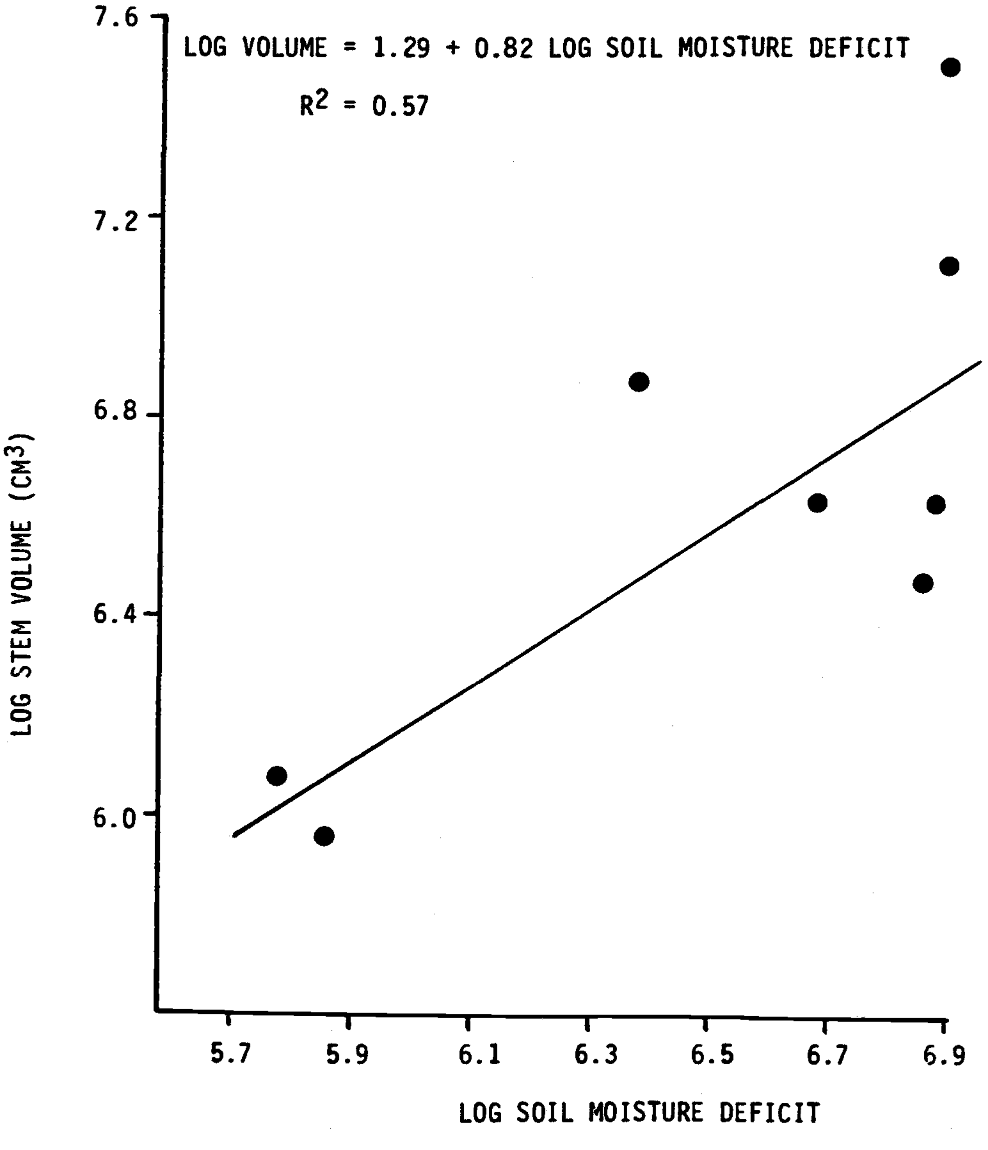


Figure 3-19. Fifth year stem volume of ponderosa pine as a function of variation in MSR induced in years 3 and 4.

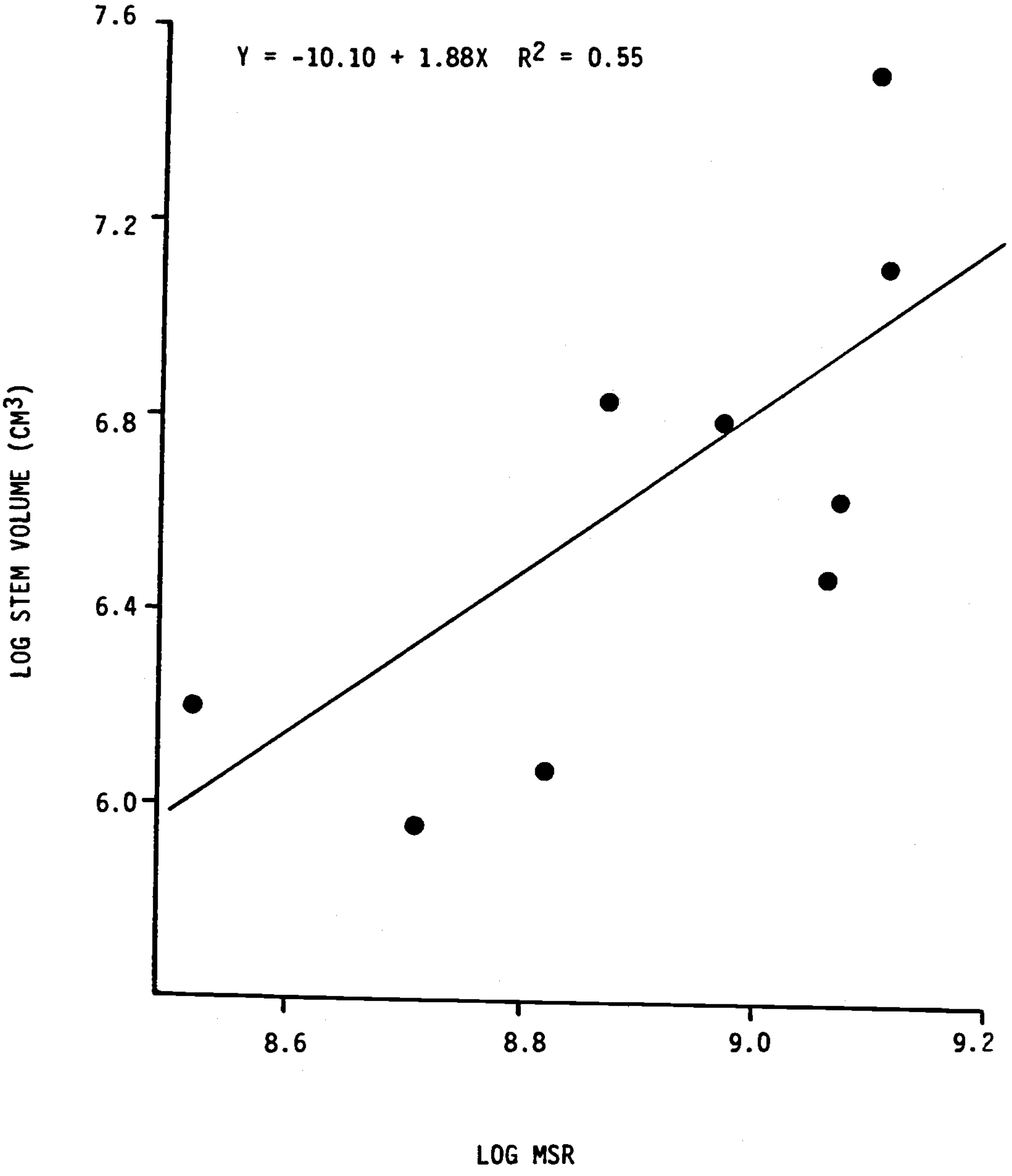
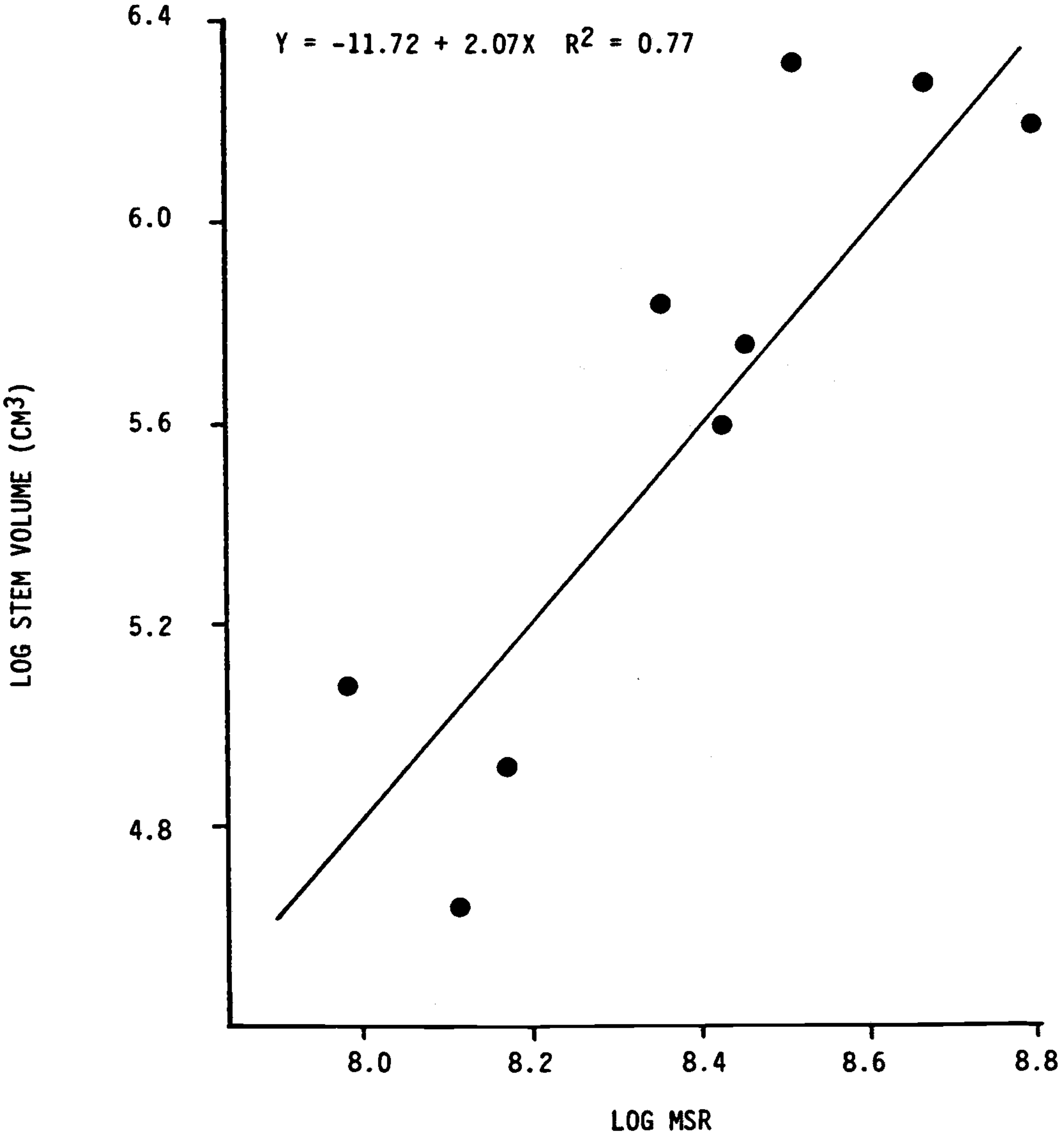


Figure 3-20. Fifth year stem volume of Douglas-fir as a function of variation in MSR induced in years 3 and 4.



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CONCLUSION

The growth of both conifers and shrubs, at the beginning of a new conifer plantation on interior foothill sites in southwest Oregon, can be determined by the density of whiteleaf manzanita seedlings and the presence of herbaceous vegetation.

Density based treatments demonstrate the spacing at which onset of intra-specific competition occurs in the manzanita at three years of age, and quantify the intensity of that competition through age 5. Individual shrub growth, whether measured as basal diameter, canopy volume, biomass, or leaf area, increased as density decreased. Growth was always slower when herbaceous plants were present. Diameter showed a linear increase through age 5 in all treatments. Canopy volume, biomass, and leaf area increased linearly under high levels of competition, and exponentially with little or no competition.

Soil moisture was correlated with increased growth of both conifers and shrubs. Growth of conifers at age 5 is best correlated with early season soil moisture depletion when moisture is measured at age 3, moisture at ages 4 or 5 is a poor predictor. The different soil moisture regimes produced by the treatments were reflected in plant xylem pressure potential (PXPP) values.

In 1983 and 1984, shrubs grown with herbs had lower midday PXPP than those grown with no herbs. The PXPP of shrubs growing at densities of 13500 and 27000 seedlings/ha was similar; however, the lower density treatment sometimes resulted in higher PXPP values. The clear separation between PXPP values of shrubs grown with and without herbs was correlated with differences in growth parameters of shrubs in these two treatments. This suggests that the levels of stress attained in this study were sufficient to inhibit individual shrub growth. Stomatal conductance was also significantly decreased in shrubs that were competing with herbs. This may have contributed to a reduction in photosynthesis which would result in the reduced individual shrub basal diameter that was measured.

The community parameters LAI, biomass, and stand basal area increased most rapidly at the highest densities. The highest densities had highest PXPP and also the lowest conductance values. In the absence of herbs, the most dense stands of shrubs were growing at an accelerated rate, suggesting that full site occupancy had not occurred by age 5.

Manzanita spacing treatments resulted in plots with different levels of manzanita density, biomass, leaf area index, and canopy cover, and these parameters were used as inter-specific indices of competition for Douglas-fir or ponderosa pine. Within the ranges observed in this study, conifers did not respond significantly to interspecific competition until five years of age, although a trend was started at age 4. At year 5, a significant trend showed decreasing stem volume as the levels of manzanita competitionincreased. The trend appeared linear in the range of 0 to 27000 seedlings per hectare. Conifers growing with manzanita and herbs had significantly smaller stem volumes compared with conifers growing with manzanita alone at the same density. Conifers that were free from herb competition in years three and four, but experienced reinvasion of herbs in year five, had reduced stem volumes compared with conifers that experienced no herb competition through the duration of the study.

Conifers responded to the changes in soil moisture created by different levels of competition. Those growing with lowest rates of early-season depletion had the largest stem volumes, while those growing with increasing densities of manzanita and associated accelerated water loss, had correspondingly smaller stem volumes. Conifers growing with manzanita and herbs had the greatest water depletion and smallest stem volumes. Soil moisture deficit through June or July was more highly correlated with stem volume than soil moisture deficit through the entire season (September). Plant xylem pressure potential values reflected the different levels of soil moisture, and these were supported by the stomatal conductance values. Xylem pressure potential became more negative and conductance decreased as competition increased.

Comparisons among the species suggest that ponderosa pine is best adapted to grow on interior foothill sites because it seems able to extract adequate soil moisture to maintain high PXPP values and also keep conductance relatively high. Manzanita is next best adapted. This species apparently does not have access to soil moisture equal to that of pine, as expressed by very low values of PXPP. The stomatal conductance values of manzanita remain high, however. This species seems adapted to make immediate use of any precipitation that might occur. Douglas-fir is probably the least well adapted, and exhibits lower PXPP values than pine. Apparently, it does not have equal access to deep zones of soil moisture. Conductance values are similar or slightly lower than that of pine.

From a management perspective, herbaceous plants are important competitors in the interior valleys of southwest Oregon. They are able to induce significant growth losses in conifers. Manzanita becomes more important as a competitor as the plantation approaches five years of age. Manzanita will reduce conifer growth in the first five years unless kept at levels of less than 20 percent canopy cover. Densities higher than those studied here may reduce conifer growth at an earlier age, and trends observed in lower densities may cause losses later.

The choice of conifer species is also important. Douglas-fir does well for at least five years if competition can be kept to a minimum. If this is not practicable, ponderosa pine will be more successful on the site.

Overall, reforestation of the hot, dry, interior foothill region of southwest Oregon can be accomplished. Conifer species selection is important, as is the recognition that water resources are limited and even small amounts of competition can result in significant conifer growth losses.

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APPENDICES

APPENDIX A

Chapter 1 Statistical Analyses

Table A-1 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita seedling basal diameter in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	28.72	5.27	.02
Treatment	6	11.23	2.06	.14
1984				
Unit	2	49.11	7.00	.01
Treatment	6	32.95	4.70	.01
1985				
Unit	2	87.99	6.50	.01
Treatment	6	69.07	5.10	.01

Table A-2 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita seedling canopy volume in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	$9.7\mathrm{x}10^{8}$	6.43	.01
Treatment	6	$3.3\mathrm{x}10^{8}$	2.17	.12
1984				
Unit	2	$9.0\mathrm{x}10^{9}$	7.40	.01
Treatment	6	$4.8\mathrm{x}10^{9}$	3.90	.02
1985				
Unit	2	$5.0\mathrm{x}10^{10}$	9.25	.00
Treatment	6	$2.8\mathrm{x}10^{10}$	5.16	.01

Table A-3 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita seedling leaf area in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	1.6×10^{6}	5.00	.03
Treatment	6	7.0×10^{6}	2.17	.12
1984				
Unit	2	6.3×10^{6}	6.61	.01
Treatment	6	4.0×10^{6}	4.23	.02
1985				
Unit	2	1.9×10^{7}	5.85	.02
Treatment	6	1.4×10^{7}	4.29	.02

Table A-4 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita seedling biomass in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	6.4×10^{6}	4.84	.03
Treatment	6	2.9×10^{6}	2.21	.11
1984				
Unit	2	3.7×10^{7}	6.36	.01
Treatment	6	2.3×10^{7}	4.04	.02
1985				
Unit	2	1.4×10^{8}	5.54	.02
Treatment	6	1.0×10^{8}	3.98	.02

Table A-5 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita leaf area index in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	2.8×10^{-3}	1.83	.20
Treatment	6	14.6×10^{-3}	9.37	.00
1984				
Unit	2	1.8×10^{-2}	3.08	.08
Treatment	6	9.8×10^{-2}	16.31	.00
1985				
Unit	2	5.4×10^{-2}	2.17	.16
Treatment	6	2.9×10^{-2}	11.79	.00

Table A-6 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita community biomass in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	2.8×10^{11}	1.84	.20
Treatment	6	9.3×10^{11}	6.13	.00
1984				
Unit	2	2.5×10^{12}	3.11	.08
Treatment	6	8.8×10^{12}	11.04	.00
1985				
Unit	2	8.7×10^{12}	2.14	.16
Treatment	6	31.7×10^{12}	7.81	.00

Table A-7 Values from ANOVA tables, 1983, 1984, and 1985, analysis on manzanita community basal area in relation to treatment.

Source of variation	df	MS	F value	P
1983				
Unit	2	5.8×10^{8}	1.83	.20
Treatment	6	29.6×10^{8}	9.37	.00
1984				
Unit	2	3.7×10^{9}	3.08	.08
Treatment	6	19.8×10^{9}	16.31	.00
1985				
Unit	2	1.1×10^{10}	2.17	.16
Treatment	6	5.9×10^{10}	11.79	.00

APPENDIX B

Chapter 2 Statistical Analyses

Table B-1. Predawn plant xylem pressure potential means of units (-MPa)

	Treatment			
	OC	27000C	13500C	13500CH
1983 June				
Douglas-fir	.36	.44	.43	.72
Pine	.25	.30	.23	.24
Manzanita		.49	.42	.67
July				
Douglas-fir	.69	.75	.75	1.14
Pine	.52	.58	.46	.78
Manzanita		.66	.67	.85
August				
Douglas-fir	.80	1.26	.94	1.46
Pine	.61	.75	.69	1.18
Manzanita		1.03	1.03	1.29
September				
Douglas-fir	.79	.98	.83	.91
Pine	.58	.55	.65	.62
Manzanita		.55	.58	.58
1984 June				
Douglas-fir	.59	.81	.73	.90
Pine	.37	.34	.40	.62
Manzanita		.64	.57	.58
July				
Douglas-fir	1.15	1.49	1.28	1.60
Pine	.66	.70	.65	.93
Manzanita		1.41	.123	1.48
August				
Douglas-fir	1.10	1.48	1.33	1.78
Pine	.81	.89	.72	1.05
Manzanita		1.68	1.05	1.71
September				
Douglas-fir	1.07	1.73	1.35	1.64
Pine	.74	.87	.84	1.24
Manzanita		1.78	1.62	1.95
1985 June				
Douglas-fir	.63	.88	.80	1.07
Pine	.55	.56	.53	.63
Manzanita		.81	.73	.72

Table B-1 Continued

	Treatment			
July				
Douglas-fir	1.14	2.02	1.61	1.68
Pine	.89	1.10	.93	1.33
Manzanita		2.98	2.21	2.46
August				
Douglas-fir	1.48	2.75	1.95	2.09
Pine	1.12	1.31	.99	1.21
Manzanita		4.06	3.17	2.24
September				
Douglas-fir	1.34	2.48	2.03	2.14
Pine	1.18	1.17	1.00	1.24
Manzanita		2.99	3.01	2.31

Table B-2. Midday plant xylem pressure potential (-MPa) Means of units

	Treatment			
	OC	27000C	13500C	13500CH
1983 June				
Douglas-fir	1.47	1.55	1.48	1.70
Pine	.56	.35	.54	.53
Manzanita		1.69	1.66	2.02
July				
Douglas-fir	1.62	1.72	1.69	1.97
Pine	1.50	1.51	1.43	1.76
Manzanita		2.16	1.99	2.61
August				
Douglas-fir	1.67	2.06	2.10	2.32
Pine	1.28	1.53	1.51	1.91
Manzanita		2.16	1.99	2.61
September				
Douglas-fir	1.99	2.24	2.14	2.55
Pine	.91	1.75	1.93	2.18
Manzanita		2.02	2.50	2.65
1984 June				
Douglas-fir	1.46	1.68	1.48	1.48
Pine	.91	1.01	.76	1.02
Manzanita		2.06	1.21	1.49
July				
Douglas-fir	1.98	2.32	2.20	2.58
Pine	1.62	1.77	1.89	1.83
Manzanita		3.07	3.07	3.37
August				
Douglas-fir	2.07	2.72	2.70	2.85
Pine	1.69	1.73	1.71	2.13
Manzanita		3.81	3.48	3.62
September				
Douglas-fir	2.28	2.63	2.48	2.87
Pine	1.68	1.85	1.85	2.07
Manzanita		3.21	3.46	3.83
1985 June				
Douglas-fir	1.67	1.81	1.81	1.92
Pine	1.53	1.67	1.61	1.73
Manzanita		2.43	2.38	2.45

Table B-2 Continued

	Treatment			
	0C	27000C	13500C	13500CH
July				
Douglas-fir	2.01	2.73	2.36	2.46
Pine	1.78	1.91	1.86	1.20
Manzanita		4.89	4.37	4.15
August				
Douglas-fir	2.46	3.38	2.83	2.80
Pine	1.97	1.93	1.88	1.89
Manzanita		5.39	4.58	3.74
September				
Douglas-fir	2.54	3.03	2.80	2.85
Pine	1.97	1.97	2.07	2.18
Manzanita		4.40	3.98	3.39

Table B-3. Values from ANOVA table for soil moisture depletion

Source of variation by season	df	MSE	F	p
Early season				
Unit	2	615.56	14.52	.005
Treatment	2	840.78	10.24	.027
Unit*Treatment	4	82.10	1.94	.224
Year	1	1605.56	37.88	.001
Treatment*Year	2	744.50	17.56	.003
Late season				
Unit	2	88.49	0.78	.480
Treatment	2	1918.04	6.19	.060
Unit*Treatment	4	310.10	2.74	.079
Year	2	1064.09	9.39	.004
Treatment*Year	4	529.29	4.67	.017

Table B-4. Values from ANOVA table for predawn and midday plant xylem pressure potential

		All species predawn		
Source of Variation	df	MSE	F	p
Block	2	79.11	2.18	.085
Treatment	1	172.63	6.95	.025
Species	2	711.18	28.63	.000
Treatment*species	2	23.75	.96	.417
Block*treatment*species	10	24.75	2.19	.022
Year	2	1244.91	109.99	.000
Month (year)	9	316.37	27.95	.000
Year*species	4	151.50	13.38	.000
Year*treatment	2	39.01	3.45	.035
Year*treatment*species	4	20.14	1.78	.137
Month (year)*species	18	30.52	2.70	.001
Month (year)* treatment	9	14.19	1.25	.269
Month (year)* treatment*species	18	6.51	.57	.912

Table B-4 Continued

All species, midday			Conifers, predawn				Conifers, midday		
MSE	F	P	df	MSE	F	P	MSE	F	P
10.81	.28	.762	2	7.76	.84	.461	18.88	2.48	.133
152.68	3.95	.075	2	243.81	26.29	.000	217.26	28.55	.000
2889.83	74.84	.000	1	918.02	99.00	.000	1556.87	204.55	.000
1.91	.05	.952	2	41.01	4.42	.042	15.47	2.03	.182
38.62	3.77	.000	10	9.27	2.26	.018	7.61	2.53	.008
1049.25	102.49	.000	2	522.66	127.14	.000	423.74	140.74	.000
550.72	53.80	.000	9	158.28	38.50	.000	307.99	102.44	.000
170.04	16.61	.000	2	37.10	9.03	.000	6.57	2.18	.117
86.82	8.48	.000	4	3.73	.91	.462	7.15	2.38	.055
27.84	2.72	.032	4	8.86	2.16	.077	1.80	.60	.663
62.06	6.06	.000	9	9.66	2.35	.017	31.30	10.41	.000
8.00	.78	.634	18	5.10	1.24	.238	6.96	2.31	.004
6.04	.59	.902	18	2.36	.57	.913	3.39	1.13	.333

Table B-5. Mean seasonal predawn and midday plant water potential (-MPA) of whiteleaf manzanita, ponderosa pine and Douglas-fir averaged over treatments.

All species, treatments
Manzanita, manzanita+ herbs

Predawn

Year	Species	Month June	July	August	September
1983	Manzanita	.55	.76	1.16	.58
	Pine	.24	.62	.93	.64
	Douglas-fir	.57	.95	1.20	.87
1984	Manzanita	.57	1.35	1.38	1.78
	Pine	.46	.84	.88	1.04
	Douglas-fir	.81	1.44	1.55	1.50
1985	Manzanita	.73	2.34	2.07	2.66
	Pine	.58	1.13	1.10	1.12
	Douglas-fir	.93	1.64	2.02	2.09

Tukey HSD .05=0.75

Midday

1983	Manzanita	1.84	2.33	2.30	2.57
	Pine	.53	1.59	1.71	2.05
	Douglas-fir	1.59	1.83	2.21	2.35
1984	Manzanita	1.35	3.22	3.55	3.65
	Pine	.89	1.86	1.92	1.96
	Douglas-fir	1.48	2.39	2.78	2.67
1985	Manzanita	2.41	4.26	4.16	3.69
	Pine	1.67	1.93	1.89	2.13
	Douglas-fir	1.87	2.41	2.82	2.83

Tukeys HSD .05=0.71

Conifers only, treatments =
no manzanita, manzanita,
manzanita + herbs

Table B-5 Continued

Predawn

		Month			
Year	Species	June	July	August	September
1983	Pine	.24	.59	.83	.62
	Douglas-fir	.50	.86	1.07	.85
1984	Pine	.43	.78	.86	.94
	Douglas-fir	.74	1.34	1.40	1.35
1985	Pine	.57	1.05	1.11	1.14
	Douglas-fir	.83	1.47	1.84	1.84

Tukeys HSD .05=0.38

Midday

1983	Pine	.54	1.56	1.57	1.89
	Douglas-fir	1.55	1.76	2.03	2.23
1984	Pine	.89	1.78	1.84	1.86
	Douglas-fir	1.47	2.25	2.54	2.54
1985	Pine	1.62	1.88	1.92	2.07
	Douglas-fir	1.80	2.28	2.70	2.73

Tukeys HSD .05=0.45

Table B-6 Values from ANOVA table of conductance

		All species		
Source of Variation	df	MSE	F	p
Unit	1	.0137	16.35	.001
Treatment	1	.0143	20.47	.000
Time	1	.0435	62.18	.000
Species	2	.0186	26.54	.000
Time*treatment	1	.0002	.24	.637
Species*treatment	2	.0003	.38	.692
Species*time	2	.0008	1.17	.345
Species*time*treatment	2	.0001	.09	.913
Unit*species*time* treatment	11	.0007	.83	.610
Month	2	.0732	87.41	.000
Month*treatment	2	.0069	8.18	.002
Month*time	2	.0005	.64	.578
Month*species	4	.0100	11.97	.000
Month*time*treatment	2	.0002	.21	.810
Month*species*treatment	4	.0005	.54	.706
Month*species*time	4	.0005	.58	.677
Month*species*time* treatment	4	.0001	.07	.991

Table B-6. Continued

Conifers only

df	MSE	F	p
1	.0025	1.16	.310
2	.0089	4.18	.045
1	.0581	27.33	.000
1	.0098	4.63	.055
2	.0008	.36	.708
2	.0004	.19	.829
1	.0008	.28	.549
2	.0004	.21	.814
11	.0021	2.62	.023
2	.0339	41.82	.000
4	.0017	2.04	.121
2	.000	.01	.988
2	.0015	1.86	.177
4	.0002	.19	.940
4.	.0005	.62	.656
2	.0010	1.19	.321
4	.0000	.06	.993

APPENDIX C

Chapter 3 Statistical Analyses

Table C-1 Values from ANOVA table for comparison of hoed and unhoed conifer stem volume in 1985, using 1984 stem volume as a covariate.

Source of Variation	df	MSE	F	P
Douglas-fir				
Unit	2	227704.5	34.69	.000
Treatment	5	103237.4	15.73	.000
Hoeing	1	360225.3	54.88	.000
Treatment * Hoeing	5	25254.0	3.85	.013
Volume 1984	1	531861.6	81.02	.000
Ponderosa pine				
Unit	2	41672.1	2.57	.100
Treatment	5	573885.3	35.41	.000
Hoeing	1	1217126.5	75.10	.000
Treatment * Hoeing	5	48465.2	2.99	.034
Volume 1984	1	1863022.9	114.95	.000