AN ABSTRACT OF THE THESIS OF

Bradford A. Withrow-Robinson for the degree of Master of Science in Forest Science presented on December 9, 1994.

Title: Pruning Young Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in a Western Oregon Agroforestry Setting: Changes in Tree Water Relations and Effects on Forage Production

Abstract approved: Signature redacted for privacy.

William H. Emmingham

There is renewed interest in agroforestry as a management strategy for marginal agricultural lands in western Oregon. Silvopastoral systems combine tree and forage production, which involve crops and practices familiar to the area.

The objective of this study was to determine how management influences the physiology and ecological interactions of two silvopastoral crop components. Changes in water relations and growth of 9 to 12 year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) trees were examined in response to pruning and pasture competition. Four buffered nine-tree treatment plots were installed at each of the four western Oregon sites, in a randomized complete block design, each site was a block. Approximately 50% of the crown length was removed in the pruning treatment. The unimproved pasture community was either retained or removed chemically. Forage production beneath pruned and unpruned trees was measured and modeled.

With no understory competition, Pruned trees showed consistently lower moisture stress than Unpruned trees. The differences were generally small and were significant only twice in 1992, and once in 1993. With pasture competition, pruning appeared to have the opposite effect, and Pruned trees had more negative pressure potentials than Unpruned trees once in 1992, and three times in 1993. No differences were found between trees growing with and without pasture when the trees were unpruned.

Both pruning and pasture removal treatments had an influence on tree growth. Pruning appeared to have a stronger effect on the radial growth than pasture competition. The growth rate of Pruned trees with Pasture was lower than all others.

The regression models of forage production in the Unpruned treatments explained more variability each year (69% and 73%) than did the models for the Pruned treatments (60% and 45%). The models for the Unpruned treatments explained similar amounts of the total variability in both years although the models were quite different. The amount of variability explained by models fitted to the pruned treatments declined from the first to the second year.

The results of this study are consistent with the general notion that removing foliage from trees will reduce water use and tree growth. It also appears that forage communities continue compete with trees for moisture. The measured trends were, however, small and of little concern from a management perspective. Thus, pruning to increase wood value and maintain forage production appears to have few negative effects. Pruning should be undertaken when managers feel that the expense will be paid for by increased wood value.

Pruning Young Douglas-fir (*Pseudotsuga menziesii* [mirb.] Franco) in a Western Oregon Agroforestry Setting: Changes in Tree Water Relations and Effects on Forage Production

by

Bradford A. Withrow-Robinson

A THESIS
submitted to
Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

Completed December 9, 1994
Commencement June 1995

ACKNOWLEDGEMENT

I wish to express my great appreciation to the members of my committee: Dr. Bill Emmingham, Dr. David Hibbs and Mr. Rick Fletcher for their role in getting me back in school, and their guidance and support in getting through. Their patience was helpful, but it was their own enthusiasm which provided the necessary inspiration. My thanks also to Dr. Logan Norris for his support of my program. Thanks also to Starker Forests, Thompson Timber Co., Dr. Mike Newton and, Carl and Darleen Joines who generously gave me access to their property for my project.

My Master's program has been more enjoyable and enriching because of the friendships and daily contacts within the Department of Forest Science. I am indebted to the entire faculty and staff for their commitment to research and education, to Tom Sabin for his patience, to Dr. Joe Zaerr and the rest of my subcommittee for keeping me physically as well as mentally fit, and of course to my own dear cohort of fellow students, for adding variety to daily life.

Finally, I wish to thank my family and friends outside of school, who also endured my Masters program. Thank you Tina and Johannah, Mom and Dad, for your love and affection and especially, lack of doubt when I had plenty. Thank you Ian, for your taste in beer and buoyant gift of cynicism.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF EQUATIONS

Pruning Young Douglas-fir (*Pseudotsuga menziesii* [mirb.] Franco) in a Western Oregon Agroforestry Setting: Changes in Tree Water Relations and Effects on Forage Production

INTRODUCTION

Agroforestry in Western Oregon

Recent changes in public attitudes, land-use policies and economic trends have increased interest in agroforestry in western Oregon. Agriculture and forestry are important parts of Oregon's economy. Integration of the two may offer biological and economic benefits for landowners. Local familiarity with forage and timber production suggests that combining the two in silvopastoral agroforestry systems would be acceptable to many landowners. The presence of an established forest products infrastructure also creates favorable conditions for the adoption of agroforestry in the area.

Agroforestry is not entirely new to western Oregon. Grazing has been a common practice since settlement, first in the native oak savannas and later in young conifer plantations (Hedrick and Keniston 1966, Jaindl and Sharrow 1988, Doescher et al. 1989). These practices were generally opportunistic, rather than designed.

Silvopastoral agroforestry continues to be the most common system, but practices are changing to fit current situations. The use of agroforestry now tends to be a more deliberate part of a management plan; a strategy for vegetation control or for converting marginal agricultural lands to forestry production. Current agroforestry practices are also more management intensive than in the past, and are likely to involve pasture improvement plus tree pruning and thinning. The desired results include increased and extended grazing returns, and improved wood quality and value at harvest.

Agroforestry is practiced in other temperate and Mediterranean regions of the world as well. Silvopastoral agroforestry has been extensively developed as a management practice in New Zealand, where radiata pine (*Pinus radiata*) and other conifers are grown on grazed pastures and intensively managed for high value clear-wood (Hawke 1991, Knowles 1991). Silvopastoral agroforestry is also practiced in Australia (Anderson et al. 1988), the Mediterranean basin (Le Houérou, 1990), northern Europe (Gold and Hanover 1987) and the United States, particularly the Southeast and West (Lewis and Pearson 1987, Byington 1990). Agrisilicultural systems combining agronomic crops with trees are used in temperate China, and also the United States and Europe (Gold and Hanover 1987, Garrett et al. 1991). These combinations are less important in the temperate zone than in the tropics. Falling values of livestock products such as meat and wool, and intensive management requirements may limit future expansion of temperate zone agroforestry.

Environmental and Ecological Constraints

An agroforestry system in western Oregon must be adapted to the region's Mediterranean climate. Fall, winter and spring are generally moist and mild. But the summer is warm and dry, with little or no rainfall for up to three months. Plants must depend on stored soil moisture during most of the growing season. Individual crops must be adapted to these conditions. Also, the crop combinations and management practices chosen must reflect individual crop needs, and minimize competitive interactions. Forage plants whose active growth periods coincide with the tree's dormant period may lend themselves to combination with tree crops (Lewis et al. 1984).

Silvopastoral agroforestry systems in western Oregon are made up of an agricultural component, (pasture and livestock), and a tree component. The objective is to manage the growth and interactions of the two components to optimize their combined output. To do this, it is important to understand the interactions between the pasture and trees, and how the balance between the two crops changes with time as the trees grow.

Plantation silviculture experience in western Oregon provides a foundation for understanding the interactions of young trees and herbaceous plants (Cleary et al. 1978). There is less knowledge about the interactions of established trees with the pasture understory, or how the interactions may be affected by agroforestry management practices.

Grasses and other pasture plants develop very rapidly, occupy the site quickly and can be very competitive tree seedlings, particularly for soil moisture. Grasses, which dominate western Oregon pasture, typically have very dense root systems compared to trees (Nnyamah and Black, 1977, Atkinson and Thomas, 1985, Sheffer et al. 1987, Garwood and Sinclair 1979). Grasses can capture soil moisture more effectively than trees, since water uptake is directly related to root abundance (Bowen 1985). Herbaceous competition increases summer moisture stress and reduces growth and survival of tree seedlings (Preest 1973, Sands and Nambiar 1984, Eissenstat and Mitchell 1983). Grass competition continues to influence moisture stress and growth of Douglas-fir well beyond initial establishment in western Oregon (Cole and Newton 1987, Carlson et al. 1994). It is not apparent how long pasture understory continues to affect the moisture stress and growth of the trees, or if that is influenced by management.

A tree may be able to escape some below-ground competition for moisture as it grows. Grasses keep a competitive advantage for moisture near the soil surface due to their higher rooting density. As trees grow, they can gain access to other soil moisture reserves by penetrating to deeper soil profiles less well utilized by grasses (McMinn 1963, Nnyamah and Black 1977, Eastham and Rose 1990). Nonetheless, pasture may be able to exploit soil moisture from soil profiles a meter deep (Doty et al. 1990) and continue to have an important effect on soil moisture availability and tree growth, even after establishment.

As the agroforest matures, the trees become increasingly competitive and dominant in stature and productivity. Pasture production progressively decreases with increasing crown cover (Sibbald et al. 1991, Percival and Knowles 1983, Dodd et al. 1972). The overstory structure influences the spatial and temporal pattern of light distribution (Jackson 1983, Reid and Ferguson 1992) as well the quality of light reaching the understory (Vézina and Péch 1964).

Pruning periodically reduces the extent and distribution of shade and so may extend the productive life of pasture. Initial spacing, thinning and pruning may be used to regulate shading and other competitive influences. However, accumulations of slash and patterns of animal use also contribute to the variability and decline in pasture productivity (Percival and Knowles 1983).

Pruning can be expected to influence tree growth and water use as well. When live branches are pruned, the leaf area is temporarily reduced, which may reduce photosynthesis, transpiration and growth (Helms 1964, Sato and Sugawara 1984, Daniel et al. 1979). Small reductions in tree growth have been reported in response to light pruning of conifers (Stein 1955, Staebler 1963, O'Hara 1991). Details about how pruning affects the moisture stress and growth of Douglas-fir with understory competition are lacking.

So although we have good knowledge about the behavior of very young trees and herbaceous plants, we do not have a very complete understanding of how they interact in later stages of development. In particular, we do not know if pasture continues to affect the moisture stress and growth of trees that are fully established, how trees affect the growth of the pasture, or how pruning may influence that competitive relationship.

My goal in this study was to develop a better understanding of how pruning influences the growth and interaction of the trees and pasture in a western Oregon agroforestry setting. To do this, I altered the competitive ability of each crop to examine 1) effects of pruning on moisture stress and growth of trees, 2) effects of pasture on moisture stress and growth of established trees, and 3) the effects of pruning on pasture productivity patterns.

METHODS

Study Sites

Four plantations representing potential agroforestry systems with Douglas-fir and pasture were chosen in western Oregon for this study. Two sites were in the Willamette Valley, and two in the Oregon Coast Range (Figure 1). All sites represented the mild, moist climate with the warm, dry summers typical of western Oregon valleys.

Sites were selected to meet the criteria of having: Douglas-fir trees of an operational pruning size, i.e., taller than 4 meters, but with a canopy that had not yet closed; an established understory dominated by grasses; and topographical uniformity within each stand to provide plots of similar aspect and slope.

There were sharp contrasts in weather between the two growing seasons during which this experiment was conducted. In 1992, annual precipitation was very much below normal (Table 1). The spring was particularly dry. No precipitation was recorded in May. There were more thunderstorms than normal in July and August, although precipitation remained low. In 1993, annual precipitation was near normal. In sharp contrast to 1992, the spring and early summer were very wet, and precipitation for the growing season reached a record high.

Alsea

The Alsea site was located in the upper end of the Alsea Valley, within the Coast Range, 19 miles southwest of Corvallis. The trees were planted in 1980, approximately 3 meters apart in a square grid pattern.

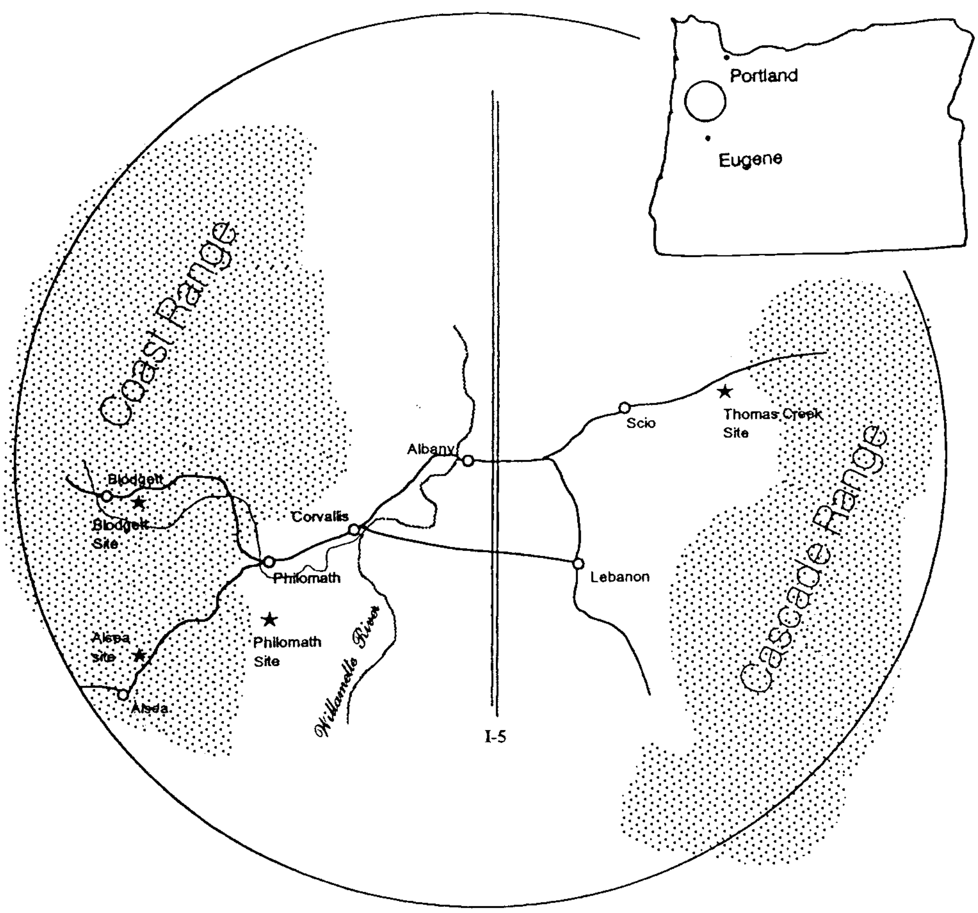

Figure 1. Map indicating the locations of the four study sites in Western Oregon.

Table 1. Precipitation at Corvallis, Oregon. Values (in mm) are given for 30 year normal and the two years of this experiment. Annual, (October 1 - September 30 annual water year) and the Growing Season, (March 1 - September 30 growing season).

	Annual	Growing Season
30 yr. Normal	1085	335
1992	750	215
1993	1060	495

The plantation was established on abandoned pasture and spot sprayed at planting to control competition. It was not fertilized or grazed. Tall fescue dominated the pasture community. The soil was a Chitwood silt loam, a deep, moderately well to poorly drained alluvial soil (Corliss 1973). This site was exposed to a stronger marine influence, with the highest precipitation of the four sites. Additional site and stand characteristics are presented in Table 2.

Blodgett

The Blodgett site was located in the Mary's River Valley, within the Coast Range, 12 miles west-northwest of Corvallis. The trees were planted in 1981 for Christmas tree production and thinned between 1987 and 1989 to roughly a 3 meter spacing in a square grid pattern. At plantation establishment, the site was in abandoned pasture. Broadcast chemical weed control was applied at planting and maintained through the harvest of the

Christmas tree crop. The fertilization history is not known. The plantation was not grazed. Tall fescue dominated the pasture community. The soil was a Waldo silty clay loam, a deep, poorly drained soil alluvial soil (Knezevich 1975). The Blodgett site was intermediate in precipitation but experienced similar interior climatic influence as the Willamette Valley. Additional site and stand characteristics are presented in Table 2.

Philomath

The Philomath site was located on the western edge of the Willamette Valley, 8 miles southwest of Corvallis. The trees were planted in 1984 into a young Christmas tree plantation, thinned between 1988 and 1990 to an average 3.3 meter irregular grid. Prior to Christmas tree production, the site had been used for grain and grass seed production. The plantation was chemically weeded through 1988. It was not fertilized after 1980, when it received 335 Kg N/ha. Highland bentgrass dominated the pasture community. The soil was a Bellpine silty clay loam, a moderately deep, well-drained soil (Knezevich, 1975). The Philomath site receives the least precipitation of the four sites. Additional site and stand characteristics are presented in Table 2.

Thomas Creek

The Thomas Creek site was on the eastern edge of the Willamette Valley, 33 miles northeast of Corvallis. The trees were planted in 1984, approximately 4 meters apart in a square grid pattern. Prior to tree planting, the site was salvage harvested and cleared of brush in 1983,

Table 2. Summary of Site Characteristics. Precipitation values estimated from 30 year Normal Annual (Taylor 1993). Stand Density values are means of all four treatment plots per site. Tree Height values are means of the two Pasture sites only, measured as part of forage analysis.

	Alsea	Blodgett	Philomath	Thomas Creek
Elevation (meters)	180	185	145	220
Aspect	S	NW	N	S
Slope (%)	0-3	0-3	0-3	2-4
Soil series	Chitwood	Waldo	Bellpine	Salkum
Precipitation (mm)	2030-2290	1780-2030	1250-1400	1400-1650
Year Planted	1980	1981	1984	1984
Stand Density (trees/ha)	1140	1030	880	540
Tree Height (meters)	6.5	5.8	5.3	5.4

then aerially seeded to pasture and fertilized at a rate of 108 Kg N/ha in 1984. Pasture competition was controlled by spot spray herbicide treatments in 1984 and 1985. The agroforest was grazed by sheep from 1986 until 1989, not grazed for two seasons, then grazed by cattle from 1991 to the present. Livestock were excluded from the forage plots in 1993. Tall fescue, bentgrass and orchardgrass were all similarly represented in the pasture community. The soil was classified as a deep, well-drained, Salkum cobbly silty clay loam (Langridge 1987). Additional site and stand characteristics are presented in Table 2.

The plantations at the two Coast Range sites were older than the two Willamette Valley sites, and the trees larger. Stand densities (Equation 1) were considerably higher at Alsea and Blodgett than at Philomath and Thomas Creek. As a result, tree crowns were beginning to grow together at Alsea and Blodgett. At Philomath, the irregular spacing pattern resulted in a mixed pattern of closure and open crown. At Thomas Creek there was open space between all trees.

Equation 1. Plot Stand Density, trees/ha.

$$\text{Density} = 10{,}000\text{m}^2/\text{ha} \,/(\text{mean distance (m) between trees})^2$$

Tree crowns extended to the ground at all sites. Circular patches of bare ground, with little or no pasture cover, were under most trees at all sites. Much of the variability in cover reflected the bare patches under trees. These patches extended from the trunk to about 2/3 the diameter of the crown, and persisted (at all sites but Thomas Creek) into the second growing season with little herbaceous recolonization.

Design and Treatments

The experiment was arranged in a randomized complete block, two by two factorial design. A site is a block. The experimental unit was a plot, each randomly assigned to a treatment. Factors included pruning trees, "Pruned" and not pruning trees, "Unpruned"; removal of pasture competition "No Pasture" and retaining pasture competition "Pasture" (Figure 2). Each plot consisted of nine measurement trees surrounded by a single-tree-wide buffer (Figure 3A).

	No Pasture	Pasture
Pruned Trees	Pruned No Pasture (PN)	Pruned Pasture (PP)
Unpruned Trees	Unpruned No Pasture (UN)	Unpruned Pasture (UP)

Figure 2. Treatment Design.

Treatments were applied to the entire plot and buffer. In the Pruned treatments, both measurement and buffer trees were pruned. In No Pasture treatments, the understory was completely removed to the outer crown line of the buffer trees (Figure 3A).

The plots were chosen with the objective of maximizing uniformity of the four plots within each site according to similarity in: tree size and density, forage condition and composition, aspect, slope. Woody weed species did not exceed 10% cover overall in any plot.

Pruning

In the Pruned treatments, all branches were removed from the bottom of the tree to approximately half the tree's height. The trees had not been pruned previously so this treatment was equal to roughly a 50% reduction in crown length. Pruning was done in the spring of the first year (late April 1992), after the start of active tree growth. In the Unpruned treatments, none of the crown was removed. Tree crown characteristics were recorded in the Pasture treatments only, for use in the regression analysis of forage production (Table 3).

Table 3. Tree crown characteristics of Pasture plots. Includes average tree height (Ht), average pruning height (PHt), average percent of crown length removed (Cr. Rem.) and average crown diameter (Cr. Diam.).

Site	TMT	Ht (cm)	PHt (cm)	Cr. Rem. (%)	Cr. Diam. (cm)
Alsea					
	PP	700	303	43	236
	UP	598	-		324
Blodgett					
	PP	580	266	45	212
	UP	580	-		308
Philomath					
	PP	533	256	48	207
	UP	522	-		317
Thomas Cr					
	PP	572	249	49	195
	UP	511	-		260

Pasture Removal

In the No Pasture treatments, all understory vegetation was chemically removed from the plot. Roundup (registered) herbicide (glyphosate, 1.5% by volume), was applied as a directed spray in April 1992, and again as a spot spray treatment in July 1992 and June 1993. Velpar (registered) pre-emergent herbicide (Hexazinone, 1.5 lbs

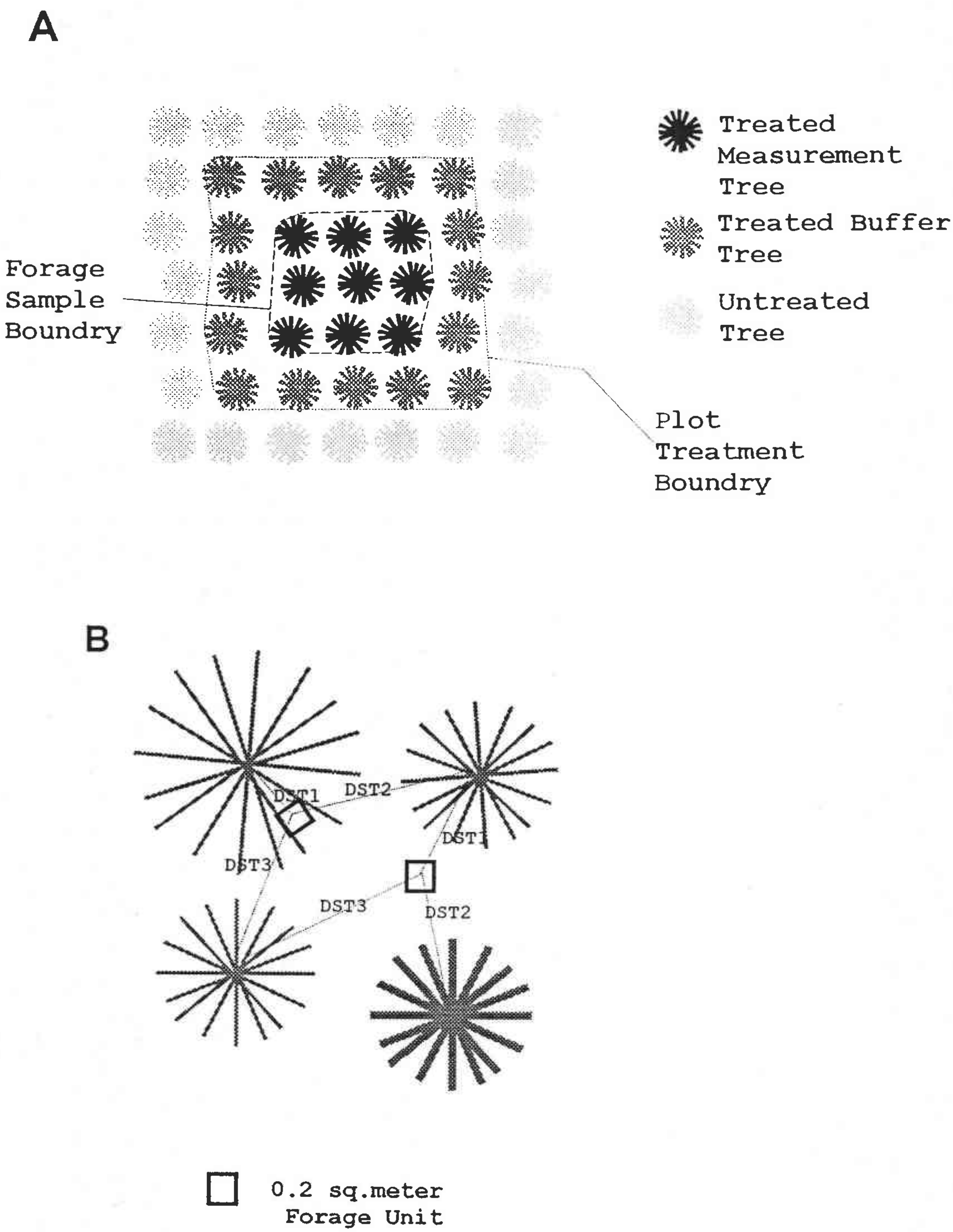

Figure 3. Treatment Plot Layout. A). Indicating positions of treatment boundary and forage sample boundary. B). Detail illustrating measurement of distance from each forage unit to each of the three nearest trees.

a.i./ acre) was applied in March 1993. In the Pasture treatments, the existing unimproved pasture was retained.

Pasture plants were not evenly distributed within the plots. The pasture had died in the densely shaded areas directly beneath the crown of nearly every tree, and an area of bare ground extended nearly to the outer edge of the crown. These bare spots generally persisted under pruned trees into the second season after treatment.

Sampling Procedure

Moisture Stress

Predawn xylem pressure potential, as described by Scholander et al. (1965), and Waring and Cleary (1967), was used as an index of tree moisture stress. In 1992, a series of five measurements were made at approximately three week intervals, beginning in early July and ending in mid September. Six of the nine trees per plot were sampled in random order. In 1993, a series of four measurements were made at approximately monthly intervals, beginning in late June and ending in early October. All nine measurement trees in each plot were sampled.

A single twig was cut from the third or fourth branch whorl from the top of the tree. Samples were collected before dawn in small sub-units of 3 to 6 trees. Sample twigs were individually bagged and briefly iced while xylem pressure potential readings were made in the field, within 10 minutes of cutting, in the order collected.

Incremental Growth

A ratio of post-treatment and pre-treatment radial increments was used as an index of tree growth (Schoenmackers et al. 1985). A single increment core was taken at breast height from the north quadrant of each measurement tree in October 1993. Cores were glued to boards, dried and sanded before measurement. Ring widths were measured to the nearest 0.1 mm for the two year post-treatment ("response") and pre-treatment ("calibration") growth periods and used to calculate the Growth Ratio Index (GRI), (Equation 2), (Schoenmackers et al. 1985).

Equation 2. Growth Ratio Index (GRI). Growth increments in mm.

GRI =(92increment+93increment)/(90increment+91increment)

Forage

Forage biomass production was measured directly once each season in June, when the standing crop was estimated to be near its peak. Twenty forage sample units, each 0.2 m^2, were measured in each Pasture treatment plot. Forage measurements were taken from within an sample area defined by the collective outer crown edges of the nine measurement trees. Measurements were made between and beneath individual trees (Figure 3B). Sampling did not extend into the buffers. Percent cover was estimated visually and recorded before clipping. Samples were clipped to within 5 cm of the ground, bagged, dried in ovens at 50°C for 48 hrs and weighed.

To facilitate regression modeling, forage sample units were positioned to capture the full range of variability. Both extremes of pasture growth were included in the sample, from bare ground to the apparently most productive area. Similarly, a range of proximities to the nearest tree were included. Sample units were positioned independently each season. Forage production (and associated light summaries) were descriptive data from subjectively selected, not a randomized or stratified collection of points and were not suited to statistical tests of differences among treatments.

Crown characteristics, proximity of trees to individual forage units and an index of light received were used as indicator variables to model forage production. Total height, pruning height, and crown diameter were recorded for measurement and buffer trees in Pasture plots for the start of each growing season. Crown length (total height-pruning height) and crown volume (Equation 3) were calculated from these data. The distance from each forage unit to the three nearest trees was also measured (Figure 3B).

Equation 3. Tree Crown Volume, (cm^3).

$$\text{Crown Volume} = ((.25)*(3.14159)*(\text{Crown Diameter})^2) / 3*(\text{Crown Length})$$

An estimate of the proportion of total irradiation received in a day at ground level was used as an index of the understory light environment. Light at ground level was measured at each forage sampling unit using a Diazo paper Light Integrator (DLI) described by Friend (1961), and Emmingham (1971). Readings were made once each season under clear sky conditions (Atzet and Waring 1970, Emmingham 1971) near the fall equinox, when the DLI's were in place for an entire dawn to dusk period. The DLI's were calibrated with a Li-Cor Quantum Meter (model LI 190SA and LAI-2000 Plant Canopy Analyzer Data Logger) placed in full sun. Regression equations were developed to convert the DLI values to an estimate of Photosynthetic Photon Flux Density (PPFD 400-700NM) according to Friend (1961), (Equations 4 and 5).

Equation 4. Conversion of Diazo values to PPFD, 1992.

$$PPFD = 10^{(3.0877 + (0.092537 * diazo)}$$

Equation 5. Conversion of Diazo values to PPFD, 1993.

$$PPFD = 10^{(4.709552 + (0.042198 * diazo)}$$

Each value was then expressed as a proportion of the PPFD received in full sun at that site, on that day.

Analysis

An analysis of variance (ANOVA) was performed on tree moisture stress data. A separate ANOVA was performed for each sampling date. The Bonferroni method was used as a means separation test. This test is equivalent to the Least Significance Difference test, but dividing alpha by the number of comparisons to generate the significance level, in this case p=0.0083 (Stafford and Sabin 1993). This test allowed for comparison of all treatment factor combinations. In 1993, a log base$_{10}$ transformation of moisture stress was used to correct for unequal variance and non-normal distributions. The 1993 analysis and results presented are for transformed data. The 1992 data were more nearly normal in their distribution and so were not transformed.

The experimental structure suggested the use of repeated measures and covariate analyses. A repeated measures analysis was performed on each of the two years' data, but not utilized in this report. The analyses indicated a significant effect of time on moisture stress, but no interaction of time with either treatment factor. Combining the multiple sampling dates gives a higher degree of freedom, and should result in more analytical power. However, fewer significant differences developed in the repeated measures analysis than in ANOVA, which reflects a loss of statistical power. The loss of significant differences relative to the analysis by individual dates indicates a violation of statistical assumptions that were not corrected by transformation (Sabin 1994). The repeated measures test was therefore considered inappropriate and ANOVA selected for reporting.

A covariate analysis (ANCOVA) was also performed but not accepted. Plot stand density was tested as a covariate. No significant effect of plot stand density on moisture stress was indicated. There was a loss of significant differences in the ANCOVA relative to the individual ANOVA, indicating a loss of statistical power rather than an increase (Sabin 1994). The ANOVA was selected for reporting.

Incremental growth data was analyzed using ANOVA. A single ANOVA was performed on the Growth Ratio Index to compare treatment affects. A Bonferroni least squares means test (alpha=0.0083) allowed for comparison of all treatment factor combinations and was used to separate treatment means.

A stepwise multiple linear regression procedure was used in the forage yield analysis. The log $base_{10}$ transformation of forage yield was used for the response variable. Indicator variables are listed in Table 4. A Logit transformation was used for the proportional variable of light (Equation 6) and log $base_{10}$ transformations used for distance variables. (Stafford and Sabin, unpublished).

Equation 6. Logit Transformation of percent full light.

LGTRL = log $base_{10}$(% full light*0.1)/(1-% full light*0.1)

In 1992, the results reported are from an analysis of just three of the four sites. The Thomas Creek site was excluded because it was heavily grazed before the treatments were installed.

A DOS PC version of SAS statistical software (SAS Institute, 1985) was used for each analysis.

Table 4. List of variables offered for the stepwise regression models for forage yield of Pruned and Unpruned data sets.

VARIABLE	DESCRIPTION
Response Variable:	
LOGWT	Log base $_{10}$ transformation of weight (grams per meter squared) produced at sample forage unit (FU).
Indicator Variables:	
LGTRL	Logit transformation of the ratio of light received at FU to light received in full sun position (micromoles per second per square meter).
LDST1	Log base $_{10}$ transformation of distance (cm) from FU to the nearest tree (tree 1).
LDST2	Log base $_{10}$ transformation of distance (cm) from FU to second nearest tree (tree 2).
LDST3	Log base $_{10}$ transformation of distance (cm) from FU to third nearest tree (tree 3).
LMDST	Log base $_{10}$ transformation of mean distance (cm) from FU to three nearest trees, as an index of density.
V1T1	Crown volume (cm^3) of tree 1, start of first growing season (1992).
V1T2	Crown volume (cm^3) of tree 2, start of first growing season.
V1T3	Crown volume (cm^3) of tree 3, start of first growing season.
CL1T1	Crown length (cm) of tree 1, start of first growing season.
CL1T2	Crown length (cm) of tree 2, start of first growing season.
CL1T3	Crown length (cm) of tree 3, start of first growing season.

Table 4. (Continued).

VARIABLE	DESCRIPTION
CR1T1	Crown width (cm) of tree 1, start of first growing season.
CR1T2	Crown width (cm) of tree 2, start of first growing season.
CR1T3	Crown width (cm) of tree 3, start of first growing season.
H1T1	Tree height (cm) of tree 1, start of first growing season.
H1T2	Tree height (cm) of tree 2, start of first growing season.
H1T3	Tree height (cm) of tree 3, start of first growing season.
V2T1	Crown volume (cm^3) of tree 1, start of second growing season (1993).
V2T2	Crown volume (cm^3) of tree 2, start of second growing season.
V2T3	Crown volume (cm^3) of tree 3, start of second growing season.
CL2T1	Crown length (cm) of tree 1, start of second growing season.
CL2T2	Crown length (cm) of tree 2, start of second growing season.
CL2T3	Crown length (cm) of tree 3, start of second growing season.
CR2T1	Crown width (cm) of tree 1, start of second growing season.
CR2T2	Crown width (cm) of tree 2, start of second growing season.
CR2T3	Crown width (cm) of tree 3, start of second growing season.
H2T1	Tree height (cm) of tree 1, start of second growing season.
H2T2	Tree height (cm) of tree 2, start of second growing season.
H2T3	Tree height (cm) of tree 3, start of second growing season.

RESULTS

Moisture Stress

During the 1992 growing season there was a trend for tree moisture stress to increase through late summer then level off or decline, following light rains. This trend was evident at all sites (Fig 4). Plot means ranged from -0.31 MPa to -1.23 MPa. The Alsea and Blodgett sites showed the most stress (most negative xylem pressure potentials), greatest differences between treatments and the most distinct decline in late summer moisture stress. Peak moisture stress developed most rapidly at Blodgett. The Thomas Creek site developed the least negative xylem pressure potentials, while Philomath was intermediate. Both showed a leveling rather than distinct decline in late summer moisture stress.

At the Alsea and Blodgett sites, there was a trend for trees in the Pruned/Pasture treatment to show the most stress, and in Pruned/No Pasture to show the least stress. There was less development of a trend at Philomath and Thomas Creek, although the Unpruned/No Pasture treatment showed the most stress at the end of the growing season.

The 1992 treatment means of all four sites showed a pattern of increased moisture stress through late August, followed by a decline in mid September to levels similar to those recorded in early August, prior to late summer rainfall (Figure 5).

In 1992, there were few differences (at $p=0.05$) between treatment factors (please refer to ANOVA tables, Appendix, Tables 1-5). Comparing individual treatments within individual sapling dates, trees in Pruned/No Pasture tended to be less moisture stressed than the other

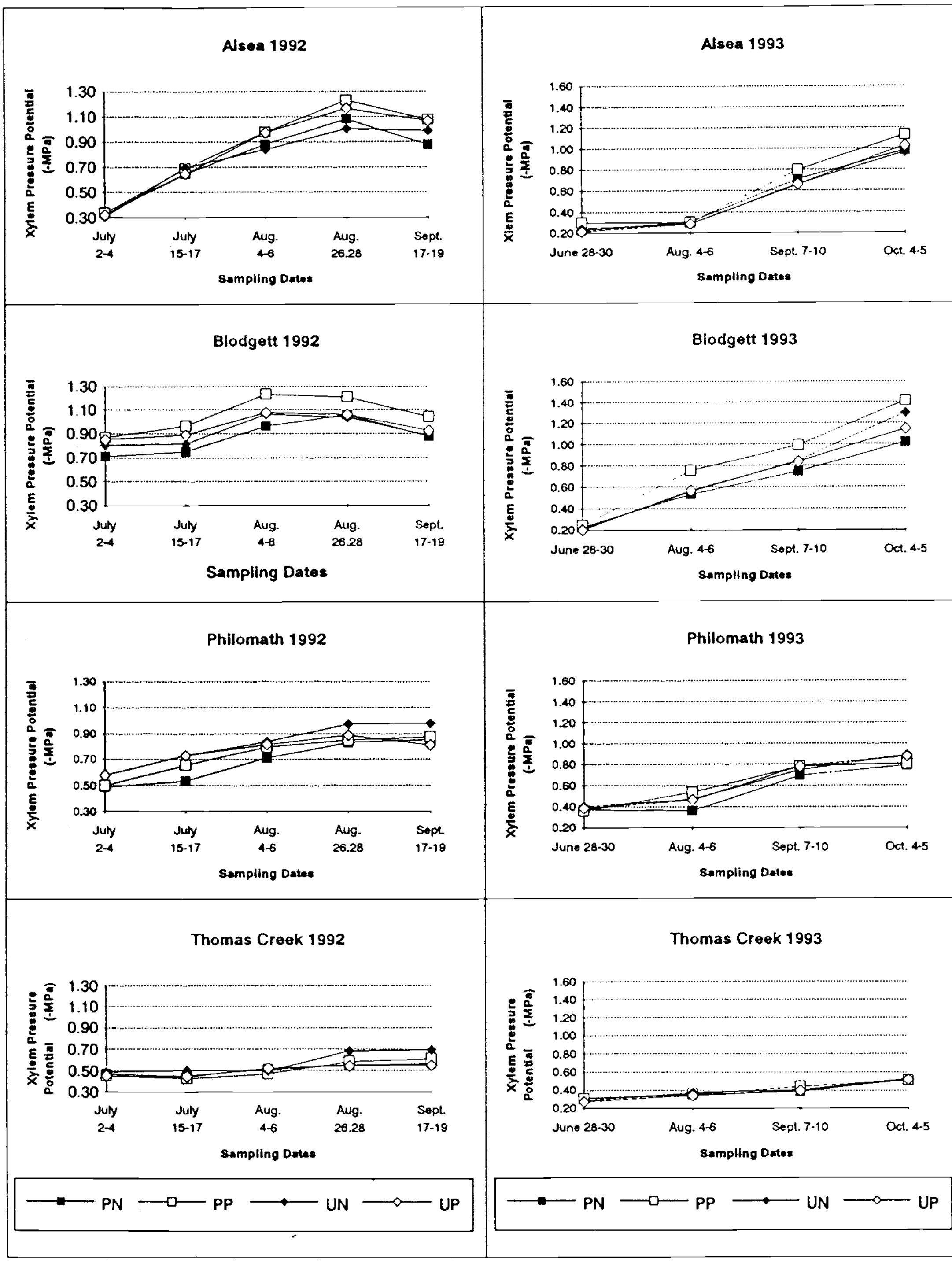

Figure 4. 1992 and 1993 Predawn xylem pressure potentials for individual study sites, Alsea, Blodgett, Philomath and Thomas Creek. Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), and Unpruned/Pasture (UP).

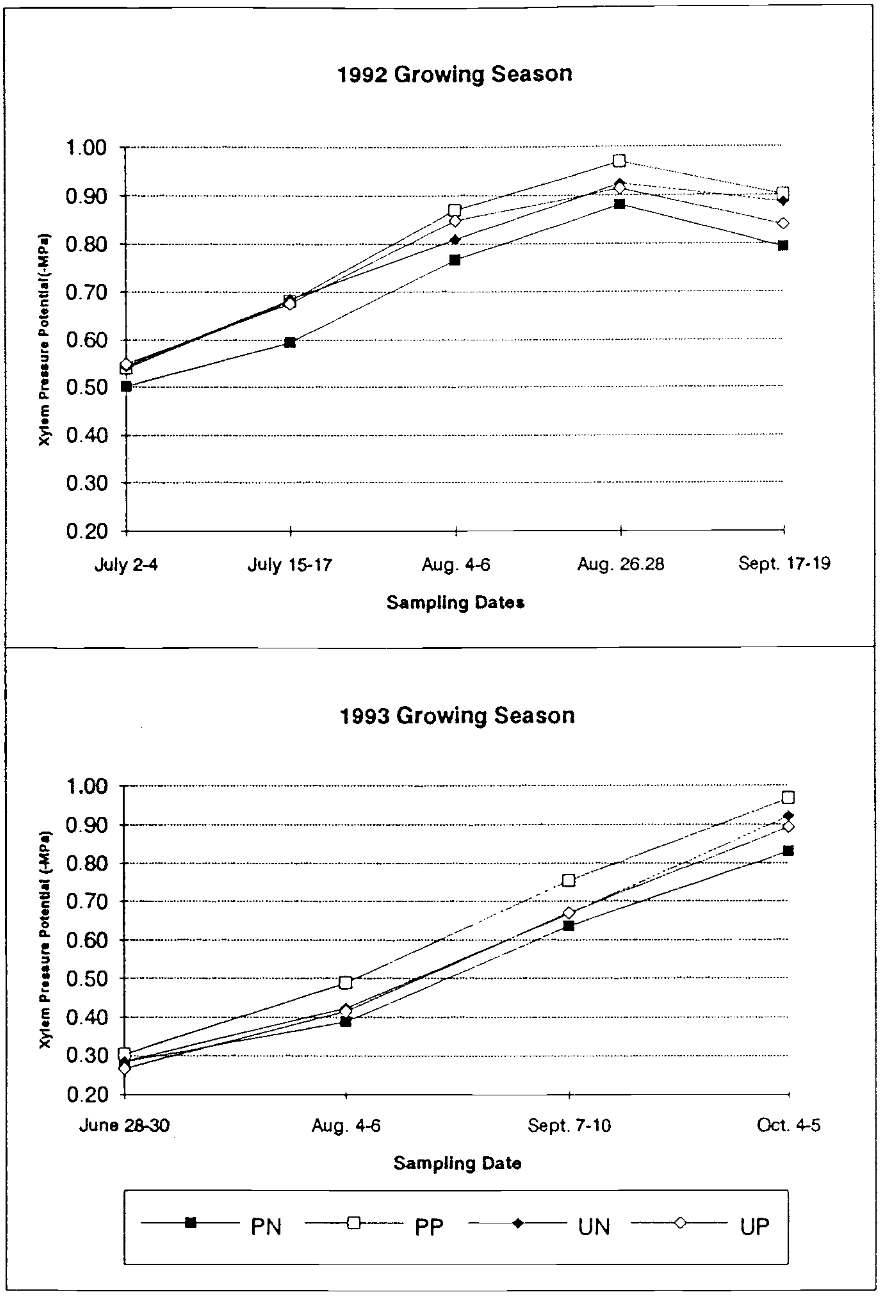

Figure 5. Predawn xylem pressure potential treatment means, all four study sites. A). 1993 growing season. B). 1992 growing season. Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), and Unpruned/Pasture (UP).

treatments. Tree moisture stress in Pruned/No Pasture treatment was lower than all others in July, lower than Pruned/Pasture in early August, and lower than Pruned/Pasture and Unpruned/Pasture treatments in September (Tables 5 & 6). Trees in Pruned/Pasture tended to develop more moisture stress and earlier than the other treatments. Tree moisture stress was higher in Pruned/Pasture than in Pruned/No Pasture treatments, on the mid-July, early August and September sampling dates (Tables 5 & 6).

In 1992, there was a trend for an interaction between the two treatment factors, where pruning influenced the effect of pasture. The interaction was significant ($p=0.0457$) only on the mid September sampling date (Appendix, table 5). Where trees were Pruned, pasture removal (No Pasture) decreased moisture stress compared to Pasture. The differences in moisture stress between Pruned/No Pasture and Pruned/Pasture were significant in September ($p=0.0001$), as well as in mid-July ($p=0.0001$) and early August ($p=0.0010$). Where trees were Unpruned, pasture removal (No Pasture) tended to increase moisture stress compared to Pasture. The differences in moisture stress between Unpruned/No Pasture and Unpruned/Pasture were insignificant in all cases.

Table 5. 1992 predawn xylem pressure potential (-MPa), by individual sampling dates. Standard Errors in ().

Factor	July 2-4	July 15-17	Aug. 4-6	Aug. 26-28	Sept. 17-19
Pruned No pasture	0.4750 (0.0318)	0.6035 (0.02330)	0.7604 (0.0388)	0.8804 (0.5240)	0.7921 (0.0333)
Pruned pasture	0.5538 (0.0450)	0.6971 (0.0353)	0.6819 (0.0549)	0.9578 (0.0615)	0.9005 (0.0429)
Unpruned No pasture	0.5410 (0.0370)	0.6921 (0.0230)	0.8119 (0.0404)	0.9233 (0.0349)	0.8861 (0.0305)
Unpruned Pasture	0.0667 (0.0468)	0.6897 (0.0298)	0.8448 (0.0445)	0.9128 (0.0534)	0.8388 (0.0440)

Table 6. 1992 p-value comparisons, predawn xylem pressure potential. Bonferroni test for significance (p=0.0083). Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), Unpruned/Pasture (UP).

July 2-4, 1992

	PN	PP	UN	UP
PN	.	0.1143	0.0656	0.0442
PP	0.1143	.	0.8103	0.6338
UN	0.0656	0.8103	.	0.8022
UP	0.0442	0.6338	0.8022	.

July 15-17

	PN	PP	UN	UP
PN	.	0.0001	0.0001	0.0001
PP	0.0001	.	0.8775	0.7662
UN	0.0001	0.8775	.	0.6532
UP	0.0001	0.7662	0.6532	.

August 4-6

	PN	PP	UN	UP
PN	.	0.0010	0.1704	0.0086
PP	0.0010	.	0.0470	0.4800
UN	0.1704	0.0470	.	0.1955
UP	0.0086	0.4800	0.1955	.

August 26-28

	PN	PP	UN	UP
PN	.	0.0180	0.2358	0.3503
PP	0.0180	.	0.2205	0.1354
UN	0.2358	0.2205	.	0.7911
UP	0.3503	0.1354	0.7911	.

September 17-19

	PN	PP	UN	UP
PN	.	0.0001	0.0008	0.0850
PP	0.0001	.	0.6004	0.0253
UN	0.0008	0.6004	.	0.0844
UP	0.0850	0.0253	0.0844	.

In 1993, tree moisture stress increased throughout the growing season at all sites (Fig 4). Plot means ranged from -0.20 MPa to -1.42 MPa. The Alsea and Blodgett sites again developed the most stress (most negative xylem pressure potentials), and showed the greatest differences between treatments. The Thomas Creek site developed the least negative xylem pressure potentials, and Philomath was intermediate.

In 1993 as in 1992, there was a trend at Alsea and Blodgett for trees in the Pruned/Pasture treatment to show the most stress (Figure 4). The Pruned/No Pasture treatment showed the least stress at Blodgett, although it was not evident at the other sites. There was little trend development at Philomath and Thomas Creek (Figure 4).

The 1993 treatment means of all four sites showed a trend for increasing stress through the end of the growing season (Figure 5). Trees in the Pruned/Pasture treatment again showed a trend of the greatest moisture stress, and in Pruned/No Pasture showed the least.

In 1993, there were few differences (at p=0.05) between treatment factors (please refer to ANOVA tables, Appendix, Tables 6-9). Comparing individual treatments, Pruned trees in No Pasture tended to be least stressed for moisture, although this trend was less pronounced in 1993 than in 1992. Tree moisture stress in Pruned/No Pasture was lower than Pruned/Pasture in August and September, and October, and Unpruned/No Pasture in October (Tables 7 & 8). Pruned trees in Pasture developed the most moisture stress, a trend which was more pronounced in 1993 than in 1992. Tree moisture stress was greater in the Pruned/Pasture than the other three treatments in August and September, greater than Unpruned pasture in June and greater than Pruned/No Pasture in October (Tables 7 & 8).

Table 7. 1993 predawn xylem pressure potential (-MPa), untransformed data, by individual sampling dates. Standard Errors in ().

Treatment Factor	June 28-30	Aug.4-6	Sept. 7-10	Oct. 4-5
Pruned No pasture	0.2875 (0.0159)	0.3878 (0.0180)	0.6350 (0.0288)	0.8300 (0.0395)
Pruned Pasture	0.3033 (0.0125)	0.4883 (0.0310)	0.7536 (0.0368)	0.9672 (0.0617)
Unpruned No pasture	0.2857 (0.0187)	0.4247 (0.0211)	0.6675 (0.0310)	0.9211 (0.0513)
Unpruned Pasture	0.2695 (0.0187)	0.4158 (0.0217)	0.6706 (0.0326)	0.8925 (0.0440)

Table 8. 1993 p-value comparisons, predawn xylem pressure potential. Log transformed values, test for significance (p=0.0083). Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), Unpruned/Pasture (UP).

June 28-30

	PN	PP	UN	UP
PN	.	0.1136	0.8704	0.1081
PP	0.1136	.	0.0785	0.0018
UN	0.8704	0.0785	.	0.1431
UP	0.1081	0.0018	0.1431	.

August 4-6

	PN	PP	UN	UP
PN	.	0.0001	0.0370	0.1258
PP	0.0001	.	0.0051	0.0008
UN	0.0370	0.0051	.	0.5720
UP	0.1258	0.0008	0.5720	.

September 7-10

	PN	PP	UN	UP
PN	.	0.0001	0.1360	0.1420
PP	0.0001	.	0.0004	0.0004
UN	0.1360	0.0004	.	0.9819
UP	0.1420	0.0004	0.9819	.

October 4-5

	PN	PP	UN	UP
PN	.	0.0003	0.0067	0.0372
PP	0.0003	.	0.3283	0.1052
UN	0.0067	0.3283	.	0.5165
UP	0.0372	0.1052	0.5165	.

In 1993 as in 1992, there was a trend for an interaction between the two treatment factors, where pruning influenced the effect of pasture. The interaction was suggestive (p=0.0583) in August and significant (p=0.0134) in September (Table 8). Where trees were pruned, pasture removal (No Pasture) decreased moisture stress compared to Pasture. The differences in moisture stress between Pruned/No Pasture and Pruned/Pasture were significant in August (p=0.0001) September (p=0.0001) and October (p=0.0003), (Table 8). Where trees were Unpruned, pasture removal (No Pasture) tended to increase moisture stress Compared to Pasture. The differences in moisture stress between Unpruned/No Pasture and Unpruned/Pasture were insignificant in all cases.

Incremental Growth

Annual incremental (radial) growth averaged 8.5 mm/yr over the four years of calibration and response growth, all four sites combined. Average growth appeared greater in the two years following treatment (8.62 mm/yr) than in the two before treatment (8.38 mm/yr). As a result, the Growth Ratio Index (GRI) was generally greater than 1.0, but ranged from 0.92 to 1.13. (Figure 6).

The GRI decreased with Pruning (p=0.0014) and Pasture (p=0.039) treatments (Tables 9 & 10). Pruning had the larger effect. The GRI was lower for trees in Pruned/Pasture than the other three treatments, none of which were significantly different from each other. (See ANOVA table, Appendix, Table 10). There was no interaction between treatment factors.

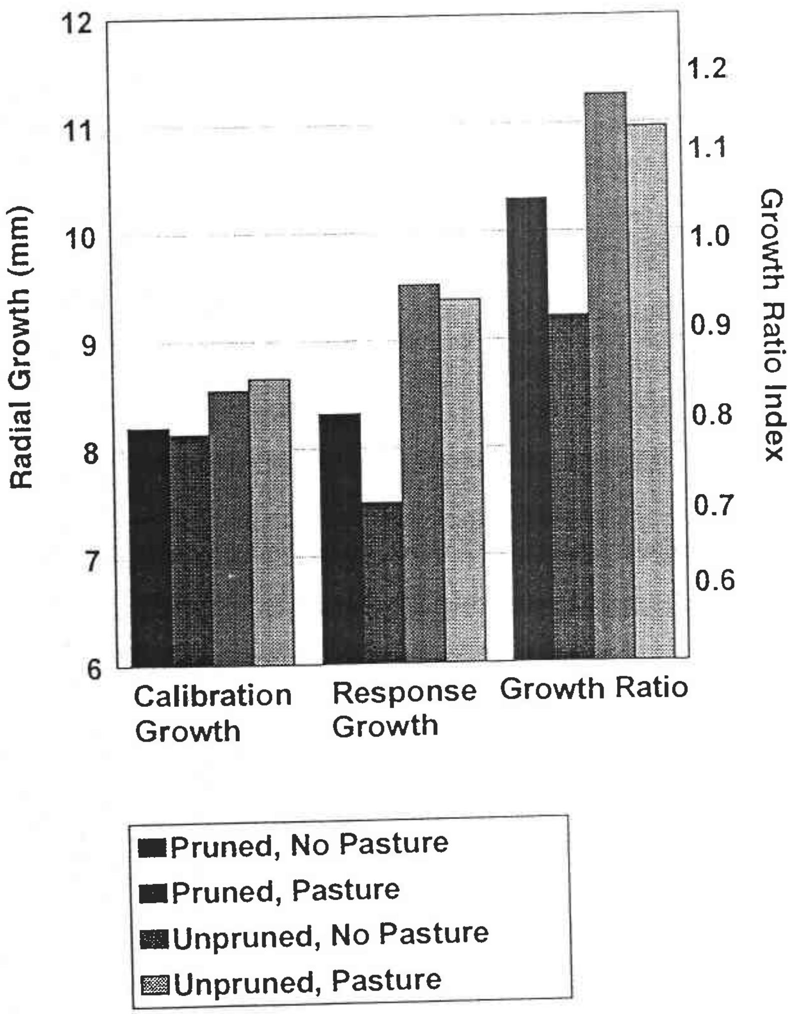

Figure 6. Growth Ratio Index treatment means, all study sites. Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), and Unpruned/Pasture (UP).

Table 9. Means Table for Growth Ratio Index. Upper value is treatment mean representing two years growth before treatment (calibration) or after (response), in millimeters. (Standard Error).

Treatment Factor	Calibration	Response	Growth Ratio Index
Pruned No pasture	8.20 (0.226)	8.32 (0.198)	1.033 (0.029)
Pruned pasture	8.14 (0.181)	7.49 (0.210)	0.921 (0.018)
Unpruned No pasture	8.54 (0.294)	9.51 (0.344)	1.128 (0.032)
Unpruned Pasture	8.64 (0.296)	9.37 (0.303)	1.097 (0.025)

Table 10. Growth Ratio Index, Least Squares Means comparisons of treatment differences p-values. Bonferroni method test for significance (p=0.0083). Pruned No pasture (PN), Pruned/Pasture (PP), Unpruned No pasture (UN), Unpruned/Pasture (UP).

	PN	PP	UN	UP
PN	.	0.0024	0.0119	0.0815
PP	0.0024	.	0.0001	0.0001
UN	0.0119	0.0001	.	0.4194
UP	0.0815	0.0001	0.4194	.

Forage Production

Forage biomass production patterns were highly variable within plots and between sites in both years of the study. The pasture plants had died in the densely shaded areas directly beneath the tree crown. Bare ground extended nearly to the outer edge of the crown. These bare spots persisted under pruned trees into the second season after treatment. The bare areas were only recolonized at Thomas Creek. Sample yields ranged from zero Kg/ha (bare ground) to 8616 Kg/ha.

The ratio of full light received was also highly variable within plots and between sites. In 1992, measured light values ranged from 15% to 81% of full sun in Pruned treatments, and from of 0.9% to 53% full sun in Unpruned treatments. In 1993, measured light values ranged from of 11% to 74% full sun in Pruned treatments and form 1.2% to 42% of full sun in Unpruned treatments.

In 1992, using transformed data, forage yield in the Pruned treatment showed a significant correlation with distance to the nearest tree only. In the Unpruned treatment forage yield showed a strong correlation with the ratio of light received, the distance from the nearest tree, and average distance to the three nearest trees. (See correlation matrixes, Appendix A, Tables 11 and 12).

For the 1992 Pruned data, a five variable regression model was produced to describe forage production patterns. The final model included variables for distance to the nearest tree, distance to the second nearest tree, average distance to the three nearest tees, crown volume of the nearest tree and height of the third nearest tree. It had an R-square of 60 (Equation 7).

Equation 7. Regression Equation, Pruned/Pasture, 1992.

Log of Forage Yield = 1.755 +
(3.034) Log of distance to nearest tree +
(2.629) Log of distance to the 2nd nearest tree -
(5.195) Log of mean distance to nearest 3 trees -
(0.00331) Crown diameter of the nearest tree +
(0.000816) Height of the 3rd nearest tree

R-square = 0.60

Variables were entered in the order shown, with partial R-squares of 0.491, 0.068, 0.067, 0.035, 0.017 respectively.

Another five variable regression model was produced for 1992 Unpruned data. The model included variables for the ratio of light received, crown volume of the nearest tree, the distance to the nearest tree, distance to the second nearest tree, and crown diameter of the second nearest tree. It explained 69% of the total variability (Equation 8).

Equation 8. Regression Equation, Unpruned/Pasture, 1992.

Log of Forage Yield = -2.913 +
(0.551) Logit transformation of light index -
(4×10^{-8}) Crown volume of the nearest tree +
(1.364) Log of distance to nearest tree +
(1.652) Log of distance to 2nd nearest tree -
(0.00189) Crown diameter of the 2nd nearest tree

R-square = 0.69

Variables were entered in the order shown, with partial R-squares of 0.53, 0.044, 0.0371, 0.057, 0.019 respectively.

In 1993, using transformed data, forage yield in the Pruned treatment showed a significant correlation with distance to the nearest tree, average distance to the nearest three trees and crown volume of the second nearest tree. In the unpruned treatments there was a significant correlation with the ratio of light received, the distance from the nearest tree, average distance to the three nearest trees and the crown diameter and crown volume of the second nearest tree. (See correlation matrixes, Appendix, Tables 13 and 14).

For the 1993 Pruned data, a two variable regression model was produced to describe forage production patterns. The final model included only the distance to the nearest tree, and average distance to the nearest three trees and explained just 45% of the variability (Equation 9).

Equation 9. Regression Equation, Pruned/Pasture, 1993.

Log of Forage Yield = -5.118 +
(1.710) Log of distance to nearest tree +
(1.548) Log of mean distance to nearest 3 trees

R-square = 0.45

Variables were entered in the order shown, with partial R-squares of 0.420, and 0.033 respectively.

For the 1993 Unpruned data, a three variable regression model was produced. The model included variables for distance to the nearest tree, ratio of light received and crown volume of the second nearest tree. It explained 73% of the variability (Equation 10).

Equation 10. Regression Equation, Unpruned/Pasture, 1993.

Log of Forage Yield = -1.139 +
(1.780) Log of distance to nearest tree +
(0.474) Logit transformation of light index -
(1×10^{-8}) Crown volume of the 2nd nearest tree

R-square = 0.73

Variables were entered in the order shown, with partial R-squares of 0.603, 0.107 and 0.017 respectively.

The production models fitted for Unpruned data explained more variability (69% and 73%) than did the models for the Pruned data sets (60% and 45%). The models fitted to the Unpruned treatments explained similar amounts of the total variability in both years although the models were quite different. The amount of variability explained by models fitted to the Pruned treatments declined from the first to the second year.

The variable for distance to the first tree was included in the regression formulae for both Pruned and Unpruned treatments for both years. It was the first variable entered and explained the most variability in all but the Unpruned pasture treatment in 1992. Variables for the distance to the second nearest tree or the average distance to the three nearest trees (an index of relative density) were often included. Values of crown length, width and volume were not consistently included. In all cases yield was also strongly correlated to percent cover. Percent cover is itself an expression of forage growth, and so is not of interest as a prediction variable, and not included in the analyses.

DISCUSSION

Moisture Stress

I hypothesized that Pruned trees would develop less moisture stress than Unpruned trees. I anticipated that by decreasing the size of the crown, pruning would reduce transpiration by the trees, reduce the rate of soil water depletion and thus prolong the availability of soil moisture in the two seasons following treatment.

I hypothesized that trees growing without competing understory pasture would develop less moisture stress than trees growing with competition. I anticipated that pasture removal would decrease transpiration and soil water use overall and thus prolong the availability of the soil moisture in the two seasons following treatment. I hypothesized no interaction between the treatment factors, but expected an additive response to each treatment. Thus, trees in the Pruned/No Pasture treatment were expected to show the least moisture stress, Unpruned/No Pasture and Pruned/Pasture would be intermediate, and Unpruned/Pasture would show the most stress.

Pruning

My hypothesis that Pruned trees would show less moisture stress than Unpruned trees was not strongly supported by my results. Comparing the treatments with no understory competition (No Pasture), Pruned trees showed consistently lower moisture stress than Unpruned trees. The differences were generally small and were significant only twice in 1992, and once in 1993. This suggests that in the absence of other evapotranspirational losses, pruning led to a small improvement in tree moisture status as predicted. With pasture competition however, pruning appeared to have the opposite effect. Pruned (Pasture) trees had more negative pressure potentials than Unpruned (Pasture) trees once in 1992, and three times in 1993.

Overall, pruning failed to reduce tree moisture stress. In 1992, Pruned trees tended to show slightly less moisture stress than Unpruned trees, a trend which was reversed in 1993.

So what happened in my study, that it did not clearly demonstrate the hypothesized effect of pruning? One possibility, in contrast to my hypothesis, is that pruning had little or no influence on water use or xylem pressure potential. That is, the pruning treatment was not severe enough to alter the net transpiration from the crown. Pruned and unpruned trees transpired similar amounts, and so no differences developed.

Another possibility is that pruning did reduce transpiration and water use by the tree as hypothesized, but also led to other losses of soil moisture. An increase in bare-soil evaporation or understory transpiration could offset any reductions in moisture use caused by crown removal. This may have prevented anticipated responses in soil moisture and xylem pressure potential.

The literature indicated the potential of crown removal to reduce water use by the tree, and thus reduce moisture stress. Helms (1964) found that thinning and pruning treatments improved water availability to Douglas-fir trees, possibly because of the reduced transpirational surface. Soil water use has been shown to be influenced by stand density. Soil water depletion was reduced by thinning conifer stands (Butcher 1977, Haberland and Wilde 1961, de Vries and Wilde 1962, Riegel 1992), and by initial spacing of Eucalyptus (Eastham et al. 1990) and apple trees (Atkinson and Thomas 1985). These reports are consistent with my observations of differences in moisture stress between sites. Trees at Alsea and Blodgett were larger, and planted at higher densities than trees at Philomath and Thomas Creek. Alsea and Blodgett received greater precipitation, but the trees at these sites developed more moisture stress each season.

Decreased water use and improved moisture status following manipulation of individual tree crowns have also been reported. Pruning has been observed to reduce water use in temperate deciduous fruit trees, and has been used to insure survival of trees suffering severe drought conditions (Mika 1986). Xylem pressure potentials increased following pruning of fruit trees (Ferree et al. 1984). Osman and Sharrow (1993) reported a reduction of moisture stress in the season following 25% defoliation of current year's growth of 3 year-old Douglas-fir. However, moisture stress increased following more severe defoliations (50% and 75%), and no effects were observed in the season of defoliation.

Sato and Sugawara (1984) reported that severe pruning of young Sakhalin Spruce (*Picea glehnii*) trees (more than half the crown length removed), lowered the heat pulse velocity of xylem sap nearly two months later. This indicated a reduction in water use. Summer pruning caused an immediate but temporary increase in the xylem pressure potential. The change lasted less than 2 hours in this observational study. Sato and Sugawara's heat pulse results support my hypothesis that pruning would reduce tree water use, although trees in their study failed to show my expected response of less negative pressure potentials. No understory was described in the Sato and Sugawara study, so it is not clear whether any competing vegetation was present. If competing vegetation was present, then their lack of a persistent change in xylem pressure potential would be in agreement with the trends observed in my study.

Evidence supporting the possibility that pruning did not alter water use and moisture stress was also reported. The increased photosynthetic activity of the remaining foliage after pruning (Helms 1964, Ericsson et al. 1985, Ferree et al. 1984) suggests an increase in transpiration that might offset losses in leaf area. Stomatal regulation responds to both internal and atmospheric conditions (Running 1976), and daily regulation could function to compensate for changes in crown size.

I concluded that the pruning treatment in my experiment caused a small reduction in water use by the trees. Without an increase in other evapotranspirational losses, pruning led to a small reduction in tree moisture stress as predicted. This was illustrated by higher xylem pressure potentials for trees in Pruned/No Pasture compared to Unpruned/No Pasture treatments and supported by the literature. The lack of a response to pruning with pasture competition, was likely the result of increased moisture use from the understory.

Pasture Removal

The hypothesis that pasture removal would reduce the moisture stress of the trees was only weakly supported by my results. No differences were found between trees growing with and without pasture when the trees were Unpruned. However when pruned, trees growing with pasture tended to experience the most moisture stress, while those without pasture competition experienced the least stress. I observed differences three times in 1992 and three times in 1993. Differences in moisture stress developed briefly each summer, but were not maintained later into the season.

So what happened in my study, that it did not clearly demonstrate the hypothesized effect of pasture removal? One possibility is that pasture plants no longer influenced moisture stress of the established Douglas-fir trees because the trees had gained access to additional moisture beyond the influence of herbaceous competition. If so, removal of the pasture had no influence on water use or moisture stress of the trees because each crop was using a separate source of moisture.

Another possibility is that pasture plants could still compete with established Douglas-fir for moisture, but only did so when well illuminated. That is, pasture competition was limited by the lack of light reaching the understory. Pruning restored some of the understory's competitiveness and so contributed to a response. Even where pasture competition did maintain higher overall rates of water use, only a temporary difference in moisture stress might be observed. With either treatment, transpirational demand each season is likely to exceed the moisture resource. Moisture stresses at the end, like the beginning of the season, are likely to be very similar. The rates of soil drying, however, may differ with treatment and be detectable mid-season.

The literature supports the hypothesized effects of herbaceous competition with trees. Herbaceous plants were shown to be very competitive with conifer seedlings for moisture. In western Oregon, competition decreased growth and survival of Douglas-fir seedlings (Preest 1973, Hedrick and Keniston 1966), and increased moisture stress (Preest 1973, Doescher et al. 1989), compared to where herbaceous vegetation was removed. Cole and Newton (1986) found that the negative impacts of competing grasses on water relations and growth of Douglas-fir in western Oregon continued until the fifth year.

Grass root growth and moisture uptake is not restricted to the surface profile (Sheffer et al. 1987, Garwood and Sinclair 1979). One deeply rooted species, Tall Fescue (*Festuca arudensis)*, extracted significant amounts of water to a depth of 100 cm (Garwood and Sinclair 1979, Sheffer et al. 1987, Doty et al. 1990). This ability of grasses to tap into such large parts of the soil profile supports the hypothesis that a competitive effect of pasture would still be evident. However, my data failed to show this clearly.

The literature also indicated mechanisms by which trees may avoid or reduce the competitive impact of an understory. As trees grow they occupy a larger rooting zone, colonize deeper soil profiles (McMinn 1963, Nnyamah and Black 1977), and have an ability to increase uptake from deeper areas in response to herbaceous competition near the soil surface (Atkinson and Thomas 1985, Eastham et al. 1990). This suggests that older, established trees such as in this study, would be less subject to moisture stress caused by pasture competition, and less likely to respond to pasture removal than seedlings.

The competitive effect of a tree canopy "closing" and casting more continuous shade could also contribute to the weak response to pasture removal. Reduced crown cover affects the evaporative demand and microclimatic conditions of the understory by increasing light and heat, and decreasing relative humidity (Riegel et al. 1992). Transpiration and photosynthesis decline with increasing shade (Larcher 1983). Below-ground carbohydrate allocation also decreased with shade (Brouwer 1962, Eriksen and Whitney, 1981). A reduced root mass limits the understory's ability to extract moisture.

I concluded that pasture plants could still be competitive with established Douglas-fir trees for soil moisture. But, the influence of competition does not appear to be very important in terms of growth loss at this stage of tree development.

At Alsea and Blodgett the tree crowns had nearly closed. Understory light interception and transpiration appeared to be inadequate to influence tree moisture stress in the Unpruned plots. With pruning, the pasture appeared to increase its water use. This response was not observed at Philomath or Thomas Creek, but was strong enough at Alsea and Blodgett to influence the overall treatment means and significance of the analysis.

The lack of trends or treatment responses to pruning or pasture removal at Philomath and Thomas Creek was interesting. The wider spacing and smaller size of the trees at those sites likely promoted greater contact between the two crops. This led me to expect a greater treatment response at these sites. But, the lower density apparently also minimized competition between the trees. The lack of observed response suggested that competition for moisture between trees had become relatively greater than the competition from the understory. The trees at Philomath and Thomas Creek may have experienced less understory competition because their rooting had expanded to below the level of intense root competition with grasses. At Alsea and Blodgett however, there was likely more interaction among the roots of trees, and competition for moisture would be intense throughout the soil profile. As a result, the upper-profile moisture, and understory competition to utilize it, may have increased in relative importance.

Incremental Growth

I hypothesized that Pruned trees would have a lower rate of growth than Unpruned trees. I anticipated that the reduced transpirational and photosynthetic surface of the tree would result in reduced radial growth. I hypothesized that trees growing where pasture was removed would have a higher rate of growth than trees growing with pasture. I anticipated no interaction between the treatment factors. Thus, trees in the Pruned/Pasture treatment were expected to show the least growth, Unpruned/No Pasture and Pruned/Pasture would be intermediate, and Unpruned/No Pasture would show the greatest growth.

My results generally support these hypotheses, although not strongly. Both treatment factors of pruning and pasture removal had a significant influence on growth, with no interaction between the factors. It appeared that Pruned/Pasture trees had the least growth (smallest GRI), Pruned/No Pasture and Unpruned/Pasture trees were intermediate, and Unpruned/No Pasture had the most growth (largest GRI), as anticipated. Pruning appeared to have a stronger effect on the GRI than pasture competition. The growth ratio of Pruned/Pasture trees was significantly lower than all other treatments.

This growth response to pruning and pasture removal is consistent with the literature. Stein (1955) reported decreased growth in both DBH and height when 50% or more of the live crown of young Douglas-fir was removed. O'Hara (1991) concluded that up to 1/3 of the live crown could be removed without important losses in growth; more severe pruning may increase or prolong the period of growth depression.

Pruning has also been reported to alter patterns of growth along the trunk. Staebler (1963) reported that severe pruning (more than 1/2 of the live crown removed) led to greater reductions at breast height than within 2 meters of the crown. In my study, breast height was within 2 meters of the crown, so growth at breast height was considered a sensitive measure.

Pasture competition has been shown to reduce xylem pressure potential and growth of conifer seedlings (Preest 1973, Doescher et al. 1989, Cole and Newton 1986). Small changes in the plant's water potential have an important influence on photosynthetic activity. Daily average leaf conductance declined approximately 80% in response to a decline in predawn xylem pressure potentials from -0.3 MPa and -1.0 MPa (Emmingham and Waring 1977). In the course of conserving water, stomatal control also reduces photosynthesis, which may affect growth more than moisture stress.

I concluded that pruning and pasture competition tended to have a negative effect on radial growth. Both effects were relatively small, so only the combined effect of pruning and pasture competition produced significant differences.

The 1/2 of the crown pruning treatment was chosen to accentuate the responses of the tree to pruning and help discern differences between treatments. It is more severe than approximately 1/3 crown removal recommended for operational pruning (O'Hara 1991), but does not disagree with expectations of noticeable but unimportant losses of growth.

Forage Production

Forage production patterns were more related to neighboring tree crown characteristics, proximity and light interception in the unpruned treatments than in pruned treatments. This is illustrated by the greater amount of variability explained by the Unpruned regression models (69% and 73%) than in the Pruned regression models (60% and 45%).

So why was there a stronger predictive relationship in Unpruned treatments than in Pruned treatments? One possibility is that pruning increased the uniformity of forage production. Another is that pre-treatment patterns of production persisted, and were not well explained by post-pruning descriptive variables.

Light is a major factor affecting production of understory vegetation (Dodd et al. 1972, Eriksen and Whitney 1981, Larcher 1983, Allard et al. 1991). Overstory characteristics such as % cover (Dodd et al. 1972, Mitchell and Bartling 1991), green crown length (Percival and Knowles 1983), basal area (Wolters 1973), stand density index (Moore and Deiter 1992) have been used to predict understory productivity at a stand level. These reports indicated a trend toward declining understory production beneath more dense canopies, as suggested by my study. But, they apply at a stand-level scale rather than describe patterns of production within a stand.

The strong relationship between understory production and overstory density (which strongly influences solar radiation) illustrates that light may be limiting in many systems (Dodd et al. 1972, Moore and Deiter 1992). All indexes of overstory density, while reflecting light conditions, integrate more than light transmission. Moisture and nutrients may also vary and influence production (Riegel et al. 1992)

Crop responses have been illustrated on a finer scale as well. Understory crop yields declined with decreasing distance to trees in alley crop systems (Rosencrance et al. 1992, Yamoah et al. 1986), as well as to individual trees in pasture (Sibbald et al. 1991). Crops are affected by both above ground shading and below-ground influences of the tree (Ssekabembe and Henderlong 1991).

In my study, pruning altered the understory light environment by reducing the size and changing the relative position of individual tree crowns. Pruning removed the widest, densest portion of the crown and left the remaining crown farther away from the pasture crop (Figure 7A and 7B, Table 3 in Methods). The shade cast by a pruned tree was smaller, less complete and more mobile than the shadow of an unpruned tree (Vandermeer 1989, Jackson 1983, Reid and Ferguson 1992) (See Figure 8). The Unpruned tree cast a larger shadow which moved slowly near the base and produced areas of near continuous shade.

Although pruning increased the irradiation and eliminated most areas of intense shade in the understory, it did not have much effect on pasture productivity patterns. This was illustrated by the bare spots which persisted beneath pruned trees even in the second growing season. The reason is likely that the trees were pruned in late spring during the first growing season, when pasture growth had nearly ended for the season. The response of the pasture community to the new light environment in the second growing season was thus restricted to a single rainy season (fall 1992 through spring 1993). This appeared to be an inadequate amount of time for the understory to respond. This change in overstory variables with inadequate time for the understory to respond, reduced the predictive ability of my model.

The affect of an existing canopy on understory productivity would have been better examined with other experimental methods. Growth patterns in newly reseeded pasture might reflect the competitive pressures of the overstory better than an established pasture, with a

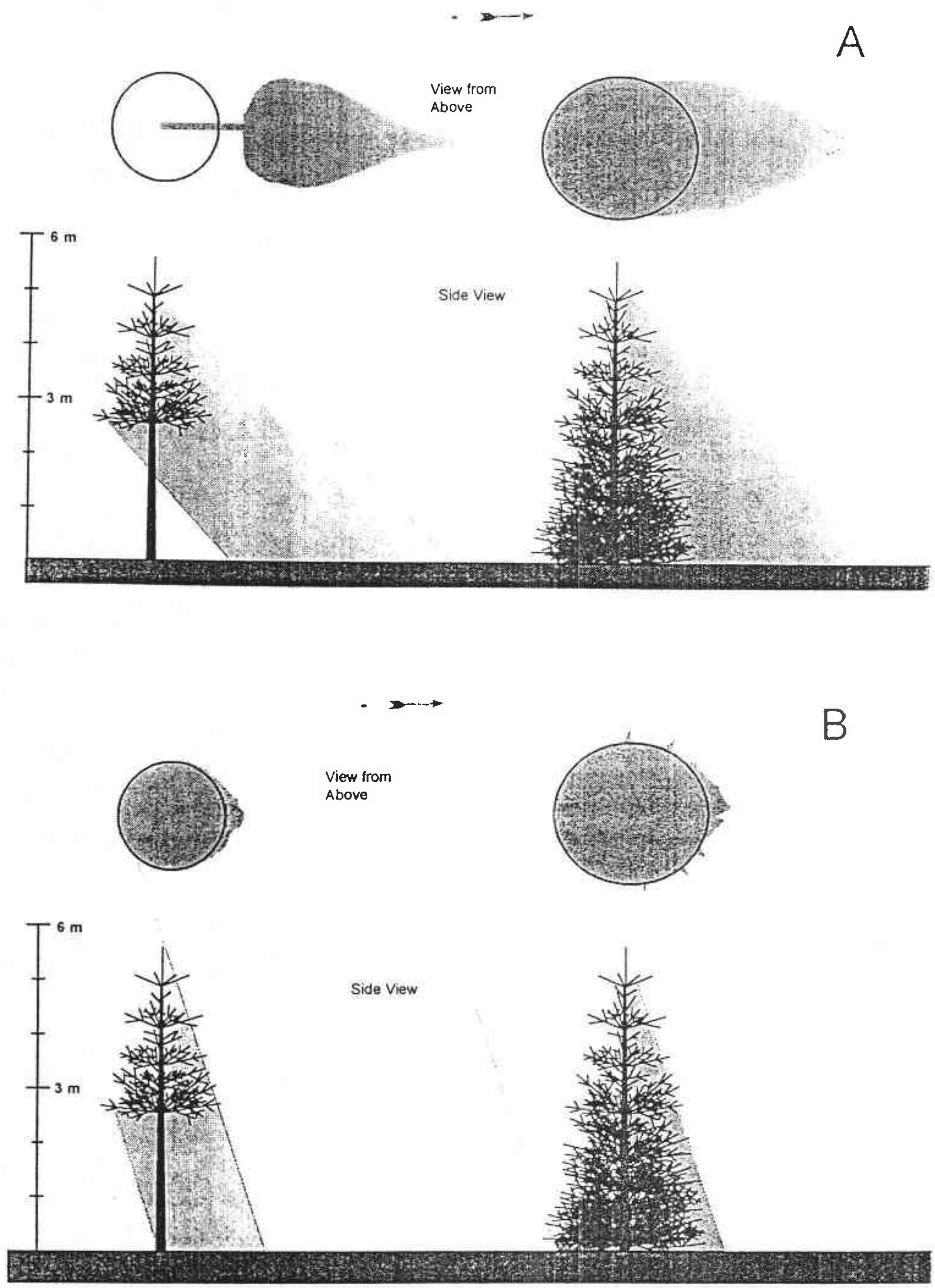

Figure 7. Stylized midday shade patterns cast by typical Pruned and Unpruned trees in this study. (A) Depicts pattern on the solar equinox (may 21, September 21) with a sun angle of 46°. (B) Depicts pattern on the summer solstice (June 21) with a sun angle of 69.5°.

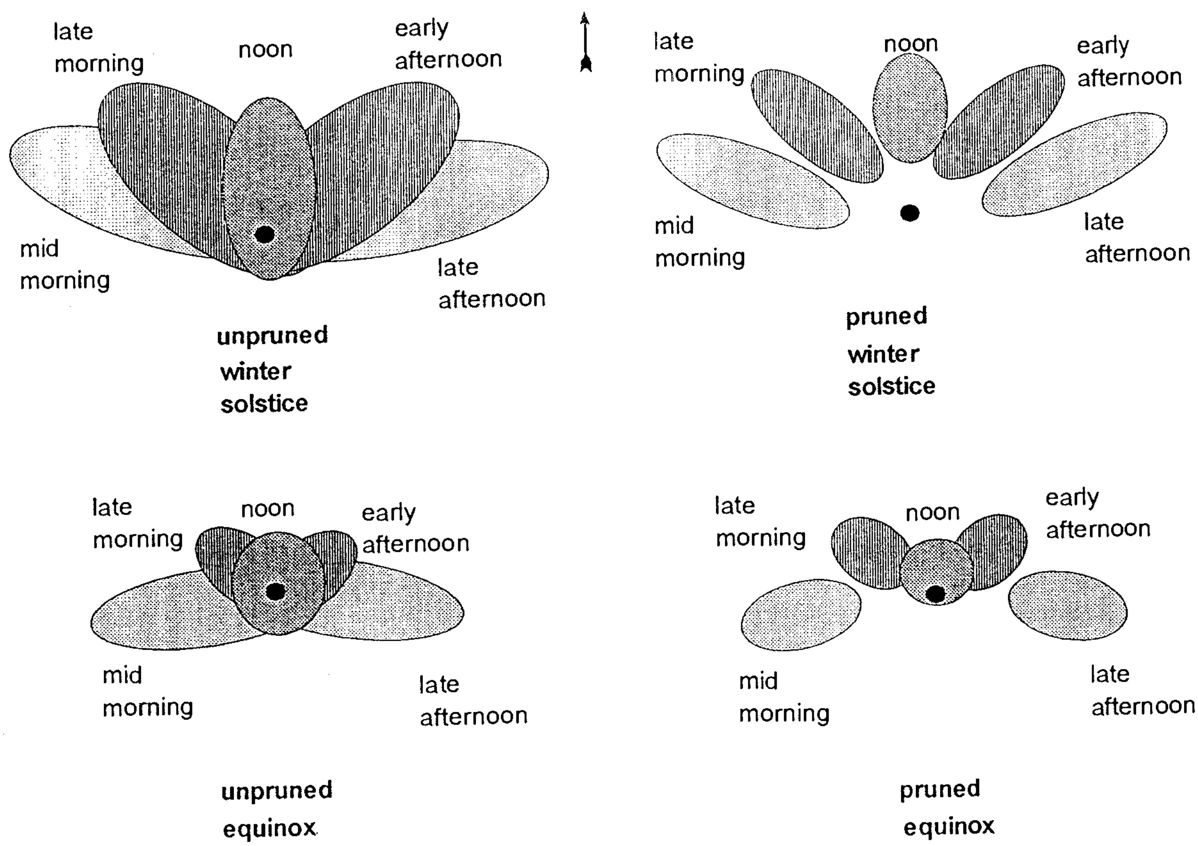

Figure 8. Simplified shadows of Pruned and Unpruned trees. Stylized representation of shadows cast at five points during the day, in two different seasons. Adapted from Vandermeer (1989).

legacy of past interactions. Newly reseeded pasture would not have as extensive rooting and would not represent the effect of established pasture on established trees very well. Pot or trench-plot methods might be used to separate above and below-ground effects.

Benefits to understory production from pruning might be increased with more frequent pruning. Reestablishment of pasture displaced beneath low crowns was slow, and established cover would likely respond more rapidly to changes in the light environment. Operationally, bare spots beneath trees could be reseeded and/or the pasture fertilized to enhance a pasture response to pruning and help improve yields.

Conclusion and Implications

Pruning and pasture competition do not appear to have a strong influence on the water relations or growth of well-established Douglas-fir trees. The pruning treatment appeared to have a very weak tendency to reduce water use by the tree, and tended to reduce moisture stress in the absence of pasture competition. A small and sometimes measurable decrease in growth also supports the conclusion of a reduction in water use by the pruned trees.

Pasture competition appeared to have a weak ability to influence moisture stress and growth of trees. The influence of pasture was dependant on the overstory condition, and tended to increase moisture stress trees were pruned.

Competition for moisture between trees appeared to have become relatively greater than the competition from the understory. Higher tree densities appeared to have a stronger influence on moisture stress than did pasture competition.

It can be inferred from my observations that pasture competition and operational pruning are unlikely to have important negative effects on the moisture status or growth of established trees in western Oregon. Pruning for the objectives of improved wood quality and prolonged pasture do not appear to conflict with the objectives of good tree growth, and should be employed by manages who feel that the expense is justified by the promise of improved future returns. Competition among established trees is likely to have a greater influence on tree performance than will either of these agroforestry management practices. For this reason, stand density management is likely to have a greater influence on the rate of growth than will the inclusion of understory pasture, the choice of pasture species or whether or not trees are pruned.

LITERATURE CITED

Allard, G., C.J. Nelson, and S.G. Pallardy. 1991. Shade effects on growth of tall fescue: I. leaf anatomy and dry matter partitioning. Crop Science. 31:163-167.

Anderson, G.W., R.W. Moore, and P.J. Jenkins. 1988, The integration of pasture, livestock and widely-spaced pine in south western Australia. Agroforestry Systems. 6:195-212.

Atkinson, D., and C.M.S. Thomas. 1985. The influence of cultural methods on the water relations of fruit trees. Acta Horticulturae. 171:371-379.

Atzet, T., and R.H. Waring. 1970. Selective filtering of light by coniferous forests and minimum light energy requirements for regeneration. Canadian Journal of Botany. 48:2163-2167.

Bowen, G.D. 1985. Roots as a component of tree productivity. p. 303-315 in Attributes of Trees as Crop Plants. Cannell, M.G.R. and J.E., Jackson eds. Institute of Terrestrial Ecology, Natural Environment Research Council.

Brouwer, R. 1962. Distribution of dry matter in the plant. Netherlands Journal of Agricultural Science. 10:361-376.

Butcher, T.B. 1977. Impact of moisture relationships on the management of *Pinus pinaster* Ait. plantations in western Australia. Forest Ecology and Management. 1:97-107.

Byington, E.K. 1990. Agroforestry in the Temperate Zone. p. 228-289 in Agroforestry: Classification and Management. MacDicken, K.G., N.T. Vergara, eds. John Wiley and Sons, NY USA.

Carlson, D.H. 1987. Effects of grazing management and tree planting pattern in a young Douglas-fir agroforest. Oregon State University, Master's Thesis. 168 p.

Carlson, D.H., S.H. Sharrow, W.E. Emmingham and D.P. Lavender. 1994. Plant-soil-water relations in forestry and silvopastoral systems in Oregon. Agroforestry Systems 25:1-12.

Cole, E.C., and M. Newton. 1986. Nutrient, moisture, and light relations in 5-year-old Douglas-fir under variable competition. Canadian Journal of Forest Research. 16:727-732.

Cole, E.C., and M. Newton. 1987. Fifth-year responses of Douglas-fir to crowding and nonconiferous competition. Canadian Journal of Forest Research. 17:181-186.

Cleary, B.D., R.D. Greaves and R.K. Hermann eds. 1978. Regenerating Oregon's Forests: A Guide for the Regeneration Forester. Oregon State University Extension Service. Corvallis, OR 97331

Corliss J.F. 1973. Soil Survey of Alsea Area, Oregon. USDA Soil Conservation Service. Washington D.C. 82p.

Daniel, T.W., J.A. Helms, and F.S. Baker 1979. Principles of Silviculture, 2nd Edition. McGraw-Hill Book Co. 527 p.

De Vries, M.L., and S.A. Wilde. 1962. The effect of the density of red pine stands on moisture supply in sandy soils. Netherlands Journal of Agricultural Science. 10 (3):235-239.

Dodd, C.J.H., A. Mclean, and V.C. Brink. 1972. Grazing values as related to tree-crown covers. Canadian Journal of Forest Research. 2, 185-189.

Doescher, P.S., S.D. Tesch, and W.E. Drewien. 1989. Water relations and growth of conifer seedlings during three years of cattle grazing on a southwest Oregon plantation. Northwest Science. 63:232-240.

Doty, J.A., S.W. Braunworth Jr., S. Tan, P.B. Lombard, and R.D. William. 1990. Evapotranspiration of cool-season grasses grown with minimal maintenance. HortScience. 25(5):529-531.

Eastham, J., and C.W. Rose. 1990. Tree/ pasture interactions at a range of tree densities in an agroforestry experiment. I. Rooting patterns. Australian Journal of Agricultural Research. 41, 683-695.

Eastham, J., C.W. Rose, D.M. Cameron, S.J. Rance, T. Talsma and D.A. Charles-Edwards. 1990. Tree pasture interactions at a range of tree densities in an agroforestry experiment. II. Water uptake in relation to rooting patterns. Australian Journal of Agricultural Research. 41, 697-707.

Eissenstat, D.M. and J.E. Mitchell. 1983. Effects of seeding grass and clover on growth and water potential of Douglas-fir seedlings. Forest Science, 29:(1)166-179.

Emmingham, W.H. 1971. Conifer growth and plant distribution under different light environments in the Siskiyou Mountains of southwestern Oregon. Oregon State University, Master's Thesis. 50p.

Emmingham, H.E., and R.H. Waring. 1977. An index of photosynthesis for comparing forest sites in western Oregon. Canadian Journal of Forest Research. 7:(1) 165-174.

Ericsson, A., C. Hellqvist, B. Langsrtom, S. Larsson, and O. Tenow. 1985. Effects on growth of simulated and induced shoot pruning by *Tomicus piniperda* as related to carbohydrate and nitrogen dynamics in scots pine. Journal of Applied Ecology. 22, 105-124.

Eriksen, F.I. and A.S. Whitney. 1981. Effects of light intensity on growth of some tropical forage species. I. Interaction of light intensity and nitrogen fertilization on six forage grasses. Agronomy Journal 73:427-433.

Ferree, D.C., S.C. Myers, C.R. Rom and B.H. Taylor. 1984. Physiological aspects of summer pruning [container grown apple and peach trees]. Acta Horticulturae 146: 243-252.

Friend, D.T.C. 1961. A simple method of measuring integrated light values in the field. Ecology. 42:577-580.

Garrett, H.E., J.E. Jones, J. Haines, and J.P. Slusher. 1991. Black walnut nut production under alleycropping management: An old but new cash crop for the farm community. The 2nd Conference on Agroforestry in North America.159-165.

Garwood, E.A., and J. Sinclair. 1979. Use of water by six grass species 2. Root distribution and use of soil water. Journal of Agricultural Science, Cambridge. 93, 25-35.

Gold M.A., and J.W. Hanover. 1987. Agroforestry systems for the temperate zone. Agroforestry systems. 5:109-121.

Haberland, F.P., and S. A. Wilde. 1961. Influence of thinning of red pine plantation on soil. Ecology 842:584-586.

Hawke, M.F. 1991. Pasture production and animal performance under pine agroforestry in New Zealand. Forest Ecology and Management. 45:109-118.

Hedrick, D.W., and R.F. Keniston. 1966. Grazing and Douglas-fir growth int the Oregon white-oak type. Journal of Forestry. 64:735-739.

Helms, J.A. 1964. Apparent photosynthesis of Douglas-fir in relation to silvicultural treatment. Forest Science. 10:433-442.

Jackson, J.E. 1983. Light climate and crop-tree mixtures. p. 365-378 in Plant Research and Agroforestry. Huxley, Peter A., ed. International Council for Research in Agroforestry,

Jaindl, R.G., and S.S. Sharrow. 1988. Oak/Douglas-fir/sheep: a three crop silvopastoral system. Agroforestry Systems. 6:147-152.

Knezevich, C. A. 1975. Soil Survey of Benton County Area, Oregon. USDA Soil Conservation Service. Washington D.C. 119 p.

Knowles, R.K. 1991. New Zealand experience with silvopastoral systems: A review. Forest Ecology and Management. 45:251-267.

Krueger, W.C. 1981. How a forest affects a forage crop. Rangelands. 3:70-71.

Langridge, R.W. 1987. Soil Survey of Linn County Area Oregon. USDA Soil Conservation Service. Washington D.C. 343 p.

Larcher, W. 1983. Physiological Plant Ecology. Corrected printing of the Second Edition. Springer-Verlag, Berlin. 303 p.

Le Houérou, H.N. 1990. Agroforestry and sylvopastoralism to combat land degradation in the Mediterranean Basin: old approaches to new problems. Agriculture, Ecosystems and Environment, 33:99-109.

Lewis, C.E. and H.A. Pearson, 1987. Agroforestry using tame pastures under planted pines in the southeastern United States. p 195-212 in Agroforestry: Realities, Possibilities and Potentials. Ghols, Henry L., ed. Martinus Nijhoff, Dordrecht, the Netherlands.

Lewis, C.E., G.W. Burton, W.G. Monson, and W.C. McCormick. 1984. Integration of pines and pastures for hay and grazing. Agroforestry Systems. 2:31-41.

McMinn, R.G. 1963. Characteristics of Douglas-fir root systems. Canadian Journal of Botany. 41:105-122.

Mika, A. 1986. Physiological responses of fruit trees to pruning. Horticultural Reviews. 8:337-368.

Mithchell, J.E. and N.P.S. Bartling. 1991. Comparison of linear and nonlinear overstory-understory models for ponerosa pine. Forest Ecology and Management 42:195-204.

Moore, M.M., and D.A. Deiter. 1992. Stand density index as a predictor of forage production in northern Arizona pine forests. Journal of Range Management. 45: 267-271.

Nnyamah, J.U., and T.A. Black. 1977. Rates and patterns of water uptake in a Douglas-fir forest. Soil Science Society of America Journal. 41(5) 972-979.

O'Hara, K.L. 1991. A biological justification for pruning in coastal Douglas-fir stands. Western Journal of Applied Forestry. 6(3): 59-63.

Osman, K.A., and S.H. Sharrow. 1993. Growth responses of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) to defoliation. Forest Ecology and Management. 60:105-117.

Percival, N.S., and R.L. Knowles. 1983. Combinations of Pinus radiata and pastoral Agriculture on New Zealand hill country: Agricultural Productivity. p. 185-202 in Foothills for Food and Forests. Hannaway, David B. (ed)., Oregon State University College of Agricultural Sciences, Symposium Series No. 2.

Preest, D.S. 1973. Summer Soil Moisture Dynamics in a Young Douglas-fir Plantation as Influenced by three Herbaceous Weed Communities. Oregon State University, Master's Thesis. 93 p.

Reid, R., and I.S. Ferguson. 1992. Development and validation of a simple approach to modeling tree shading in agroforestry systems. Agroforestry Systems. 20:243-252.

Riegel, G.M., R.F. Miller and W.C. Krueger. 1992. Competition for resources between understory vegetation and overstory *Pinus ponderosa* in northeastern Oregon. Ecological Applications 2(1):71-85.

Rosencrance, R. C., J.L. Brewbaker, and J.H. Fownes. 1992. Alley cropping of maize with nine leguminous trees. Agroforestry Systems. 17:159-168.

Running, S. W., 1976. Environmental control of leaf water conductance in conifers. Canadian Journal of Forest Research. 6: 104-112.

Sabin, T. 1994. Research Assistant, statistician, Department of Forest Science, Oregon State University. Personal Communication.

Sands R. and E.K.S. Nambiar. 1984. Water relations of *Pinus radiata* in competition with weeds. Canadian Journal of Forest Research. 14: 233-237.

SAS Institute Inc. 1985 SAS/STAT guide for personal computers. Version 6 Edition. 373 pp. Cary, North Carolina, USA.

Sato, A., and S. Sugawara. 1984. The effects of pruning on sap flow and xylem-pressure potential of Sakhalin spruce saplings. Journal of the Japanese Forestry Society. 66:127-131.

Schoenmackers, A., W.H. Emmingham, R. Fletcher, and B. Udell. 1985. Comparing high and low thinning effectiveness in a young Douglas-fir stand. Oregon State University, Unpublished Document.

Scholander, P.F., H.T Hammel, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science. 148:339-346.

Sheffer, K. M., J. H. Dunn, and D. D. Minner. 1987. Summer drought response and rooting depth of three cool-season turfgrasses. HortScience. 22:296-297.

Sibbald, A.R., J.H. Griffiths, and D.A. Elston, 1991. The effects of widely spaced conifers on under-storey herbage production in the U.K. Forest Ecology and Management. 45:71-77

Ssekabembe, C. K., and P. R. Henderlong. 1991. Below-ground interactions in alley cropping; Appraisal of first-year observations on maize grown in black locust (*Robinia pseudoacacia* L.) alleys. The 2nd Conference on Agroforestry in North America. p. 58-73.

Staebler, G.R. 1963. Growth along the stems of full-crowned Douglas-fir trees after pruning to specified heights. Journal of Forestry. 61:124-127.

Stafford, S.G. and T.E. Sabin. 1993. Statistical analysis for the natural resources and ecological sciences with the SAS programming language. Oregon State University, Department of Forest Science, Unpublished Document.

Stein, W.I. 1955. Pruning to different heights in young Douglas-fir. Journal of Forestry. 53:352-355.

Taylor, G.H. 1994. Oregon Climate Service. Oregon State University, Corvallis Oregon.

Vandermeer, J.H. 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge, Great Britain. 237 p.

Vézina, P.E., and G. Péch. 1964. Solar radiation beneath conifer canopies in relation to crown closure. Forest Science. 10:443-451.

Waring, R.H. and B. D. Cleary, 1967. Plant moisture stress: evaluation by pressure bomb. Science 155, 1248-31254.

Wolters, G.L. 1973. Southern pine overstories influence herbage quality. Journal of Range Management. 26(2) 423-426.

Yamoah, C. F., A. A. Agboola, and G. F. Wilson. 1986. Nutrient contribution and maize performance in alley cropping systems. Agroforestry Systems. 4:247-254.

APPENDIX

Table 1. ANOVA table for xylem pressure potential, July 2-4, 1992.

Source	df	Mean Squares	P Value
Site	3	1.0985	0.0001
Prune	1	0.0171	0.2819
Pasture	1	0.0109	0.3838
Prune*Pasture	1	0.0059	0.5179
Error(S*P*P)	9	0.0130	

Table 2. ANOVA table for xylem pressure potential, July 15-17, 1992.

Source	df	Mean Squares	P Value
Site	3	0.8283	0.0001
Prune	1	0.0588	0.2075
Pasture	1	0.0506	0.2395
Prune*Pasture	1	0.0763	0.1563
Error (S*P*P)	9	0.0319	

Table 3. ANOVA table for xylem pressure potential, August 4-6, 1992.

Source	df	Mean Squares	P Value
Site	3	1.4492	0.0001
Prune	1	0.0027	0.7590
Pasture	1	0.1332	0.0544
Prune*Pasture	1	0.0264	0.3511
Error (S*P*P)	9	0.0273	

Table 4. ANOVA table for xylem pressure potential, August 26-28, 1992.

Source	df	Mean Squares	P Value
Site	3	1.4204	0.0001
Prune	1	0.0008	0.8879
Pasture	1	0.0367	0.3473
Prune*Pasture	1	0.0566	0.2495
Error (S*P*P)	9	0.0373	

Table 5. ANOVA table for xylem pressure potential, September 16-18, 1992.

Source	df	Mean Squares	P Value
Site	3	0.7242	0.0001
Prune	1	0.0061	0.6428
Pasture	1	0.0218	0.3871
Prune*Pasture	1	0.1420	0.0457
Error (S*P*P)	9	0.0264	

Table 6. ANOVA table for xylem pressure potential, transformed data, June 28-30, 1993.

Source	df	Mean Squares	P Value
Site	3	0.2139	0.0001
Prune	1	0.0274	0.0815
Pasture	1	0.00003	0.9495
Prune*Pasture	1	0.0223	0.1101
Error (S*P*P)	9	0.0071	

Table 7. ANOVA table for xylem pressure potential, transformed data, August 4-6, 1993.

Source	df	Mean Squares	P Value
Site	3	0.6533	0.0001
Prune	1	0.0046	0.6193
Pasture	1	0.0513	0.1189
Prune*Pasture	1	0.0811	0.0583
Error (S*P*P)	9	0.0173	

Table 8. ANOVA table for xylem pressure potential, transformed data, September 7-10, 1993.

Source	df	Mean Squares	P Value
Site	3	0.7015	0.0001
Prune	1	0.0081	0.2345
Pasture	1	0.0462	0.0140
Prune*Pasture	1	0.0470	0.0134
Error (S*P*P)	9	0.0050	

Table 9. ANOVA table for xylem pressure potential, transformed data, October 4-5, 1993.

Source	df	Mean Squares	P Value
Site	3	0.8962	0.0001
Prune	1	0.0022	0.6613
Pasture	1	0.0167	0.2449
Prune*Pasture	1	0.0337	0.1108
Error (S*P*P)	9	0.0108	

Table 10. ANOVA table for Ratio of Linear Growth.

Source	df	Mean Squares	P Value
Site	3	0.0942	0.0090
Prune	1	0.6416	0.0014
Pasture	1	0.1785	0.0394
Prune*Pasture	1	0.0607	0.1936
Error (S*P*P)	9	0.0307	

Table 11. Correlation Matrix for Pruned/Pasture treatments, 1992. Thomas Creek excluded. Pearson correlation coefficient, (p-value).

	LOGWT	LGTRL	LDST1	LDST2	LMDST	V1T1	CR1T1	CR1T2	H1T3
LOGWT	1.000 0.0	-0.158 0.226	0.641 0.0001	0.099 0.450	0.151 0.246	-0.211 0.105	-0.214 0.100	-0.047 0.719	0.056 0.670
LGTRL	-0.158 0.226	1.000 0.0	0.105 0.423	-0.415 0.001	0.082 0.529	-0.022 0.082	-0.191 0.142	-0.350 0.006	0.066 0.611
LDST1	0.641 0.0001	0.1052 0.423	1.000 0.0	-0.238 0.066	0.288 0.025	-0.042 0.744	-0.001 0.991	-0.117 0.373	0.024 0.854
LDST2	0.099 0.450	-0.415 0.001	-0.238 0.067	1.000 0.0	0.523 0.0001	-0.136 0.299	-0.155 0.269	0.0335 0.799	0.154 0.238
LMDST	0.152 0.247	0.0829 0.529	0.289 0.025	0.523 0.0001	1.000 0.0	-0.196 0.132	-0.118 0.365	-0.217 0.094	0.132 0.314
V1T1	0.211 0.106	-0.226 0.082	-0.043 0.745	-0.136 0.299	-0.196 0.132	1.000 0.0	0.943 0.0001	0.009 0.941	0.305 0.017
CR1T1	-0.214 0.100	-0.191 0.142	-0.001 0.991	-0.144 0.2694	-0.118 0.365	0.943 0.0001	1.000 0.0	0.008 0.945	0.332 0.009
CR1T2	-0.047 0.719	-0.350 0.006	-0.117 0.373	0.0335 0.799	-0.217 0.094	0.009 0.0941	0.008 0.945	1.000 0.0	0.154 0.238
H1T3	0.056 0.671	-0.067 0.611	0.0241 0.854	-0.154 0.238	-0.132 0.314	0.305 0.0176	0.332 0.009	0.154 0.238	1.000 0.0

Table 12. Correlation Matrix for Unpruned treatments, 1992. Thomas Creek excluded. Pearson correlation coefficient, (p-value).

	LOGWT	LGTRL	LDST1	LDST2	LMDST	V1T1	CR1T1	H1T3
LOGWT	1.000 0.0	0.71716 0.0001	0.54653 0.0001	0.14249 0.2774	0.31926 0.0129	-0.1635 0.2119	-0.1445 0.2705	-0.1255 0.3433
LGTRL	0.71716 0.0001	1.000 0.0	0.46281 0.0002	0.18993 0.1461	0.42995 .0006	-0.0505 0.7012	-0.0418 0.7510	-0.1637 0.2154
LDST1	0.54653 0.0001	0.46281 0.0002	1.000 0.0	-0.3609 0.0046	0.35180 .0058	0.13186 0.3189	0.19151 0.1427	0.04238 0.7500
LDST2	0.14249 0.2774	0.18993 0.1461	-0.3609 0.0046	1.000 0.0	0.40226 0.0014	0.11297 0.3901	0.06541 0.6195	0.12435 0.3480
LMDST	0.31926 0.0129	0.42995 0.0006	0.35180 0.0058	0.40226 0.0014	1.000 0.0	0.25576 0.0486	0.28276 0.0286	0.08564 0.5190
V1T1	-0.1635 0.2119	-0.0505 0.7012	0.13086 0.3189	0.11297 0.3901	0.25576 0.0486	1.000 0.0	0.90119 0.0001	-0.0836 0.5286
CR1T1	-0.1445 0.2705	-0.0418 0.7510	0.19151 0.1427	0.06541 0.6195	0.28276 0.0286	0.90119 0.0001	1.000 0.0	-0.1071 0.4191
CR1T2	-0.1255 0.3433	-0.1637 0.2154	0.04238 0.7500	0.12435 0.3480	0.08564 0.5190	-0.0836 0.5286	-0.1071 0.4191	1.000 0.0

Table 13. Correlation Matrix for Pruned treatments, 1993. Pearson correlation coefficient, (p-value).

	LOGWT	LGTRL	LDST1	LDST2	LMDST	V2T1	V2T2
LOGWT	1.000 0.0	0.07809 0.4911	0.64782 0.0001	-0.0650 0.5666	0.30934 0.0052	-0.0812 0.4740	-0.0787 0.4873
LGTRL	0.07809 0.4911	1.000 0.0	0.10978 0.3324	0.36953 0.0007	0.45355 0.0001	-0.2645 0.0177	-0.36895 0.0008
LDST1	0.64782 0.0001	0.10978 0.3324	1.000 0.0	-0.2722 0.0146	0.20298 0.0710	-0.0503 0.4785	-0.0408 0.7191
LDST2	-0.0650 0.5666	0.36953 0.0007	-0.2722 0.0146	1.000 0.0	0.77626 0.0001	-0.1672 0.1381	-0.3391 0.0021
LMDST	0.30934 0.0052	0.45355 0.0001	0.20298 0.0710	0.77626 0.0001	1.000 0.0	-0.2449 0.0285	-0.3351 0.0024
V2T1	-0.0812 0.4740	-0.2645 0.0177	-0.0803 0.4758	-0.1672 0.1381	-0.2449 0.0285	1.000 0.0	0.32774 0.0030
V2T2	-0.0787 0.04873	-0.3689 0.0008	-0.0408 0.7191	-0.3391 0.0021	-0.3519 0.0024	0.32774 0.0030	1.000 0.0

Table 14. Correlation Matrix for Unpruned treatments, 1993. Pearson correlation coefficient, (p-value).

	LOGWT	LGTRL	LDST1	LDST2	LMDST	V2T1	V2T2
LOGWT	1.000 0.0	0.7503 0.0001	0.7968 0.0001	0.0740 0.5138	0.4685 0.0001	-0.087 0.4380	-0.290 0.0100
LGTRL	0.7503 0.0001	1.000 0.0	0.6392 0.0001	0.3033 0.0062	0.6301 0.0001	-0.1821 0.1058	-0.263 0.0197
LDST1	0.7968 0.0001	0.6392 0.0001	1.000 0.0	-0.094 0.4041	0.3810 0.0005	0.0965 0.3945	-0.107 0.3488
LDST2	0.0740 0.5318	0.3033 0.0062	-0.094 0.4041	1.000 0.0	0.7535 0.0001	-0.270 0.0152	-0.156 0.1710
LMDST	0.4685 0.0001	0.6301 0.0001	0.3810 0.0005	0.7535 0.0001	1.000 0.0	-0.224 0.0450	-0.222 0.0505
V2T1	-0.087 0.4380	-0.182 0.1058	0.0965 0.3945	-0.270 0.0152	-0.224 0.045	1.000 0.0	0.2636 0.0197
V2T2	-0.290 0.0100	-0.263 0.0197	-0.107 0.3488	-0.156 0.1710	-0.222 0.0505	0.2636 0.0197	1.000 0.0