AN ABSTRACT OF THE THESIS OF

Lorraine E. Flint for the degree of Master of Science in Soil Science presented on August 29, 1985.

Title: Effects of Soil Surface Shading, Mulching, and Vegetation Control on Douglas-fir Seedling Growth and Microsite Water Partitioning.

Redacted for Privacy

Abstract approved: ______________________

Dr. Stuart W. Childs

A two year study with 500 seedlings was conducted in the harsh, drought prone southwest Oregon environment to assess the effects of 12 soil surface shading, mulching and vegetation control techniques on soil temperature and moisture environments and seedling growth. Treatments modified, to various degrees, soil surface temperatures, reduced soil surface evaporation and reduced vegetative competition for water in the seedling root zone.

These modified conditions affected seedlings by reducing soil water loss to increase water available for seedling use and adjusting the timing of seedling growth. Seedlings in treatments where competing vegetation was removed had significantly larger final

shoot volumes and stem diameters. Soil water loss was significantly less in treatments where soil surface evaporation was controlled by mulching or controlling competing vegetation. Shaded and control treatments used the most water over the season. Soil water loss in treatments with vegetation controlled by herbicide was significantly less than those with vegetation control by scalping which disturbs the soil surface by removing the loose soil and duff layer. Therefore, seedlings grew the most with treatments that elicited the most efficient use of available microsite water either by reducing soil surface evaporation or vegetative competition.

Transpiration data supported these conclusions by showing more than twice the water was transpired by competing vegetative species per unit leaf area than by seedlings. In addition, estimates of percent cover by seedlings and all vegetative species occupying the site showed competing vegetation to cover 78.6% of the site compared to 2.4% cover by the seedlings. This illustrates the degree of competition the vegetation gives to the seedling over the whole site even in an environment where water is a limiting resource.

Effects of Soil Surface Shading, Mulching and Vegetation Control on Douglas-fir Seedling Growth and Microsite Water Partitioning

by

Lorraine E. Flint

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed August 29, 1985

Commencement June 1986

APPROVED:

Redacted for Privacy

Professor of Soil Science in charge of major

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Date thesis is presented August 29,1985

ACKNOWLEDGEMENTS

I would initially like to acknowledge Forestry Intensified Research and assisting agencies without whose insight this project would never have been funded. I would also like to thank Stuart Childs for his undying enthusiasm, and for his tolerance and patience with me.

Most of my gratitude goes to Alan, who has supported me mentally, emotionally and spiritually throughout my educational career. I thank him for his love and devotion, his patience, his editing and for many long hours of computer assistance.

Thanks go to Craig for being quiet in the office when told to be, yet ready to talk whenever he was needed. I thank Theresa for much support in the field. Michael, thanks for the good culinary diversions. And thanks to Becky and Joyce just for being good friends.

Thanks go to my mother and my big brothers, Robert and Richard for so much initial and continual encouragement. And my three sets of parents are wonderful for their love, and of course, financial support.

Megan and Melissa deserve many hugs for their tolerance. Honest, it will all be worth it someday.

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INTRODUCTION

Douglas-fir seedling regeneration in southwest Oregon has been limited by harsh environmental conditions (Franklin and Dyrness, 1973). There are 700,000 acres, about 12%, of publicly owned commercial forest land in southwest Oregon identified by land managers as having regeneration problems (Hobbs et al., 1983). Reforestation problems due to limited water supply are usually encountered in shallow, skeletal soils on steep slopes with southerly aspects. Approximately 60% of the forest soils in this area are classified as skeletal, with greater than 35% of the soil volume being rock fragments bigger than 2 mm (Wert et al., 1977). These soils have low water-holding capacities. In addition, the Mediterranean climate of the area (xeric soil temperature regime) causes seedlings to experience long hot, dry periods during the growing season. Regeneration failures have been reduced in southwest Oregon with an increased awareness of improved stock quality and proper handling of seedlings (Duryea and Landis, 1984). However, particularly harsh sites require a careful evaluation of the environmental resources and special management techniques in order to prescribe an appropriate regeneration system which is more critical in this location. This thesis provides information regarding the effects of management techniques aimed at ameliorating harsh environmental conditions and increasing seedling growth and water use efficiency by modifying soil temperature and soil moisture depletion.

Soil moisture depletion is due to evaporation from the soil surface, vegetative competition for water in the seedling root zone and seedling water use. Because of the limited water resource and xeric conditions, remaining components of the water balance, drainage and subsurface flow, are not generally of much importance during the growing season. High temperatures also affect soil moisture depletion. They increase the leaf to air vapor gradient (Kramer, 1983), which increases seedling water use, thereby increasing soil water depletion. In this way, low water contents, high temperatures and high vapor pressure deficits all interact to increase plant moisture stress (Kramer, 1983; Cleary, et al., 1978).

The mechanism by which low soil water contents adversely affect seedlings is related to the role of water in the processes of photosynthesis and transpiration. Water is a component of the photosynthetic reaction and transports nutrients necessary to photosynthesis and other metabolic processes. Water also maintains plant turgor. In addition, stomatal resistance increases and transpiration decreases as soil water potential and soil water availability decrease (Tan et al., 1977; Zavitkovsky and Ferrell, 1970). As resistance to flow of both water vapor and CO_2 increases, or as soil water content is decreased, the photosynthetic process is slowed, CO_2 assimilation is reduced, and plant growth and productivity are decreased (Larson, 1974; Sinclair, et al., 1984; Osmond, et al., 1980).

High soil temperatures may have a direct effect on seedling growth and survival in addition to their effect on soil moisture depletion. Conifer seedlings can tolerate soil temperatures up to 54°C but higher soil temperatures can damage seedling tissue and impede vascular transport (Silen, 1960). Temperatures up to 76°C are common on south-facing slopes in southwest Oregon and maximum soil surface temperatures of 86°C have been recorded (Hallin, 1968). These conditions can be alleviated by limiting the solar radiation load to the soil surface around seedlings. This not only reduces soil surface temperatures but also helps to maintain water in the soil by reducing evaporation rates (Papendick et al., 1973), and vapor flow, which is strongly temperature dependent (Hammel, et al., 1978). Maintaining water in the soil is important not only for plant use but also for reduction of soil temperatures. Water increases soil thermal conductivity, and this, along with the high specific heat of water, makes the soil a more effective heat sink. Temperatures in the seedling root zone are therefore reduced with an increase in soil water content (de Vries, 1975).

All available soil water in the seedling root zone is used up by the end of the season in most years (Youngberg, 1957; Childs and Flint, 1984) and often as early as late June (Newton, 1964). Considering the finite amount of water available on a site and particularly within a seedling microsite, water allocated to the seedling for transpiration and biomass production must be maximized. Under these conditions, the soil water supply for seedling use can be effectively increased by reducing vegetative competition for water in the root zone and by either limiting radiation input or mulching to reduce soil surface evaporation. Many methods for treating the soil surface or modifying the seedling microclimate to conserve moisture or ameliorate high temperatures have been tried with variable results (Hermann, 1964b; Takatori, et al., 1964; Hunt, 1968; Ryker and Potter, 1970; Cleary, et al., 1978; Helgerson, et al., 1982; Hobbs, 1982; Tonn and Graham, 1982; Peterson, 1982). One common technique is to use shadecards to reduce radiation input to the soil surface. Though not significantly reducing average soil temperatures, shadecards do reduce maximum soil temperatures and soil heat flux (Childs et al., 1985).

Mulching is another treatment which has been shown to increase seedling survival by reducing water loss due to surface evaporation and competing vegetation (Hermann, 1964a, 1965). A black plastic mulch was shown by Smith et al.(1968) and Takatori et al.(1964) to lower temperature extremes. Waggoner et al.(1960) suggest that black plastic mulch absorbs most of the incoming radiant energy but transmits little of it to the soil due to the insulating effect of the still air layer between the mulch and the soil. This principle applies to mulch treatments on a site with an uneven surface duff layer which probably increases the still air layer even more. The heating of the mulch itself does not cause heating of the seedling stem if the mulch is not in contact with the seedling. The effect of mulches as radiation barriers causes the average temperature to be lowered only slightly or not at all but reduces temperature extremes, whether short or long term.

Techniques designed only for vegetation control have resulted in dramatic increases in seedling growth and survival (Newton, 1964; Passof, 1978) and have reduced seedling water stress (Sands and Nambiar, 1983). One such method is scalping the soil surface free of vegetation. However, this method also removes the loose surface or duff layer of the soil and increases evaporative water loss (Hammel et al., 1981). An alternate technique is herbicide application which kills vegetation in place and maintains the soil surface layer.

Several studies have been conducted in the harsh environment of southwest Oregon. Causes of poor regeneration were shown to be high soil temperatures and rapid soil moisture depletion during the growing season. Several methods (shading, mulching and vegetation control) have been used operationally to alleviate some of the problems although no literature shows comparisons of all these treatments in the same study under identical experimental conditions. In addition, there has been little documentation of intensive measurements of soil water loss with depth beneath seedlings. For these reasons, the main purpose of this study was to assess the effects of various operational and experimental soil surface shading and mulching treatments and two vegetation control techniques on soil temperature, soil water, and growth and water use of Douglas-fir seedlings.

METHODS

This study was conducted near Wolf Creek, Oregon (latitude 42°43'N, longitude 123°17'W, 715 m elevation) northeast of Grants Pass. The site is a steep (30 percent), south-facing (190 degrees) slope, that had been clearcut and burned during the previous winter. The soil is a moderately deep, loamy-skeletal, mixed, mesic Typic Xerochrept. Average soil depth is 660 mm ranging between 480-685 mm. Total water available in the seedling root zone, 0-250 mm, averages 40.6 mm of water or 16 percent. Vegetation that grew during the two years following harvest included Arbutus menziesii, 66% of total vegetative cover after two years; Ceanothus sanguineus, 12%; Holodiscus discolor, 4%; Penstemon sp., 3%; Rubus ursinus, 3%; and Rhus diversiloba, 1%. (For a more complete list of plant species present on the site, see Table 4).

Five hundred 2-0, bareroot, Douglas-fir seedlings were selected for uniformity and planted in a completely randomized experimental design in March of 1982. Means at planting time of seedling height, diameter at root collar, shoot volume, root volume and shoot/root ratio were 267 mm, 5 mm, 14,250 mm^3, 10,000 mm^3 and 1.4 respectively. After two growing seasons, all seedlings were harvested in September 1983 for final growth measurements.

Treatments

I developed hypotheses concerning the effects of current operational soil surface treatments on the soil environment. These hypotheses lead to variations of these treatments to correct particular problems in the study area. Treatments used in the study and hypotheses concerning their effects on soil temperature and water and plant responses are shown in Table 1. Twelve treatments were used as protection from high soil temperatures or rapid soil water loss. Treatment design was chosen primarily to be in keeping with current operational techniques. In addition, a group of untreated seedling locations was used as an experimental control, and soil temperature and moisture measurements were made on additional sites with no seedlings. Treatments were randomly applied over the entire site with 24 to 27 replicates per treatment.

After the first year several treatments were chosen to be excluded as individual treatments. An aluminum foil mulch and a no site preparation treatment were included as additional control treatments. The aluminum foil was in very poor condition by the end of the first season. The no site preparation treatment

Table 1: Treatments and expected responses: soil temperature, soil water, and seedling growth.

Treatment[1]	Seedling[2] growth	Shoot: root	Bud burst	Bud set	Seasonal seedling transpir.	Avail. soil water	Soil surface evap.	Soil temp.	Soil temp. fluctuation	Comp.[3] veg.
Shadecards (5 orientations)	+						–	–	–	++
Mulches:										
Black plastic	+	–	earlier	later	+	+	–	+	+	+
White plastic	+			later	+	+	–	–	–	+
Paper mulch	+			later	+	+	–	–	–	+
Stem shade:										
Styrofoam cup										++
Pyramid	+				+	+	–	–	–	++
Scalp	+	–	earlier		+	+	+	+	+	none
Herbicide	+			later	+	+	–	+	+	none
Control										++

1 Treatments explained in materials section.
2 All responses relative to control treatment. Blanks show no expected effect due to treatment.
3 ++ indicates much competing vegetation, + indicates some competing vegetation.

was initially to be different from the control, as the control used a current Forest Service planting technique of providing a small shelf on which to plant the seedling. Shortly into the season, however, there was no apparent difference between the treatments, probably due to site disturbances and ravel and they were combined for future analysis. Another treatment using surface duff and loose soil mounded up around the base of the seedling was originally planned. However, the result of this procedure was not different from the scalp treatment so the data from each were combined. Similarly, a treatment using a paper collar instead of a styrofoam cup was combined with the styrofoam cup group.

Shadecards: A conventional 200 mm X 300 mm shadecard was staked into the ground next to each seedling. Shadecards were placed in five directional orientations around seedlings: W, SW, S, SE, and E.

Mulches: 760 mm X 760 mm sheets of black plastic, white plastic and cardboard paper mulch were placed around seedlings.

Stem shade: A 240 mL styrofoam cup with the bottom cut out was inverted and placed around the stem of the seedling at the soil surface. Another form of stem shade was a three-sided cardboard pyramid with a 350 mm x 350 mm base and 70 mm x 70 mm hole in the top placed around the seedling with the open side facing north. These treatments were expected to protect against lethal tissue damage from possible high soil surface temperatures.

Scalp: The soil surface layer and any accompanying vegetation were scraped away in a 1.2 m x 1.2 m square around the seedling and maintained vegètation-free throughout the growing season. This removed vegetative competition while increasing surface evaporation. As the soil volume under consideration for use by the Douglas-fir rooting system is a cylinder of soil 300 mm in diameter by an average of 600 mm in depth, its water status is unlikely to be influenced by roots of surrounding vegetation.

Herbicide: A mixture of 20 g Atrazine and 30 g 2,4-D per kg water was used to spray a 3.3 m x 3.3 m area around the seedling. Standard techniques in herbicide application usually involve spraying an entire site, so a larger surface area was treated with herbicide than was scalped to simulate standard techniques. One application in the spring of the second season maintained the soil free of vegetation throughout the season. This treatment eliminated vegetative competition while leaving the soil surface and any dead vegetation intact.

Seedling Growth Measurements

In situ height and diameter measurements were made on all seedlings. Other measurements were made to examine treatment responses in more detail.

1. Initial, first year, second year and final height were measured.

2. Initial and first year total (outside) diameter were measured with calipers at the root collar. At the end of the experiment, I cut all the seedlings at the root collar and measured both the outside diameter and the diameter inside the bark. I also measured first and second year radial growth.

3. Initial and final root and shoot volumes, (final root volumes done on a 45 tree subset), were determined using water displacement.

4. First and second year needle lengths and final budsize were measured. Yearly occurrence of browse was noted. In addition, periodic observations were made of survival, budburst and budset of seedlings.

Soil Temperature

Site visits were made approximately every two weeks from early May to mid September. Soil surface temperatures were measured at hourly intervals for two to three days every visit with an infra-red soil thermometer (Model Raynger II, Raytek, Inc., Santa Cruz, CA). Soil temperature profiles were measured with thermistor probes at 20, 40, 80, 160, and 320 mm depths below the soil surface beneath the seedlings. Temperatures were monitored every 15 minutes on data loggers (Model CR5 Digital Recorder, Campbell Scientific, Inc., Logan, Utah) for 2-3 days every site visit. Measurements were made beneath 18 seedlings on control, herbicide spray, mulch, shadecard and pyramid treatments.

Soil Water Loss

Soil water loss was determined using a two probe gamma ray attenuation device (Model 2376 Troxler Instrument Co., Research Triangle Park, NC), which was calibrated daily before use. Water loss in the seedling root zone was measured across a 300 mm pathlength in 25-mm depth increments to either 760 mm or bedrock. This volume is considered to be the seedling microsite for soil water. Measurements were made during every site visit beneath 60 seedlings distributed among 5 representative treatments (shadecard, mulch, scalp, pyramid, and herbicide spray), plus control and no-tree locations.

Net water extracted from a given microsite over the season was calculated from measured data. Rainfall values were added to net water use over the growing season to determine total water use; only rainfall that did not wet the soil above field capacity was used in these calculations. Available water storage (average of 26 mm for all seedlings in 1983) is the difference between water left in the soil at the driest part of the year (15 mm for 1983) and the soil water content at field capacity (41 mm). Precipitation exceeding field capacity occurred three times during the season, early May, early June, and early September, totalling 28 mm.

Porometry

Seedling transpiration was measured with a steady state, null balance diffusion porometer (Model 1200, Li-Cor, Inc., Lincoln, Nebraska). Measurements were made on 45 seedlings representing four treatments: pyramid, black plastic mulch, southwest shadecard, and control. Leaf areas were measured periodically during season to correct for growing tissue.

Transpiration measurements were also taken on five samples of each of five competing vegetation species in order to estimate competition for available water by transpiring vegetation. The competing species measured were those estimated to be the most predominant: Ceanothus sanguineus, Rubus ursinus, Holodiscus discolor, Rhus diversiloba, and Arbutus menziesii. Instantaneous transpiration values were used to calculate total daily transpiration values by trapezoidal integration. Zero gm/cm^2 of water at sunrise and at sunset was assumed.

Estimates of Vegetative Cover

Four random transects were examined to estimate cover on the site, including percentages of Douglas-fir, bare ground, woody debris and competing species. This was done in an effort to assess the magnitude of vegetative competition on a whole site basis. Total leaf areas of all species were estimated using whole plant measurements and allometric equations. Madrone leaf areas were calculated using allometric equations developed by Harrington et al. (1984).

Statistical Analyses

Chi-square analyses were done on data from the periodic observations. Analysis of variance techniques were used for all growth data. Least significant differences were determined using total analysis of variance to compare all treatments. The same methods were used for analyses of soil water loss. Evaluations of growth data were done at a significance level of $p = 0.20$, as we feel this is acceptable for management decisions based on measurements taken in a highly variable environment. A correlation matrix was calculated for all growth measurements on the total population. Standard deviations were presented with temperature data, as sample sizes were too small for statistical analysis.

RESULTS AND DISCUSSION

Seedling Growth

Weather was mild during the 1982 and 1983 growing seasons with no extreme temperature events. Daytime temperatures in 1983 ranged from 6.4°C to 35.7°C, and 59 mm of precipitation fell between May 1 and September 15. Seedling survival was 98% during the two year study and growth trends were similar in both years. Although there were no statistical differences in first year growth among treatments, there were significant differences in the second year. This is probably due to a combination of effects of nursery conditions and transplanting stresses on first year outplanted seedlings. The lack of much vegetative competition until the second season is likely to have reduced the impact of different treatments. The small differences in height growth among treatments may have been due to deer browse which occurred on 49% of the seedlings in 1982. The severity of browse damage and its even distribution among all treatments probably contributed to the smaller difference in seedling response among treatments that first growing season. Browse was successfully controlled with a repellent spray in 1983. For clarity of presentation I discuss only second year results.

Table 2 shows means of all final growth measurements and includes least significant difference values. For most measurements there were no significant differences among groups of treatments formed based on the hypotheses shown in Table 1. These groups were used for analyses presented in Figures 1-6. The styrofoam cup treatment, designed solely for protection from high soil surface temperatures, resulted in growth trends which were not statistically different from those of the controls and was included with the control treatment for analysis. The pyramid treatment, originally conceived to provide combined protection against high temperatures and soil surface evaporation, did produce different growth results than the controls, and were thus maintained as a separate group.

Several interesting interpretations can be made from the data in Table 2. Under black plastic mulch, for example, height growth values are quite large for both years, and first year needles are the longest. Second year needle growth, all diameter measurements and bud size do not vary widely from the population means for this treatment.

The interpretation of bud size data is unclear, but it is interesting that the treatments with the

Table 2- Means of all final growth measurements in 1983 for thirteen treatments.
Abbreviations: Diam=diameter, Yr=year, incr=increase, W=west, SW=southwest, S=south, SE=southeast, E=east, S:R=shoot to root ratio.

TREATMENT	SHOOT VOLUME	ROOT VOL	TOTAL DIAM	TOTAL HEIGHT	1st YR HEIGHT	2nd YR HEIGHT	1st YR NEEDLE	2nd YR NEEDLE	INSIDE DIAM	1st YR DIAM	2nd YR DIAM	BUD SIZE	INCR SHOOT VOLUME	INCR DIAM	S:R
	(mm^3)	----------------	----------------	----------------	----------------	(mm)	----------------	----------------	----------------	----------------	----------------	(mm^3)	(%)	(%)	
W Shadecard	775.0		10.5	427.0	44.0	116.0	18.7	31.9	8.6	1.3	2.4	51.7	76.8	43.5	
SW Shadecard	661.0	32.8	10.1	436.0	45.0	127.0	18.7	31.5	8.2	1.2	2.3	45.3	75.2	46.2	2.3
S Shadecard	667.0		10.0	447.0	46.0	133.0	19.4	31.8	8.3	1.3	2.2	37.7	73.6	46.4	
SE Shadecard	721.0		10.1	459.0	46.0	142.0	19.0	32.7	8.3	1.3	2.4	55.4	77.0	44.6	
E Shadecard	618.0		9.7	429.0	47.0	115.0	18.8	32.4	7.9	1.1	2.1	49.7	73.5	46.2	
Pyramid	700.0	31.7	9.9	451.0	56.0	140.0	18.2	29.7	8.1	1.1	2.3	50.8	77.7	48.0	2.9
Scalp	866.0		11.5	442.0	42.0	132.0	17.8	31.1	9.3	1.3	2.6	58.4	78.6	51.1	
Paper Mulch	775.0		11.2	449.0	44.0	133.0	18.2	31.6	9.3	1.3	2.6	48.5	76.0	49.5	
White Plastic	806.0		10.9	439.0	46.0	123.0	17.7	31.2	9.0	1.2	2.6	41.0	80.3	51.3	
Black Plastic	847.0	37.8	11.4	455.0	55.0	148.0	19.1	31.3	9.2	1.4	2.6	46.8	80.4	51.2	2.8
Styrofoam Cup	747.0		10.9	438.0	41.0	121.0	17.7	30.0	8.5	1.2	2.3	44.4	76.9	42.9	
Control	833.0	37.8	10.6	437.0	44.0	136.0	17.5	32.3	8.8	1.3	2.5	47.9	79.3	48.2	
Herbicide Spray	904.0		12.4	431.0	44.0	132.0	17.4	28.9	10.5	1.5	3.2	61.8	82.2	55.4	2.5
Mean	763.0	35.0	10.7	443.0	47.0	130.0	18.3	31.0	8.9	1.3	2.5	49.2	77.6	47.9	2.6
Std. Deviation	426.0	3.2	2.4	85.5	2.5	53.5	2.8	4.8	2.1	.5	.9	31.5	12.1	11.5	.3
Least significant difference															
p=0.95	227.4	11.4	1.2	50.3	14.9	31.2	1.5	2.5	1.0	.3	.4	17.9	6.3	5.8	.7
p=0.80	148.1	7.3	.8	32.8	9.7	20.4	1.0	1.7	.7	.2	.3	11.7	4.2	3.8	.5

largest seedlings, herbicide spray and scalp, had significantly larger buds than most other seedlings.

Another interesting point is that seedlings treated with herbicide spray, which had significantly larger diameters than seedlings in all other treatments, did most of their growth in the second year of the study. This is despite the fact that surrounding vegetation gave much more competition the second year for available resources.

There were few trends within the shadecard group, though seedlings with east shadecards were consistently the smallest of the group. Second year height growth under west and east shadecards was less than growth under southwest, south, and southeast shadecards. This trend which is supported by data taken by Miller, et al. (1982), who found that temperatures were reduced much more by shadecards on the southern sides of the seedlings. Total height shows the same trend.

Total diameters and shoot volumes were the most sensitive indicators of differences among treatments (Fig. 1). The seedlings with surrounding vegetation controlled (herbicide and scalp) had larger diameters and shoot volumes than the control treatment while shaded seedlings (shadecard and pyramid) were smaller than the control. Herbicide spray seedlings did have significantly larger diameter growth than all other

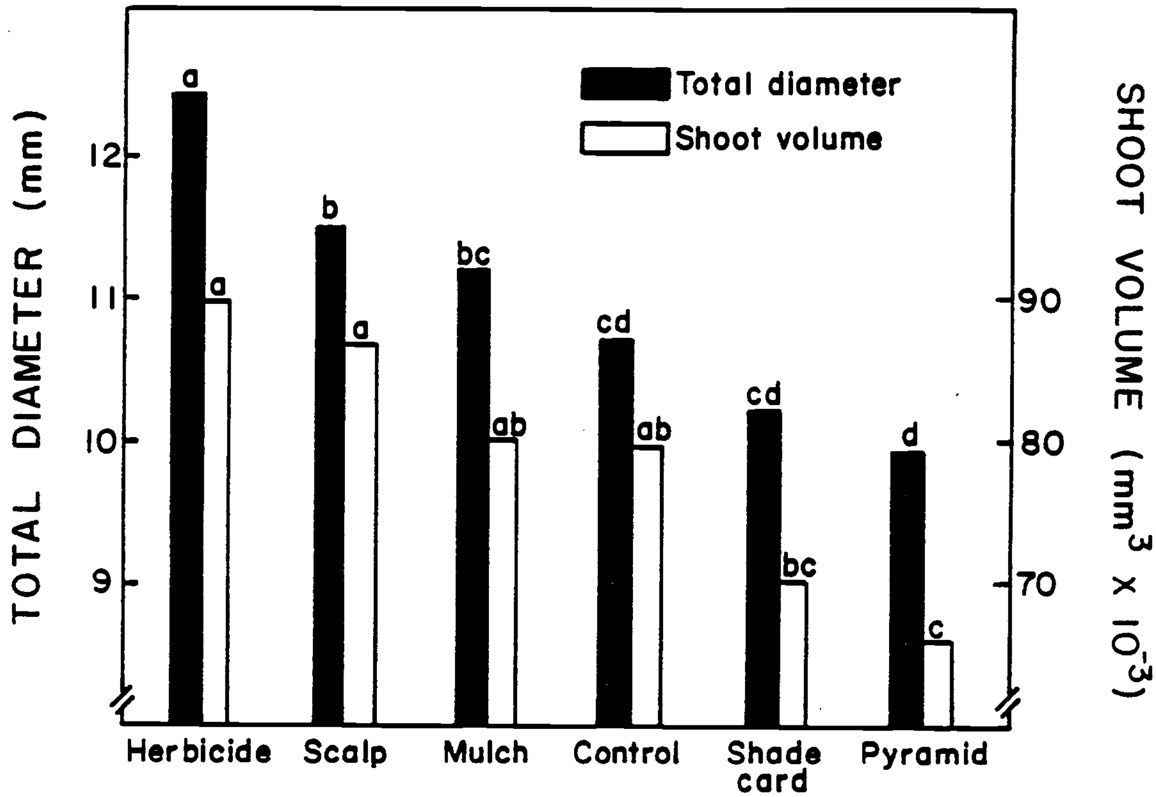

Figure 1: Final seedling total diameters and shoot volumes for six treatment groups. Mean values between bars with same letters do not differ significantly at the level of p=0.20.

seedlings. Calculations of percentage increases in total diameter and shoot volume showed the same significant differences among treatments as did the direct measurements indicating that differences were not due to initial sizes of the seedlings.

Additional Growth Data

Additional growth measurements were taken to assess the possibility of relating various nonstandard growth measurements to the treatments and to each other. The ability to predict growth and determine the adequacy of standard field measurements were considerations in the choice of these measurements.

We were unable to develop regression equations that would adequately predict growth. However, correlations among growth measurements provide some interesting interpretations. The complete correlation matrix is shown in Appendix I. Only those measurements with R values greater than 0.80 are shown in Table 3. Inside diameter measurements made after destructive sampling are highly correlated with standard field caliper measurements. Both inside and outside diameters measured at the end of the experiment were well correlated with shoot volumes. Shoot to root

Table 3: Correlations of growth measurement data. All possible correlations were performed on the entire data set. Only correlations above R = 0.8 are listed.

	R
Total diameter vs. inside diameter	.958
Initial S:R vs. final S:R	.910
Initial root volume vs. final root volume	.900
Final shoot volume vs. inside diameter	.843
Final shoot volume vs. total diameter	.820
Second year height growth vs. total height	.809

ratios before planting were highly correlated with final shoot to root ratios which indicates that treatments had little effect on the final ratios. This suggests that shoot to root ratios during the first.few years after outplanting are influenced strongly by the dimensions of the nursery stock used. Since smaller shoot to root ratios have been shown to be beneficial on droughty sites (Hermann, 1964b), the data presented here corroborate the importance of selecting appropriately sized seedlings for outplanting.

Relative root growth was similar for all seedlings, regardless of treatment. As larger root biomass increases absorptive capacity and increases the volume of soil to be utilized for water and nutrient collection, the importance of planting seedlings with initially large root systems is apparent.

Timing of Seedling Growth

The growth patterns for seedlings in treatments that resulted in more or less growth than the controls may be partially explained by the length of time during the season that seedlings subjected to different treatments were actively growing. This was determined by the percentage of seedlings in each treatment that had undergone budburst (started active growth for the season) by May 4, and the percentage that had set their buds (had stopped active growth for the season) by July 14 (Fig. 2). These dates were chosen because about 80% of all seedlings had achieved budburst by May 4, and about 50% had set buds by July 14. The treatments are displayed in the same order as in Figure 1, from those resulting in the most growth to those with the least.

There were trends in the budburst data and differences among some treatment means. Soil temperature, which has been found to influence the date of early season growth initiation (Sorensen and Campbell, 1973) differed among treatments in the early season (Fig. 5). However, it would appear that scalp and pyramid are the only treatments affected. Bare soil temperature data, which simulate a scalp treatment, were higher throughout the season. This may explain why the budburst data for scalp had the most seedlings with buds burst by May 4. Soil temperatures under pyramids were lower in the early season than other treatments and supports later budburst and the least seedling growth.

A shadecard, clearcut, shelterwood comparison (Childs and Flint, 198X) in which budburst was not altered by treatment, showed that, as in our study, treatments had a significant effect on the timing of

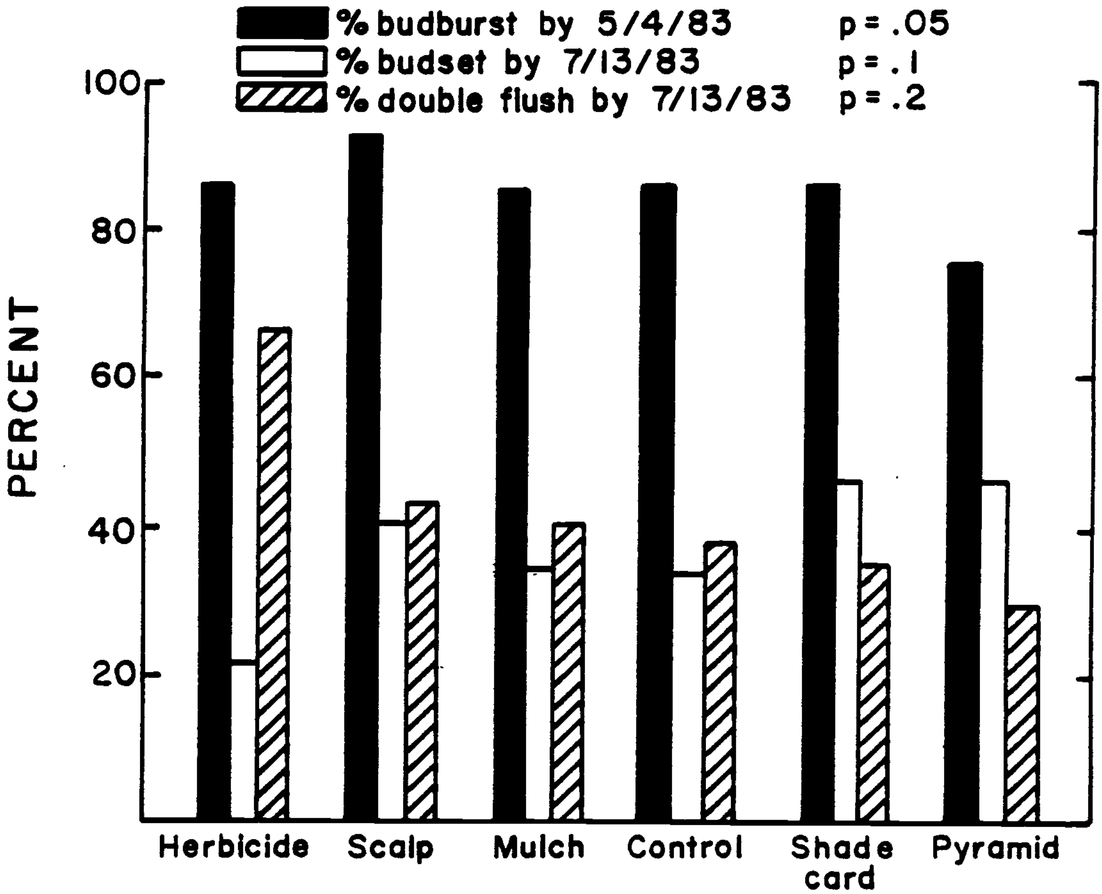

Figure 2: Percentage of seedlings undergoing budburst by May 4, 1983, and budset or double flushing by July 13, 1983. Chi square analyses were done and indicate differences among treatments at corresponding p value of 0.05 for budburst, 0.10 for budset, and 0.20 for double flushing.

budset. Our data indicate that treatments with seedlings that grew the most had lower percentages of trees with buds set. This suggests that more seedlings were still actively growing even in mid-July. Conversely, the shadecard treatment contained more seedlings that had set buds. These seedlings had stopped active growth by this time.

The data for double flushing (Fig. 2) show that seedlings which set buds later in the season also produced a second flush of growth. Double flushing is generally related to high water availability, whereas budset is primarily in response to moderate moisture stress (Cleary et al., 1978). Thus seedlings with more available water left in the soil had the opportunity to undergo additional flushing. This increases both the height and the shoot biomass of the seedling, and supplies more leaf area for photosynthesis, therefore additional diameter growth.

There may be some disadvantages to double flushing, however, especially during a harsh season. Seedlings undergoing a second flush in the nursery have lower survival on droughty sites (Lavender, 1984) because second growth is not hardy tissue. This tissue is more likely to suffer from lethal temperatures, which may occur in August after second flushes have been produced, or moisture stress has induced dormancy.

This tissue is also less likely to develop frost hardiness early enough to escape damage during fall frosts (Lavender, 1984). In addition, winter resting buds need time to harden so that growth will not resume with fall rains and they will be subjected to chilling, which increases vigor (Lavender and Cleary, 1974). The shaded treatments produced seedlings with less growth, but had more seedlings in dormancy induction in mid-July.

Timing of budburst and budset or, seasonal growth of seedlings is shown over the season in Figure 3. Included is the percentage of seedlings in each treatment that had achieved budburst but had not undergone budset during the main part of the growing season. Ranking the percentages of seedlings in each treatment actively growing between early May and mid-July shows the treatments to again be in the same order of most to least growth. This supports the analysis of Figure 2, and the assertion that an important treatment effect on seedling growth is growing season length, the time between budburst and budset.

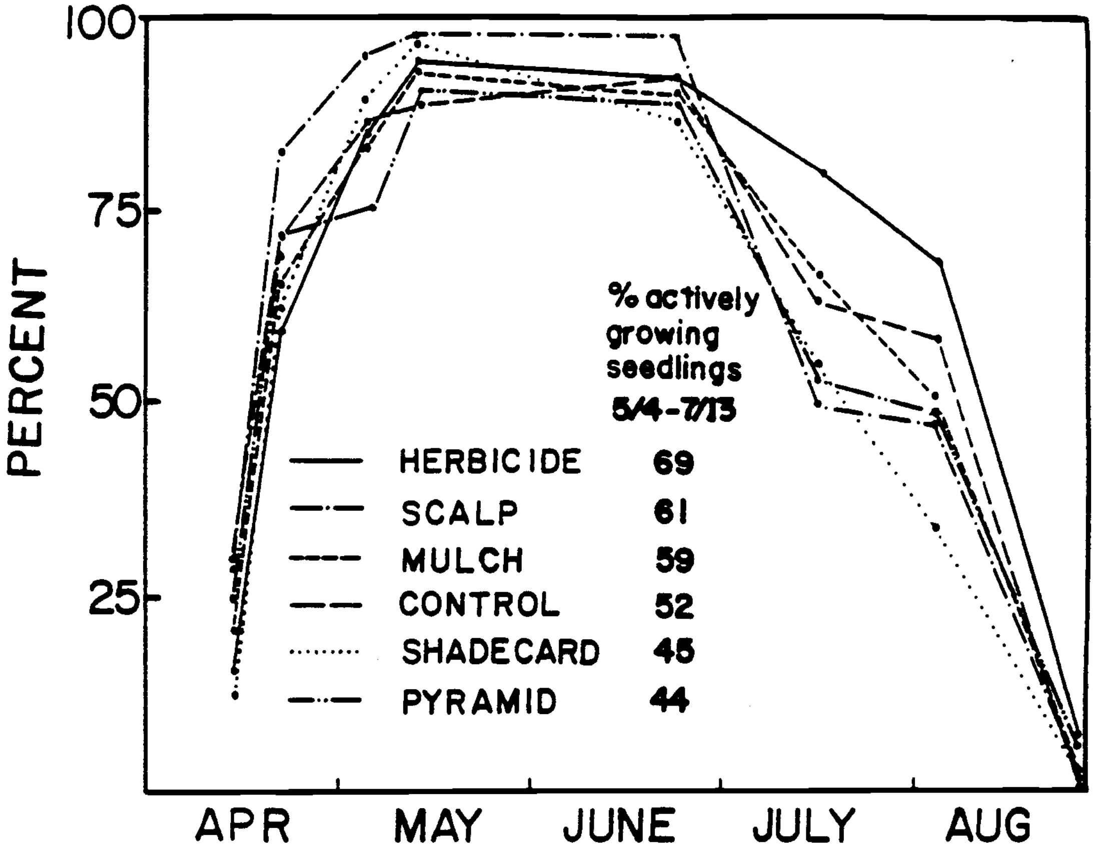

Figure 3: Percent seedlings actively growing throughout the growing season of 1983 as percent budburst for April through May and percent not budset for June through August for 6 treatments. Included is the percent of actively growing seedlings between May 4 and July 13.

Soil Temperature

Another explanation for the growth differences may be differences in soil temperature. As mentioned previously it is reasonable to use bare soil temperature data as a replacement for surface temperatures of the scalp treatment. As shown in Figure 4, treatments with the best seedling growth (herbicide and scalp) also had the highest surface soil temperatures throughout the season. Even early in the season (Fig. 4a), herbicide treated soil surfaces had temperatures up to 13°C greater than all other treatments and bare soil temperatures were even higher. The herbicide treatment resulted in nearly lethal surface soil temperatures even in a mild year (Fig.5). In a hotter growing season, surface temperatures would be greater, and shading treatments would be more likely to protect the seedlings from heat stress. Surface soil temperatures under the pyramid treatment were consistently lower than all other treatments throughout the season. This may help explain the smaller growth of the seedlings in 1983, but in a hot year the shading effect may give seedlings a competitive advantage.

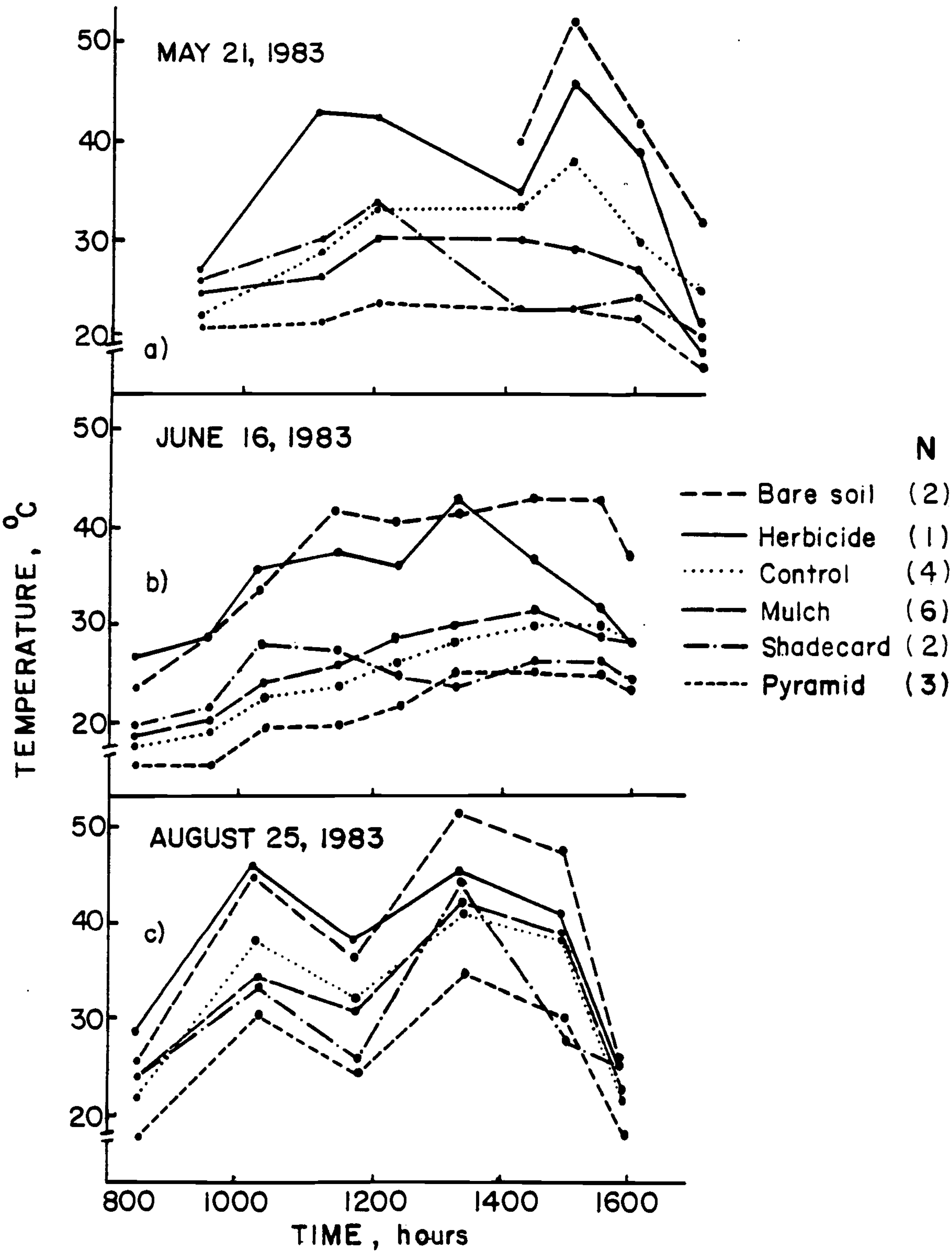

Figure 4: Soil surface temperatures for five treatments during daylight hours on May 21, June 16 and August 25, 1983.

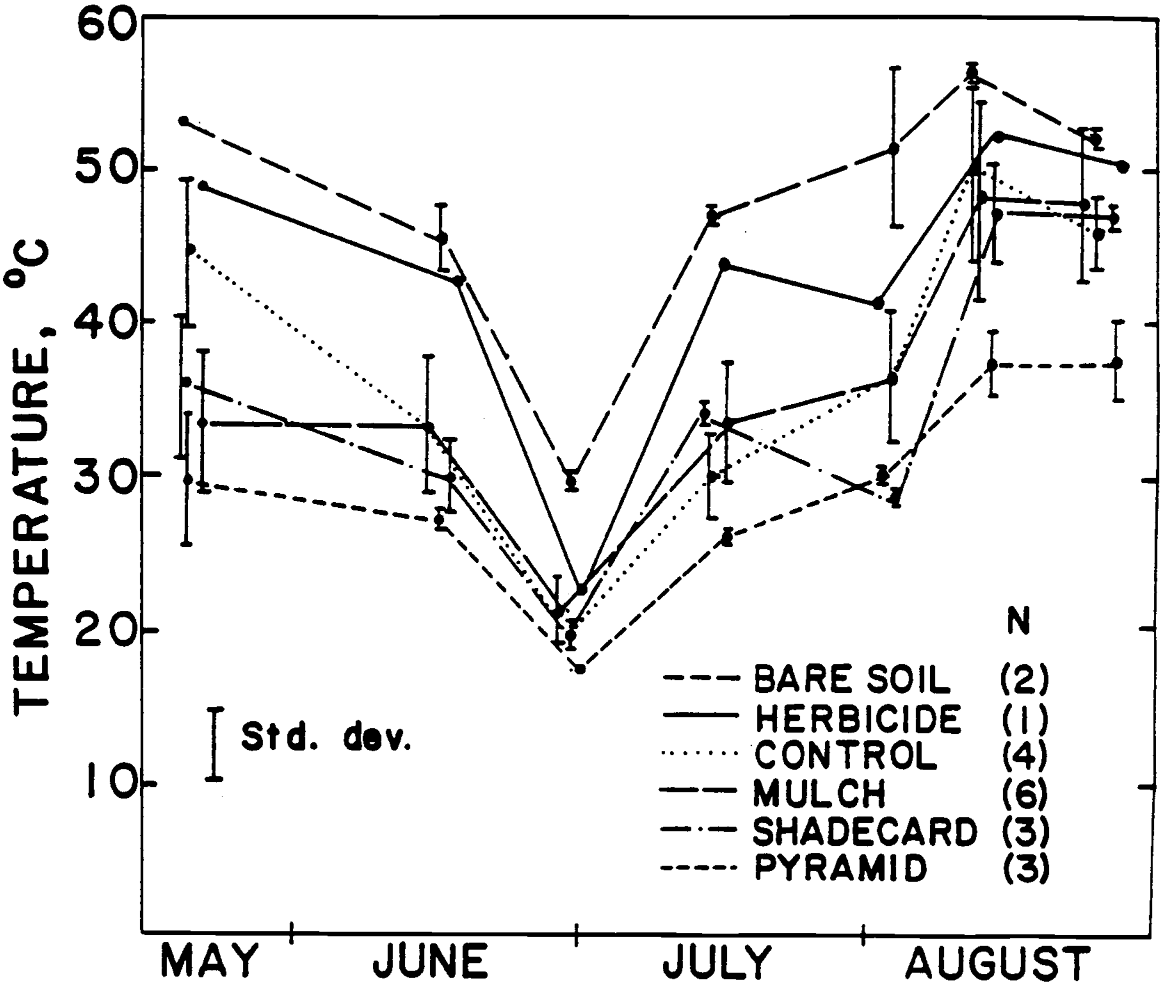

Figure 5: Soil surface high temperatures for five treatments plus bare soil for each sampling date for the 1983 season.

Microsite Water Partitioning

Seasonal soil water loss data (Fig. 6) show that treatments with no vegetation or evaporation control (control and shadecard), resulted in the most microsite water loss over the season. Those treatments that controlled some vegetation resulted in different water loss patterns due to surface shading or evaporation control. Or, in the case of the no-tree treatment the difference is due to no seedling water use. Mulch, scalp, pyramid and herbicide spray all controlled some loss of water by reducing vegetation and/or reducing surface evaporation. A notable difference in water loss due to evaporation is that between the total vegetation control treatments, scalp and herbicide. The low water loss in the herbicide treatment illustrates the effectiveness of an undisturbed soil surface layer in controlling evaporative loss of soil water.

Total water use is shown again in Figure 7 but is also divided into 3 depth increments, a surface layer (50-120 mm), estimated seedling rooting zone depth (120-250 mm), and deep soil (250-760 mm or bedrock). Significant differences are shown at each depth. The percentage of total water that was lost from the seedling root zone, 0-250 mm, averaged 65% with the

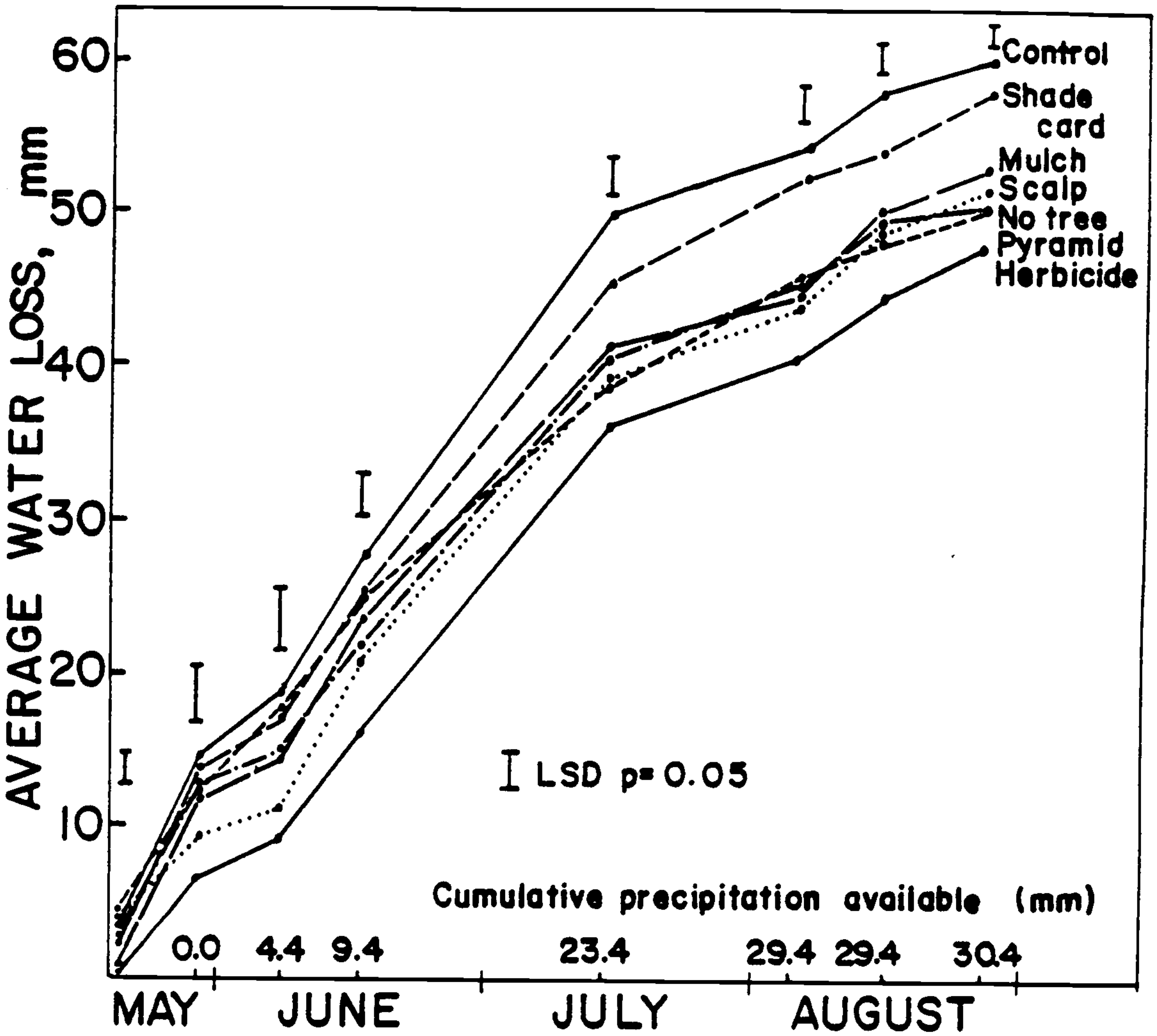

Figure 6: Seasonal cumulative water loss from the soil profile for seven treatments. Vertical bars are least significant differences determined on cumulative water used by each date at a significance level of p=0.05.

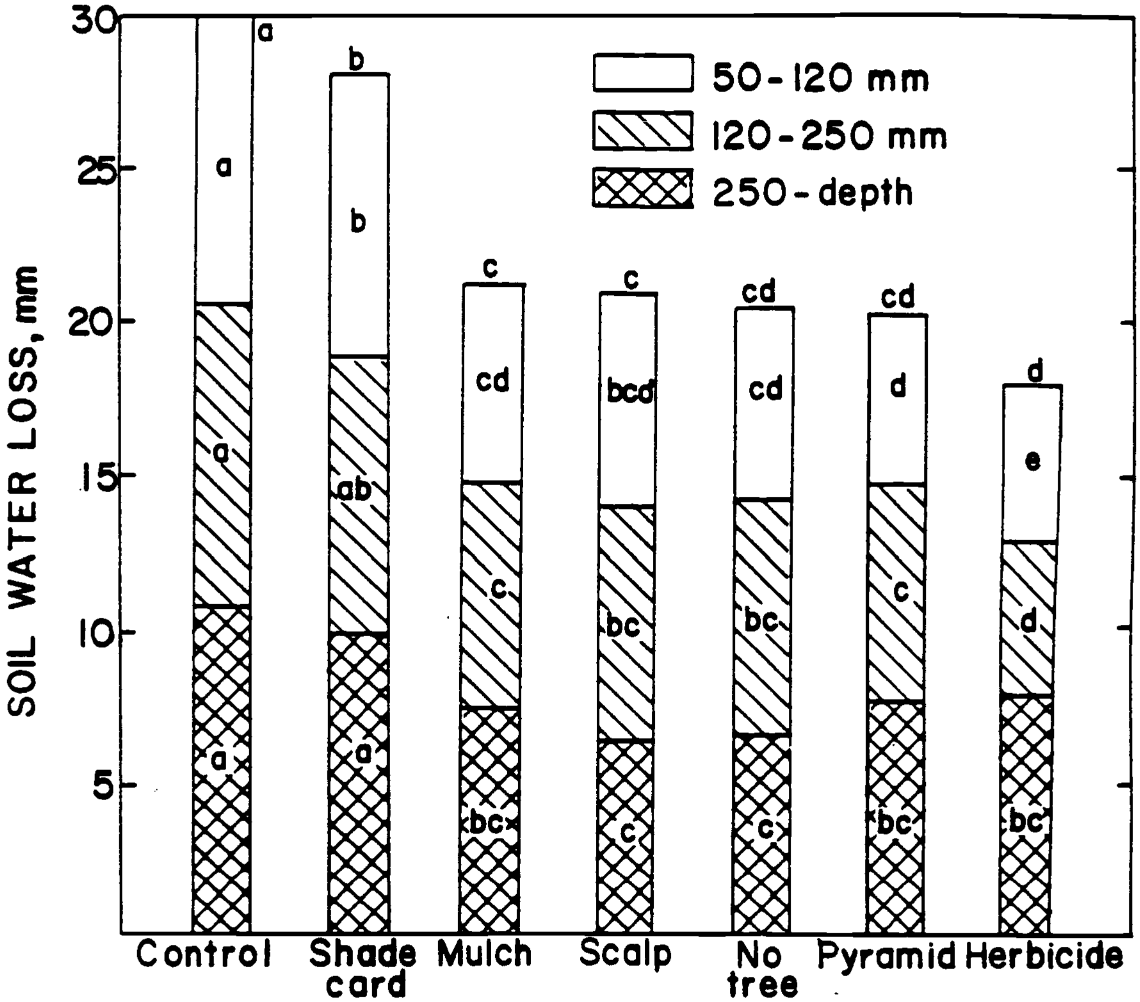

Figure 7: Soil water loss for 1983 season presented in three depth increments, 50-120 mm, 120-250 mm, and 250-depth of profile. Mean values between bars or increments with same letters do not differ significantly at a level of p=0.05.

following values for all treatments: control 65%, shadecard 64%, mulch 65%, scalp 69%, no tree 68%, pyramid 63%, and herbicide 43%. The outstanding feature of these calculations is the particularly low value for the herbicide spray treatment. As discussed previously, the control treatment did not modify water loss by vegetation and evaporation, which results in more total water loss and more water loss in each depth zone.

It would be expected that all water use components, vegetation, seedling and evaporation, used surface water, while seedlings and vegetation used water from the second zone. Water loss from deeper zones would be due primarily to deeper rooted vegetative species, but would also be influenced by upward flow in response to drying in the surface layers. This shows how the variety of vegetative species can take advantage of the whole soil profile in order to out-compete the tree seedling.

The rate of soil water loss is greatest during the period from early June to mid-July (Fig. 8). This is the period of time during which the major above ground growth takes place, and the water loss data show an interesting relationship to the growth data. Partitioning of available microsite water among seedling, competing vegetation and soil surface

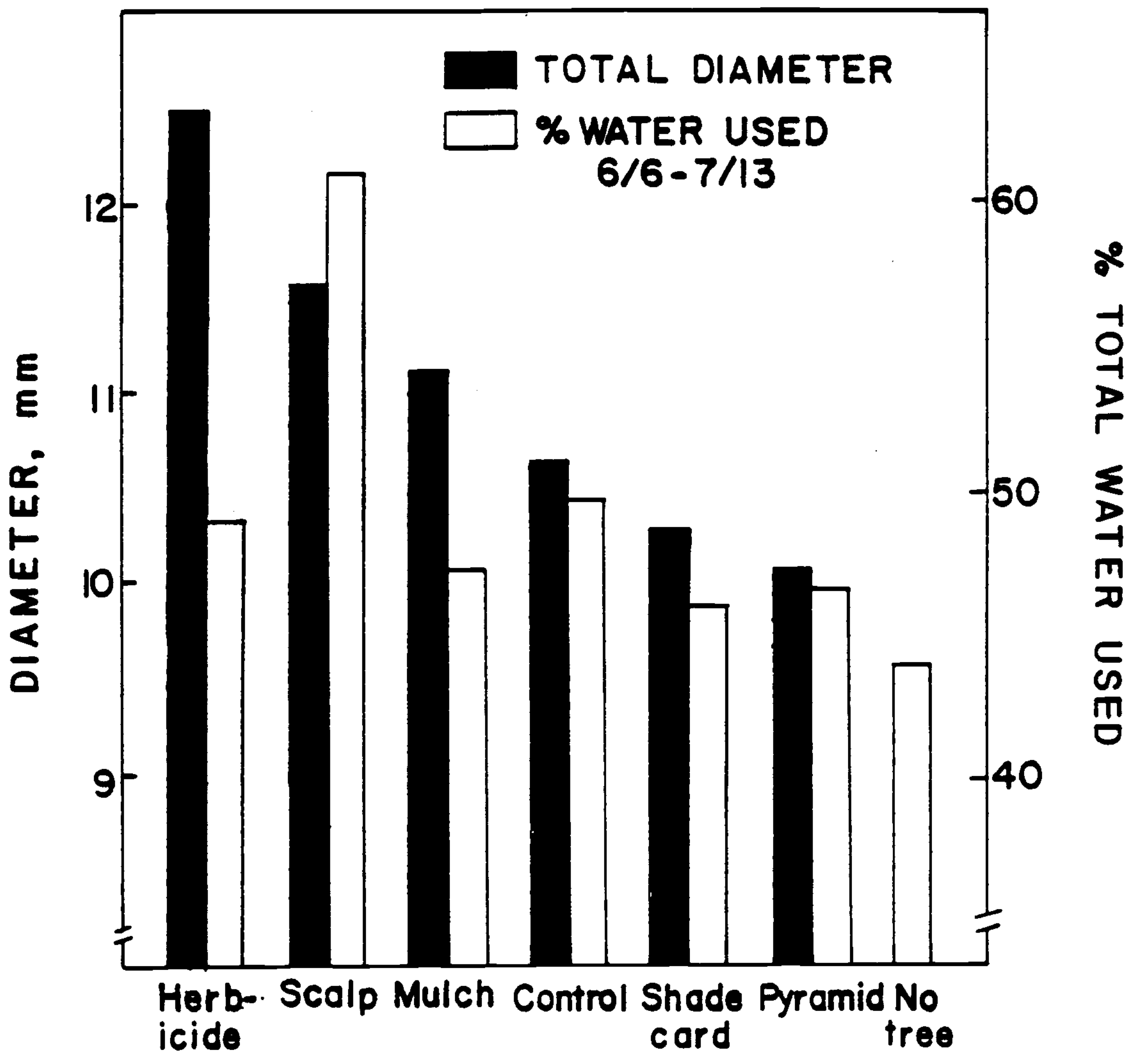

Figure 8: Final seedling total diameter vs. percentage of the total seasonal water used by seven treatments between June 5, 1983, and July 13, 1983.

evaporation is important because the relative conservation of water by herbicide, mulch, shadecard and pyramid treatments does not explain the discrepancies in tree growth among those treatments. Although the scalp treatment resulted in large diameter growth, it also resulted in more water use than the other treatments, undoubtedly to surface evaporation from higher surface temperatures (which were indicated by bare soil surface temperatures in Figures 4 and 5) and a disturbed soil surface. The herbicide treatment, by losing less water to evaporation and competing vegetation, resulted in more soil water for increased plant growth.

This can be expressed as water use efficiency (Table 4), calculated in this case as total top volume (mm^3) divided by total microsite water loss (mm). In these terms, the herbicide treatment elicited the most efficient use of site available water for seedling growth. The scalp, mulch and pyramid were less efficient, and the control and shadecard treatments were poorest.

The percentage of vegetative cover occurring in each treatment was estimated periodically throughout the growing season. A ranking of cover percentage corresponds to the water use efficiency ranking. The herbicide and scalp treatments had no vegetative cover,

Table 4: Water use efficiencies (WUE) for six treatments, calculated as shoot volume (mm^3) divided by total seasonal microsite water used (mm).

Treatment	WUE
Herbicide	140
Scalp	126
Mulch	115
Pyramid	103
Control	99
Shadecard	94

mulch and pyramid treatments partially controlled vegetation, and the control and shadecard treatments had no effect on competing vegetation. The same order of treatments occurred in the growth data in Figure 1. This is with the exception of the pyramid which, though it had a higher water use efficiency than the control and shadecard treated seedlings due to its very low seasonal water use, grew less than the seedlings in the control and shadecard treatments.

Seedling and Vegetation Transpiration

Seasonal seedling transpiration is shown in Figure 9 as average daily transpiration. Transpiration values peak when foliage growth reaches a maximum, then decrease over the season as the soil water is depleted. Seedling transpiration shows a difference between the two treatments that showed more instantaneous soil water loss, southwest shade and control and those that used less water, pyramid and mulch. This indicates that the decreased amount of water in the soil directly reflects the amount of water available for transpiration by the seedlings later in the season, and in this case increased the amount of water transpired by the treated seedlings by 40%.

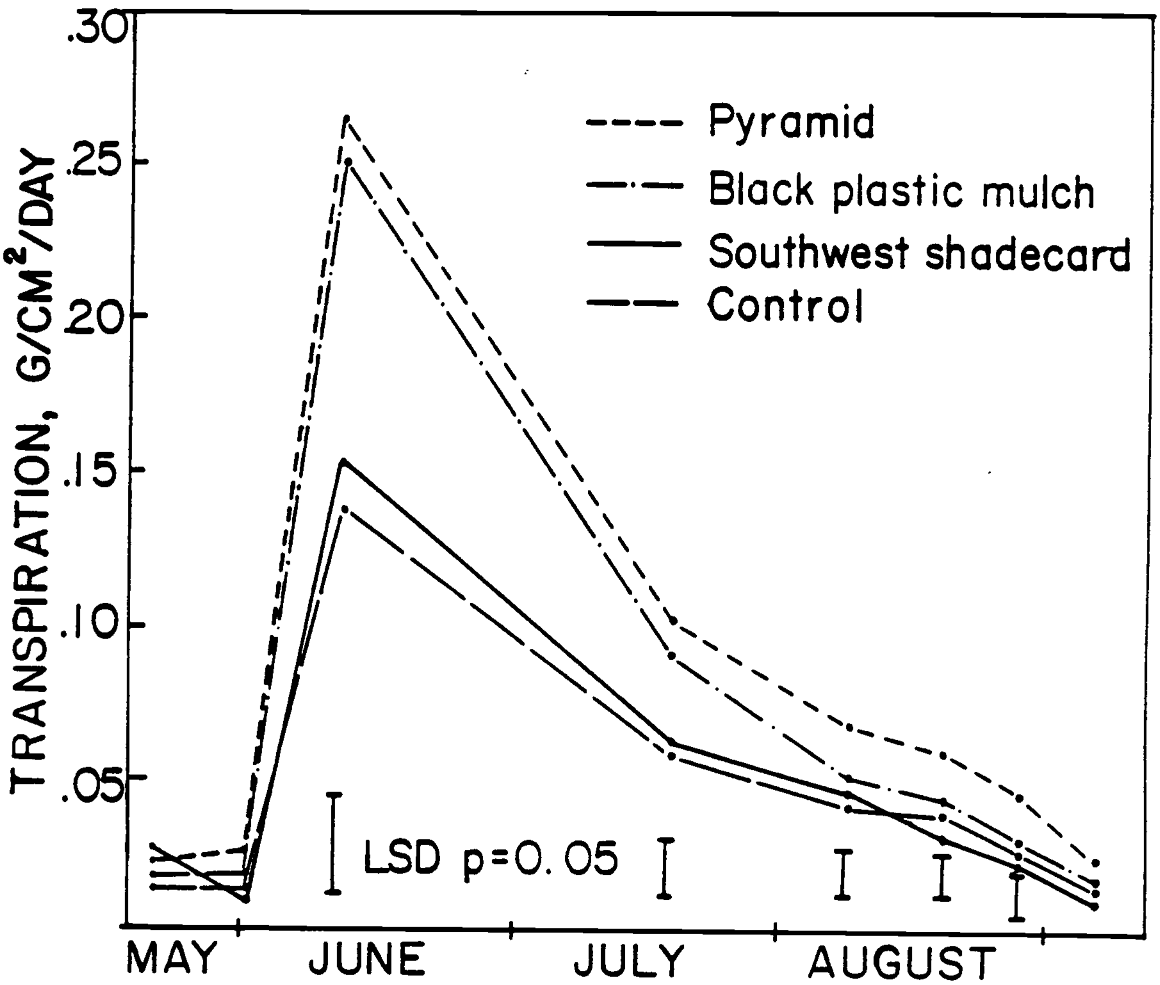

Figure 9: Douglas-fir transpiration per unit leaf area for 8 sampling dates in 1983 for 4 treatments. Each point represents 5 to 7 porometer readings.

Figure 10, which shows both competing vegetation and seedling transpiration on the same scale, shows similar seasonal trends for the vegetative species, however, the vegetation more actively reflected environmental conditions as it did not go into dormancy in July as did the seedlings. Vegetation transpiration responded well to rain input, and daily transpiration totals over the season decreased as the soil dried out.

The vegetation transpiration shows some differences between species. Early in the season the amount of water transpired correlates fairly well with leaf thickness: the thicker the leaf, the better it conserved water. Madrone has the thickest leaves, ceanothus and blackberry the thinnest. Later in the season, in August, those species that began senescence the earliest, such as blackberry, decreased daily transpiration earliest. Poison oak and ocean spray yellow and drop their leaves next, and ceanothus and madrone remain vigorous for the longest. In effect, the seasonal transpiration record indicates growing vigor and timing by species very well.

The pronounced effect that competing vegetation can have on the water balance of a site is demonstrated when both vegetation and seedling transpiration are compared on the same scale. Rain events, occasions when precipitation exceeded 5 mm in 24 hours, are

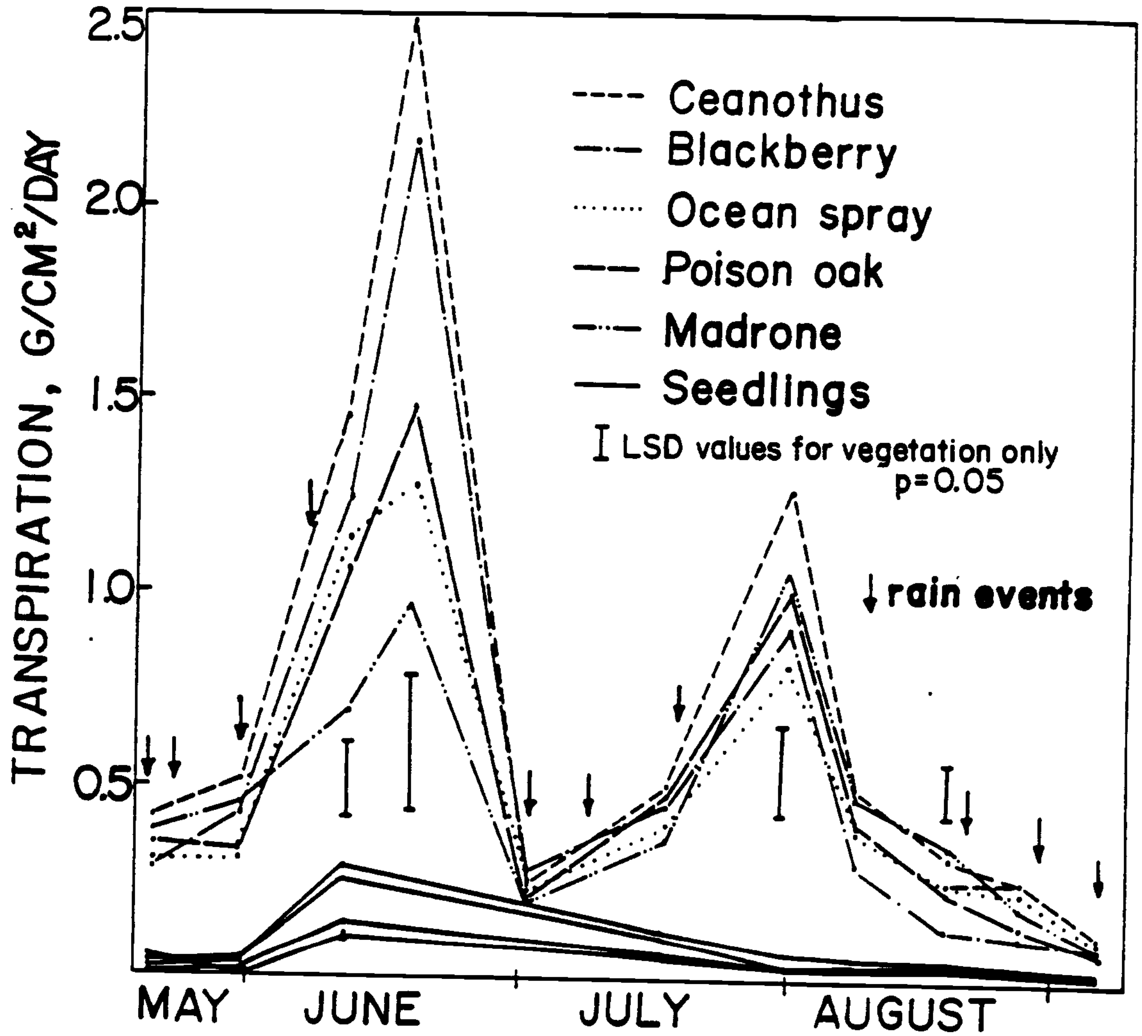

Figure 10: Vegetation transpiration per unit leaf area for 10 sampling dates in 1983 for 5 vegetative species. Each point represents 6 to 8 porometer readings. Douglas-fir seedling transpiration is included on the same scale and rain events are indicated.

indicated also, showing the effect on transpiration. As shown, competing vegetation, on a leaf area basis, transpires far more water than seedlings under all treatments.

Site Vegetative Cover

To estimate site vegetative cover on the site for interpretations of whole site water use, four random transects were taken adding up to 157.9 meters. Bare soil was encountered over 17.4% of the total transect length, and herbicide spray treatment plots and woody debris each occurred over about 1.0% of the total transect length. Even on a harsh site total vegetative cover is 80.6%. Competing vegetation covers 78.2% of the total transect length and Douglas-fir seedlings cover only 2.4%.

The competition for the available water is shown even more dramatically when all species are compared on a leaf area basis. Those species occupying at least 1% of the site area are shown in Table 5. Species lists and leaf area percentages may be misleading in terms of the impact of vegetation on Douglas-fir seedlings if the number of occurrences along the transects were not also considered. The data in Table 5 are given with

Table 5: Vegetative species present on the site, September 1983, and their relative abundance on a leaf area basis: the number of occurrences on transects, and estimates of the percent of the total leaf area with and without madrone used in the calculations.

Scientific name	Common name	# occur. transects	% of total leaf area (incl.mad.)	% of total leaf area (excl.mad)
Arbutus menziesii	Pacific madrone	3	66.2	--
Ceanothus sanguineus	redstem ceanothus	194	11.7	34.7
Holodiscus discolor	ocean spray	14	3.6	10.5
Penstemon sp.	penstemon	110	3.0	6.0
Rubus ursinus	trailing blackberry	92	2.9	8.6
Pseudotsuga menziesii	Douglas-fir	24	2.4	7.0
Rhus diversiloba	poison oak	12	1.0	2.5
Graminae sp.	grasses	17	0.1	0.3
Corylus cornuta	hazel	4	9.1	26.9
Berberis nervosa	dwarf Oregon grape	4	0.6	1.9
Archtostaphylos patula	greenleaf manzanita	6	0.1	0.3
Rubus parviflorus	thimbleberry	3	0.2	0.6
Rosa sp.	rose	18	0.0	0.1
Polysticum munitum	sword fern	2	0.0	0.1
Asclepias sp.	milkweed	14	0.1	0.3
Rubus leucodermis	western raspberry	3	0.1	0.4
Iris sp.	iris	1	0.0	0.1
Fragaria sp.	strawberry	11	0.1	0.4
Cruciferae	mustard	98	0.1	0.2
Compositae	thistle	16	0.6	1.3
Miscellaneous (all species < 0.01% of total area)		44	2.4	0.7

and without madrone included in the calculations. Madrone occupied 66.2% of the total leaf area of the site yet only occurred 3 times on the transects as the plants were very large. Another consideration is the rooting depth of the various species. In this case the large madrone plants, which are predominately sprouts, have deep and extensive rooting systems and while they probably use the entire soil profile to extract water they are not competing exclusively in the upper layers of the soil profile as are the shallower rooting species, including Douglas-fir. Therefore, they probably impacted the overall Douglas-fir seedling population less, whereas redstem ceanothus, only occupying 11.7% of the total area occurred 194 times, was much more evenly distributed, had similar rooting patterns and probably had a much greater impact on the seedlings.

SUMMARY AND CONCLUSIONS

This study showed that during a mild growing season seedlings with different treatments had different water loss patterns and seasonal growth. These differences were due to various interactive effects of temperature, timing of growth and increased availability of water due to treatment control of evaporation or competing vegetation. Competing vegetation was demonstrated to be most important in influencing water available for seedlings, as the degree of treatment control of vegetation correlated well with seedling growth, seasonal water loss and water use efficiency. The importance of surface evaporation as a mechanism of water loss was clearly shown by herbicide treated sites which used significantly less water and had a higher water use efficiency than the scalp treated sites.

Timing of budburst and budset had a large influence on seedling growth. Temperature may have had an influence on early season growth while increased water availability and decreased moisture stress later in the season delayed budset and increased double flushing. The net result of these factors was increased growth for the herbicide treated seedlings and reduced growth for the seedlings with shaded treatments, shadecard and pyramid. Control seedlings, though they used the most water, probably grew more earlier in the season as they were not shaded. Control seedlings therefore had a longer growing season and grew more than seedlings with shadecard and pyramid treatments. Because water loss to competing vegetation was large for the control treatment, water use efficiency was not increased above that of the pyramid. These calculations of water use efficiency were made on a seedling microsite basis, not as on a seedling basis. These values can therefore be used to assess the partitioning of water in a seedling microsite. There is a finite amount of water available in the soil of the microsite and the greater the amount of water that is allocated to seedling use, rather than to vegetation or evaporation, the more the seedling can grow.

Direct measurements of plant transpiration showed how differences in microsite water loss, even early in the season have a large effect on transpiration. Seedlings in the control and southwest shadecard treatments, which had the greatest soil water loss, were limited by the lower soil water contents and transpired only half as much as the pyramid and mulch treated seedlings in early June. Transpiration by competing vegetation responded in the same way to soil moisture content, but the magnitude of transpiration per unit leaf area was about five times that of seedlings during peak times.

Competing vegetation was found to occupy 78.2% of the site, compared to 2.4% cover of Douglas-fir seedlings. In consideration of the transpiration rate, the more extensive rooting habits, and the proliferance of the competing vegetation over the whole site, it appears that competing vegetation, at least in a mild year, can far outcompete, and has the greatest impact on the successful growth of young Douglas-fir seedlings.

While the necessary first step to understanding the environmental dynamics of a site is on a microsite level, these approaches also need to be considered from a management perspective. In this particular environment, management decisions must assess the probability of occurrence of a severe drought or heat stress season. Either may greatly reduce survival of the tree crop. A manager must select either a regeneration program based on establishment and survival only, or a program enhancing seedling growth and biomass production. There is also the more intensive and costly selection of incorporating both alternatives. It has been shown that shading can improve seedling survival in a very harsh year (Childs and Flint, 198X). We supported this in our study in a mild year by showing earlier budset and lower soil temperatures for shaded treatments. This was accompanied by less seedling growth and larger water loss resulting in lower water use efficiencies. Therefore, shading as a safeguard for survival in the event of a harsh year is at the expense of enhanced growth in good years. It has yet to be shown, but may certainly be true, that an increase in water use efficiency may also help to increase survival as moister soils will be cooler, and more efficient plants may withstand water stress better. While survival is the ultimate goal, treatments that increase microsite efficiency of available soil water partitioning may also help to increase seedling survival beyond that of standard shading techniques.

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APPENDIX

APPENDIX I- Correlation matrix of all growth measurements: initial, 1982 and 1983 growth measurements, for 13 treatments.

Treatments:

1-Total growth	5-S/R (82/83)	9-83 top volume	13-2nd yr diam	17-Treatment #	21-83 needle length
2-Initial height	6-1st yr height	10-Total diameter	14-Total height	18-83 root volume	22-82 root volume
3-1982 shoot/root	7-2nd yr height	11-Inside bark	15-Init.ht./diam	19-Budsize	23-Initial diameter
4-1983 shoot/root	8-82 top volume	12-1st yr diam	16-Top vol(82/83)	20-82 needle length	

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	-.076	-.022	-.026	-.008	.461	.802	-.061	.407	.286	.302	.134	.289	.850	-.171	-.289	-.108	.000	.550	.132	.034	-.013	-.099
2		.046	.044	.034	.015	.031	.611	.251	.268	.287	.208	.188	.155	.291	.155	.126	.056	.076	.064	.116	.098	.558
3			.909	.928	.046	-.021	.085	.066	.130	.067	.066	.038	-.042	-.027	-.053	-.057	.862	-.044	.003	-.081	.807	.065
4				.746	.141	-.250	.068	.111	.138	.082	.083	.042	-.047	-.031	-.075	-.009	.825	-.038	.026	-.087	.846	.073
5					.045	-.007	.087	.036	.135	.076	.070	.045	-.022	-.033	-.034	-.021	.885	-.033	.031	-.062	.764	.056
6						.405	-.022	.278	.259	.271	.174	.170	.458	-.075	-.168	-.016	.206	.340	.134	.002	.177	.045
7							.003	.435	.336	.358	.184	.314	.808	-.108	-.281	-.004	.017	.624	.142	.953	-.017	.032
8								.418	.407	.423	.262	.275	.074	.095	.228	.039	.110	.077	.123	.104	.188	.586
9									.819	.842	.403	.697	.347	-.179	-.357	.120	.130	.389	.229	.082	.123	.229
10										.957	.466	.791	.258	-.191	-.030	.184	.198	.347	.195	.073	.166	.314
11											.471	.827	.273	-.186	-.292	.185	.143	.364	.209	.082	.106	.311
12												.163	.157	-.184	-.193	.093	.162	.208	.108	.043	.170	.260
13													.280	-.303	-.386	.153	.079	.271	.181	.069	.044	.166
14														-.125	-.276	-.063	-.017	.590	.124	.055	-.024	.093
15															.766	.387	-.048	.067	.064	.023	.022	.125
16																-.042	-.066	-.204	-.074	-.027	-.038	.132
17																	.000	-.002	-.147	-.066	-.014	.141
18																		-.005	.046	-.079	.897	.094
19																			.111	.121	-.020	.115
20																				.349	.053	.029
21																					-.082	.000
22																						.147