AN ABSTRACT OF THE THESIS OF

THOMAS DEMEO for the degree of MASTER OF SCIENCE

in FOREST SCIENCE presented on JULY 27, 1987

Title: RELATIONSHIPS OF TREE GROWTH TO NITROGEN AND WATER AVAILABILITY IN A SHEEP-TREE-PASTURE SYSTEM IN DOUGLAS COUNTY, OREGON: FIELD CASE STUDY AND SHADEHOUSE SIMULATION

Abstract approved: Signature redacted for privacy.

David E. Hibbs

This thesis consists of three parts: 1) a field case study involving tree growth, moisture stress, and foliar nitrogen response to sheep-grazed pasture treatments; 2) a shadehouse (potted-plant) study of simulated grazing effects on tree growth and moisture use; and 3) a summary, synthesizing results of the field and shadehouse studies and relating both to previous research.

Part I. Field Case Study

In a two-year-old agroforestry planting near Roseburg, Oregon, tree growth in grazed forb-dominated, grazed grass-dominated pasture, and bareground treatments was compared. Grazing by sheep was intensive. Trees were the KMX pine hybrid (*Pinus attenuata* X *P. radiata*) and Douglas-fir (*Pseudotsuga menziesii*).

Significantly greater height and diameter growth of trees was found on the bareground treatment. KMX pine absolute growth was

always superior to that of Douglas-fir. On a relative basis, however, both species were growing at about the same rate. Predawn tree xylem potential did not differ significantly among pasture treatments, but KMX pine values were significantly greater (less stress) than those of Douglas-fir during summer drought. Tree foliar nitrogen concentrations of both species were consistently high; species and treatment differences were generally insignificant. Soil total nitrogen likewise did not differ between treatments.

Superior growth of KMX pine, compared with that of Douglas-fir, appeared related to lower summer xylem moisture stress. KMX pine produced superior growth, compared with Douglas-fir, due to lower xylem moisture stress during summer months. For the site and conditions investigated, moisture rather than nitrogen appear to be limiting growth. On sites similar to the one investigated, it was concluded nitrogen recycled in animal waste is unlikely to induce a tree foliar N response in the establishment phase (0-3 years) of tree plantations.

Part II. Shadehouse Grazing Simulation

Effects of simulated grazing of interplanted forage plants on growth and water use of three tree species were evaluated in a semi-controlled environment (open shadehouses). Varied proportions of perennial ryegrass (Lolium perenne) and subterranean clover (Trifolium subterraneum) were planted in pots with individual KMX pine, Douglas-fir, and Eucalyptus glaucescens. A tree-only treatment was also included. Forage in pots was clipped monthly for one growing season (May until October 1986). To simulate animal waste nitrogen return, 80 percent of nitrogen removed was returned as urea after each clipping. A second set of forage treatments was clipped but received no urea.

KMX pine showed significantly (p=0.05) greater diameter growth and total biomass than eucalyptus or Douglas-fir. Eucalyptus had the greatest height growth of the three species.

Generally, trees with clover only or with no competing vegetation showed greater (p=0.10) growth than trees with grass or mixed clover-grass competition. High grass competition had a depressing effect on tree growth. Eucalyptus appeared most affected by forage treatments, followed by Douglas-fir. KMX pine was least affected. Fertilization had no effect on tree growth, although it significantly (p=0.05) increased eucalyptus shoot/root ratio.

Moisture stress experiments indicated trees with no competing vegetation lost the most water over time. Because of a watering regime predisposing trees to stress, soil moisture content could not be correlated with tree predawn xylem potentials.

A comparison of tree foliar nitrogen (N) in October 1985 (forage establishment) and October 1986 (harvest) showed no significant difference between forage/fertilization treatments at either time. Total soil nitrogen likewise did not change during the study period.

Ryegrass biomass production consistently exceeded that of subterranean clover in grass-clover mixtures. Ryegrass dominated clover when ryegrass proportion was 20 percent or greater (unfertilized) and 10 percent or greater (fertilized). Fertilization approximately doubled ryegrass biomass yield but had no effect on clover yield.

Forage growth in association with KMX pine markedly decreased. Douglas-fir had no effect on forage growth. Eucalyptus was intermediate.

I conclude that tree growth in the simulation was limited by moisture. Added urea nitrogen benefited ryegrass growth. Trees with the least amount of vegetative biomass competition produced the greatest growth. Clover was neutral in effect on tree growth. Results suggest young tree plantations in grazed western Oregon pastures are unlikely to benefit from animal waste nitrogen return. On dry sites, summer moisture stress will limit tree growth and inhibit uptake of animal waste nutrient return.

RELATIONSHIPS OF TREE GROWTH TO NITROGEN AND WATER AVAILABILITY IN A SHEEP-TREE-PASTURE SYSTEM IN DOUGLAS COUNTY, OREGON: FIELD CASE STUDY AND SHADEHOUSE SIMULATION

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 27, 1987

Commencement June 1988

ACKNOWLEDGEMENTS

Every master's degree involves a considerable amount of work. I wish to sincerely thank all those who aided my efforts. Bill Emmingham had the foresight and initiative to write a grant proposal for a project involving agroforestry, research concept in its infancy in the Northwest. Throughout the project his attitude was supportive and encouraging, coupled with insight into problems as they arose. Dave Hibbs graciously agreed to assume responsibility for the thesis when Bill left on sabbatical leave. He was instrumental in the design of the shadehouse study, and provided editing and comments which shaped the written thesis. Steve Sharrow and Paul Doescher in Rangeland Resources kept us foresters honest. Steve's comments in particular considerably strengthened the field study. Kermit Cromack supplied a supportive attitude and useful remarks on soils. Enoch Small showed exceptional interest for a Graduate Representative.

Many other professors and students assisted in many ways over the past two years. Faculty and staff who provided instruction and assistance include Stuart Childs, Carolyn Choquette, Carol Glassman, Bud Graham, Mike Newton, Tom Popham, Steve Radosevich, Wieger Schaap, Susan Stafford, and Barbara Yoder. Fellow student laborers include Jim Carlson, Dave Coates, Julie Concannon, Jeff Graham, Sybille Haussler, Cindy Lipp, Onesimus Mmolawa, Klaus Puettmann, Brian Richardson, Brad St. Clair, and Tom Savage. Margaret Richardson helped with data collection and prepared final drafts of the thesis figures. Work-study student Shane Harms conscientiously recorded much of the shadehouse study biomass data. Bob Logan and Dan Austin of the Douglas County Extension Service provided essential cooperation and support for the field study. I apologize if I have omitted anyone's name.

Custom may dictate that I close with thanks to my wife for baking cookies and doing the typing, but I will dispense with that. Julie provided very insightful comments on the design and analysis of both field and shadehouse studies, as well as encouragement and moral support. She is a true professional.

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Introduction

A. THE CONCEPT OF AGROFORESTRY

Agroforestry has been defined by numerous authors (e.g., Huxley et al. 1982, Batini et al. 1983, Mosher 1983) to involve the integration of forestry and agricultural needs on the same land unit. In various forms, this integration has been practiced for centuries (von Maydell 1985). Agroforestry as a scientific discipline is new, however, and research directions are still being defined (Huxley 1983). In 1977, an international agroforestry research center (ICRAF) was established Nairobi, Kenya. Several international journals, such as Agroforestry Systems and the International Journal of Tree Crops are devoted exclusively to the topic and attest to worldwide interest.

In the Pacific Northwest of North America, resource managers have taken interest in one aspect of agroforestry--the integration of live-stock grazing and tree production. While their concerns and objectives may be very different than those of their Third World counter-parts, there is a common interest in meeting economic and resource management needs.

The following literature review briefly outlines research relevant to tree growth in livestock-tree systems of the Pacific Northwest. Since factors affecting tree growth in these systems are still poorly understood, I chose this as my thesis topic.

Specifically, I addressed nitrogen and water relationships affecting tree growth in an intensive sheep-tree-pasture system. This work is presented as a research paper.

To further elucidate these relationships, I conducted a pot experiment in a semi-controlled environment (Part II). Tree and forage species were the same as in the field study.

The conclusion of the thesis (Part III) is a discussion integrating findings of both field and potted-plant studies to previous research. Finally, I offer suggestions for future research.

B. VEGETATIVE GROWTH

A number of researchers have examined the effects of competing vegetation on tree growth. McDonald (1986) presented an overview of effects of grasses on young conifer growth. Grasses can exclude competing shrubs (Norris et al. 1982, Klingler 1982). Negative effects include pre-emption of light, water, and nutrients (Barrett 1982, Oliver 1984), attraction of harmful insects and animals, and increased fire potential. Allelopathic effects of grasses can inhibit both competing shrubs and the tree crop (McDonald 1986).

Nambiar and Zed (1980), working with *Pinus radiata* in Australia, reported tree seedling mortality of up to 40% in competition with weeds. In British Columbia, Clark and McLean (1981) reported reduced height growth of lodgepole pine (*Pinus contorta*) grown with grasses.

On a moist Coast Range site, Preest and Newton (1982) reported 20 percent survival of Douglas-fir after 8 years. Height growth losses due to grass competition were found in each of the five years following planting, and then tapered off (Newton and Preest 1987). Klingler (1982) points out the high variability in tree growth when grown with grass competition. Climatic variation from year to year, site quality, stocking density and topography can influence effects of vegetative competition on trees (Clark and McLean 1978, Klingler 1982).

C. EFFECTS OF GRAZING ON TREE GROWTH

Interest in using livestock to control competing vegetation has increased markedly in recent years. Hedrick et al. (1986) recommended 60-75 percent forage removal to benefit tree growth. Research in brush-tree competition indicates substantial removal of competing vegetation (70 percent) may be necessary if trees are to benefit (Oliver 1984), particularly in dry climates.

Intensity of grazing, however, must be balanced with the need to avoid browse damage. Sharrow and Leininger (1983) report sheep browse damage to seedlings at levels greater than about 65% forage removal.

The effects of competing vegetation on tree survival and growth has been the subject of numerous studies (Beveridge et al. 1973, McKinnell 1974, Currie et al. 1978, Bartolome and Kosco 1981, Lewis et al. 1984, Hedrick et al. 1986, Hedrick and Kenniston 1966). In the Willamette Valley of western Oregon, Hedrick and Kenniston (1966) found superior juvenile growth on Douglas-fir trees in grazed pasture compared to a non-grazed treatment. In northern California, 8artolome and Kosco (1981) reported no difference in tree growth on grazed versus non-grazed treatments five years after planting. They further state no differences were expected until about 10 years after establishment, but offer no evidence.

Clark and McLean (1981), examining lodgepole pine (Pinus contorta) growth in response to grass and fertilization treatments in interior 8ritish Columbia, found no significant differences in survival between treatments. Early height growth, however, was significantly reduced by high-density grass competition. In contrast, Klingler (1982) found no difference in height growth in western Oregon on seeded versus unseeded plots five years after planting, possibly due to higher rainfall in this region. Clark and McLean (1981) conclude, as do 8artolome and Kosco (1981), that long-term tree performance remains an open question. They predict combining grazing with trees will result in moderate to high forage yield and moderate growth of lodgepole pine seedlings.

Data on animal damage has been reported by numerous authors (Currie et al. 1978, Bartolome and Kosco 1981). McKinnell (1974), working with sheep grazing and radiata pine in Australia, reported severe tree browsing. He was unable, however, to determine whether this was due to insufficiently large pines or grazing at a time when the forage was unsuitable for feed. Alejandro and Doescher (personal communication), working in southwest Oregon, reported browse damage significantly greater by wildlife than by livestock. Trampling of seedlings, however, was found to be greater with livestock than with wildlife. This agrees with work by Wheeler et al. (1980), who found similar results in eastern Oregon, and Bartolome and Kosco (1981), in northern California. In the southeastern U.S., Lewis et al. (1984) recommend a three- to four-year delay of grazing after planting slash pine to avoid browse damage to trees. Tree damage can be minimized if: 1) livestock are only grazed during the appropriate season (McKinnell 1974, Monfore 1983); 2) they are carefully managed (Bartolome and Kosco 1981, Monfore 1983); and 3) grazing is sufficiently intense to maintain forage in an early vegetative, and hence palatable, stage (Monfore 1983).

D. TREE MOISTURE STRESS RESPONSE

In northern Idaho, a Douglas-fir plantation was seeded with a grass-legume mix (Eissenstat and Mitchell 1983). During the following growing season, predawn Douglas-fir water potentials were significantly reduced (greater stress) on the seeded treatment versus no seeding. Two seasons after planting, however, there was no significant difference in moisture stress, probably because root systems were sufficiently established by then. Although seeding grass on certain sites caused a significant reduction in tree height and diameter growth, tree moisture stress could not be related to the growth parameters measured. They concluded water, though limiting, was probably not the only factor limiting growth on the site. This region receives some summer precipitation, which may have made moisture stress less critical.

Squire (1977) compared effects of grass competition, fertilization, and cultivation on juvenile growth of *Pinus radiata* in Australia. He found grass competition to be the most important of these effects. Grasses directly inhibited tree growth, apparently by usurping available moisture, and severely limited tree ability to respond to soil fertility. Significant increases in growth due to fertilization or cultivation were found only when weed competition was removed.

Sands and Nambiar (1984), working with *P. radiata* in Australia, showed that weed competition resulted in tree growth depression. To examine this effect, they sampled soil moisture conditions and tree water potential and stomatal resistance. They found trees with weeds showed severe water stress but that this stress decreased with tree age. By the second growing season, trees could extract water to a depth of 2 m and were not water stressed, regardless of weed competition. They consider this strong evidence that trees rooted to a sufficient depth will not be adversely affected by weed competition for moisture. Newton and Preest (1987) found a positive correlation between moisture stress relief (effected by controlling competing vegetation with herbicides) and 5-year volume growth of Douglas-fir on a moist site in the Oregon Coast Range.

E. GRAZED PASTURES AS NITROGEN SOURCES FOR TREE GROWTH

Nitrogen-fixing pasture legumes add nitrogen to the soil, as high as 100-150 kg/ha/yr (Silver and Hardy 1978). Nitrogen can also be added to the soil using chemical fertilizers.

Studying the effect of N source on tree growth, Waring and Snowdon (1985) compared mixed clovers and urea as nitrogen sources for fertilizing Pinus radiata. In the first and third growing seasons, growth of trees with clover was depressed; trees fertilized with urea were significantly taller. At the end of seven years, however, there was no significant difference in tree height between clover- and urea-treated areas; further, both were significantly taller than the non-treated area. Grazing was not involved in the study.

Where livestock are grazed with trees, it has been suggested nutrients (particularly nitrogen) in animal waste will recycle faster than by turnover of dead plant material due to weathering and microbial action. Studies thus far conducted, however, fail to show tree response to nutrients returned during grazing by animals. Petersen et al. (1956) found no significant increase in total soil phosphorus (P) under a grazed pasture. Animal waste is typically poorly distributed in a pasture (Gillingham 1983, Petersen et al. 1956), so benefit to trees is likely to be scattered and may require considerable time to develop

F. SUMMARY

Livestock-tree-pasture systems clearly involve complex biological interactions. Tree growth response is likely to vary with climate and topography (Clark and McLean 1978, Klingler 1982), soils (Clark and McLean 1978), pasture species, seasonal distribution of forage (McKinnell 1974, Monfore 1983), tree species, livestock species and breed (McKinnell 1974), and grazing regime (Monfore 1983). In temperate climates experiencing summer drought, it appears water is often the factor limiting tree growth. (Preest 1975, Eissenstadt and Mitchell 1983, Newton and Preest, 1987). No tree nitrogen response to nutrients directly recycled by animals has yet been shown. A fully integrated, intensive management system of mixed perennial ryegrass (Lolium perenne) and subterranean clover (Trifolium subterraneum) pasture, sheep-grazing, and the short-rotation KMX pine (Pinus attenuata X P. radiata) is being introduced in southwest Oregon (Douglas County). The following paper describes tree growth in this system, and relates tree moisture stress and foliar nitrogen concentration under varied grazing treatments to this growth.

Part I. Relationships of Tree Growth to Nitrogen and Water Availability in a Sheep-Tree-Pasture System in Douglas County, Oregon

Abstract:

In a two-year-old agroforestry planting near Roseburg, Oregon, tree growth in grazed forb-dominated pasture, grazed grass-dominated pasture, and bareground treatments was compared. Grazing by sheep was intensive. Tree species were the KMX pine hybrid (Pinus radiata X P. attenuata), Douglas-fir (Pseudotsuga menziesii), and Eucalyptus glaucescens.

Significantly greater height and diameter growth of trees was found in the bareground treatment. KMX growth was always superior to that of the other tree species. Predawn tree xylem potential values did not differ significantly between treatments; but KMX pine values were significantly greater (less stress) than those of Douglas-fir during summer drought. Tree foliar nitrogen concentrations of all three species were consistently high; species and treatment differences were generally insignificant. Soil total nitrogen likewise did not differ between treatments.

KMX pine produced superior growth, compared with Douglas-fir, due to lower xylem moisture stress during summer months. For the site and conditions investigated, moisture rather than nitrogen appears to be limiting growth. On sites similar to the one investigated, nitrogen recycled in animal waste is unlikely to induce a tree foliar response in the establishment phase (0-3 years) of tree plantations.

A. INTRODUCTION

Tree growth in grazed pastures has been addressed in numerous studies (Hedrick and Keniston 1966, Wheeler et al. 1980, Sharrow and Leininger 1983), but effects of grazing and competition with forage species on tree growth remain poorly understood. Pasture plants, particularly grasses, may compete with trees for nutrients and water (Squire 1977, Cole and Newton 1986, McDonald 1986) but but can also eliminate less desirable competitors, such as shrubs. Pasture legumes, by fixing nitrogen (N), can add significant quantities of nitrogen to the soil (Silver and Hardy 1978, Zavitkovski et al. 1979, Vaughn and Murphy 1982, Dawson 1983, Heichel 1983).

Grazing animals add complexity to pasture-tree interactions, possibly benefiting tree growth in several ways. Grazing reduces the amount of vegetation competing with trees and can also favor species less deleterious to tree survival and growth (McDonald 1986). Nutrients are returned to soil in animal excrement, particularly nitrogen and phosphorus (Petersen et al. 1956, Dawson and McGuire 1972, Bromfield and Jones 1970, Gillingham 1983). They are readily available forms. If improperly managed, however, livestock can damage trees by browsing or trampling (Lewis et al. 1984).

My objective was to describe tree-growth response under two grazed pasture treatments and compare this with bareground. In addition, I measured water and nitrogen availability as the two environmental factors most likely to be affected by forage plants and grazing. Water and nitrogen are the usual limiting factors in the region of the study (Preest 1975, Newton and Preest 1987).

B. SITE DESCRIPTION

An established, two-year-old agroforestry planting near Roseburg, Oregon (43 10'N latitude, 123 10' W longitude) was used as the study study site. Winters are cool and rainy; summers are hot and dry. Mean annual rainfall is 84.7 cm, but rainfall from July to October is negligible (Appendix A). Slope is slight (2 percent) with a western aspect. The site is exposed to full sunlight.

Soil parent material is alluvium of the nearby North Fork of the Umpqua River. The soil is Packard loam, with 25 percent rocks (mostly cobbles) and 15 percent surface stones. While cation exchange capacity is adequate (average 21 meq/g), the soil dries down rapidly in summer and requires supplemental irrigation for field crops. The site is classified as land use capability class II--suitable for all but the most intense agricultural uses (Brady 1984). During the twenty years prior to establishment of the agroforestry planting, the site was planted with field crops (particularly wheat) and used for forage production.

Prior to initiation of the study, the site was an abandoned pasture with a high proportion of weeds. Herbicide treatments in 1983 created two pasture types--one dominated by subterranean clover (*Trifolium subterraneum*), the other considered a mix of this clover and perennial ryegrass (*Lolium perenne*). The area designated bareground remained as weeds until late 1984, when it was treated with herbicide. Clover was seeded in this area during the spring of 1985, but removed by herbicide application and hand weeding in June 1985, just prior to my study. During the winter of 1983-84, trees were planted-- the KMX pine hybrid (*Pinus radiata* X *P. attenuata*), Douglas-fir (*Pseudotsuga menziesii*) and *Eucalyptus glaucescens*. KMX pine and eucalyptus seedlings were planted as plug-one stock. Douglas-fir seedlings were 2-0 bareroot, with the exception of the first row of seedlings (from the north fence), which were 2-1 bareroot. Trees were planted in sets of three rows, one each of pine, Douglas-fir, and eucalyptus. Space between the rows was 1.5 m; within-row spacing was 1.5 m for KMX pine and eucalyptus; spacing varied from 1 to 2.5 m for Douglas-fir. Competition between trees in a row was considered insignificant at this stage in plantation development. Each set of rows was separated by a pasture grazing lane 20m wide (Fig. I.1). The agroforestry planting had been established as a demonstration, so treatments were neither randomized nor replicated. I elected to use the site, primarily because 1) other suitable established sites were lacking and 2) too much time was required to start a new one. I consider my work a case study, with inferences limited to this site.

To check for soil uniformity, I sampled at 8 random locations across the study area in July 1985 and found no significant difference in CEC or texture. Soil profiles (one dug in each pasture treatment) were likewise similar, although toward the west end of the

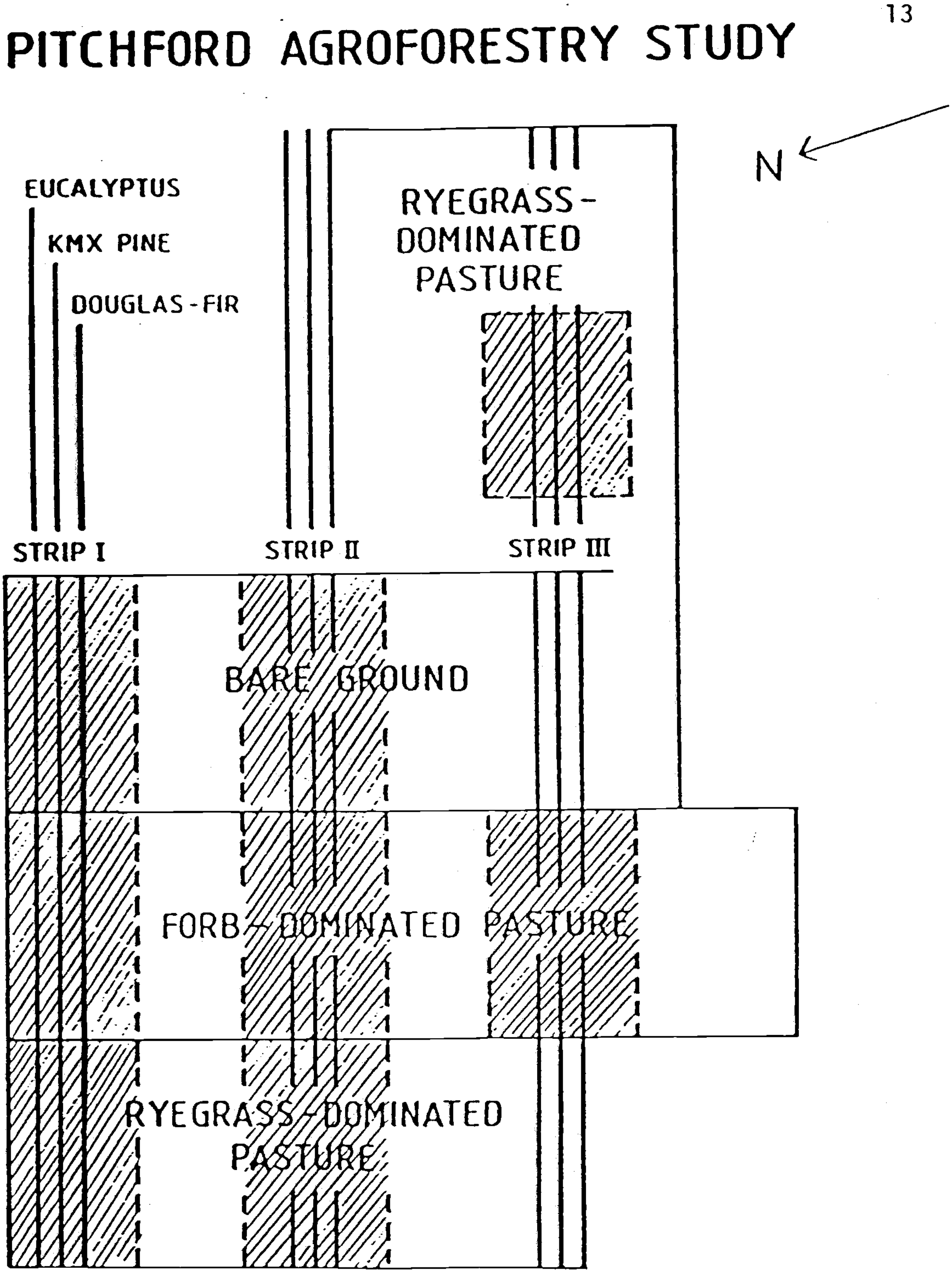


Figure I.1. Pitchford study site, showing the arrangement of pasture treatments and tree rows. Vertical lines indicate tree rows; dashed lines denote study plot boundaries. One cm on the diagram represents 4 m in the field.

site a weakly cemented cobble layer was found at 1 m depth. I do not consider this an impediment to tree growth.

C. MATERIALS AND METHODS

Experimental Design

The main treatment effect was tree species: KMX pine, Douglas-fir, and eucalyptus. Eucalyptus data cannot be presented because of frost mortality and insufficient sample size. The trees were planted in sets of three rows, one of each species. The three pasture treatments of bareground, forb-dominated pasture, and ryegrass-dominated pasture are set across the sets of tree rows (Fig. I.1), forming a set of tree-pasture plots. These plots, three each for the forb- and ryegrass-dominated treatments, and two of bareground, were considered experimental units and pseudoreplications (Hurlbert 1984). Sampling units are the individual trees. Five trees per plot were used for growth measurements, three for moisture stress measurements, and four for nitrogen sampling.

Sheep grazed the forb- and ryegrass-dominated treatments three times in each of the 1985 and 1986 seasons (March-July). Both wide pasture areas (Fig. I.1, areas between sets of tree rows) and narrow lanes between tree rows (Fig. I.1, areas within tree rows) were grazed. Grazing was intensive and short-term. (Mean utilization for the 1986 season was 81 percent; see Appendix D.) Wide pastures were grazed for three days and narrow lanes for one day. Areas were rotated systematically, so grazing was continuous over the study area during the season. Sheep were kept from browsing trees by portable electric (New Zealand) fencing. Fencing was placed along tree rows to a height of about 50 cm and at a distance of about 30 cm from the trees.

Tree Growth Response

Tree height (nearest 5 cm) and basal diameter (nearest 0.1 mm) measurements began in July 1985 and continued quarterly (October, January, April, and July) until October 1986.

Tree Moisture-Stress Response

Tree xylem moisture-stress response was measured in a pressure bomb (Scholander et al. 1965, Waring and Cleary 1967) using cut twigs. Moisture stress was measured pre-dawn (2:00 to 5:00 A.M.) quarterly from July 1985 to October 1986. During the expected peak period of stress (July to early September), moisture stress was measured every three weeks.

Tree Foliar Nitrogen (N) Response

Foliage samples were taken from three or four trees per plot. Foliage was sampled from the current year's growth in the upper crown of the tree, in a standard procedure described by Lavender (1970). Typically, five twig tips (current year's growth) were removed per tree. Samples were dried (70 degrees C), finely ground, and digested using a microKjeldahl technique (Allen et al. 1974). Digested solutions were processed with a Technicon II autoanalyzer to determine total N concentration.

Soil Total and Mineralizable Nitrogen

Soil (0-15 cm depth) samples were collected from the plots at the beginning (July 1985) and conclusion (October 1986) of the study. Three samples in both tree rows (50 cm from tree) and adjacent pasture areas (150 cm from tree) were collected in each plot, then bulked by distance from tree within plot.

Samples were stored below freezing until processed. They were then oven-dried (100 degrees C) and digested as described for foliage samples. Carbon content subsamples were analyzed by the LECO dry combustion technique (Allen et al. 1974)

In October 1985 and October 1986, fresh-soil subsamples were used to determine a soil nitrogen mineralization index using a 1-week incubation at 40 degrees C (Keeney and Bremner 1966). Before incubation, samples were sifted using a 1 mm mesh screen to remove rocks and stones. A one-week delay in processing the October 1985 samples resulted in impossibly low numbers, so these data are not presented. Soil bulk density (0.77-0.99 g/cm^3) and percent rock content were used to calculate nitrogen content in kg/ha.

Statistical Analysis

Although the arrangement of tree rows and pastures suggested a split-strip design (Petersen 1985), lack of randomization and replication limited statististical interpretation. Mean separation techniques were not valid. Comparisons were therefore made on the basis of t-tests between one species on all treatments or two species on the same treatment, but not between species-treatment combinations. Means of sampling unit values on each plot were used in comparisons.

D.RESULTS

Tree Height and Diameter Growth

No significant treatment effects on tree height and diameter growth (October 1985-October 1986) were found. KMX pine mean height growth (1.11 m) was significantly (p=0.05) greater than that of Douglas-fir (0.43 m). Diameter growth likewise reflected significant species differences (37 mm for KMX pine versus 15 mm for Douglas-fir).

Expressed as percent increase (Table I.1), there were again no significant treatment effects on height and diameter growth. Further, species differences were less clear. KMX showed superior height growth compared to Douglas-fir, but not on all treatments. No consistent percent diameter growth differences were found between the species.

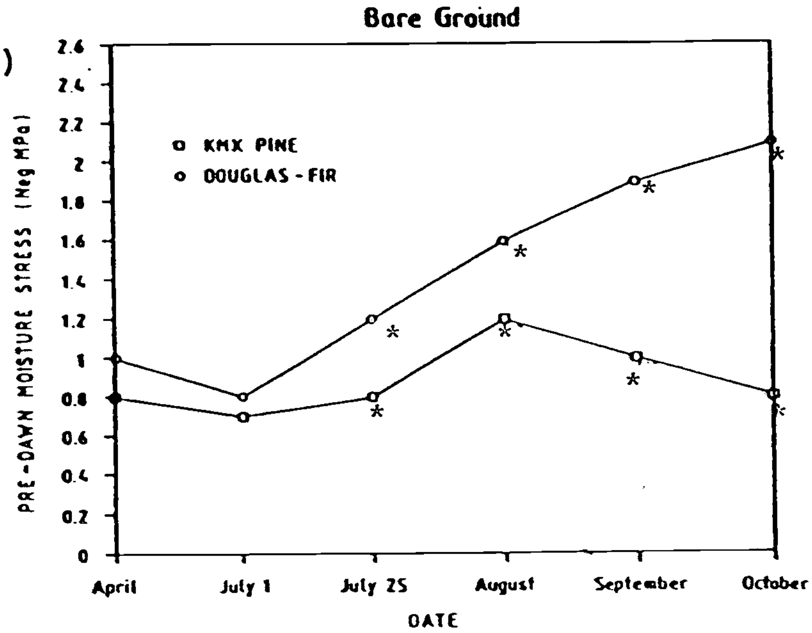
Predawn Moisture Stress

Predawn xylem moisture stress (PMS) of KMX pine and Douglas-fir differed significantly on the three treatments by mid- to late summer (Fig. I.2a,b,c). PMS of KMX pine showed no trends among treatments or through the season (Fig. I.2d), except at the August measurement date. In contrast, Douglas-fir PMS was greater than that of KMX

Table I.1. Pitchford height and diameter growth expressed as percent increase over initial height, KMX pine and Douglas-fir, October 1985-October 1986. Values (for a given species) followed by the same letter are not significantly different at the 0.05 level.

Treatment	Height Growth Increase (Percent)	Diameter Growth Increase (Percent)
KMX Pine		
Bareground	68a	70a
Forb-dominated	88a	65a
Ryegrass-dominated	71a	71a
Douglas-fir		
Bareground	38b	60b
Forb-dominated	66c	48b
Ryegrass-dominated	58bc	65c

(a)



(b)

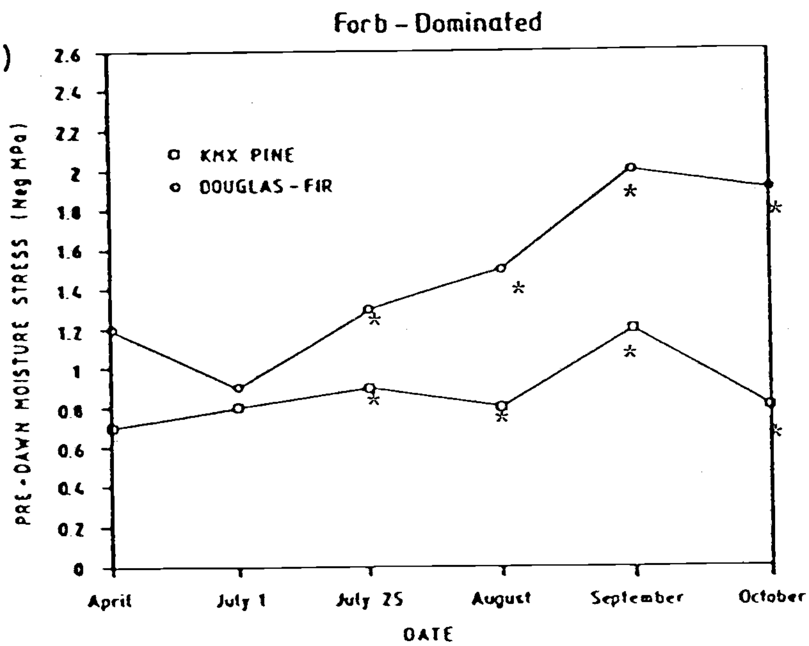
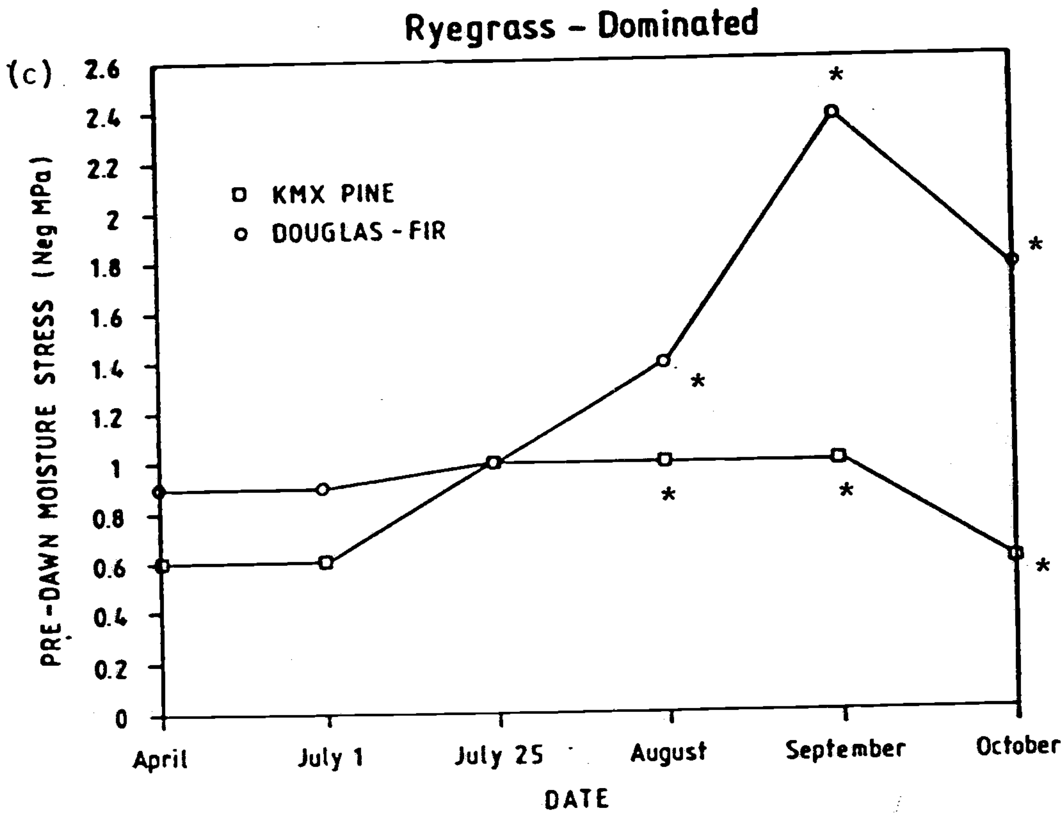


Fig. I.2. Pitchford predawn xylem potential of KMX pine and Douglas-fir on three pasture treatments, April to October 1986. For a given date, asterisks denote significant differences at the 0.05 level. (a) Bareground treatment comparison of KMX pine and Douglas-fir; (b) Forb-dominated treatment comparison of KMX pine and Douglas-fir; (c) Ryegrass-dominated comparison; (d) Douglas-fir, all treatments; (e) KMX pine, all treatments.



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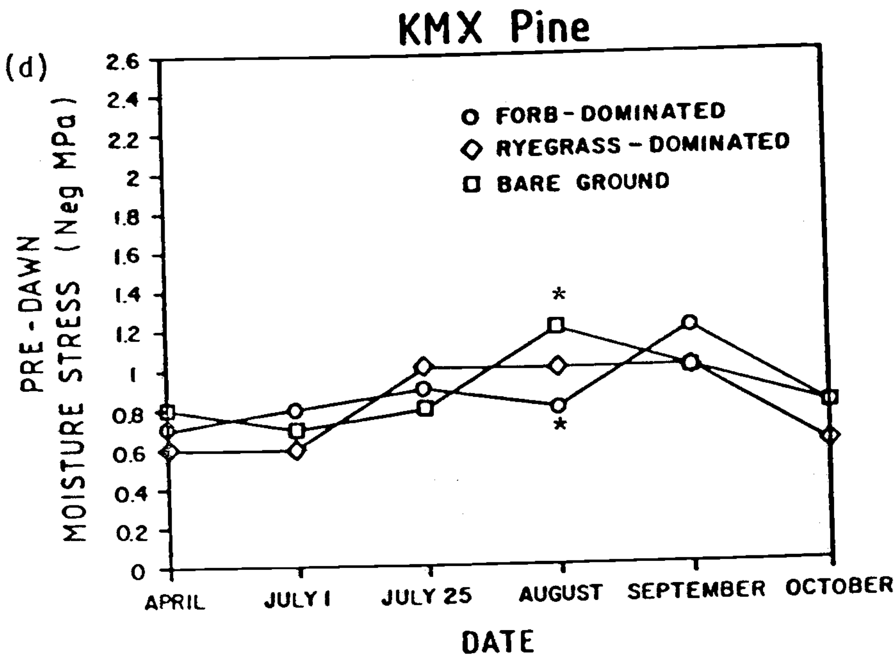


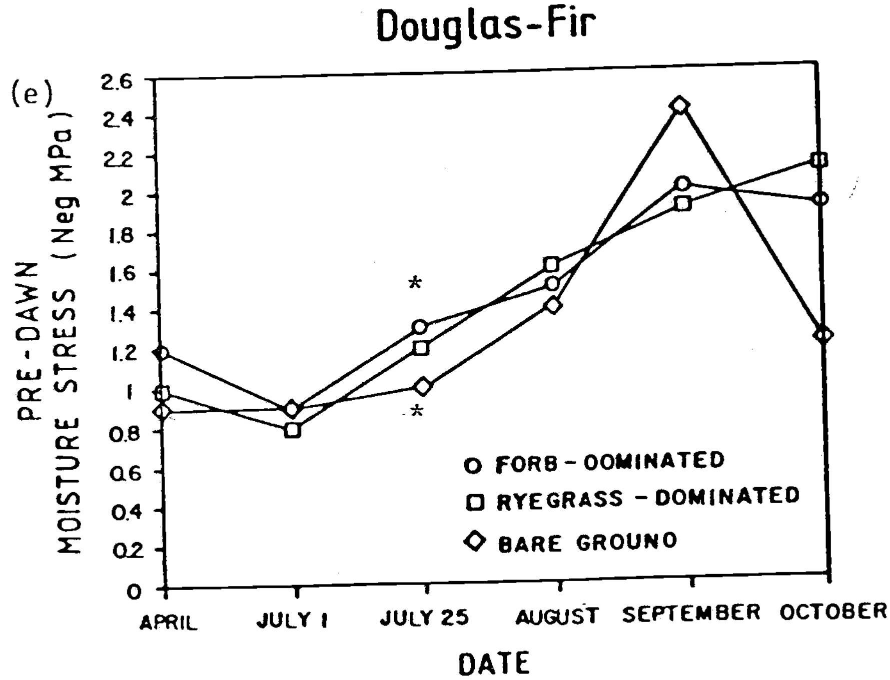


Fig. I.2 (Continued)

throughout time (Fig. I.2e) and treatments (Fig. I.2a,b,c), once soil moisture was depleted (by July 1). For Douglas-fir, only the July data showed a treatment difference at the 0.05 level.

Tree Foliar Nitrogen (N)

Foliar nitrogen-concentration (percent) means were similar for both species and treatment, with one exception (Tables I.2 and I.3). In July 1985, the bareground value was significantly greater than for the ryegrass-dominated treatment, for both KMX pine and Douglas-fir. This may have been caused by the weeding of clover on these plots at the beginning of the study, or from decomposition of plants weeded the previous year.

Soil Total and Mineralizable N

Total soil and mineralizable N values in October 1986 (Table I.4) showed no significant differences among treatment. Soil sampled in the adjacent pasture had mineralizable values nearly twice those of the tree rows (50 cm from trees), but the difference was statistically insignificant ($p > 0.10$). Carbon to nitrogen ratios were less than 30, favorable for N mineralization (Mengel and Kirkby 1982).

E. DISCUSSION

Tree Height and Diameter Growth

KMX pine clearly showed superior height and diameter growth compared to Douglas-fir, regardless of pasture treatment. When

Table I.2. Pitchford mean foliar nitrogen concentration (percent) of KMX pine on pasture treatments. Values are means of 6-8 samples. Those for a given date do not differ significantly if followed by the same letter.

	Date			
Treatment	July 1985	Oct 85	July 86	Oct 86
Bareground	1.65b	1.40a	1.30a	1.43a
Forb-dominated	1.17a	1.35a	1.17a	1.58a
Ryegrass-dominated	1.05a	1.38a	1.04a	1.38a

Table I.3. Pitchford mean foliar nitrogen concentration (percent) of Douglas-fir on pasture treatments. Values are means of 6-8 samples. Those for a given date do not differ significantly if followed by the same letter.

	Date			
Treatment	July 1985	Oct 85	July 86	Oct 86
Bareground	1.79b	1.80a	1.00a	1.59a
Forb-dominated	1.15a	1.85a	1.20a	1.50a
Ryegrass-dominated	1.16a	1.38a	1.17a	1.43a

Table I.4. Total soil nitrogen (N), carbon (C), and mineralizable N in surface soil (0-15 cm) of KMX pine rows (50 cm from tree) and adjacent pasture (150 cm from tree). All values for the same date and distance are not significantly different at the 0.05 level. Mineralization values include both ammonium and nitrate mineralization.

Treatment	July 1985 Total N (Percent)	July 1985 Estimated Total C (Percent)	October 1986 Total N (Percent)	October 1986 Total C (Percent)	October 1986 Mineralizable N (kg/ha)
Tree Row (50 cm from tree)					
Bareground	0.09	1.47	0.07	1.70	24.01
Forb-dominated	N/A	1.47	0.07	1.56	29.51
Ryegrass-dominated	0.09	1.47	0.07	1.53	34.30
Adjacent Pasture (150 cm from tree)					
Bareground	0.10	1.95	0.08	1.86	19.68
Forb-dominated	N/A	1.95	0.08	1.72	27.65
Ryegrass-dominated	0.11	1.95	0.07	1.70	56.95

growth is expressed as percent increase over intitial height and diameter, however, both species were growing at about the same rate.

Studies of effects of forage competition on tree growth show varied results (Hedrick and Kenniston 1966, Sharrow and Leininger 1983, Clark and McLean 1978), probably due to differing climate, soils, and other factors (Klingler 1982). In considering effects, studies should be separated based on age of plantation. Effects of grazing are likely to be quite different on newly-planted seedlings compared to well-established plantations.

Moisture Stress

Both Douglas-fir and KMX pine experienced summer moisture stress, as evidenced by predawn xylem potentials of less than -1.0 MPa (Fig. I.2). Douglas-fir, however, showed significantly greater predawn moisture stress in mid to late summer than did KMX pine. Pre-dawn moisture stress in KMX was constant throughout the season, but that of Douglas-fir climbed in July and remained high before dropping slightly in October. Growth of Douglas-fir was therefore limited by moisture stress, while KMX pine was able to maintain substantial height and diameter growth during the study period.

One explanation for this is that pines generally exhibit better stomatal control than Douglas-fir (Lopushinsky and Klock 1974). Probably the best explanation to lower pine stress, however, is that pine roots had reached a soil depth sufficient to alleviate stress. Sands and Nambiar (1984) demonstrated this effect with *Pinus radiata* in Australia, finding 2 m root depth penetration after two seasons.

This was sufficient to alleviate moisture stress, even with increasing weed competition. In my study, Douglas-fir roots may not have yet expanded sufficiently to exploit moisture at depth.

Although the data show a clear difference in species response, I cannot distinguish between stomatal control and rooting depth (or possibly other reasons) as explanations for the differences in species response.

No differences in tree moisture stress response was found between the grazed and bareground treatments. Grazing was apparently sufficiently intense to reduce tree moisture stress to that of bareground. Grazing regimes have been found to reduce moisture stress (Eissenstadt and Mitchell 1983, Squire 1977, Sharrow and Leininger 1983).

Tree Foliar Nitrogen (N)

Trees sampled on the bareground treatment in July 1985 had higher foliar N concentrations, perhaps as a response to N released in decomposing vegetation weeded in 1984 or early 1985. After July 1985, no significant differences in treatment were found.

Gessel (1966) defined 1.1-1.6 percent N as an adequate range for Douglas-fir growth. As Tables I.2 and I.3 illustrate, much of the data, for both KMX pine and Douglas-fir, fall in this range. Nitrogen is apparently not limiting tree growth on this site.

During the study, there was no additional nitrogen benefit to trees from either nitrogen fixed by clover or nitrogen recycled by animals. (Animals were kept at least 30 cm from trees by electric fencing, however.) At least in the establishment phase (0-3 years) of tree growth on our site, this appears to refute the popular contention that rapid nitrogen cycling by grazing animals is beneficial to tree growth. This cycling, however, may be of benefit to forage plants, particularly grasses (Watkin and Clements 1978). I also cannot say whether or not a long-term (5 to 10 years or more) N benefit to trees from animal cycling will occur.

Nitrogen effects of grazed pastures on tree growth have been only cursorily examined by researchers (e.g. Vallis 1978). Few if any studies have dealt directly with nitrogen effects. Gillingham (1983) described the problem of poor animal waste distribution acting against benefit to trees. To my knowledge, no study dealing specifically with tree nitrogen response has been conducted, and this remains an important research need.

Soil Total and Mineralizable N

No significant differences in total soil N were found among the treatments in July 1985 or October 1986. Soil total N normally changes very slowly over time (Waring and Schlesinger 1985) and so was not expected to change over the course of the study.

Mineralizable N in adjacent pasture appeared greater than that in tree rows in October 1986, suggesting N input to pastures by clover or animal waste or both. Although preferential redistribution of waste to trees has been suggested (Hilder 1969), no such pattern was found in this study. Trees on the Pitchford site were protected by portable electric fencing; sheep could not rest underneath them.

F. MANAGEMENT IMPLICATIONS

Our results indicate grazing on the Pitchford site was probably sufficiently intense to remove moisture stress differences between pasture and bareground treatments, although a non-grazed control would be be needed to provide more conclusive evidence. This finding is substantial in a region that experiences severe summer drought, and where land management objectives can include both growing trees and producing forage.

Nutrient return from animal waste during the study period had no effect on increasing foliar N in trees. Further, no consistent differences in soil or foliar N were found between any of the treatments. Neither a legume (subterranean clover) nor animal wastes were sufficient to induce a foliar N response. I caution, however, that these conclusions are valid only for the site, grazing regime, and time period I investigated.

Part II. Effects of Simulated Grazed Pasture on the Growth of KMX Pine, Douglas-fir, and *Eucalyptus glaucescens*: A Potted-Plant Study

A. INTRODUCTION

Integration of pastures, grazing, and tree production is being examined as a land management option for southwest Oregon. The KMX pine (*Pinus attenuata* X *P. radiata*) is the tree component of this system, and shows rapid growth on dry sites. *Eucalyptus glaucescens* offers potential as a fast-growing firewood species Douglas-fir (*Pseudotsuga menziesii*) is the dominant timber species of the region. Each of these species can be grown in grazed pastures, although the latter two are used for comparison in this study. Interactions in similar systems continue to be the focus of numerous research efforts. Of interest are competitive effects of pasture plants on tree growth (Preest 1975, Squire 1977, Nambiar and Zed 1980) but also the effect of grazing on tree growth (Black and Vladimiroff 1963, Hedrick and Kenniston 1966, Sharrow and Leininger 1983). Pasture plants compete with trees for water and nutrients (Squire 1977). Clover in a forage mix may provide nitrogen (Watson et al. 1984). Grazing removes competing vegetation (Sharrow and Leinininger 1983) and recycles nutrients rapidly through animal waste products (Petersen et al. 1956, Gillingham 1983).

In tree plantation establishment, control of competing vegetation is considered essential for tree survival and growth (Preest 1975, Squire 1977, Newton and Preest 1987). Whether grazing

Soil nitrogen is a key factor in determining the outcome of forage competition (Donald 1963). Increased available soil nitrogen usually favors grass over clover, but reasons for this are not fully understood (Vallis 1978). Grasses have diffuse, spreading root systems, more efficient than clover taproots for uptake of nutrients in solution (Barber 1984). Secondly, increased levels of N have been shown to inhibit symbiotic nitrogen fixation associated with clover (Templeton 1978). Finally, in early spring grasses can benefit from available soil nitrogen while clover nodules are still forming (Vallis 1978).

Many aspects of forage physiology and competition have been determined with pot experiments in Australia and New Zealand (e.g., Donald 1961, Donald 1963, Vallis 1978). Pot experiments offer greater control over factors influencing plant growth than field experiments. None to my knowledge have combined forage with tree competition. I therefore decided to conduct a pot experiment to further augment a field observational study of grazing effects on tree growth.

Because effects of grazed pasture on tree growth are still poorly understood, my primary objective was to compare tree growth response of KMX pine, eucalyptus, and Douglas-fir to simulated grazing of perennial ryegrass and subterranean clover. To explain these responses, I further sought to relate tree nitrogen and water response to a range of simulated grazing treatments. Soil nitrogen changes and forage biomass response to intra- and interspecific competition were also measured.

B. MATERIALS AND METHODS

Location and Materials

In order to control more carefully the factors affecting growth in an integrated sheep-tree-pasture system, I developed a semi-controlled environment (shadehouse) study at the Oregon State University Forest Research Lab. A shadehouse is simply planting beds shaded by a roof covered with translucent fiberglass sheets. Trees are thus exposed to ambient environmental conditions, although the roof and a surrounding short wall offer some protection from wind and direct sunlight. Precipitation, except for small amounts, is excluded.

Soil used for the experiment was the A and upper B horizons of a Jory silty clay loam (Knezevich 1975). Soil was collected from a Douglas-fir forest near Corvallis, Oregon. Jory was chosen because it is typical of hillside sites in the Willamette Valley, sites considered suitable for sheep-tree-pasture systems.

Trees were planted in paper pots in August 1985. Species used were the KMX pine hybrid, Douglas-fir, and *E. glaucescens*. Each pot had a top diameter of 30 cm and a volume of about 9500 cm^3. Pots were carefully filled with soil so that each pot had the same soil volume. In October 1985, perennial ryegrass and subterranean clover were seeded in tree pots in varying proportions. A complete set of treatments was also sown in pots without trees.

Pots were watered at regular intervals. Watering was from above, until the first moisture stress experiment began (see pp. 37-38) in August 1986. In August 1986, each pot was enclosed in a plastic bag, and watering was subsequently from below for the remainder of the study.

Length of intervals between watering depended on season and atmospheric conditions. During summer months (both 1985 and 1986), pots were watered weekly, through the fall every two weeks, and in the winter once every three weeks. Equal amounts of water were given to all pots, but roughly one-third was lost by seepage from the bottom of the pots (prior to enclosure with plastic bags). From mid-April to mid-October 1986, the watering regime resulted in a series of wet-dry cycles; i.e., pots were watered and subsequently reached permanent wilting (-1.5 MPa soil moisture suction) in about one week. Enclosure of pots with the plastic bags allowed pots to remain at saturation longer but did not signifigantly alter the time in which permenant wilting was reached.

As a result, trees were severely moisture stressed during most of the active growing season (March to October). In April predawn xylem potentials were -0.8 MPa (KMX pine), -1.5 MPa (eucalyptus), and -2.7 MPa (Douglas-fir) one week after watering. The moisture regime trees experienced can therefore be considered stressful, and roughly comparable to summer soil moisture conditions in southwest Oregon.

Jory soil is often low in phosphorus. To remove low phosphorus availability as a limiting factor, all pots were fertilized with single superphosphate in February 1986, just prior to the active growing season. Rate of application was equivalent to 224 kg of superphosphate per ha, the recommended field application rate. Superphosphate also contains sulfur, another potentially limiting nutrient in western Oregon pastures (Dawson and McGuire 1972). Molybdenum is required for symbiotic nitrogen fixation in clovers (Silver and Hardy 1978), so a micronutrient mix including this element (at the equivalent of 70 g molybdenum per hectare) was also applied.

Experimental Design

Forage treatments were established as in Fig. II.1. Fifty ryegrass or clover plants was considered full density or 100 percent. Proportions of ryegrass/clover were 100/0, 90/10, 50/50, 10/90, and 0/100. This range of grass-clover combinations formed a replacement series (deWit 1960, Harper 1977, Radosevich and Holt 1984). Pots with trees only were also included.

Pots were laid out in a split-split-plot arrangement (Petersen 1985) of four blocks (replications). Each block was grouped by species and then randomly split into forage treatments. Groups of forage treatments were further split into two classes, those clipped and fertilized, and those only clipped (Fig. II.1.).

Grazing Simulation

All pots with forage underwent a simulated "grazing season" during 1986. From May until October pots were clipped once monthly.

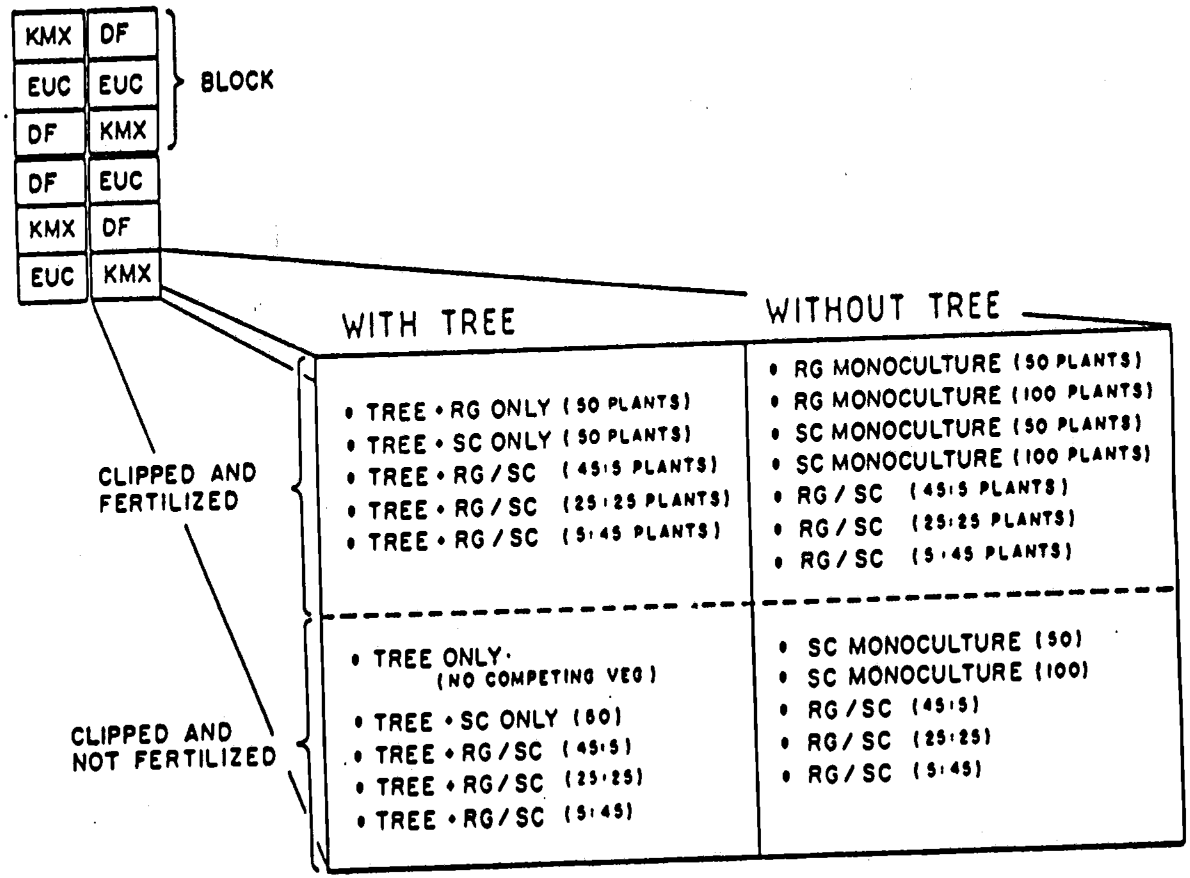


Fig. II.1. Forage and fertilization treatments in the shadehouse study. Each block contains one replication of each species and its associated treatments. Within each species grouping, forage treatments are split into tree/no tree groups, and further into fertilization/ no fertilization groups.

The clippings were carefully weighed to determine total biomass. After each of the first three clippings, 20 samples each of ryegrass and clover were randomly selected and analyzed for total nitrogen (N); thereafter, mean percentages from these clippings were used as an estimate of N content.

Floate (1970) estimated that sheep return 80 percent of N consumed in urine. Therefore, of the estimated N removed by clipping, 80 percent was returned in the form of a urea fertilizer solution. Six clippings and additions were conducted. Mean N content of forage was about 2 percent; each fertilization added N in the range of 0.03 to 0.50 g N per pot, or the equivalent of 5 to 80 kg/ha. Pots with substantial forage biomass production were thus well fertilized, and even those at the low end of the range probably received adequate nitrogen for tree growth.

A second set of replications was clipped but received no urea return. My simulation was very simple; I assumed return of nutrients to the spot where they were consumed, and also that grazing was non-selective.

Tree Growth Response

Growth analysis can take many forms (Hunt 1982). To measure tree response to treatments, absolute (final-initial) and relative (percentage increase) height and diameter were selected. Trees were measured at the time of forage seeding (October 1985), and again in April, July, and October 1986. Height was measured with a meter of competing vegetation affects trees is still unclear. Several authors report beneficial effects (Hedrick and Kenniston 1966, Wheeler et al. 1980, Sharrow and Leininger 1983), and others no effect (Clark and McLean 1978). Variation in results is probably due to climate, topography, and other factors (Klingler 1982).

Perennial ryegrass (*Lolium perenne*) and subterranean clover (*Trifolium subterraneum*) compose a commonly-used forage mix on Oregon hill pastures (Mosher and DeBell 1983). The two species differ in phenology, canopy morphology, root structure, and relative competitive ability (Templeton 1978).

To assess competitive advantages of ryegrass and clover it is useful to compare their regeneration characteristics. Ryegrass has smaller seed, and thus less stored carbohydrate for germination. Clover seed does not all germinate at the same time. Since ryegrass germination is prompt and fairly uniform, it may have a competitive advantage. Clover seed germinates earlier than grass seed (Rossiter 1978, Vallis 1978). Ryegrass has a faster early rapid growth rate, however, which may more than compensate for the disadvantage of smaller seed or later germination (Rossiter 1978).

In canopy morphology, ryegrass quickly develops a position above the clover and is thus better able to intercept light. Subterranean clover has a prostrate form, and is photosynthetically efficient at low light intensities (Watson et al. 1984). Given these differences in regeneration, growth, and form, it appears the species occupy different niches, although some overlap is probably involved.

stick; diameter was measured at ground level with dial calipers. Tree total mass (dry wt. basis) was measured at harvest in October 1986, and separated into shoot and root components. Using these components, shoot/root ratio was determined.

Tree Foliar Nitrogen

Foliar samples were collected from the upper portion of each seedling in October 1985 and at harvest in October 1986. Three or four twig tips (current growth) were collected in accordance with the protocol of Lavender (1970). Samples were oven-dried at 70 degrees C for 48 h, ground to pass a 40-mesh sieve, and then acid-digested using a standard microKjeldahl technique (Allen et al. 1974). Resultant extracts were autoanalyzed for N content on a percentage basis.

Tree Moisture Stress Response

Two moisture stress experiments were conducted, one each in early August and mid-October. Just prior to the August experiment, pots were enclosed in plastic bags (as described above). Before each experiment pots were watered to saturation. Soil moisture was then monitored daily by weighing each pot. Soil moisture was then monitored daily by weighing each pot. Soil moisture content was derived using the soil bulk density, and in turn related to soil moisture potential using the soil moisture characteristic curve (Appendix C.)

Because measurements were time consuming, only KMX pine was selected for investigation. During each drydown experiment, pots were weighed in late afternoon or at dusk. The following morning, before sunrise, predawn moisture stress of each KMX pine was determined using needle fascicles.

The August experiment was ended after 10 days, as the grass in the pots was seen to be wilting and soil moisture content had reached the point of permanent wilting. Pots were then rewatered. The October drydown was ended after 5 days, as further drying was expected to be slow due to cool and humid conditions.

Soil Nutrient Analysis

Soil samples from selected treatments were bulked and analyzed for total N. Sampling was conducted in February 1986, prior to the growing season. At harvest (October 1986) samples were again taken to evaluate changes, if any, in levels of these nutrients. Samples were oven-dried for 48h at 110 degrees C, ground to a fine powder, acid-digested using a microKjeldahl procedure (as for foliar nitrogen), and subsequently autoanalyzed to determine N on a percentage basis.

Subsamples were also analyzed for total carbon on a percentage basis using a LECO furnace (Allen et al. 1974) in order to determine the carbon/nitrogen ratio (Mengel and Kirkby 1982).

Forage Biomass Response

Total forage biomass yields for the season (6 clippings) for each treatment were compared using absolute and relative yield diagrams (deWit 1960, Radosevich and Holt 1984). These allow determination of species relative competitiveness, and also a rough assessment of the interaction between species (Radosevich and Holt 1984).

C. STATISTICAL ANALYSIS

Tree Growth Response

In March 1986, ryegrass and clover germinants were found in proportions other than the intended ones of 90/10, 50/50, and 10/90. As a result, mixed (both ryegrass and clover) pots were regrouped in three categories based on proportion of total density: (1) those with ryegrass proportion >0 and <=33; (2) those in the mid-range (>33 and <=66); and (3) those >66 but <100 Thus there are six possible forage treatments affecting the trees-- tree only (no forage), tree with ryegrass monoculture, tree with clover monoculture, and the three mixed treatments mentioned above. All treatments were duplicated in fertilization/no fertilization effect, except that there was no un-fertilized ryegrass monoculture.* Grouping of trees into mixed-forage categories resulted in an unbalanced design. Replications of treatments ranged from 2 to 6; most were replicated 4 times. This was accounted for in statistical analyses. Analysis was conducted using the general linear models procedure of the SAS personal computer package (SAS Institute, Inc.

* The experiment was originally designed to include destructive sampling of pots containing clover during the study, in order to examine nodulation. A complete extra set of these pots was therefore planted. The clipping and fertilization scheme was developed later.

1986). In order to fully assess outcomes, analysis was conducted using three approaches: regression (Satoo and Madgwick 1982, Neter et al.1983), analysis of variance (ANOVA) (Petersen 1985, Dixon and Massey 1983), and orthogonal contrasts (Petersen 1985, Chew 1976, Mize and Schultz 1985). A description of each procedure follows.

Regression. Regression was used to provide a concise analysis of tree growth response over time. Using regression, variation can be partitioned and attributed to sources on a percentage basis. Height and diameter were separately regressed as functions of time elapsed since forage seeding. No account was made of treatment differences. My objective was to determine what portion of variation in height and diameter was accounted for by tree growth without regard to influences of fertilization or forage competition. Natural logarithm transformations of variables were used where needed to remove trends among residuals (Neter et al. 1983).

Analysis of Variance. Analysis of variance was performed using treatment means of tree growth response. Means of significant effects, where present, were further separated using LSD t-tests (Petersen 1985).

Orthogonal Contrasts. Because mean separation showed few significant differences, I made comparisons using another aspect of ANOVA: orthogonal contrasts. Use of contrasts allows comparisons of groups of means of interest, and is particularly appropriate with proportional data (such as the forage proportions) (Mize and Schultz 1985).

Moisture Stress Experiments

Soil moisture content values were pooled by treatment to form a mean for a given day. Differences between treatments means were tested using t-tests.

Foliar Nitrogen Response

Analysis of variance was used to determine significance of main effects (species, fertilization, and forage treatment) on tree foliar nitrogen response. Where appropriate, means of significant effects were separated using LSD t-tests (Petersen 1985).

D. RESULTS

Tree Growth Response

Regression. Regression response models for height and diameter growth over time are shown in Table II.1. Seventy-one percent of the variation in KMX height growth, and 81 percent of the variation in diameter growth, was explained by the time since forage planting. Comparable coefficients of determination for eucalyptus and Douglas-fir were lower. High r^2 values for KMX pine height and diameter over time suggest its growth is largely determined by innate characteristics.

Models were constructed using forage and fertilization treatments as variables; however, these variables often did not enter the models (0.15 significance level). I therefore elected to use analyses of variance with mean separation to test for possible

Table II.1 Response models for height and diameter over time for tree species in the shadehouse study. "Date"= no. of days since forage seeds seeds were planted in October 1985. Note that a natural logarithmic transformation was performed on the response variables.

Species	Model	r^2
Height		
KMX Pine	ln (height) = date	0.71
Eucalyptus	ln (height) = $(date)^2$	0.51
Douglas-fir	ln (height) = date	0.22
Diameter		
KMX Pine	ln (diameter) = date + $(date)^2$	0.81
Eucalyptus	ln (diameter) = date	0.68
Douglas-fir	ln (diameter) = date	0.40

differences.

Analysis of Variance With Mean Separation. Table II.2 shows that height and diameter response differed significantly (p=0.05) between species. Diameter response on an absolute basis followed the sequence KMX pine > eucalyptus > Douglas-fir. On a relative basis, eucalyptus diameter growth was the greatest, followed by KMX pine and Douglas-fir. Absolute height growth also followed this sequence. On a relative height basis, eucalyptus and KMX pine were growing at about the same rate; both grew faster than Douglas-fir.

Comparison of biomass between species provides information on species resource allocation. Tree total and root biomass at harvest both followed the sequence KMX pine > eucalyptus > Douglas-fir (Table II.3). These differences were significant (p<0.05). Shoot/root ratio, an index of relative allocation, showed a different sequence. Eucalyptus shoot/root ratio was very high (about 2.5), and significantly greater (p=0.05) than that of KMX pine (about 1.5) and Douglas-fir (about 1.0). Height growth can be related to biomass allocation patterns. Eucalyptus can sustain substantial height growth (132-142 percent on a relative basis) with roughly the same amount of root biomass as Douglas-fir. KMX pine showed the greatest (significant at p=0.05) above- and below-ground biomass of all three species.

Mean separation using LSD t-tests revealed no significant differences between treatment effects on KMX pine, confirming the inference from regression analysis that the species was largely

Table II.2 Comparieon of epeciee-fertilization combinatione for tree diameter and height growth variablee, Shadehouse Study, October 1985-October 1986. See text for explanation of fertilizer treatmente. Valuee within a column followed by the eame letter are not eignificantly different at the 0.05 level.

Speciee	Fertilization	Mean Diameter Increment (mm)	Mean Diameter Increaee (%)	Mean Height Increment (cm)	Mean Height Increaee (%)	N
KMX Pine	Fertilized	8a	97a	29a	70a	20
	Non-fertilized	7a	91a	29a	67ab	20
Eucalyptue	Fertilized	6b	142b	41b	67ab	16
	Non-fertilized	6b	132b	41b	63b	20
Douglae-fir	Fertilized	4c	87c	9c	26c	22
	Non-fertilized	4c	90a	10c	29c	20

Table II.3. Comparison of species-fertilization combinations for tree biomass variables at harvest (October 1986). Values (for a given parameter and species) followed by the same letter are not significantly different at the 0.05 level.

Species	Fertilization	Mean Total Tree Biomass (g)	Mean Root Biomass (g)	Mean Shoot/ Root Ratio	N
Kmx Pine	Fertilized	98.6a	41.1a	1.45a	20
	Non-fertilized	90.0a	36.1a	1.56a	20
Eucalyptus	Fertilized	38.7b	11.6b	2.51b	16
	Non-fertilized	51.7b	16.0b	2.33c	20
Douglas-fir	Fertilized	28.9c	13.7c	1.13c	22
	Non-fertilized	29.8c	15.2c	1.07d	20

unaffected by treatments (Table II.4). Eucalyptus absolute diameter growth, when grown alone or with clover only, was significantly greater ($p<0.05$) than with other treatments. Height growth, both absolute and relative, was also significantly greater ($p=0.05$) than with other treatments. This pattern (greater growth when alone or with clover only) also followed for Douglas-fir, but was not statistically significant.

On a biomass basis (Table II.5), KMX pine was not affected by treatments. Eucalyptus total and root biomass was significantly greater for trees grown alone than for trees grown with forage. Douglas-fir total and root biomass was much greater when trees were grown alone than with competing forage, but because of variation, the differences were not significant.

Orthogonal Contrast Comparisons. Table II.6 lists the comparisons analyzed. In Tables II.7-II.11, only those comparisons significant at the 0.15 level are presented. The 0.15 level was selected in order to describe trends which might have become significant in a longer experiment or with additional replication.

Treatment effects on KMX pine (Table II.7) were all found to be statistically weak ($p > 0.05$). Trees without competing vegetation showed greater growth ($p=0.08$) compared to all forage treatments combined. Grass competition appeared to depress diameter growth. Pots with clover appeared to have a beneficial effect on diameter growth; clipped and fertilized clover appeared more beneficial than clover not fertilized.

Table II.4. Comparison of tree height growth response variables by species as affected by forage treatments, October 1985-October 1986. Values (for a given species and parameter) followed by the same letter are not significantly different at the 0.05 level.

Treatment	Mean Dia. Increment (mm)	Mean Dia. Increase (%)	Mean Ht. Increment (cm)	Mean Ht. Increase (%)	N
KMX Pine					
Tree Only	7.6a	90a	34.25a	78a	4
Grass Only	6.7a	82a	30.50a	72a	4
Clover Only	8.4a	100a	29.00a	69a	8
Mixed, Low Grass	8.0a	99a	26.67a	68a	9
Mixed, Middle	8.2a	97a	28.00a	66a	7
Mixed, High Grass	7.1a	86a	25.86a	61a	7
Eucalyptus					
Tree Only	7.9a	147a	52.00a	84a	4
Grass Only	5.1b	113a	37.67b	64b	3
Clover Only	8.3a	194a	47.43a	75a	7
Mixed, Low Grass	6.0b	124a	39.17b	58b	6
Mixed, Middle	4.8b	102a	37.12b	56b	8
Mixed, High Grass	5.9b	131a	35.75b	60b	8
Douglas-fir					
Tree Only	5.1a	106a	14.25a	45a	4
Grass Only	4.0a	91a	8.00a	24a	4
Clover Only	5.1a	95a	11.14a	28a	7
Mixed, Low Grass	4.5a	93a	8.67a	25a	7
Mixed, Middle	4.4a	80a	8.80a	25a	5
Mixed, High Grass	3.4a	65a	8.00a	23a	10

Table II.5. Comparison of tree biomass response to forage treatments by species, October 1985-October 1986. Values (for a given species and parameter) followed by the same letter are not significantly different at the 0.05 level.

Treatment	Tree Total Biomass (g)	Root Biomass (g)	Shoot/Root Ratio	N
KMX Pine				
Tree Only	99.2a	37.3a	1.66a	4
Grass Only	97.9a	40.8a	1.41a	4
Clover Only	103.5a	42.4a	1.49a	8
Mixed, Low Grass	96.5a	41.4a	1.38a	9
Mixed, Middle	89.6a	35.4a	1.55a	7
Mixed, High Grass	92.6a	39.4a	1.45a	7
Eucalyptus				
Tree Only	89.0a	27.2a	2.30ab	4
Grass Only	30.2a	11.4b	2.05b	3
Clover Only	53.8b	14.8b	2.69a	7
Mixed, Low Grass	38.3b	11.8b	2.56ab	6
Mixed, Middle	41.9b	12.9b	2.47ab	8
Mixed, High Grass	33.1b	10.7b	2.20ab	8
Douglas-Fir				
Tree Only	24.9a	14.9a	1.05a	4
Grass Only	9.8a	9.7a	0.99a	4
Clover Only	11.9a	17.8a	1.10a	7
Mixed, Low Grass	19.1a	13.5a	1.31a	7
Mixed, Middle	14.9a	15.8a	1.05a	5
Mixed, High Grass	12.6a	13.9a	0.99a	10

Table II.6. List of orthogonal contrasts used to selectively compare forage/fertilization treatment effects on tree growth parameters.

1. Fertilized vs. Non-Fertilized (Including Tree Only)
2. Tree Only vs. All Other Treatments
3. Fertilized vs. Clipped and Non-Fertilized
4. Clipped Fertilized Ryegrass (No Clover) vs. All Other Clipped and Fertilized
5. Ryegrass Proportions > 0.66 vs. All Other Treatments
6. Fertilized Clover vs. Non-Fertilized Clover
7. All Ryegrass Proportions > 0.66 vs. All Clover Proportions > 0.66
8. All Ryegrass Proportions < 0.33, Fertilized vs. All Ryegrass Proportions > 0.66, Non-Fertilized
9. Clover Non-Fertilized vs. All Others Non-Fertilized

Table II.7. Orthogonal contrast comparisons (p 0.15) of KMX pine height and diameter response (October 1985-October 1986) to forage/fertilization treatment comparisons. All other comparisons (listed in Table II.6.) were not significant.

Treatment Comparison	Corresponding Means	p-value
Absolute Height Growth (cm)		
Tree Only vs. All Other Treatments	34.3 vs. 27.2	0.08
Absolute Diameter Growth (mm)		
Clipped Fertilized Ryegrass (No Clover) vs. All Others Clipped & Fertilized	6.7 vs. 8.6	0.06
Ryegrass Proportions > 0.66 vs. All Other Treatments	7.0 vs. 8.1	0.14
Fertilized Clover vs. Non-Fertilized Clover	9.5 vs. 7.4	0.12
Ryegrass Proportions > 0.66 vs. All Other Treatments	7.0 vs. 8.2	0.09
Relative Diameter Growth (%)		
All Ryegrass Proportions > 0.66 vs. All Clover Proportions > 0.66	84.8 vs. 99.7	0.10

Table II.8. Orthogonal contrast comparisons ($p < 0.15$) of Eucalyptus height and diameter response (October 1985-October 1986) to forage/fertilization treatment comparisons. All other comparisons (listed in Table II.6) were not significant.

Treatment Comparison	Corresponding Means	p-value
Absolute Height Growth (cm)		
Tree Only vs. All Other Treatments	52.0 vs. 36.8	0.13
Fertilized Clover vs. Non-Fertilized Clover	48.0 vs. 22.0	0.07
Relative Height Growth (%)		
Tree Only vs. All Other Treatments	84.0 vs. 58.4	0.07
Fertilized Clover vs. Non-Fertilized Clover	76.0 vs. 38.0	0.01
Absolute Diameter Growth (mm)		
Tree Only vs. All Other Treatments	7.9 vs. 6.1	0.07
Clover Non-Fertilized vs. All Others Non-Fertilized	8.2 vs. 5.5	0.01
Relative Diameter Growth (%)		
All Ryegrass Proportions > 0.66 vs. All Clover Proportions > 0.66	125.3 vs. 163.3	0.12
Clover Non-Fertilized vs. All Others Clipped and Non-Fertilized	188.0 vs. 108.3	0.01

Table II.9. Orthogonal contrast comparisons ($p < 0.15$) of Douglas-fir height and diameter response (October 1985-October 1986) to forage/fertilization treatment comparisons. All other comparisons (listed in Table II.6) were not significant.

Treatment Comparison	Corresponding Means	p-value
Absolute Height Growth (cm)		
Tree Only vs. All Other Treatments	14.3 vs. 9.0	0.02
Ryegrass Proportions > 0.66 vs. All Other Treatments	8.0 vs. 10.5	0.13
Clover Non-Fertilized vs. All Others Non-Fertilized	12.0 vs. 6.8	0.05
Relative Height Growth (%)		
Tree Only vs. All Other Treatments	45.0 vs. 25.0	0.01
Absolute Diameter Growth (mm)		
Ryegrass Proportions > 0.66 vs. All Other Treatments	3.6 vs. 4.8	0.08
Fertilized Clover vs. Non-Fertilized Clover	3.7 vs. 6.2	0.09
Clover Non-Fertilized vs. All Others Non-Fertilized	6.2 vs. 4.4	0.02
Relative Diameter Growth (%)		
All Ryegrass Proportions < 0.33 Fertilized vs. All Ryegrass Proportions > 0.66, Non-Fertilized	115.0 vs. 65.0	0.14
Clover Non-Fertilized vs. All Others Non-Fertilized	118.0 vs. 62.2	0.07

Table II.10. Orthogonal contrast comparisons ($p < 0.15$) of eucalyptus biomass response (October 1985-October 1986) to forage/fertilization treatment comparisons. All other comparisons (listed in Table II.6) were not significant.

Treatment Comparison	Corresponding Means	p-value
Total Biomass (g dry wt.)		
Fertilized vs. Non-Fertilized (Including Tree Only)	47.8 vs. 51.7	0.02
Tree Only vs. All Other Treatments	89.0 vs. 39.8	0.0001
Ryegrass Proportions > 0.66 vs. All Other Treatments	32.2 vs. 50.5	0.003
All Ryegrass Proportions > 0.66 vs. All Clover Proportions > 0.66	32.2 vs. 44.9	0.04
Clover Non-Fertilized vs. All Others Non-Fertilized	53.1 vs. 38.8	0.12
Root Biomass (g dry wt.)		
Fertilized vs. Non-Fertilized (Including Tree Only)	14.5 vs. 16.0	0.05
Tree Only vs. All Other Treatments	27.2 vs. 12.2	0.0001
Ryegrass Proportions > 0.66 vs. All Other Treatments	10.9 vs. 15.0	0.08
All Ryegrass Proportions > 0.66 vs. All Clover Proportions > 0.66	10.9 vs. 12.9	0.06
Shoot/Root Ratio		
Ryegrass Proportions > 0.66 vs. All Other Treatments	2.2 vs. 2.5	0.12

Table II.11. Orthogonal contrast comparisons ($p < 0.15$) of Douglas-fir biomass response (October 1985-October 1986) to forage/fertilization treatment comparisons. All other comparisons (listed in Table II.6) were not significant.

Treatment Comparison	Corresponding Means	p-value
Total Biomass (g dry wt.)		
Clover Non-Fertilized vs. All Others Non-Fertilized	42.2 vs. 25.3	0.10
Shoot/Root Ratio		
All Ryegrass Proportions < 0.33, Fertilized vs. All Ryegrass Proportions > 0.66, Non-Fertilized	1.3 vs. 1.0	0.14

In contrast, eucalyptus height and diameter growth (Table II.8) was clearly affected by forage treatments. Clover not fertilized (clipped only) was associated with significantly (p=0.01) increased absolute and relative diameter growth. Grass depressed relative diameter growth, compared to trees grown with clover.

Fertilized clover height growth was greater than with non-fertilized clover on an absolute (p=0.07) and relative (p=0.11) basis. Once again, trees without competing vegetation tended to show greater height growth (p=0.13). Height of Douglas-fir grown alone was significantly greater on both an absolute (p=0.02) and relative (p=0.01) basis, than when grown with competing vegetation (Table II.9). Clover not fertilized also was associated with significantly (p=0.05) greater height growth. Grass depressed height growth when compared with all other treatments (p=0.13). Competing vegetation per se did not appear to restrict Douglas-fir diameter growth. Trees with fertilized clover showed greater growth than those with non-fertilized clover (p=0.09). Tree growth with clover not-fertilized was significantly greater than with all others on an absolute (p=0.02) and relative (p=0.07) basis. Trees with clover and no fertilization had greater growth (p=0.07) than all others.

Tree Biomass

No significant effects ($p < 0.15$) of treatments on KMX pine biomass were found, a strong implication that juvenile growth is unaffected by grazed forage competition.

Eucalyptus biomass, as with height and diameter growth, was greatly affected by treatments as indicated by a number of significant comparisons (Table II.10). Trees not fertilized had significantly greater total ($p=0.02$) and root biomass ($p=0.05$) than those fertilized. Trees with no vegetative competition showed significantly greater biomass ($p=0.0001$) than trees with vegetation. Grass had a depressing effect on total and root biomass when compared with clover, and also with all others. Shoot/root ratio was virtually the same for all treatments. One comparison, grass versus all others, was significant at the 0.12 level.

Douglas-fir biomass appeared largely unaffected by treatments (Table II.11). Clover not fertilized vs. all others only clipped was associated with greater total biomass ($p=0.10$). Low grass density showed high shoot/root ratio compared to high grass density ($p=0.14$).

Foliar Nitrogen Concentration

In October 1985, eucalyptus foliage had significantly more nitrogen than KMX pine (1.28% vs. 0.72%) ($p < 0.0001$). In October 1986, at the conclusion of the study, no significant differences in species or fertilization were found.

Significant ($p< 0.05$) treatment differences were found between clover and grass treatments; response with clover was greater than with grass (Table II.12). Both KMX pine and eucalyptus foliar N levels were similar when grown alone or with clover. Trees grown alone or with clover had significantly ($p< 0.05$) greater foliar N levels than those grown with grass or clover/grass mixtures.

Table II.12. Tree foliar nitrogen (percent) in the shadehouse study. October 1986. Values for a given species followed by the same letter are not significantly different at the 0.05 level. Because no difference was found between fertilized and non-fertilized treatments, these values were pooled for each forage treatment presented below.

Forage Treatment	Foliar N (Percent)	Number of Samples
KMX Pine		
Tree Only	0.94a	4
Ryegrass Only	0.87bc	4
Clover Only	0.90a	8
Mixed, Low Ryegrass	0.88bc	9
Mixed, Middle Ryegrass	0.79bc	7
Mixed, High Ryegrass	0.86b	7
Eucalyptus		
Tree Only	0.91a	4
Ryegrass Only	0.74bc	2
Clover Only	1.12a	7
Mixed, Low Ryegrass	0.86bc	6
Mixed, Middle Ryegrass	0.85bc	8
Mixed, High Ryegrass	0.73b	8

Moisture Stress Experiments

Moisture depletion curves for different treatments in the August experiment are presented in Figure 2. Compared with ryegrass treatments (Fig. 2a), trees with no forage competition showed the lowest moisture content soon after pots dropped below saturation (42 % moisture content). Pots with non-fertilized ryegrass showed the highest moisture content; non-fertilized ryegrass treatments appeared intermediate in response. T-test differences were not significant at the 0.05 level, however. Pots with a fertilized grass-clover mixture (Fig. 2b) lost less moisture over time compared to tree-only pots. Pots with clover (Fig. 2c) showed a consistent response and were similar in moisture depletion to the tree-only treatment. The non-fertilized mixture responded essentially the same as the tree-only treatment. No consistent patterns of tree predawn moisture stress response to treatments were found.

The drydown-curve of the August experiment shows a sharp drop in moisture soon after dropping below saturation. Hot, dry weather during the experiment caused rapid moisture loss. Consequently, soil moisture tension increases rapidly. An interest in more fully assessing this part of the curve resulted in the October experiment. Pots were expected to dry down more slowly because of cooler temperatures and higher humidity in October.

Fig. II.3 illustrates results of the October experiment. Only responses in the moisture content range from saturation to 33 percent are presented. Results were similar to those of the August

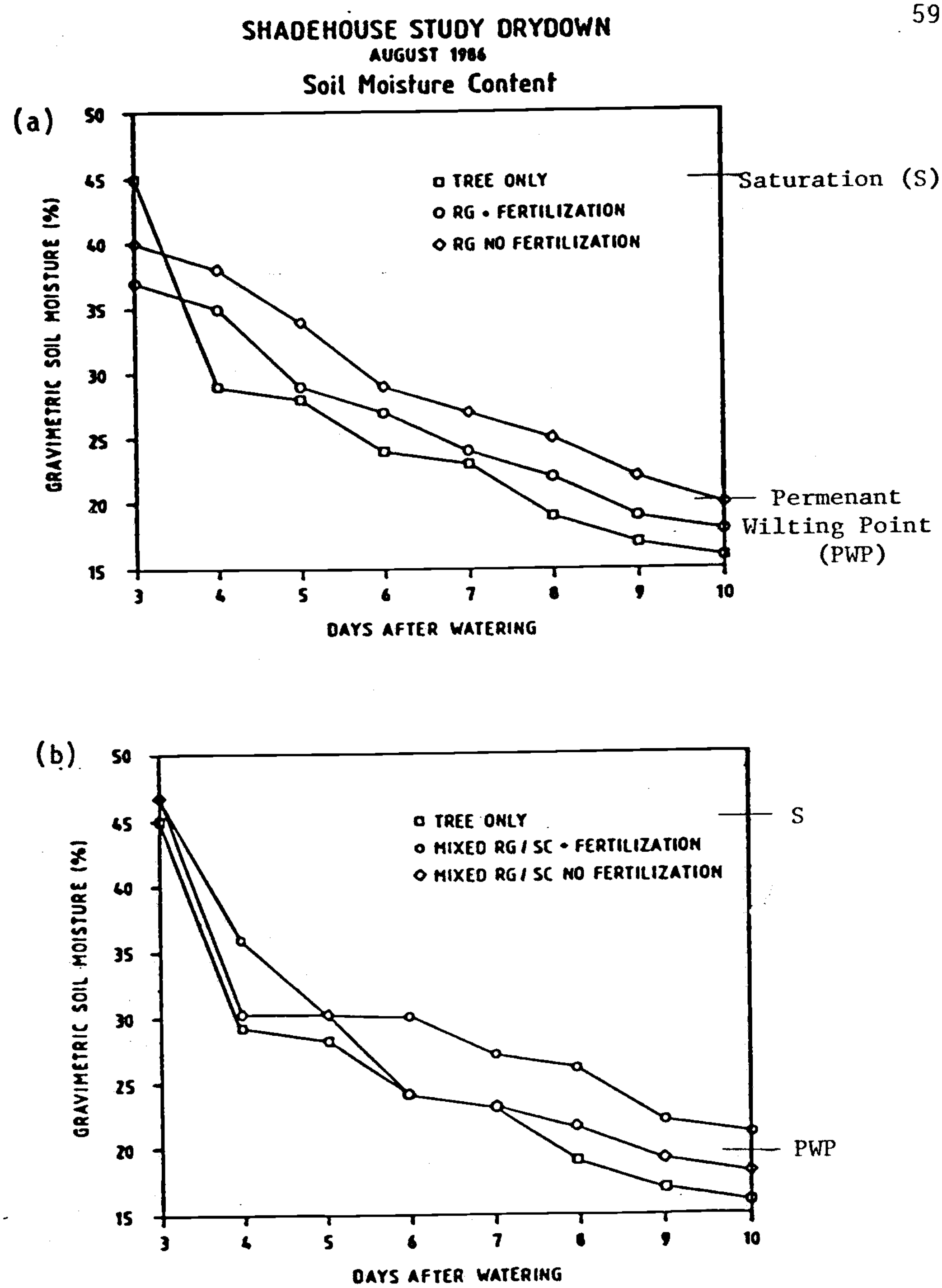


Figure II.2. Treatment comparison of soil moisture content over time in the shadehouse study August 1986 moisture stress experiment. (a) Trees with no competing vegetation compared with ryegrass treatments; (b) Trees only compared with mixed ryegrass/clover treatments; (c) Trees only compared clover treatments.

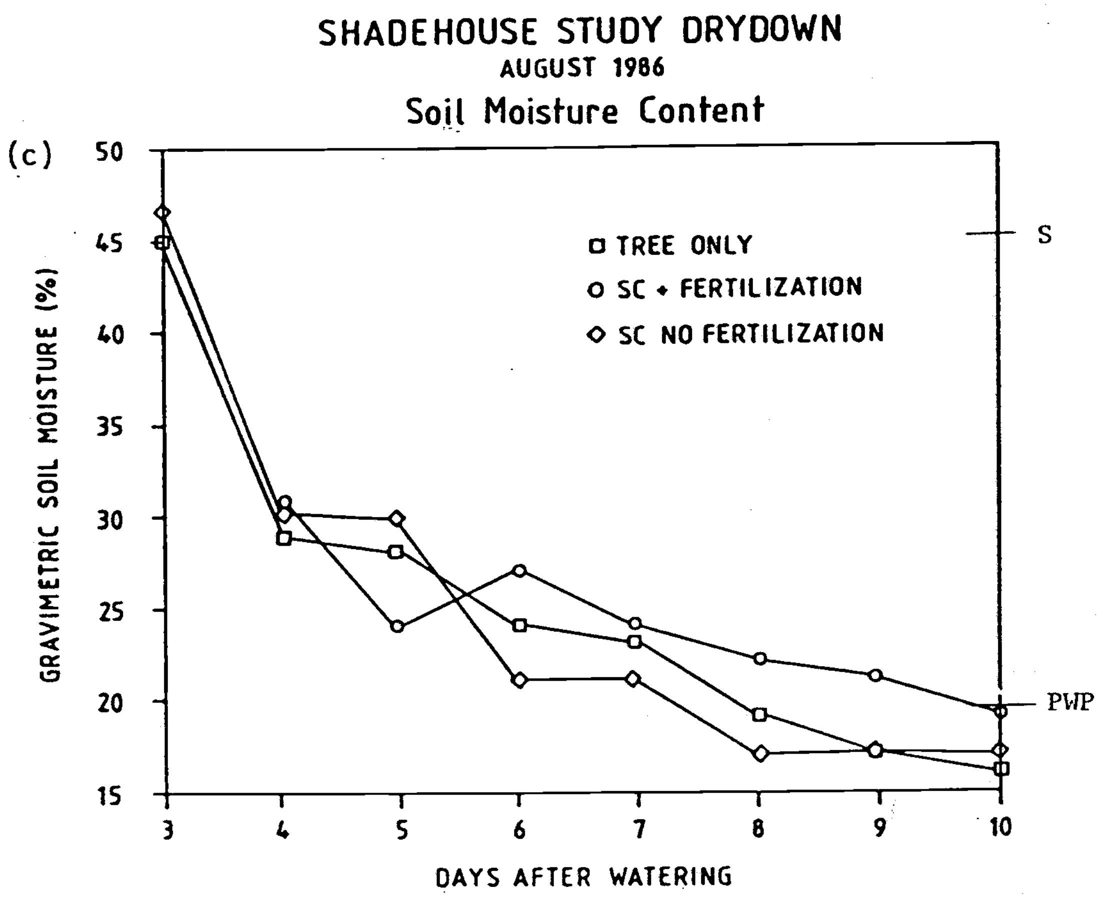
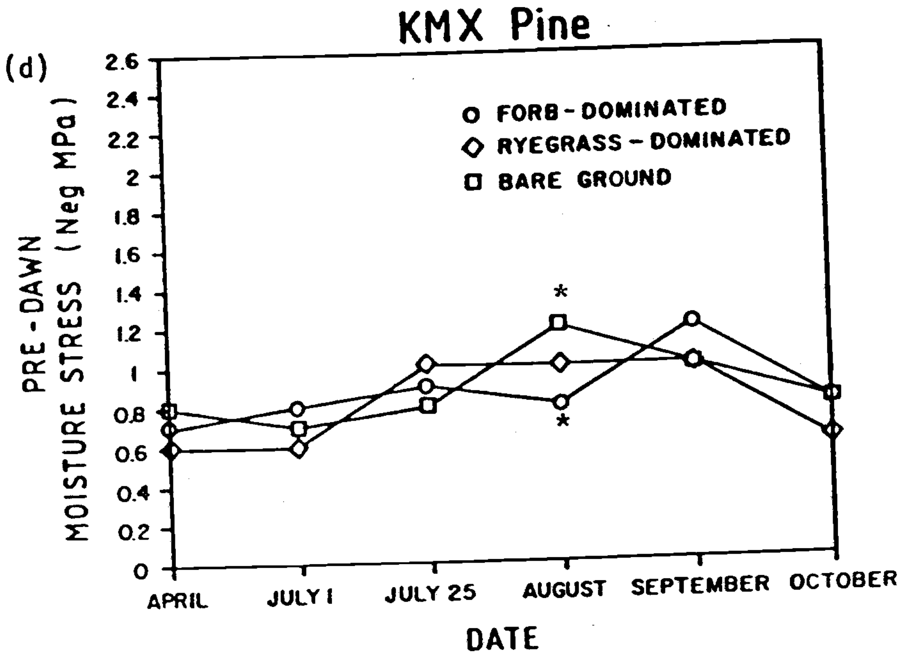
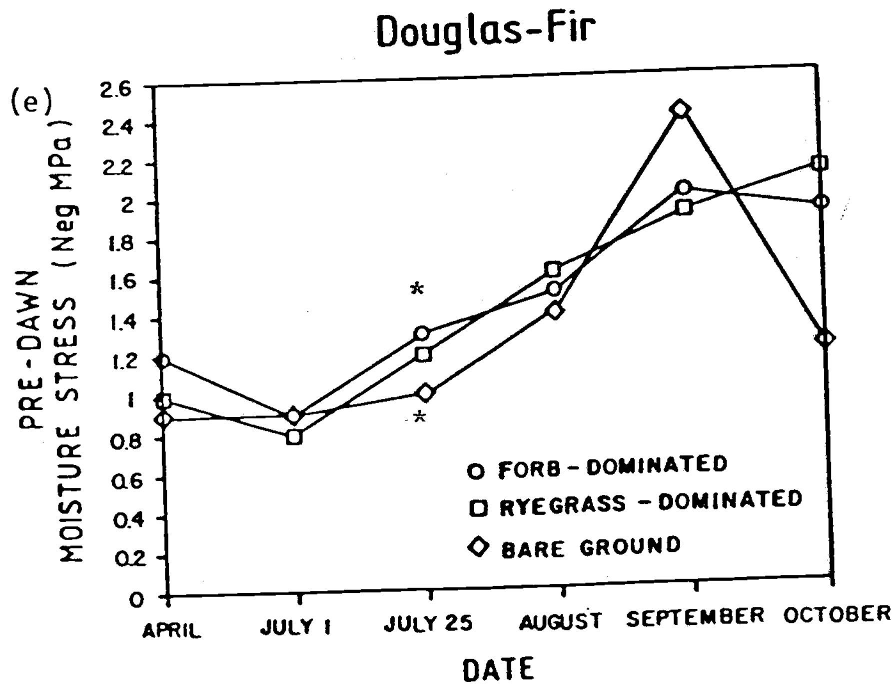


Fig. II.2. (Continued)





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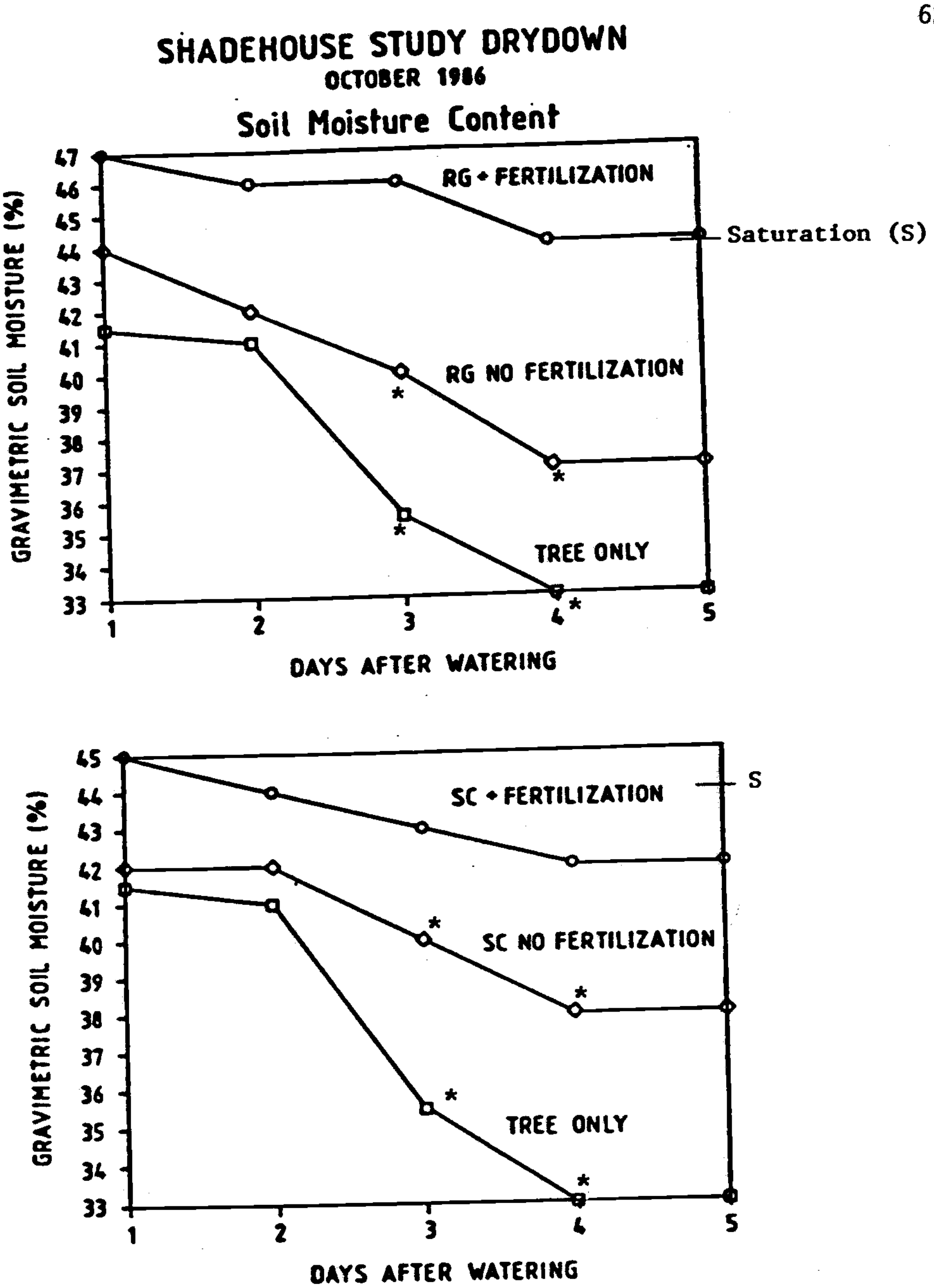


Fig. II.3. Treatment comparison of soil moisture content over time in the shadehouse study October 1986 moisture stress experiment. (a) Trees with no competing vegetation compared with ryegrass treatments; (b) Trees only compared with subterranean clover treatments; (c) trees compared with mixed ryegrass/clover treatments. * indicate significant differences (p=0.05). The October experiment was terminated before perminant wilting occurred. (20% moisture content, mass basis).

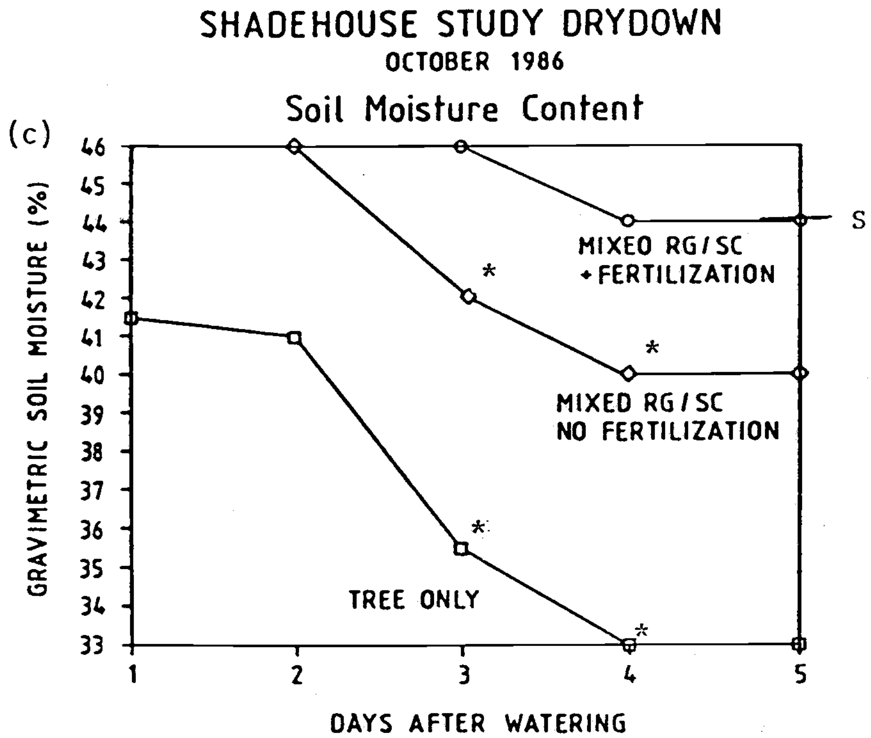


Fig. II.3 (Continued)

experiment, except that trends were more consistent and differences between lines significant. Fertilized treatments (Figs. II.3a, b, c) were consistently associated with less water loss than non-fertilized treatments. Tree-treatments lost the most moisture. The difference between tree-only and both fertilized and non-fertilized treatments in each case was significant at the 0.05 level, using a t-test. Differences between fertilized and non-fertilized treatments, although consistent, were not statistically significant.

Soil Nitrogen

Soil nitrogen (Table II.13) values were bulked by treatment, so no statistical comparison is possible. No obvious treatment differences are apparent, however. Also, no change in soil total N from February 1986 (before the growing season) to October 1986 (harvest) was evident. The mean soil nitrogen value (0.11 percent) is considered low (Brady 1984).

Forage Biomass

In examining absolute yield diagrams (Fig. II.4 and II.5), two important points are evident. One is that tree species depressed forage yields compared to forage grown without trees (compare Fig. II.4a, b, and c with Fig. II.4 d). Tree species differed in ability to suppress forage. KMX showed the greatest suppression, followed by eucalyptus. Douglas-fir showed little effect on forage; yields were virtually the same as with no tree at all, except at high (> 0.75) ryegrass proportions. Pots not fertilized (Fig. II.5) showed less forage biomass production, except with eucalyptus at higher

Table II.13 Soil nitrogen, carbon, and C/N ratio values for selected treatments in the shadehouse study, February 1986 (before growing season) and October 1986 (harvest).

		February 1986			October 1986		
Tree Species	Treatment	Carbon (Percent)	Nitrogen (Percent)	C/N Ratio	Carbon (Percent)	Nitrogen (Percent)	C/N Ratio
KMX Pine	Mixed, Middle Grass, Fertilized	N/A	0.13		N/A	0.13	
KMX Pine	Tree Only	N/A	0.13		2.29	0.08	28.59
Douglas-fir	Mixed, Middle Grass, Not Fertilized	N/A	0.07		2.85	0.09	31.62
Douglas-fir	Tree Only	N/A	0.13		N/A	0.12	
Eucalyptus	Mixed, Middle Grass, Not Fertilized	2.89	0.13	22.25	N/A	0.14	
Eucalyptus	Mixed, Middle Grass, Fertilized	N/A			2.32	0.08	29.04
Eucalyptus	Clover Only, Not Fertilized	N/A			N/A	0.13	
Eucalyptus	Tree Only	N/A	0.07				
Forage Only	Mixed, Middle Grass, Not Fertilized	2.32	0.07	33.10			
Bareground		2.33	0.13	17.95			

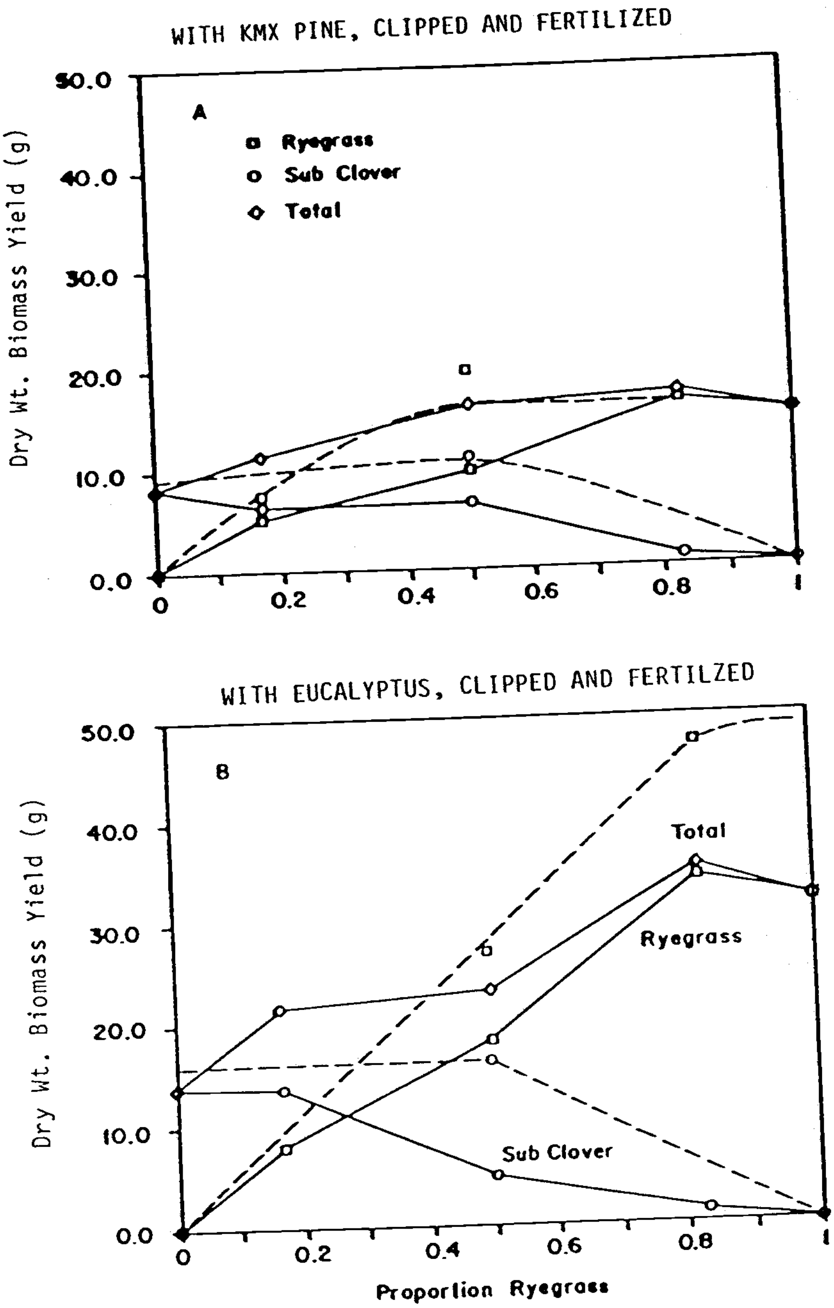


Fig. II.4. Absolute forage yields of ryegrass and clover, fertilized (solid lines). Dashed lines denote the respective monoculture yields of grass and clover. Total density= 50 plants (Proportion= 1.0).

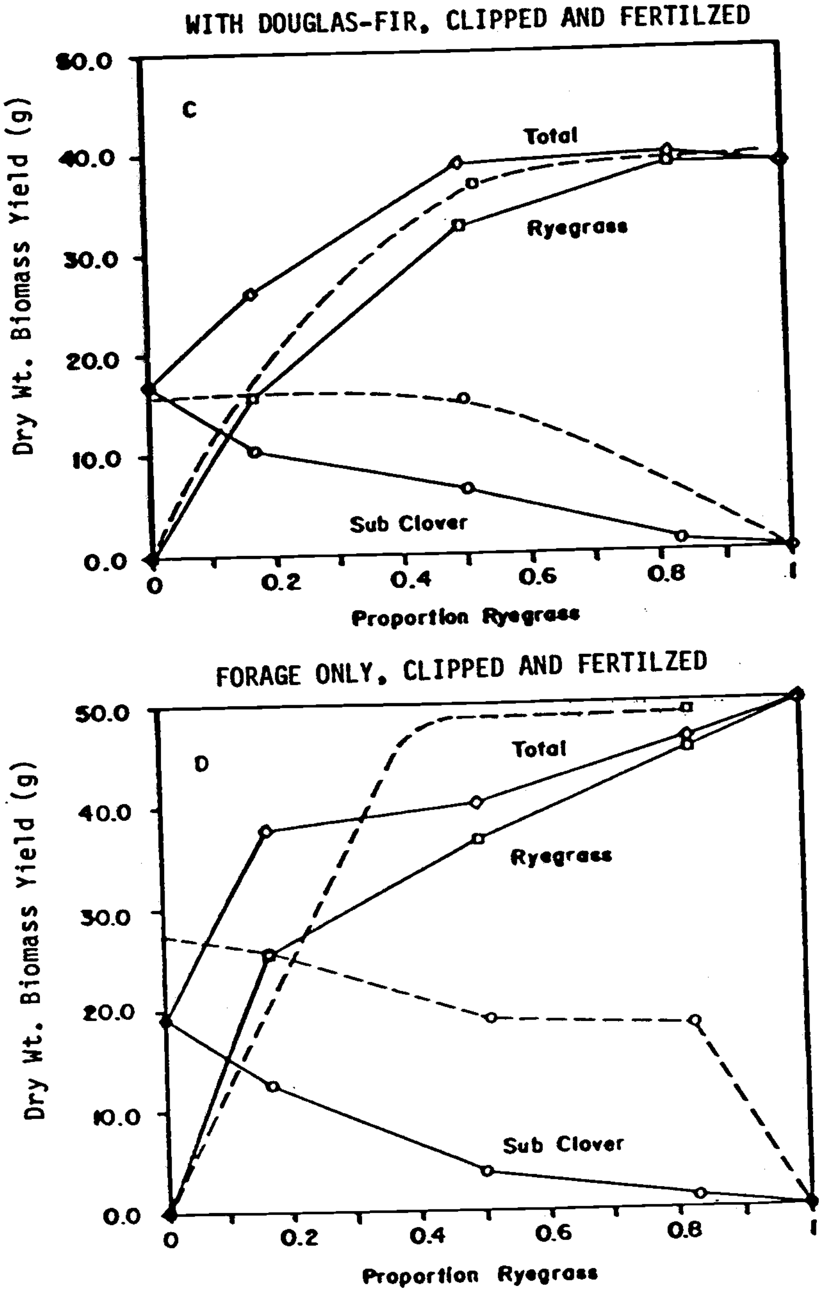
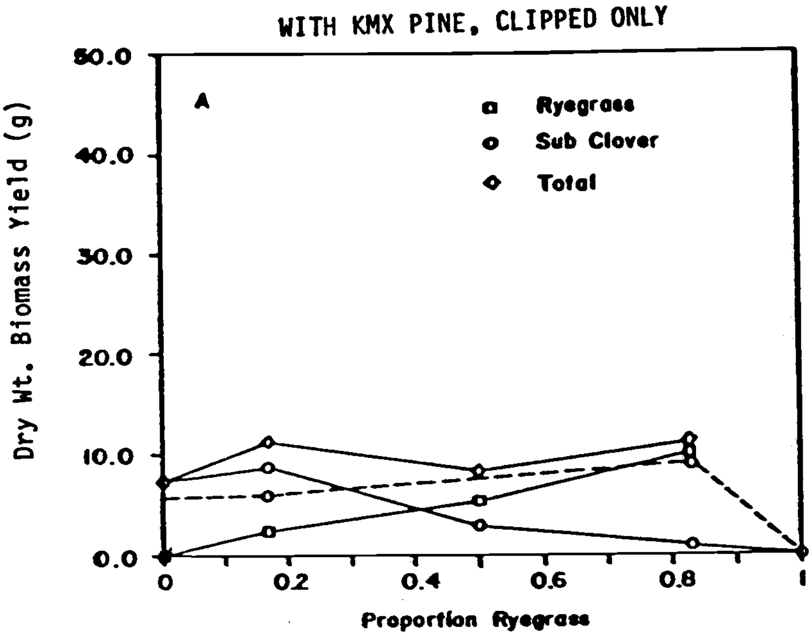


Fig. II.4 (Continued).



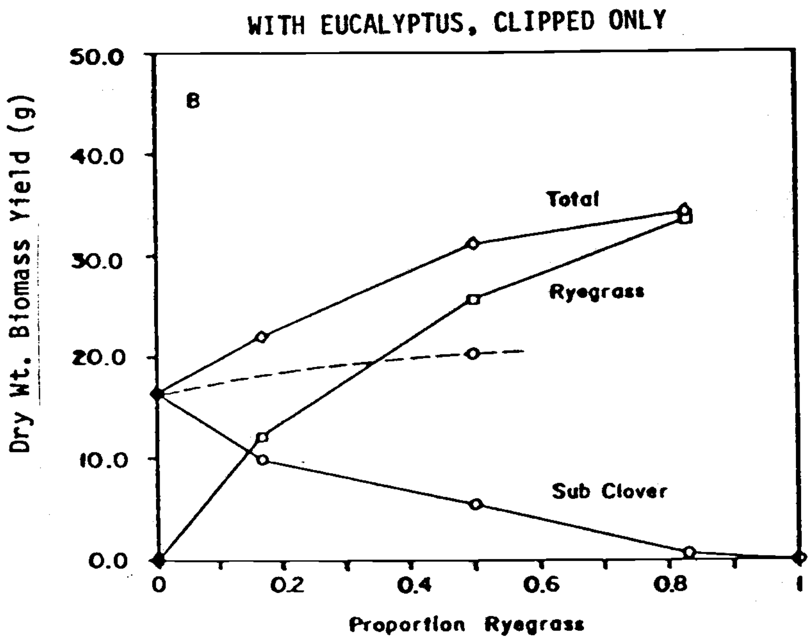


Fig. II.5. Absolute ryegrass and clover biomass yields, not fertilized (solid lines). Dashed lines denote respective grass and clover monoculture yields.

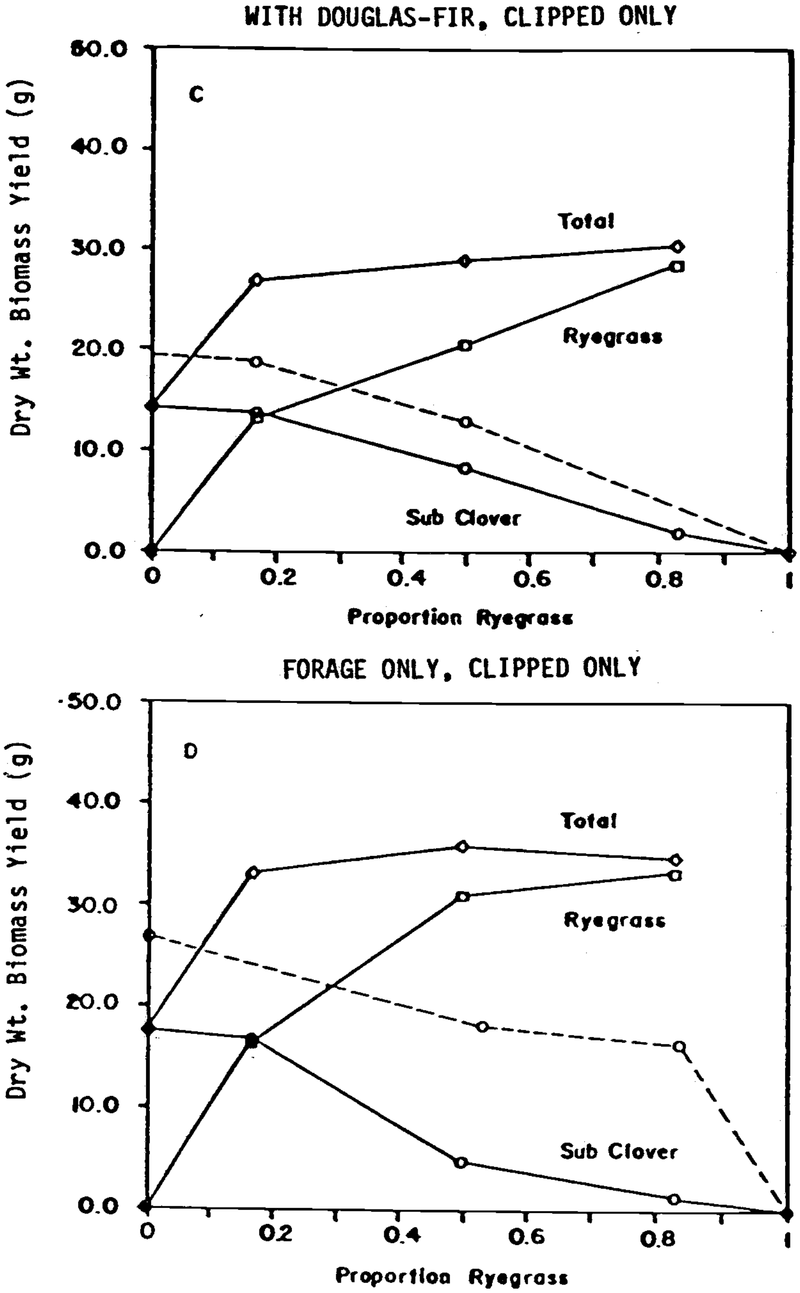


Fig. II.5 (Continued)

ryegrass proportions (> 0.50), where results were similar.

On a relative basis (Fig. II.6), only fertilized treatments are available for comparison, since an unfertilized ryegrass monoculture is missing (see footnote, p. 38). On a relative basis, ryegrass also appears to dominate clover, but the proportion at which domination begins varies with tree species. With no tree competition (Fig.II.6b), ryegrass dominates (produces a relative yield greater than 50 percent) when present as 20 percent or more of the mixture. With Douglas-fir (Fig. II.6a), this proportion is only slightly higher-about 25 percent. With eucalyptus (Fig. II.6c), the figure is about 45 percent, and with KMX (Fig. II.6d), about 50 percent.

E. DISCUSSION

Tree Species Differences

Tree growth responses to forage/fertilization treatments clearly differed by species (Tables II.2 and II.3). KMX pine produced the greatest diameter increase and total biomass. Eucalyptus produced the greatest height growth. Douglas-fir grew the least, according to all measures used.

These findings confirm previous research. Radiata pine (*Pinus radiata*), closely related to KMX pine, is often selected for reforestation due to early rapid growth rate and ability to limit moisture loss (Nambiar and Zed 1980, Sands and Nambiar 1984). Eucalypts are favored for plantation establishment in the tropics

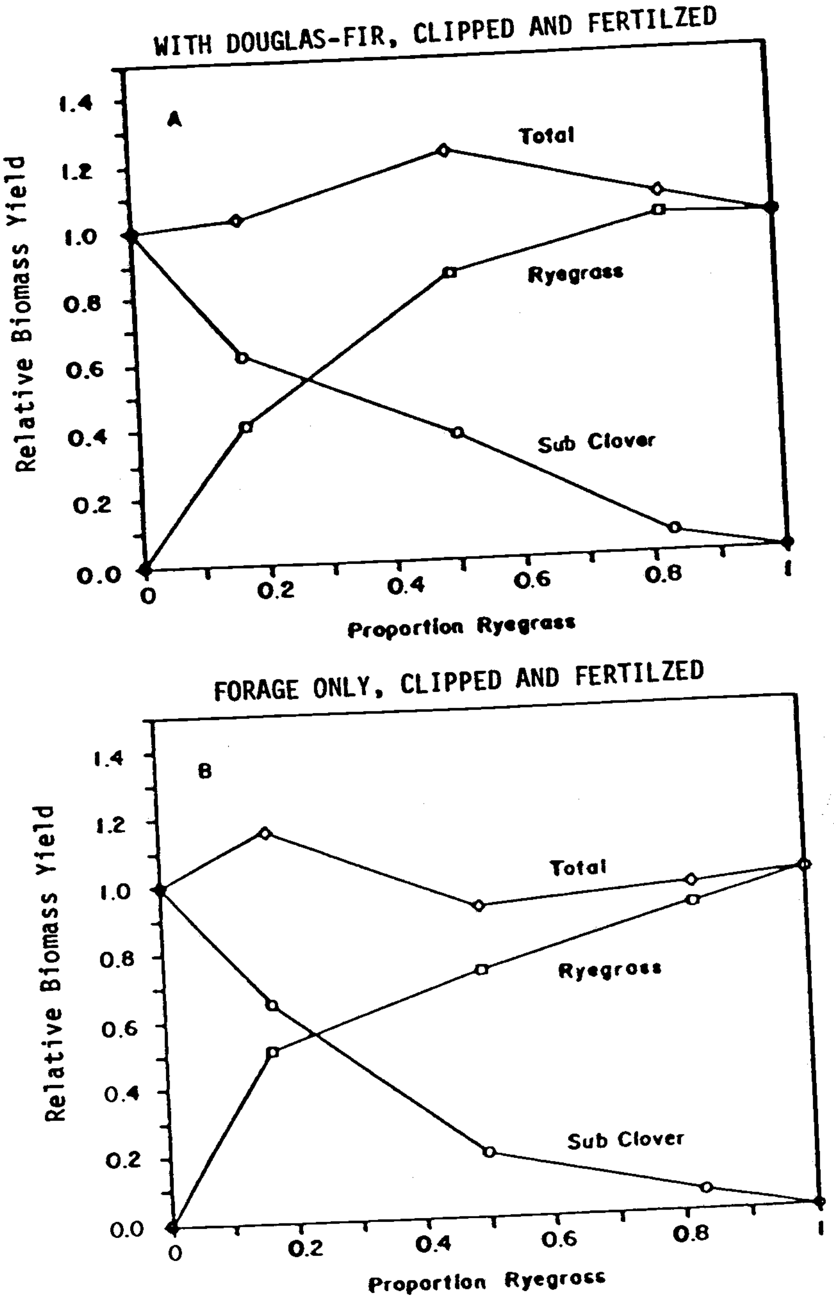


Fig. II.6. Relative forage yields, fertilized treatments only.

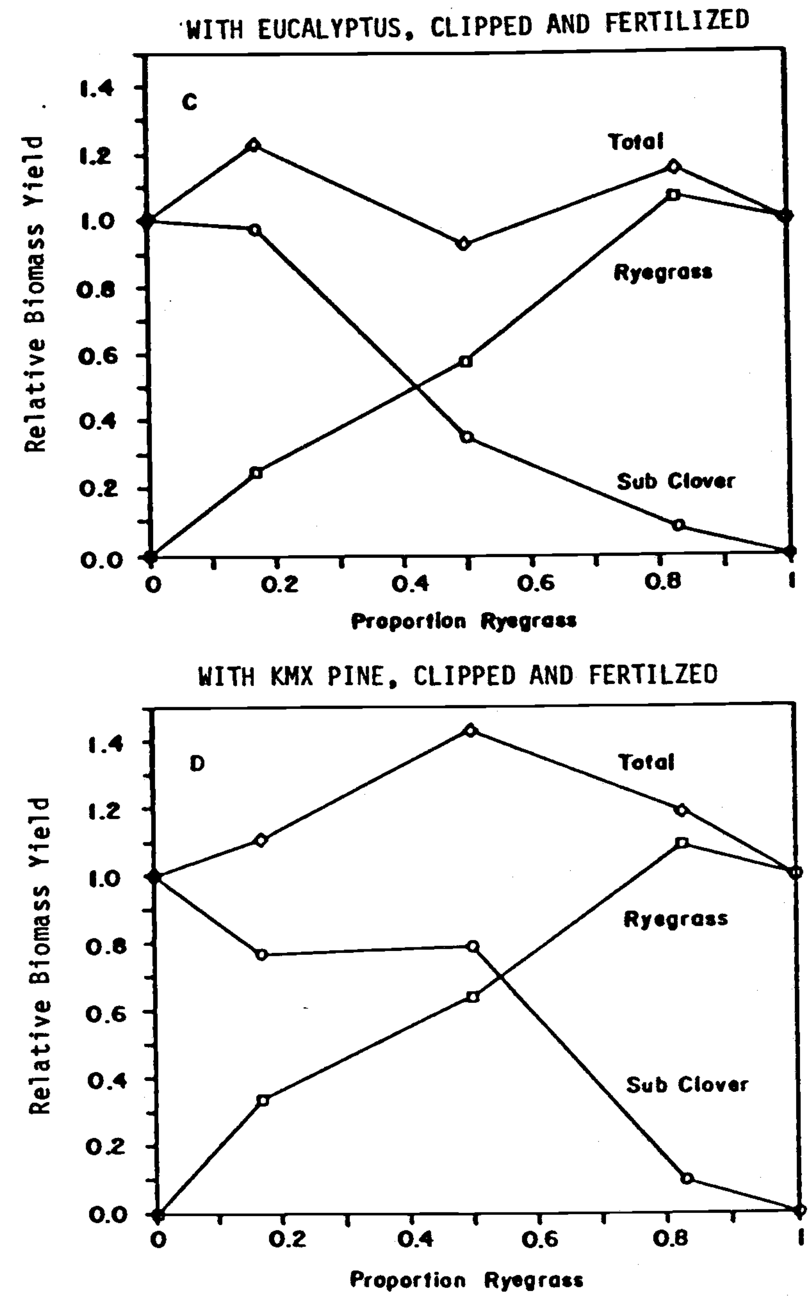


Fig. II.6 (Continued).

because of rapid height growth and biomass accumulation after planting (United Nations FAO 1979). In contrast, Douglas-fir is known to grow slowly up to three years after planting (Smith and Walters 1963, Smith et al. 1966, Carlson and Preissig 1981).

Effects of forage/fertilization treatments on the three tree species support the above findings of species differences (Tables II.4 to II.11). KMX pine height and diameter growth, as well as total biomass, were least affected by forage competition.

Growth of eucalyptus, in contrast, was much more influenced by forage treatments. Trees with clover showed greater height and diameter growth than those with grasses (Table II.8). Douglas-fir was more affected by forage compared with the other tree species; it appeared any forage competition would induce growth losses compared with growth of trees only (Tables II.9 and II.11). This agrees with previous research indicating control of competing vegetation is essential for early growth and survival of Douglas-fir (Preest 1975, Newton and Preest 1987).

In summary, evidence of both field and shadehouse studies indicates KMX pine as the superior tree competitor with forage. KMX pine also appears to be the most tolerant of moisture stress (although no conclusion can be made for eucalyptus). Eucalyptus produces the most early height growth, but is more sensitive to forage competition (Tables II.8 and II.10) and environmental stress.* Douglas-fir can withstand high moisture stress (Fig. I.2), but grows slowly in the three-year period following planting. These conclusions apply only to the tree ages and environmental conditions I investigated.

Forage Species Differences

Dashed lines on the Figs. II.4 and II.5 indicate "monoculture" yields of each species, i.e., grown without the other forage species. (Note that, except for the forage treatment, these are not true monocultures, since they are grown with the tree.) In all cases, growth of subterranean clover is depresed in mixture compared with monoculture (compare solid with dashed lines in Figs. II.4 and II.5.) Growth of ryegrass in monoculture appears to be approximately the same as in mixture. These findings indicate ryegrass as the superior competitor.

Forage-Tree Interaction

Presence of Douglas-fir did not greatly diminish the competitive advantage of ryegrass grown with clover. Both eucalyptus and KMX pine, when grown with forage, were sufficient to reduce the competitive advantage of grass over clover. The greater above-ground biomass of KMX pine and eucalyptus provided greater shade, perhaps allowing subterranean clover to compete more effectively with ryegrass. Subterranean clover photosynthesizes efficiently at low light intensities (Watson et al. 1984).

* Four eucalyptus were killed by frost and two by moisture stress during the study.

bareground remained as weeds until late 1984, when it was treated with herbicide. Clover was seeded in this area during the spring of 1985, but removed by herbicide application and hand weeding in June 1985, just prior to my study. During the winter of 1983-84, trees were planted-- the KMX pine hybrid (*Pinus radiata* X *P. attenuata*), Douglas-fir (*Pseudotsuga menziesii*) and *Eucalyptus glaucescens*. KMX pine and eucalyptus seedlings were planted as plug-one stock. Douglas-fir seedlings were 2-0 bareroot, with the exception of the first row of seedlings (from the north fence), which were 2-1 bareroot. Trees were planted in sets of three rows, one each of pine, Douglas-fir, and eucalyptus. Space between the rows was 1.5 m; within-row spacing was 1.5 m for KMX pine and eucalyptus; spacing varied from 1 to 2.5 m for Douglas-fir. Competition between trees in a row was considered insignificant at this stage in plantation development. Each set of rows was separated by a pasture grazing lane 20m wide (Fig. 1). The agroforestry planting had been established as a demonstration, so treatments were neither randomized nor replicated. I elected to use the site, primarily because 1) other suitable established sites were lacking and 2) too much time was required to start a new one. I consider my work a case study, with inferences limited to this site.

To check for soil uniformity, I sampled at 8 random locations across the study area in July 1985 and found no significant difference in CEC or texture. Soil profiles (one dug in each pasture treatment) were likewise similar, although toward the west end of the

Soil nitrogen levels were not changed. Tree foliar N levels were greatest with the least amount of applied N (trees alone and with clover) (Table II.12). In ryegrass treatments, therefore, applied N was probably taken up by the ryegrass to the detriment of trees. Soil loss through leaching was minimal, because urea nitrogen is known to adhere well to exchange surfaces and resist leaching (Otchere-Boateng 1979). Volatilization losses were likewise insignificant, because pots were generally watered soon after fertilization (Heilman et al. 1979).

Foliar N levels correspond to tree growth and total biomass. Those with the highest foliar N levels (tree only or with clover) also produced the greatest height and diameter growth. (Compare Table II.12 with Tables II.7 and II.8). This effect was not due to fertilization, because trees alone received no N fertilization and trees with clover received much less N compared to trees with grasses. I therefore conclude fertilization in this simulation had no beneficial effect on any tree height, diameter, or total biomass.

Because six clippings and fertilizations induced no tree growth or foliar N increase, this study indicates that nitrogen returned through animal waste is unlikely to benefit young plantations in the hill pastures of western Oregon. I make this conclusion only for the year following tree planting, and for the soil used and conditions simulated. Nitrogen returned is likely to benefit grasses (Templeton 1978). Long-term benefits of waste return may be possible, but have not yet been demonstrated.

Moisture Stress Effects On Tree Growth

Soil nitrogen and water often interact in complex ways, and effects on growth are difficult to separate (Brix 1979). Abundant soil N, however, will be of little use to plants if soil moisture is limit-ing (Brix 1979), because soil water is required to carry nutrients to plant roots (Barber 1984).

Adequate soil moisture after fertilization is necessary for optimal tree uptake of urea nitrogen (van den Driessche and Dangerfield 1975, Heilman et al. 1979). As stated in the methods section (pp. 30-31), the moisture regime trees experienced was stressful during spring and summer months because of rapid drying following watering. In April, tree predawn xylem potentials one week after watering were -0.8 MPa for KMX pine, -1.5 MPa for eucalyptus, and -2.3 MPa for Douglas-fir. Predawn potentials later in the summer, although not measured, probably were at least as stressed (based on Pitchford observations). This stressful period included the period of most active growth of trees (April-June), and in general roughly corresponded to soil moisture conditions in southwest Oregon.

Tree growth and biomass of all three species, as influenced by treatments (Tables II.4, II.5, and II.7-II.11), indicate trees grew the most when either grown alone or with clover competition. Under the water-stressed conditions simulated, these two treatments provide the least moisture competition for trees. As mentioned in the introduction (p. 28), subterranean clover sets seed and dies back in late spring. From June until mid-August (when clover seed produced in the spring germinated), clover provided no competition for moisture. During this period of peak moisture stress, trees with clover therefore had no vegetative competition. This is indicated by similar tree height and diameter growth, biomass, and foliar N concentration for trees alone and trees with clover. (See Tables II.4, II.5, II.7-II.11, and II.12).

In a study of Robinia pseudoacacia (a nitrogen-fixer), Plass (1977) reported elevated foliar N concentrations in associated pines and hardwoods. This does not appear to be the case here, where association with nitrogen-fixing clover did not result in elevated foliar N levels. Nitrogen fixers can sometimes decrease tree yield (Helgerson 1981), but this likewise did not occur in my study. Nitrogen fixation is severely inhibited by water stress (Sprent 1976), so N fixed by clover in the shadehouse was probably not substantial. Unlike clover, ryegrass in this simulation did not die back in June and was able to maintain competition during the entire growing season.

These findings suggest water was the resource most limiting tree growth. Trees alone had no vegetative competition for soil moisture. Clover biomass was much less than that of ryegrass (Fig. II.4 and II.5), thus providing less competition for water. Grasses are stronger competitors for water due to an extensive fibrous root system with great leaf surface area (Preest 1975, Radosevich and Holt

1984, Newton and Preest 1987). Also, substantial aboveground ryegrass biomass implies ryegrass was transpiring considerable moisture, thus making it unavailable for tree uptake.

In the moisture stress experiments (Fig. II.2 and II.3), trees with no forage competition showed the most rapid moisture loss after watering. Extensive root systems allow grasses to maintain high ratios of root surface to transpirational leaf area, thus diminishing water loss (Fitter and Hay 1981). As indicated by Fig. II.2 and II.3, pots with grasses lost the least amount of water.

During both August and October moisture stress experiments, no consistent pattern relating soil moisture to KMX pine predawn moisture stress was found. In this simulation, therefore, soil moisture was a poor predictor of tree xylem potential response.

Summary

These findings augment previous research indicating fertilization to be ineffective in moisture-limited environments (Heilman et al. 1979, Brix 1979, Landis 1975). Further, results agree with findings of the Pitchford field study (Part I), where KMX pine showed superior growth to Douglas-fir. This growth was associated with significantly less summer moisture stress of KMX pine. As in the shadehouse study, no difference in foliar nitrogen levels was found at Pitchford (Tables I.2 and I.3).

I therefore conclude, for the conditions simulated, water and not nitrogen was the factor most limiting tree growth. To my knowledge, no research to date has indicated a tree response from animal waste nutrient return. Results in both field and shadehouse studies suggest no N effect can be expected in the establishment phase (0-3 years after planting) of tree growth. Long-term effects of nitrogen from animal waste return on tree growth are unknown. This remains an important research need.

Part III. Conclusions

A. SYNTHESIS OF FIELD AND SHADEHOUSE STUDIES

Inherent species differences were evident in both field and shadehouse studies. In both studies, KMX pine showed superior height and diameter growth compared to Douglas-fir. Douglas-fir is known to exhibit slow growth up to several years after planting (Smith et al. 1966). Eucalyptus (shadehouse study only) showed the greatest absolute height growth of the three species, and was able to sustain this absolute height growth with a very high shoot/root ratio (2.5).

In both studies, nutrients returned in animal waste (actual or simulated) did not induce tree nitrogen response. In the field study, effects of grazing appeared neutral; tree growth was limited by inherent soil moisture availability. In the shadehouse study, several trends were evident. Trees grew better alone or with clover competition than with mixed forage or grass competition. Nitrogen added from simulated return was of no benefit to trees, since no foliar N response was observed and trees only (no fertilization) grew better than trees with fertilized forage. Grass competition had a depressing effect on tree growth. KMX pine was clearly the least affected by forage treatments, since 71 percent of the variation in height growth and 81 percent of the variation in diameter growth was accounted for without any consideration of treatment effects. Analysis of variance with mean separation, and orthogonal contrast comparisons also support this conclusion.

Evidence from both field and shadehouse studies indicate soil moisture availability during dry summer weather is the chief factor limiting tree growth in a sheep-tree-pasture system in western Oregon. In the field study, summer moisture stress clearly limited growth of Douglas-fir, because during most of this period Douglas-fir xylem potential was less than -1.8 MPa (Fig. I.2d). Douglas-fir cell division ceases at xylem potentials less than -1.8 MPa (Waring 1970). Pine maintained a lower stress level, partly due to better stomatal control (Babolola et al. 1968, Lopushinsky and Klock 1974). Pines were probably also able to draw water from deep in the soil due to deeper, more extensive root systems than Douglas-fir. Sands and Nambiar (1984) showed radiata pine (closely related to KMX pine) was unaffected by weed competition for moisture if its root system was well-established. This appears to be the case in the Pitchford field study.

In the shadehouse simulation, the moisture regime used resulted in moisture-stressed trees during dry weather, and so was a rough parallel to field conditions. As in the field study, KMX was able to maintain rapid growth, while Douglas-fir growth was very slow. Added nitrogen was of no benefit to tree growth in the shadehouse study because of the moisture-limited conditions simulated. This agrees with findings of numerous researchers that fertilization alone is insufficient to overcome weed competition (e.g., Zimdahl 1980). Fertilization may be of dubious benefit to trees in the seedling stage, as some authors report beneficial effects on growth (Strand and Austin 1966, Carlson and Preisig 1981, Lewis et al. 1984), while others report negative effects (Smith et al. 1966, Landis 1976).

Superior growth of ryegrass when fertilized compared with ryegrass not fertilized indicates applied nitrogen was being used by the grass.

These results present several useful implications for management. During summer months, soil moisture will most likely be the single factor most affecting tree growth (Preest 1975, Newton and Preest 1987) unless heavily grazed. (Pasture utilization at Pitchford averaged 81 percent; see Appendix D).

For the soil and grazing conditions I investigated, and the age of the trees involved, it appears nitrogen returns through animal waste will not effect a tree growth response. Nitrogen is likely to be used by competing forage, particularly grasses. In the shadehouse study, returned N had an indirectly negative effect on tree growth in some cases because it was used by ryegrass, which in turn competed with trees for soil moisture. I cannot say, however, what the long-term effect of animal waste nutrient return on tree growth would be, and this remains an important research question.

B. SUGGESTIONS FOR FUTURE RESEARCH

A number of short-term studies of grazing effects on tree growth have been conducted (Hedrick and Keniston 1966, Clark and McLean 1978, Wheeler et al. 1980, Sharrow and Leininger 1983). Effects vary with site, climate, and region (Klingler 1982). Because of logistical difficulties, such studies are difficult to replicate and randomize properly. Grazing studies involving tree growth require relatively large land area, are labor intensive (animals require herding), and require considerable start-up time (establishment of tree seedlings). Research of long-term studies (more than two or three seasons) is conspicuously absent. Yet a long-term approach is the only way in which effects on tree growth can be conclusively answered. It appears tree moisture stress from competing vegetation is most severe in the first one or two seasons after planting (Eissenstadt and Mitchell 1983, Preest 1975) and that once tree root systems are sufficiently developed, they will no longer be significantly affected by grass competition (Sands and Nambiar 1984). Effects of shrub competition may be longer lasting, however, and this needs to be researched.

To my knowledge, no studies have demonstrated direct tree growth response to nitrogen recycled by animals. The Pitchford study, as well as previous efforts (Petersen et al. 1956, Dawson and McGuire 1972) appear to indicate nutrients recycled by animals will be of questionable benefit to pasture plants, let alone trees grown in those pastures. The question of nitrogen benefit, in my opinion, can only be addressed in long-term studies where components of the grazing ecosystem relevant to nitrogen cycling (e.g., soil organic matter, mineralization rates, and fate of nitrogen ingested in forage by animals) are carefully monitored.

Semi-controlled environment studies are useful in that shade-house environmental variables better approximate field conditions than do greenhouse studies. The drawback is the increased variation associated with this. Techniques to reduce this variation are needed. Of key importance is realistic simulation of soil moisture regime in pots. In my own study, it would have been better to place pots in plastic bags and water them from below from the start of the study. Pots could have been maintained at or near saturation for months until a point was reached where a drydown experiment could be conducted. Pots could then be allowed to drydown at a slower, more realistic rate. In the shadehouse study I conducted, tree roots were subjected to repeated wetting/ /drying cycles, which predisposed them to stress, even during relatively cool and humid spring months. (This was evidenced by low (-0.8 to -2.6 MPa) predawn tree xylem potentials in April 1986). This effect predisposed trees to stress and confounded measurement of response to watering.

Another problem to overcome, particularly with fast-growing species such as KMX pine and eucalyptus, is that trees rapidly became root bound. Carlson and Preisig (1981) state that pots can restrict root growth even before there is any evidence of root binding. Smaller planting stock can be selected for studies, but then relevance to field situations is questioned. As I see it, the only improvement is the use of field studies. Microplots (e.g. 1 or 2 m^2) could be used where a single tree is grown with forage combinations. Grazing could be simulated by clipping and fertilization return, as in the shadehouse study. An advantage of this approach over operational field studies is that the nutrient regime is easier to quantify and control. Root systems could be enclosed in plastic bags so that soil, and thus nutrients, affecting roots could be quantified.

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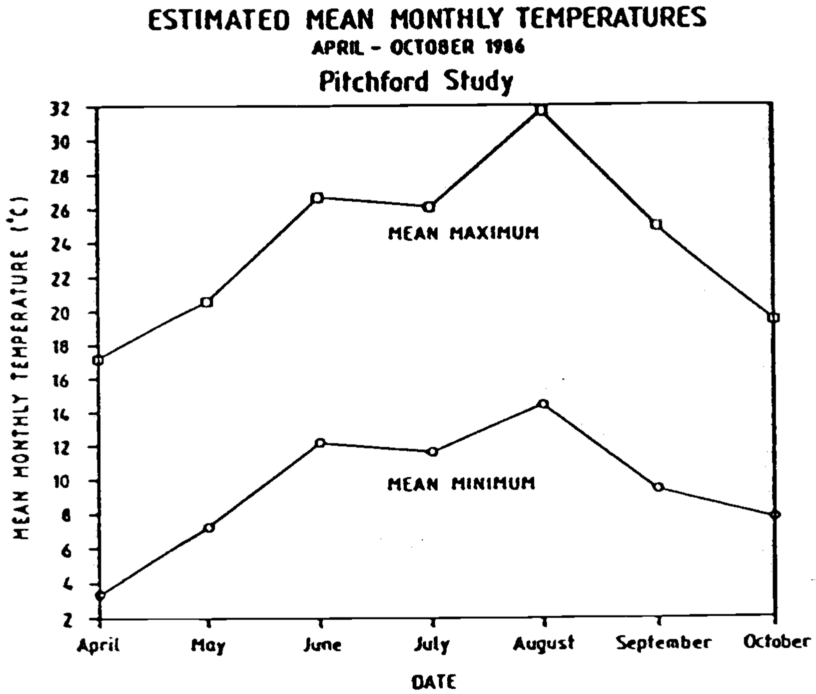
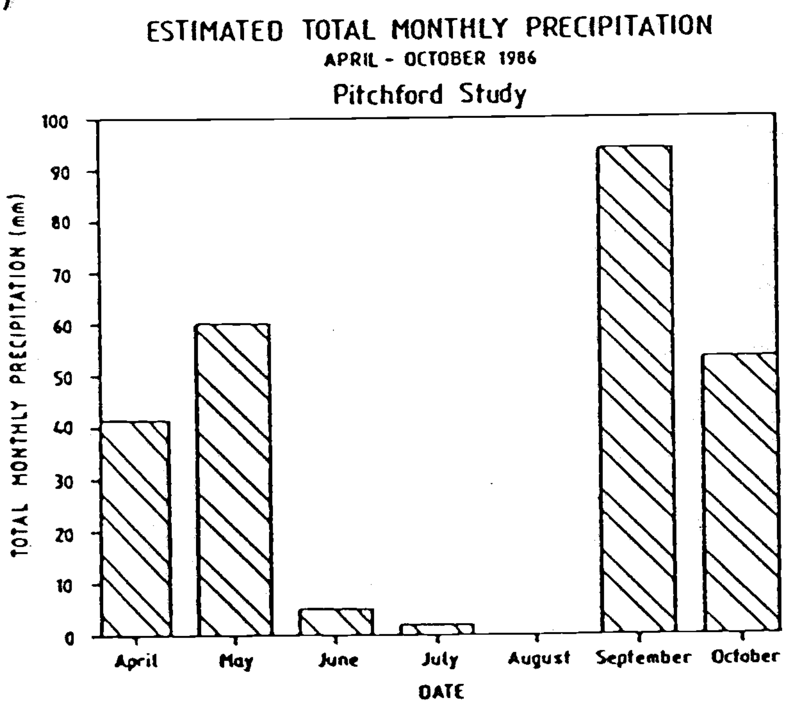
Appendices

(1)

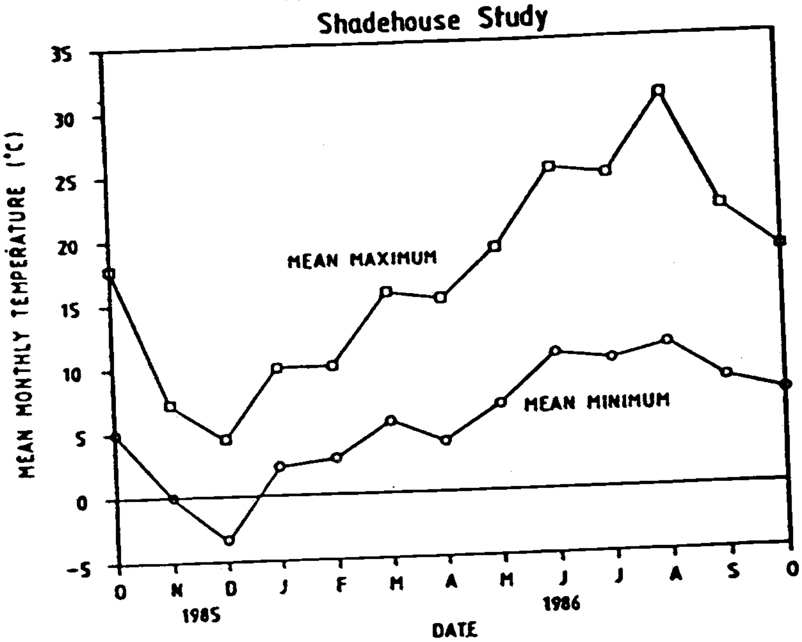


(2)

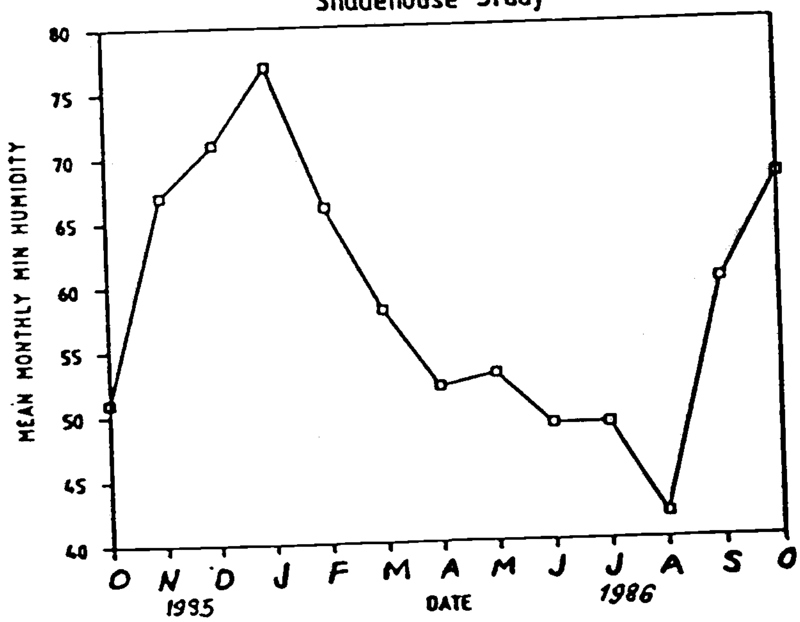


Appendix A. (1) Mean monthly temperatures at the Pitchford site during the period of moisture stress measurements. Values shown were actually recorded at the Roseburg weather station. (2) Total monthly precipitation at the Pitchford site, based on Roseburg weather station data.

ESTIMATED MEAN MONTHLY TEMPERATURES
OCTOBER 1985 - OCTOBER 1986
Shadehouse Study



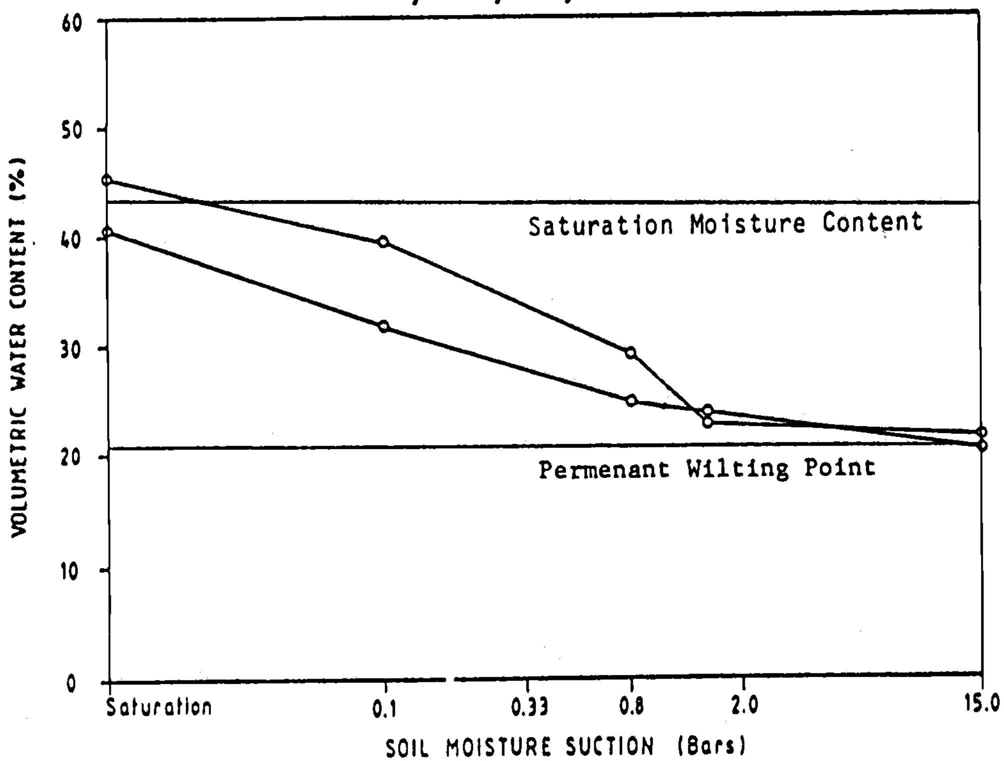
ESTIMATED MEAN MINIMUM HUMIDITY
OCTOBER 1985 - OCTOBER 1986
Shadehouse Study



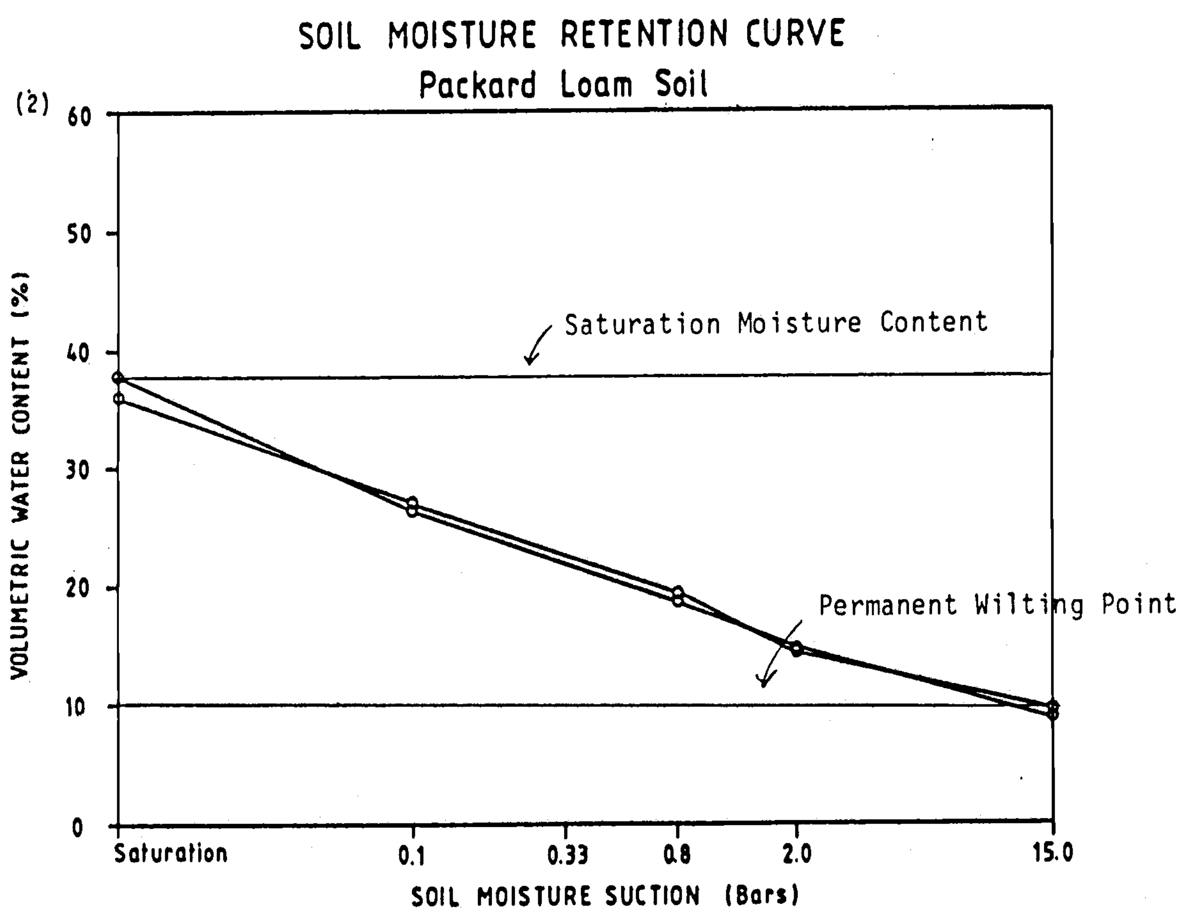
Appendix B. (1) Mean monthly temperatures during the shadehouse study, using data recorded at Hyslop research farm, Oregon State University. Mean monthly minimum humidity values, using the same data source.

(1)

SOIL MOISTURE RETENTION CURVE
Jory Silty Clay Loam



Appendix C. Soil moisture retention curves for the shadehouse (1) and field (2) studies. Each line represents the soil moisture characteristic for a sample, determined using a pressure plate technique by the Oregon State University Soil Physics Lab. Note the use of a logarithmic scale on the horizontal axis of each diagram.



Appendix C (Continued).

Appendix D. Pitchford Forage, Yield, Utilization, and Composition, 1986 Grazing Season

Introduction

Forage biomass yields of the forb- and ryegrass-dominated treatments at the Pitchford site were determined for the 1986 grazing season. These data were useful in describing biomass removed by sheep and returned in their waste, as well as offering practical information on site productivity.

Methods

Forage biomass yields were determined by a comparison of forage on the treatments before and after each sheep entry. Ten 0.2-square-meter areas were clipped to ground level. Plant material removed was oven-dried at 70 degrees C for 48 hours and weighed. The mean yield of the 10 samples was multiplied by the treatment total area to develop an estimate of biomass yield. Biomass grazed by sheep was determined by subtracting biomass after an entry from the original biomass, and then dividing this value by the original biomass. Seasonal totals were determined as the sum of biomass before the first entry and growth after each subsequent entry. Seasonal yield was the sum of the yield for each entry.

Species composition was determined before each grazing entry and also in October to determine regrowth after the growing season. Before the first entry, plants in samples collected for biomass estimation were hand separated by species. Composittion was then determined on a biomass basis. For subsequent entries, composition

Fertilization Effects

Soil. As indicated in Table II.13, soil total nitrogen levels were low before the 1986 growing season for all fertilized treatments with tree species. No significant differences were found among any fertilized treatments. In October 1986 (Table II.13), after six clippings and urea applications, soil nitrogen levels remained unchanged. No differences were found among treatments, regardless of fertilization.

Tree Foliar Response. In October 1985, no differences in tree foliar nitrogen levels were found among treatments. Eucalyptus foliage had greater nitrogen concentration than KMX pine (1.28% vs. 0.72%) ($p < 0.0001$). (Douglas-fir foliage was not analyzed due to cost limitations.) This may have expressed fertilization each species received in the nursery.

In October 1986, no difference in foliar N concentrations between KMX pine and eucalyptus was found. Trees of both species had greater foliar N when grown alone or with clover. No difference was found between trees fertilized and those not fertilized.

Forage. A comparison of Fig. II.4 and II.5 clearly indicates ryegrass biomass production was greatly increased by fertilization. Clover biomass was about the same with or without fertilization. Ryegrass is known to be a strong competitor for nutrients due to its extensive fibrous root system (Templeton 1978).

Interactions. Applied urea was probably used by ryegrass, because ryegrass biomass increased substantially when fertilized.

was determined by use of a point sampling frame (Barbour et al. 1980). Species were placed in categories, as in the table following.

Results and Discussion

Biomass production (kg/ha basis) was greater on the ryegrass-dominated treatment. Utilization was very high (84 percent on the ryegrass-dominated treatment and 76 percent on the forb-dominated treatment), implying overgrazing.

In general, throughout the season, the proportion of ryegrass on both ryegrass- and forb-dominated treatments increased. Proportion of broad-leaved weeds on the ryegrass-dominated treatment decreased, while on the forb-dominated treatment weeds increased. After the third grazing (July 1986) very little forage biomass remained. October regrowth indicated both treatments had virtually the same species composition. (See following table.)

Table D.1. Pitchford forage, utilization, and composition, 1986 grazing season. Values in parentheses are standard errors.

Sheep Entry[1]	Treatment	Forage Biomass (kg/ha) Before	After	Yield (Forage Consumed)	Utilization (Percent)
First	RD[2]	1850.1 (197.6)	732.5 (170.9)	1117.6 (272.2)	60
	FD[3]	1368.6 (224.5)	866.5 (152.4)	502.0 (271.4)	37
Second	RD	4192.7 (324.4)	1205.6 (254.2)	2987.1 (412.1)	71
	FD	2849.3 (244.6)	1128.1 (128.4)	1721.2 (130.3)	60
Third	RD	1669.0 (249.1)	914.4 (133.3)	754.6 (202.5)	45
	FD	1744.4 (265.2)	947.8 (187.1)	796.6 (324.5)	46
Seasonal Totals	RD		Production--5773.7	4859.3	84
	FD		Production--3967.6	3019.8	76

[1]Dates of grazing entries: First: 20 March to 24 April, Second: 9 May to 21 June, and Third: 27 June to 5 July

[2]Ryegrass-dominated
[3]Forb-dominated

Table D. 2
Pitchford Forage Composition, 1986 Grazing Season

	(%) Composition					
	Ryegrass	Sub Clover	Broad-leaved weeds	Other Grasses	Other Legumes	Litter
First Grazing						
Ryegrass-Dominated						
Before	55	15	29	0.3	0.7	N/A
After	34	37	26	3.0	0	N/A
Forb-Dominated						
Before	15	46	34	0.4	3	N/A
After	7	45	41	5	2	N/A
Second Grazing						
Ryegrass-Dominated						
Before	74	8	10	3	0	5
After	60	5	7	0.7	0	28
Forb-Dominated						
Before	27	33	31	0	7	2
After	28	44	10	0.8	0.8	16

Table D.2 (cont.)
Pitchford Forage Composition, 1986 Grazing Season

	Ryegrass	Sub Clover	Weeds	Other Grasses	Other Legumes	Litter
Third Grazing						
Ryegrass-Dominated						
Before	96	0	1	0	0	2
After	0	0	6	0	0	87
Forb-Dominated						
Before	39	<1	42	0.3	0	18
After	0.6	0	6	0	0	85
October Recovery						
Ryegrass-Dominated	36	38	16	4	2	4
Forb-Dominated	44	28	15	9	0.9	