

AN ABSTRACT OF THE THESIS OF

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A silvopastoral system using a Douglas-fir (Pseudotsuga menziesii) tree crop and subclover (Trifolium subterraneum) as a nitrogen-fixing forage crop was investigated near Corvallis, Oregon, during 1983-1985. Treatments included all possible combinations of three planting patterns (no trees, trees planted 2.5 m apart in a grid, and clusters of five trees each with clusters 7.7 m apart) and two grazing/understory management systems (seeded to subclover and grazed by sheep or ungrazed and unseeded).

Forage production and use by sheep was recorded each summer, fall/winter and spring grazing periods during 1983-1985. Averaged over the three years, clover/grazed plots produced approximately twice as much forage as ungrazed/unseeded plots. The tree crop had no apparent effect on forage production. However, sheep consumed only half as much forage on grid plantations as on either

cluster plantations or open pasture. Livestock management became more difficult on grid plantations over time. Grazed plots received an average of $34 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ from livestock urine. This was associated with slightly higher N content of Douglas-fir foliage in grazed than in ungrazed plantations.

Twig xylem pressure potential, measured with a pressure chamber during July-September of 1984 and 1985, indicated that trees experienced greatest summer moisture stress in August and September. During the summer, trees in grazed plantations had about 0.1 MPa and 0.05 MPa higher water potentials than trees in ungrazed plantations at pre-dawn and midday, respectively. Gravimetric soil moisture generally followed patterns in monthly precipitation and potential evaporation, but was unaffected by tree planting pattern. Averaged over the two years, the decrease in soil moisture from July to August was greater on ungrazed than on grazed plots.

Sheep removed a small percentage (< 5%) of twigs during each grazing period. Breakage, debarking and removal of terminals were minor problems which occurred during spring and summer grazing periods. Terminal shoots of trees within reach of animals in 1983-84 were browsed mostly by deer in spring prior to stocking with sheep. By 1985, most trees were out of the reach of sheep and wildlife.

Tree height and diameter were measured in the fall from 1982-1985. No effect of grazing management on tree

height and diameter growth was apparent. Differences in height and diameter growth between cluster and grid planting patterns are likely a function of planting density and tree size at the commencement of our experiment.

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Pattern in a Young Douglas-fir Agroforest

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EFFECTS OF GRAZING MANAGEMENT AND TREE PLANTING PATTERN IN A YOUNG DOUGLAS-FIR AGROFOREST

INTRODUCTION

A new emphasis in the management of natural resources was reflected in the passage of the Multiple-use Act of 1960. As more information has become available from research on multiple-use systems, there has been a movement towards "coordinated use" of resources. Coordinated use implies that combined production systems are not implemented merely for the purpose of obtaining more than one product from the same unit of land. Rather, the design is such that complementary and/or mutually beneficial effects between, and on, various components of the production system are maximized.

Agroforestry is one coordinated use production scheme that has found world-wide applicability. It is defined as "a sustainable land management system which increases the yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially on the same unit of land" (King 1979). Four subdivisions exist within agroforestry:

- 1) agrosilviculture- use of the land for the concurrent production of agricultural and forest crops.
- 2) silvopastoralism- use of the land for the concurrent production of wood and the rearing of domesticated animals.
- 3) agrosilvopastoralism- essentially a combination of 1) and 2).

4) multipurpose forest tree production- use of the land to grow forest tree species for wood and for leaves or fruit suitable for food or fodder.

In many of the forested regions of the Pacific Northwest, both public and private, agroforestry holds particular promise as a technically feasible, economically advantageous production system. On public lands, combined systems are managed for optimum levels of products. These products are numerous and varied, as defined by society, ranging from fiber and red meat production to recreation and the aesthetic qualities of unique landscapes. On private lands, the goal is often maximum net profit from the land, where a certain combination of products gives the greatest overall monetary return. Agroforestry, however, is not currently applied by many natural resources-related professionals in the United States. Land-use decision makers continue to be reluctant to consider agroforestry as a bonafide alternative land-use practice until the system is better understood.

The grazing of domestic livestock in forested regions of the United States has long been a controversial subject. Proponents of combined production emphasize the probable benefits from combining trees and livestock, while more traditional land managers have focused on the potentially damaging aspects. The objective of silvopastoral agroforestry is to "optimize the beneficial aspects of the interaction of woody components with crop and animal

components to obtain a production pattern preferable to what is usually obtained" (Nair 1983). Potential benefits include greater overall productivity, increased overall profit, improved nutrient cycling, and greater biological diversity. Detrimental effects may be decreased survival and growth of planted seedlings due to livestock browsing or trampling, competition between trees and ground vegetation, and compaction of soils.

It is desirable to evaluate potential benefits and detriments derived from the integration of production components. In a silvopastoral system, the three major components are the tree crop, the animal, and the understory (or pasture). A better understanding is needed of the sharing of resource pools between and among these three components, in space and time, in order to design more effective management practices (Buck 1986).

This study evaluates the effects of grazing a nitrogen-fixing understory on forage production and tree growth during the early years of Douglas-fir (Pseudotsuga menziesii) plantations. This small-scale silvopastoral agroforestry system employs Douglas-fir as the timber crop, subterranean clover (Trifolium subterraneum) as a nitrogen-fixing understory, and sheep as the livestock component.

LITERATURE REVIEW

Early research in forest grazing and silvopastoral systems has focused on two major concerns. These are: 1) the nature of the relationship between overstory and understory plants, and 2) the effects of mechanical impacts by livestock on tree survival and growth. The effect of the tree overstory on understory plant production has been rather extensively studied in multi-use and agroforestry systems. As the plantation ages, the forage component is controlled more and more by trees through modification of the understory microclimate (Krueger 1981). This includes not only changes in temperature and wind movement, but particularly the quantity and quality of light reaching the understory. The presence or absence of species, their size and shape, and even nutritive content are determined in part by light (Krueger 1981).

Understory production and cover decrease as the trees mature (Hedrick et al. 1968; Dodd et al. 1972; Skovlin and Harris 1974; Clary et al. 1975; Hedrick 1975; Skovlin et al. 1976; McKinnell and Batini 1978; Anderson and Batini 1979; Anderson and Batini 1983; Krueger 1983; Pearson 1983; Percival and Knowles 1983; Wolters 1983; Steele and Percival 1984; Agbede 1985). In radiata pine silvopastoral plantations, pasture production begins to fall after three years; in the final twelve years of a twenty year rotation, pasture production is one-half that of open pasture

(McKinnell and Batini 1978). For slower growing trees such as Douglas-fir, pasture production does not decline significantly until trees reach 15-20 years of age or tree canopy cover is 20-30 percent (Clary et al. 1975; Hedrick 1975; Krueger 1981). Quality and quantity of light also affects species composition of the understory. Nitrogen-fixing legumes, for example, do not tolerate shading and are at a disadvantage compared to competitive grasses when low light levels exist (Anderson and Batini 1979; Lavender and Walker 1979; Anderson and Batini 1983; Waring and Snowdon 1985).

Grazing potential appears to be directly related to degree of shading. It is, therefore, dependent on the proportion of the area planted to trees, tree species present, density of planting, and average tree size (Batini et al. 1983; Percival et al. 1984). Lower pasture yields due to tree competition and reduced accessibility of forage due to pruning and thinning debris reduce livestock carrying capacity in intensively managed agroforests. In radiata pine plantations under age five, 60-85 percent of the level of grazing in open pastures is achieved (Batini et al. 1983; Anderson and Batini 1984). Livestock gains are generally greater where trees are less densely planted (Clary et al. 1975; Pearson 1983). Logan (1983) suggests that performance of animals in young plantations does not decline until tree density is more than 200 stems ha⁻¹.

The major impact of cattle on trees is through trampling and that of sheep is through browsing (Lewis 1980a; Eissenstat et al. 1982; Batini et al. 1983; McLean 1983). Agroforesters recommend that cattle grazing be deferred until trees are four meters tall or at least until bark becomes firm (Tustin 1975; Eissenstat et al. 1982; Batini et al. 1983). Under most conditions, cattle account for only a small percentage of the total conifer mortality (McLean and Clark 1980; Wallace 1983). However, tree mortality can become quite high in localized areas if cattle distribution is not controlled (Wheeler et al. 1980; Eissenstat et al. 1982). Trees are relatively safe from sheep browsing when they are 1-2 meters tall (Anonymous 1974; Tustin 1975; Batini et al. 1983; Leininger 1984). Grazing before this time should be practiced with caution (Knowles et al. 1973; Lewis 1980b; Eissenstat et al. 1982; Lewis et al. 1984; Penaloza et al. 1985). Growth of radiata pine is largely unaffected by browsing if the terminal leader remains intact and if laterals are not completely stripped of needles (Tustin 1975; Gillingham et al. 1976; Tustin et al. 1979; Penaloza et al. 1985). Results from both actual and simulated browsing studies of other conifers suggest that up to 50 percent removal of the live crown has little silvicultural effect, and that only severe and repeated browsing has an impact on tree survival and growth (Skovlin et al. 1976; Lewis 1980b; Lewis 1980c; Neilsen 1981; Monfore 1983).

There is a general relationship between browsing impacts and availability of palatable forage. It appears that greater availability and variety of palatable forage reduces incidence of browsing (Borough 1979; McLean and Clark 1980; Winward and Rudeen 1980; Batini et al. 1983; Leininger 1984; Penaloza et al. 1985). Problems can best be avoided by not grazing when forage availability is low, when forage is of low palatability or when tree foliage is lush and very palatable (Hedrick 1975; Tustin 1975; Tustin et al. 1979; McLean and Clark 1980; Monfore 1993; Pearson 1983; Sharrow and Leininger 1983; Heinz 1984; Leininger 1984). The system of grazing employed may also influence the incidence of tree browsing by livestock. Several studies show that rotating grazing between tree and treeless areas reduces browsing and campsite development by sheep in establishing agroforests (Cole 1961; Anderson et al. 1985). Highest overall damage generally occurs where sheep rest. This seems to be a response to boredom (Anderson et al. 1985). The effects of grazing systems and stocking levels on tree damage have been variable, and are apparently influenced by site characteristics and adherence to proper grazing management practices (Skovlin and Harris 1974; McLean et al. 1978; Leininger 1984; Anderson et al. 1985).

Besides browsing, other direct impacts by livestock include breakage and debarking. While breakage of branches

through rubbing may reduce tree growth and opens the tree up to invasion by disease or insects (Lewis 1980b; Lewis et al. 1984), it is generally considered to be a minor problem (Penaloza et al. 1985). Studies suggest that debarking has little effect on the tree seedling unless it is a full girdle (Lewis 1980a; Brix and Mitchell 1985). Bark stripping occurs mostly in spring and summer to smaller trees (Anderson et al. 1985). Additional methods have been tried to reduce damage by livestock, with varying success. These methods include pre-conditioning behavior of livestock (Gillingham et al. 1976; Monfore 1983), selection of age and kind of animal (Gillingham et al. 1976; Batini et al. 1983; Leininger 1984), animal repellants (Knowles and Tahau 1979; Batini et al. 1983), and tree stock selection (Lewis 1980b).

Early grazing studies of multi-use and silvopastoral systems dealing with effects on tree growth and survival generally did not separate grazing impacts into direct effects, such as removal of photosynthetic tissue or trampling, and indirect effects, such as altered stand water relations or additions of nutrients from animal wastes (Hall et al. 1959; Cole 1961; Black and Vladimiroff 1963; Hedrick et al. 1968; Adams 1975; Hedrick and Keniston 1975; Tustin 1975; Gillingham et al. 1976; McQueen et al. 1976). In silvopastoral and multi-use systems, more recent studies indicate that the benefits of integrating trees, pasture, and livestock include: 1) altered plant-soil-water

relations, and 2) improved nutrient status and nutrient cycling (Tustin et al. 1979; Logan 1983; Anderson and Batini 1984; Krueger and Vavra 1984; Leininger 1984; Buck 1986).

Availability of water is a major factor that determines the distribution and production of vegetation (Brown 1977; Turner and Begg 1978; Gholz 1982; Murphy and Ferrell 1982). Indeed, water availability is a vital factor affecting the survival of plants in areas which experience drought during some portion of the growing season (Cleary 1971). Plant water potential is an integration of various atmospheric, plant, and soil factors (Cleary 1971; Running 1976; Jarvis 1980). The major physiological control over water status in trees is via leaf conductance (Running 1976; Murphy and Ferrell 1982). Leaf conductance in conifers has been correlated with vapor pressure deficit, light, xylem water potential, temperature, and soil moisture content (Zavitkovski and Ferrell 1970; Running 1976; Jarvis 1980; Murphy and Ferrell 1982).

The seedling is generally the stage in plant development most susceptible to adverse changes in the environment. Decreases in photosynthesis, respiration, and transpiration have all been attributed to drought (Zavitkovski and Ferrell 1970). In the Pacific Northwest, Douglas-fir is the dominant conifer and is a fairly shallow-rooted tree. Under moderate site conditions,

Douglas-fir trees which are 25 m tall have xylem water potentials of about -2.0 MPa at midday in summer, while one meter trees in the same stand have water potentials of -4.0 MPa or less (Waring and Cleary 1967). Douglas-fir seedlings on drier foothill sites experience -1.0 MPa minimum water potential in May, with water potential decreasing rapidly thereafter to a low of -5.0 MPa in September (Cleary 1971). There was 90% mortality in these trees on non-irrigated sites compared to only 10% on irrigated plots. Differences in tree seedling growth and survival is directly tied to moisture stress levels experienced by seedlings (Cleary 1971). It is water potential experienced during growth (through July) that is important, not minimum water potential experienced in late summer (Cleary 1971).

During drought, both inter- and intra-specific competition occurs between plants for soil moisture. The rate of depletion of soil moisture is a direct function of the amount of vegetation in an area (Newton 1964). Drought conditions may develop for trees as the result of water use by herbaceous vegetation. Foresters have been concerned with the effects of understory competition in both traditional and multi-use systems. Soil moisture competition between tree seedlings and understory vegetation is especially important early in rotation when tree root systems are small (Youngberg 1959; Larson and Schubert 1969; Heinz 1984; Sands and Nambiar 1984). In the Pacific Northwest, the summer precipitation pattern is very

important to survival of seedlings when accompanied by high grass competition (Cleary 1971). Some suggest that a nutrient x water interaction may be more important to tree growth and production with regards to competition than either factor alone (Brix 1979; Eissenstat and Mitchell 1983).

The removal of herbaceous vegetation by herbicides can greatly increase survival and vigor of conifer seedlings by increasing water availability (Newton 1964). Livestock harvest forage and thus also remove competitive understory vegetation. The effect of grazing on site water relations, however, has not been extensively examined. Proponents of agroforestry suggest that such systems reduce susceptibility of trees to drought by reducing understory water use (Anderson and Batini 1983; Batini et al. 1983; Logan 1983). In the Pacific Northwest, Leininger (1984) found that grazing reduced soil moisture content near the surface in young conifer plantations. At lower depths, however, soil moisture availability was greater on grazed than on ungrazed plantations. Sheep grazing appears to reduce competition for moisture between planted trees and associated vegetation through grazing on interior Willamette Valley sites (Hall et al. 1959). Black and Vladimiroff (1963) did not find this grazing effect on soil moisture in wetter coastal areas.

The nature of plant-water relations in an agroforestry plantation changes over time. As the stand matures, trees modify climatic extremes in the understory (Knowles et al. 1973; McQueen et al. 1976; Krueger 1981). Greater surface soil moisture has been noted under trees than in open pastures (McQueen et al. 1976; Anonymous 1978; Anderson and Batini 1979; Penaloza et al. 1985). It is suggested that this "extra" moisture may compensate for lower levels of light received by understory plants (Anderson and Batini 1979). This extra moisture also provides for an extended green feed period compared to open areas, greatly enhancing animal production and management (Anderson and Batini 1984; Penaloza et al. 1985). While most plant roots are located in the upper level of soils, many trees also have deep rooting which enables the tree to tap moisture not available to surface-rooted grasses. Combined systems, then, make better use of the water resource (Knowles et al. 1973). Many investigators suggest that combining trees and pasture buffers against soil erosion and therefore increases potential capacity for moisture retention (Knowles et al. 1973; Aulakh et al. 1983). Some suggest grazing may have adverse effects on soil physical characteristics (Adams 1975; Linnartz et al. 1975), while others have not found this to be so (Skovlin et al. 1976; Heinz 1984).

Nutrient cycling changes throughout the "succession" of an agroforest, and has a major impact on system

productivity. Plant performance and productivity can vary depending on the quantity and balance of nutrients available. The availability of nutrients for use by plants depends on a number of factors. Many nutrient forms are pH dependent, and this affects their solubility (Lavender and Walker 1979; Zasoski 1979). The concentration of a nutrient in the soil solution also affects its availability. Plant uptake generally increases as soil solution concentration increases (Zasoski 1979). The balance of nutrients in solution can affect uptake if nutrients are competitive or antagonistic (Spencer 1982). All these factors are influenced by the components in an agroforestry system.

The location of nutrient pools within the system, and additions and losses to these pools, changes dramatically as pasture is taken over by forest. There is a rapid turnover of nutrients early in a rotation as annual herbaceous plants die each year and nutrients are made available through microbial action (Whitehead 1970; Zasoski 1979). The significance of standing vegetation and organic matter as nutrient pools becomes much greater as the system takes on forest characteristics (Spycher et al. 1983; Cropper and Ewel 1984; Sollins et al. 1984). In younger stands, litterfall is mostly comprised of leaves (Fahey 1983). Woody litter becomes more important in older stands (Franklin and Waring 1979). Roots, especially fine roots, account for a large portion of organic matter in forest

soils (McClaugherty et al. 1984). While there is a high accumulation of organic matter and nutrients in forest litter, decomposition and mineralization processes are slow, especially in colder temperate forests. Seasonally xeric conditions may also limit organic matter decomposition (Fahey 1983).

In the Pacific Northwest, deficiencies in nitrogen, phosphorus, and potassium are common in forest soils (Sollins et al. 1980). Available forms of nitrogen in particular are normally not adequate to support vigorous tree growth required for intensive short rotation management (Heilman and Gessel 1963; Haines and DeBell 1979). Such management requires increased nitrogen replacement (Cromack et al. 1979). The quantity of nitrogen assimilated by the tree depends on the total amount of nitrogen in the soil, the rate of mineralization, the relative efficiency of tree roots and roots of competing vegetation, and the efficiency of soil microbes in absorbing inorganic nitrogen (DeBell and Miller 1979). Phosphorus, which is scarce because of its low solubility in soil solution (Powers et al. 1975), can be a particular problem for legumes in multi-use systems. In theory, continual immobilization of nutrients in the plant biomass, followed by forest removal, could lead to declining productivity (Fahey 1983). Forest productivity may decline in second rotation monocultures (Florence 1967; Alston 1981).

Fertilization is common in managed pastures and forests. Nutrient additions change uptake patterns by altering soil solution concentrations (Heilman and Gessel 1963; Turner 1982). Applications of nitrogen fertilizer lead to increased nitrogen incorporation in conifers (Heilman and Gessel 1963) and increase growth of both tree seedlings (Knight 1973; Waring and Snowdon 1985) and established trees (Geist 1976; Miller and Fight 1979; Turner 1982; Grier et al. 1984) on most sites. Nitrogen fertilization also increases the productivity and growth of pasture plants (Lemaire and Salette 1982; Reid 1983). Fertilizer applications can cause a change in comparative dry matter yields of legumes and grasses (Reid 1983; Silsbury 1984) and can lead to takeover by grass species with high potential growth rates (Geist 1976; Robinson and Rorison 1985). In mixed pasture-tree systems, established trees can be highly competitive with pasture for fertilizer nitrogen (Steele and Percival 1984).

The potential values of nitrogen-fixing plants in forested systems have been postulated (Cromack et al. 1979; DeBell 1979; Haines and DeBell 1979; Haines et al. 1979; Miller and Murray 1979; Youngberg 1979). These include additions of nitrogen, addition of organic matter which would increase the availability of water and other nutrients, and improvement of soil's physical characteristics. Where nitrogen-fixing species are included

in a system, additions of nitrogen can be appreciable (Anonymous 1978; Clark and McLean 1978; DeBell and Miller 1979; Miller and Murray 1979; Anderson and Batini 1983; Dawson 1983; Logan 1983). Only a small proportion of available mineral nitrogen is used by legumes (Whitehead 1970; Vallis 1978; Steele and Percival 1984). Senescence of annual legumes and dieback of perennial legumes when trees take over enhances nitrogen transfer (Whitehead 1970; Vallis 1978; Heichel 1983; Waring and Snowdon 1985). Transfer of fixed nitrogen occurs via release from dead tissue, decomposition of root and nodule tissue, and exudation from living roots (Whitehead 1970; Vallis 1978; Cromack et al. 1979; Heichel 1983). Microbial release of nitrogenous compounds from herbaceous vegetation is quite rapid and many decomposition products are readily available to plants (Vallis 1978; Cromack et al. 1979; Aulakh et al. 1983; Dawson 1983). The rest is converted to stable organic compounds which are more slowly available (Vallis 1978). The transfer of nitrogen from legumes to associated grasses is estimated at 20% of total nitrogen fixed over the growing season (Heichel 1983; Reid 1983).

Biological fixation accounts for as much as 70% of total nitrogen input in some ecosystems (Sollins et al. 1980). Nitrogen contributions from nitrogen-fixing species have been reported at 20-1382 kg ha⁻¹ annually (Cole 1979; Binkley 1983; Reid 1983; Binkley et al. 1984; Waring and Snowdon 1985). These inputs are more evenly distributed on

an annual basis than are additions from fertilization (Glover and Beer 1986). Nitrogen added by nitrogen-fixers may be more effective for trees than fertilizer nitrogen, because it allows for a more balanced uptake (DeBell and Miller 1979; Waring and Snowdon 1985; Glover and Beer 1986). Early in rotation when available resources exceed the demand of the principal crop, legumes accumulate nitrogen in plant tissue and soil organic matter for later use (DeBell and Miller 1979). Association with nitrogen-fixing species in forest and agroforestry systems has increased the growth of trees (DeBell and Miller 1979; Youngberg et al. 1979; Binkley 1983; Binkley et al. 1984; Waring and Snowdon 1985). Successful combinations of nitrogen-fixing understory plants with trees have been reported (Haines et al. 1979; Anderson and Batini 1983; Waring and Snowdon 1985). Presence of legumes increased the nitrogen content of loblolly pine (Dawson 1983) and radiata pine foliage (Waring and Snowdon 1985). Feasibility of using red alder and the less competitive sitka alder (Alnus sinuata) in Douglas-fir plantations continues to be investigated (Tarrant 1961; Tarrant and Miller 1963; Miller and Murray 1978; DeBell and Miller 1979; Binkley 1983; Binkley et al. 1984). Transfer of nutrients to non-nitrogen-fixers generally increases during the life of the conifer stand (DeBell 1979; Heichel 1983).

The cycling of nutrients is accelerated where animals

graze (Batini et al. 1983; Logan 1983; Heinz 1984; Russ 1984). A major nutrient cycling effect of grazing animals is the physical/chemical breakdown of plant material and an associated concentration of nutrients into more available forms (Gillingham 1983). Animal excreta is a potentially significant source of readily available nutrients (Watkin and Clements 1978). Approximately 75% of intake-nitrogen is returned in urine, 90% of which is in the form of urea or amide-nitrogen and thus readily available to associated plants (Whitehead 1970; Ball et al. 1979; Gillingham 1983). Urine also contains approximately 70% of intake-potassium, 10% of intake-phosphorus, and 70% of intake-sulfur (Whitehead 1970; Brady 1974; Watkin and Clements 1978). Nitrogen, potassium, phosphorus, calcium, and magnesium are the major nutrients found in the feces. Since they are present in organic forms, they are only slowly available for use by plants (Whitehead 1970; Watkin and Clements 1978). Return of nitrogen has been estimated at 150-221 kg ha⁻¹ yr⁻¹ where livestock graze from 4-12 months each year (Ball et al. 1979; Curll and Wilkins 1983; Leininger 1984). Grazing significantly increases soil carbon, nitrogen, and phosphorus (Batini et al. 1983; Gillingham 1983).

The actual absorption of excretal nutrients by plants depends upon the distribution pattern of excreta, proportion of total pasture forage ingested by livestock, weather, physiological condition of animals, and nutritive quality of pasture plants (Gillingham 1983). An important

impact of the grazing animal is the spatial redistribution of pasture nutrients. This is largely determined by topography and animal behavior (Gillingham 1983). The percentage of pasture affected by excreta is estimated to be 15-30% (Whitehead 1970; Ball et al. 1979). Total herbage nitrogen increases in areas where excreta is concentrated (Ball et al. 1979). It is estimated that 20-37% of urinary nitrogen is recovered by pasture plants (Ball et al. 1979; Limmer and Steele 1983). Distribution patterns also affect losses of nutrients. The concentration of excreted urine can lead to volatilization and leaching losses (Whitehead 1970; Ball et al. 1979; Gillingham 1983). Losses of ammonia and nitrous oxide gas are higher on grazed than on ungrazed pastures and are directly related to evaporation rates (Anonymous 1977; Aulakh et al. 1983). Some studies suggest the actual loss of nutrients is small (Curll and Wilkins 1983; Sherlock and Goh 1983) while others suggest losses may be as high as 60-75% of that added (Ball et al. 1979). Urine may increase pH of affected soils (Whitehead 1970; Ball et al. 1979; Sherlock and Goh 1983) which can alter microbial activity and uptake of elements (Whitehead 1970; Ruess 1984). Where urine is concentrated, high nitrogen levels reduce nitrogen fixation and legumes are eventually replaced by grasses (Ball et al. 1979; Gillingham 1983; Heichel 1983).

Differences in nutrient uptake and loss are important to plant success (Berendse 1985). In agroforestry and multi-use systems there is competition between trees and understory for nutrients (Halls 1958; Steele and Percival 1984; Waring and Snowdon 1985). There are also beneficial aspects of combined systems with regards to nutrient cycling. Combining production of agricultural and tree crops may be more efficient in recycling soil nutrients than monocultures (Glover and Beer 1986). Tree roots penetrate deeper soil layers, extracting nutrients from groundwater and deeper soil strata which are otherwise lost to shallow rooted pasture systems (Knowles et al. 1973; Ball et al. 1979; Harou 1983; Limmer and Steele 1983; Glover and Beer 1986). Dense surface mat rooting where pasture is established under trees is efficient in capture of surface nutrients released by litter decomposition (Knowles et al. 1973; Glover and Beer 1986). Combined systems also reduce soil erosion and nutrient loss more than single crop systems (Klingler 1982; Harou 1983; Heinz 1984). Several authors propose that combining the nitrogen-fixing capabilities of legumes with the phosphate-releasing powers of mycorrhizae will benefit both trees and pasture (Knowles et al. 1973; Borough 1979; Lavender and Walker 1979). Indeed, increasing the species diversity of the soil biota may be very important to continued productivity and health of managed ecosystems (Florence 1967; Alston 1982).

Successful integration requires an understanding of how agricultural and forestry components interact (Percival et al. 1984). Compatibility and complementarity of components is essential (Nair 1983) and can only be achieved through innovative management and special cultural practices.

The seeding of domestic grasses and/or legumes is common in many silvopastoral and forest grazing systems, where few preferred species are found in the native understory. Seeded species usually suppress less productive resident grasses and help prevent the establishment of undesirable herbaceous plants and shrubs (Krueger et al. 1980; McLean and Clark 1980; Klingler 1982; Vaughn and Murphy 1982; Eissenstat and Mitchell 1983; Krueger 1983). Production of introduced species is typically many times greater than that of native species (McLean and Clark 1980; Wallace 1983). Uncontrolled understory plant growth, however, may limit tree regeneration in dry, nutrient poor areas. Fewer problems arise if trees are planted when pasture is sown or before grasses are seeded.

Highly productive domestic legumes often do not tolerate the cool temperatures, low light, and nutrient-poor, acidic, or droughty soils (Perry et al. 1979; Dawson 1983; Johnson et al. 1985), typical of many forested ecosystems. In the Pacific Northwest and elsewhere, researchers continue to search for specific varieties of domestic and native legumes which are better adapted to

competition, low degree of site preparation, and adverse soil conditions (Miller and Zalunardo 1979; Alston 1981; Dawson 1983). For agroforestry applications, nitrogen-fixing plants should ideally meet the following criteria: be inexpensive, be easily established, have rapid growth, provide 20-50 kg ha⁻¹ readily available nitrogen annually, have a wide area of distribution, exert minimum competition with tree crops, control unwanted vegetation, be adapted to forest conditions, control disease, improve wildlife habitats, and produce food, forage or other products (DeBell and Miller 1979; Miller and Murray 1979; Logan 1983).

Proper grazing management is critical to the success of a silvopastoral system. Aspects of grazing management include season and duration of use by livestock, distribution of animals, kind of animal, and stocking levels. Grazing management in agroforestry systems has several objectives. One is to harvest forage, and convert it into saleable animal products. Nutrition is a primary animal management factor (Vavra et al. 1979) which is a particularly critical aspect of livestock operations (Kosco and Bartolome 1981). Because of the dynamic nature of the forage resource, it is important to match available forage with animal management and requirements (Vavra and Raleigh 1976; Smith and Dawson 1979; Krueger and Vavra 1986). Secondly, grazing is used to reduce understory competition

with the tree crop. Grazing frees crop trees from competition at an early age without unacceptable damage to seedlings (Beveridge et al. 1973; Adams 1975; Tustin 1975; Tustin and Knowles 1975; Monfore 1983; Heinz 1984). Limited stocking, low intensity of forage use, and strict control of season of grazing are sometimes employed to protect tree seedlings from direct mechanical impacts by livestock. This limited grazing can lead to problems if grass and shrubs are not reduced to the desired level (Knowles et al. 1973; Tustin 1975; Penaloza et al. 1985). If tree spacing permits, hay inter-cropping or mowing may be a viable seasonal alternative to grazing (Johnson et al. 1985). Thirdly, proper grazing ensures the continued health of the forage resource and is used to manipulate production, quality, and palatability for use by livestock and/or wildlife. Defoliation via grazing affects growth, persistence, and proportion of pasture plants (Harris 1978). Frequent defoliation is especially important in maintaining mixed grass/legume swards, keeping grasses from shading out legumes (Whitehead 1970; Curll and Wilkins 1983). Finally, appropriate grazing practices are required to minimize direct impacts by livestock on the tree crop.

There is a trade-off involved in maintaining pasture production adequate for use by livestock throughout the grazing years in a silvopastoral system. Early in the establishment phase, competition between pasture and trees may reduce tree growth. After trees begin to dominate the

ecosystem, intensive silvicultural practices may be required to maintain understory forage production. Special silvicultural practices have been employed to improve compatibility of agroforestry components throughout plantation life. New Zealand and Australian silvopastoralists manage for high quality sawlogs. These land managers suggest planting between 380-1140 trees ha⁻¹ to ensure a final crop of 50-440 trees ha⁻¹ (Knowles et al. 1973; Gillingham et al. 1976; Batini et al. 1983; Percival and Knowles 1983). Low planting density reduces planting and thinning costs (Borough 1979). Seedlings planted at wider spacings are less likely to die from drought than more densely planted seedlings (Anderson and Batini 1983; Batini et al. 1983). Possible tree planting patterns include random scatter, rows, grids, blocks, or clumps (Avery and Gordon 1983). Effects of varied spacings and patterns have been investigated (Knowles et al. 1973; Avery and Gordon 1983; Batini et al. 1983; Percival and Knowles 1983; Lewis et al. 1984; Costantoura 1985). Clumped and row plantings of trees appear to be most compatible with forage and crop production.

Regimes for pruning and thinning depend on the desired pasture and timber products and the intensity of management. Clear lumber and high quality sawlogs are valuable as specialty products. This justifies the intensive management required to produce them (Knowles et

al. 1973). Pruning and thinning increase both the grazing potential and the value of merchantable wood (Clary et al. 1975; Batini et al. 1983; Logan 1983). Trees should be thinned to the best final crop number as soon as individual crop trees are identifiable. When this is done, fewer trees need to be pruned, and maximum diameter growth of crop trees may be achieved in less time (Knowles et al. 1973; Lanner 1985). Pruning may reduce browsing by sheep (Anderson et al. 1985; Penaloza et al. 1985) and breakage by livestock rubbing against trees (Lewis et al. 1984). Thinning and pruning produce slash, which reduces pasture yields and hinders animal movements (Percival and Knowles 1983). Appropriate thinning and pruning regimes for radiata pine agroforests (Fenton et al. 1972; Knowles et al. 1973; Barr 1979; Borough 1979; Anderson and Batini 1983; Batini et al. 1983; Costantoura 1985) may also apply to slower growing conifers such as Douglas-fir, if the time scale is adjusted.

Harvesting regimes have a major impact on future site quality and tree regeneration. Clearfelling followed by burning (slash or broadcast) often greatly increases surface soil erosion and nutrient losses (Brown et al. 1973; Alston 1981; Klingler 1982; Binkley 1984; Waring and Snowdon 1985). Soil disturbance during harvesting reduces plant production and changes species composition on regeneration sites. It is therefore important to coordinate logging practices with planned understory and grazing

management in agroforestry systems (Hedrick et al. 1968).

SUMMARY

The major foci of early research in forest grazing and agroforestry systems were mechanical damage to trees by livestock and overstory-understory plant relationships. Successful integration of production activities requires a better understanding of the sharing of resource pools between and among different components, in space and time (Percival et al. 1984; Buck 1986). Recent studies have begun to focus on how integration affects the bio-geo-physical processes related to resource use. Research suggests that modified plant-soil water relations and improved nutrient status and accelerated nutrient cycling result from the integration of components in agroforestry systems. In well-designed silvopastoral systems, components provide both products and secondary benefits. The tree component provides the highly-valued wood products harvested at the end of rotation. Pasture production provides forage which is harvested by livestock. Interim income is thus provided through sale of animal products. Additional services or benefits from livestock include reduced understory competition with trees, accelerated nutrient cycling, and maintenance of pasture health. A nitrogen-fixing understory provides increased nitrogen

inputs, increased organic matter, improved soil physical characteristics, and high quality feed. The tree crop provides shelter for livestock, and ammeliorates the understory microclimate.

THE STUDY SITE

History

An experiment was initiated in 1979 by Dr. Denis Lavender (Dept. of Forest Science, Oregon State University) to evaluate a mixed-crop timber production system employing Douglas-fir as the timber crop and red alder (Alnus rubra) as a non-leguminous nitrogen-fixer. Two-year-old Douglas-fir trees (2-0 stock) were planted in two replications of two planting patterns: 1) grid = trees planted 2.5 m apart in a grid pattern (1600 stems ha⁻¹), and 2) cluster = 5 trees planted in each cluster with clusters 7.7 m apart (840 stems ha⁻¹).

There were two reasons for planting trees in a cluster pattern, first, to substantiate the supposition that clumps (as opposed to square or row patterns) could maximize the forage area while providing for a number of crop trees at rotation similar to that obtained with grid spacing (Avery and Gordon 1983). The second reason was to compare the growth of trees in a traditional grid pattern with that obtained in cluster planting, where red alder is interplanted in the space between clusters after the establishment of the Douglas-fir trees. Red alder was interplanted in early spring of 1986. During the period prior to this, the study site was used to evaluate a small-scale agroforestry system, focusing on the direct and indirect effects of grazing on tree growth and pasture

production.

Site description and preparation

The three hectare study area is located in the Genetics Nursery of McDonald Forest, approximately 16 kilometers north of Corvallis, Oregon (Section 1, T11S, R5W, Willamette Meridian). Climate of the area is typically maritime with warm dry summers and cool moist winters. Average daily maximum summer temperature is 25° C while average daily winter temperature is 4° C. The frost free period is 165-200 days. Mean annual precipitation is 110 cm, 70% of which falls from November to March (Knezevich 1975).

Soils are Xeric Haplohumults (Jory series) formed in fine textured colluvium weathered mainly from basic igneous and sedimentary material (Knezevich 1975). They are well-drained, highly weathered silty clay loams located on foothills. Slope of the study area is less than 5%. The site is well suited to commercial Douglas-fir production, with a site index of 145-165 (Knezevich 1975).

The entire site was rototilled in September 1982. The original plots (grid or cluster) together with adjacent pasture plots without trees (open) were split, and half of each plot was planted with 22 kg ha⁻¹ of inoculated subclover (Trifolium subterraneum var. Nangela) seed. Only clover-seeded subplots were grazed. The resulting subplots

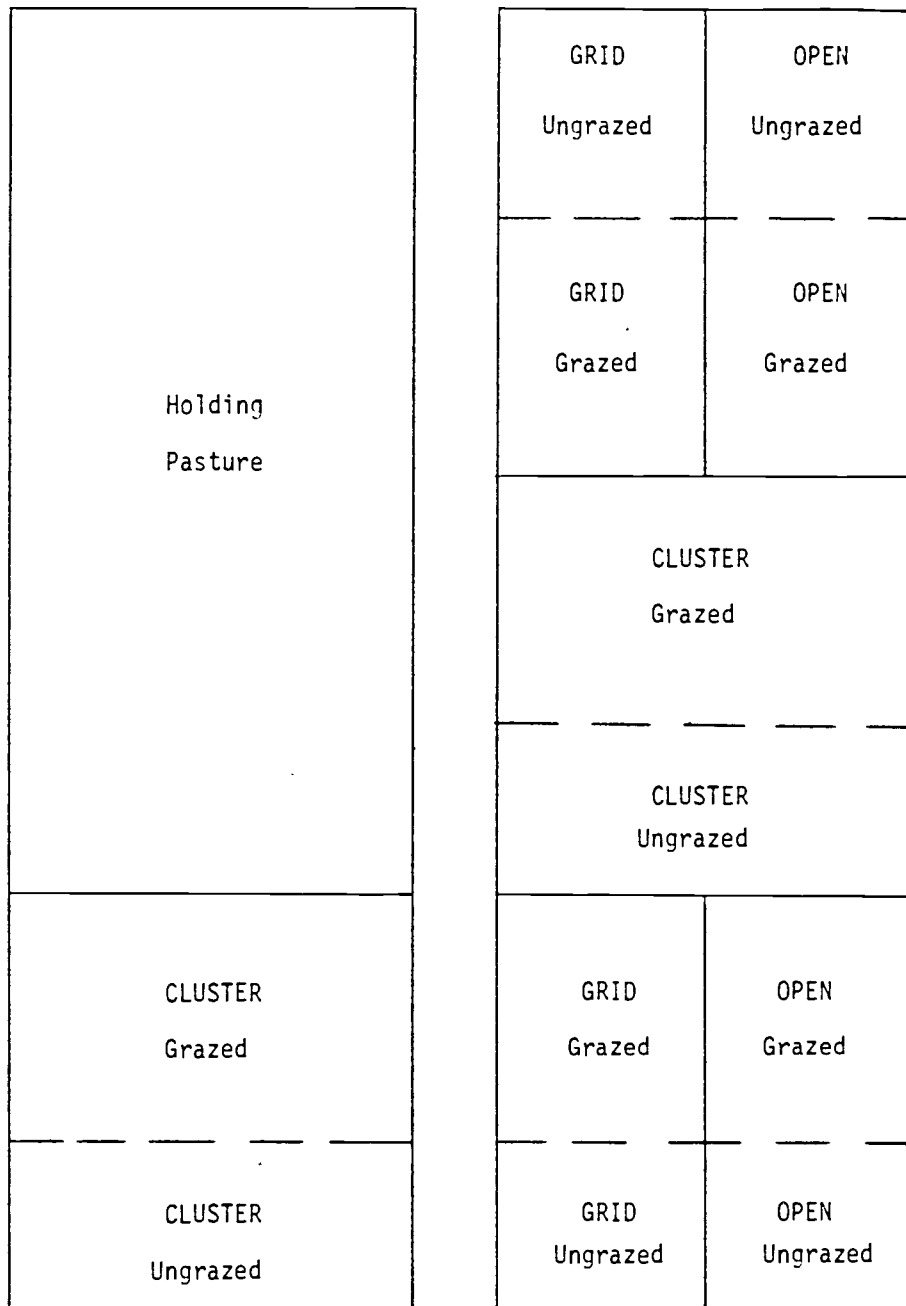


Figure 1. Arrangement of tree planting pattern and grazing management treatments.

were approximately 0.4, 0.1 and 0.1 ha in size for cluster, grid and open plots, respectively (Figure 1). A combination of ammonium sulfate and treble-superphosphate (10-24-0-12) fertilizer was applied to the entire area at a rate of 400 kg ha⁻¹ in October 1982. In addition, 1.1 kg ha⁻¹ of sodium molybdenate was applied at that time. Fertilizer applications were 150 kg ha⁻¹ of treble superphosphate (0-45-0-0) in Fall 1983 and 180 kg ha⁻¹ single superphosphate (0-25-0-10) plus 45 kg ha⁻¹ muriate of potash (0-0-60-0) in Fall 1984. The plots were individually fenced in March 1983. Grazing began in June 1983.

CHAPTER I

PASTURE PRODUCTION AND USE BY SHEEP IN A SILVOPASTORAL
SYSTEM

PASTURE PRODUCTION AND USE BY SHEEP IN A SILVOPASTORAL SYSTEM

Abstract

A silvopastoral system using a Douglas-fir (Pseudotsuga menziesii) tree crop and subclover (Trifolium subterraneum) as a nitrogen-fixing forage crop was investigated near Corvallis, Oregon, during 1983-1985. Treatments included all possible combinations of three tree planting patterns (no trees, trees planted 2.5 m apart in a grid, and clusters of five trees each with clusters 7.7 m apart) and two grazing/understory management systems (seeded to subclover and grazed by sheep or ungrazed and unseeded).

Averaged over the three years, clover/grazed plots produced twice as much forage as unseeded/ungrazed plots. The tree crop had no apparent effect on forage production. However, because of difficulty in managing livestock in the densely planted grid plantations, sheep utilized only half as much forage on grid plantations as on either cluster plantations or open pastures. Tall fescue (Festuca arundinacea) and subclover (grazed plots only) were the major forage plants. Percentage of tall fescue increased and annual plants (subclover and/or annual grasses) decreased from 1983-84 on all plots. Where tree pattern and density permitted (cluster and open plots), livestock management practices helped stabilize levels of subclover

near 1984 levels on grazed plots in 1985.

Introduction

The seeding of domestic grasses and/or legumes is common in many multi-use systems. Seeded species usually suppress less productive resident grasses, and help prevent invasion of undesirable herbaceous plants and shrubs (Vaughn and Murphy 1982; Eissenstat and Mitchell 1983; Krueger 1983). Competition between trees and understory for moisture, light and nutrients may occur in forest plantations (Halls 1958). During the establishment phase, uncontrolled understory growth may limit survival and growth of tree seedlings in some areas (McLean et al. 1978; Cole 1984). After the establishment phase, trees begin to influence forage production through modification of the microclimate and root competition (Krueger 1981). Both density and pattern of tree planting influences forage production and species composition (Anderson and Batini 1979; Avery and Gordon 1983; Anderson and Batini 1984; Lewis et al. 1984; Steele and Percival 1984; Waring and Snowdon 1985).

Livestock are used to harvest forage from silvopastoral systems. This provides intermediate incomes through red meat production (Anonymous 1974; Tustin 1975; McQueen et al. 1976; Anderson and Batini 1983; Logan 1983; Monfore 1983). Proper grazing also helps control weedy plants (Beveridge et al. 1973; Heinz 1984), reduces grass and forb competition with trees (Knowles et al. 1973;

Rennie 1978; McLean and Clark 1980) and is effective in manipulating the desired composition, production and palatability of pasture plants (Krueger 1983). The major factor contributing to reduced livestock carrying capacity in silvopastoral systems compared to open pasture is lower pasture yields due to tree competition and pruning and thinning debris (Percival and Knowles 1983).

The objectives of this study were to evaluate the effects of grazing/understory management and tree planting pattern on forage production, forage species composition, and utilization of forage by livestock in a young Douglas-fir agroforest.

Materials and Methods

The three hectare study site is located in the eastern foothills of the Coast Range approximately 16 km north of Corvallis, Oregon (Lat. $44^{\circ} 30'$, Long. $123^{\circ} 20'$). Soils are Jory Series (Xeric Haplohumults, Knezevich 1975) which have average suitability for commercial timber production with a Douglas-fir site index of 145-165 (Knezevich 1975). Climate of the area is typically maritime with warm dry summers and cool moist winters. Average daily maximum summer temperature is 25° C while average daily winter temperature is 4° C. The frost-free period is 165-200 days. Mean annual precipitation is 110 cm, 70% of which falls from November

to March (Knezevich 1975).

Two-year-old Douglas-fir trees (2-0 stock) were planted in two replications of two planting patterns in 1979: 1) grid = trees planted 2.5 m apart in a grid pattern (1600 stems ha⁻¹), and 2) cluster = 5 trees planted in each cluster with clusters 7.7 m apart (840 stems ha⁻¹). The entire site was rototilled in September 1982. The original plantations (grid or cluster) together with adjacent pasture plots without trees (open) were split, and half of each plot was planted with 22 kg ha⁻¹ of inoculated subclover (Trifolium subterraneum var. Nangela) seed. Only clover-seeded plots were grazed. The resulting subplots were approximately 0.4, 0.1 and 0.1 ha in size for cluster, grid and open plots, respectively. A combination of ammonium sulfate and treble-superphosphate (10-24-0-12) fertilizer was applied to the entire area at a rate of 400 kg ha⁻¹ in October 1982. In addition, 1.1 kg ha⁻¹ of sodium molybdenate was applied at that time. Annual fall fertilizer applications were made to all plots to sustain subclover production, following recommendations based upon N,P and K analysis of soil samples conducted by the Oregon State University Soil Testing Laboratory each year. Fertilizer applications were 150 kg ha⁻¹ of treble superphosphate (0-45-0-0) in 1983 and 180 kg ha⁻¹ superphosphate (0-25-0-10) plus 45 kg ha⁻¹ muriate of potash (0-0-60-0) in 1984.

Plots were individually fenced in March 1983. Grazing began in June 1983. A flock of dry ewes was rotated in random order through the plots, remaining in each plot until approximately 50% of the forage was consumed or until sheep began to consume tree foliage. Plots were grazed once each spring (April), summer (June-July) and fall/winter (November-January) seasons. The objectives of spring grazing were to utilize early forage growth and to avoid maturation of subclover and tall fescue (Festuca arundinacea) before sheep can return in summer. An objective of summer grazing was to remove forage canopy, thereby reducing competition between trees and forage plants for moisture. To reduce browsing by sheep, summer grazing did not commence until Douglas-fir foliage had matured. Fall/winter grazing was conducted to harvest high quality fall pasture growth and to reduce competition between grass and clover. Records of flock size and number of days the flock spent in each plot were used to calculate sheep days of use per hectare (SUD ha⁻¹, Appendix B).

Prior to grazing each season, moveable cages were randomly located in each plot (16 in clusters, 10 in grid and open plots). Immediately after sheep left each plot, one 0.2 m² circular plot was clipped within each cage (before) and a grazed plot (after), similar in composition, was clipped nearby. Clipped vegetation was dried for 72 hours at 50°C and weighed. Forage consumption was calculated as the difference between the paired before and

after plots. Total production on grazed plots each grazing year was calculated as the sum of forage consumed at each grazing period, plus the standing residual at the end of the grazing year. For our purposes, the grazing year is considered to begin with the onset of fall rains/pasture growth in October and continues until the end of the succeeding summer (September). Herbaceous plant production on ungrazed plots was determined once each grazing year by clipping nine 0.2 m^2 randomly located plots in grid and open pasture plots and fifteen 0.2 m^2 plots in cluster plots in late summer (August-September). For the summer grazing period, clipped vegetation was hand-sorted into four categories: annual grasses, perennial grasses, clover and miscellaneous forbs.

Data were analyzed as a split-split plot in time with tree planting treatments as main plots, grazing as subplots and years as sub-subplots in a completely randomized design with two replications. Means, where appropriate, were separated using the Student-Newman-Kuels technique (Snedecor and Cochran 1980). Statistical significance was assessed at $\alpha = 0.05$, unless otherwise specified.

Results and Discussion

Forage production of grazed plots exceeded ($p < 0.05$) that of ungrazed plots each year. Averaged over the three

years of the study, grazed plots produced about twice ($p < 0.05$) as much forage as ungrazed plots (Table I.1). Seeding grasses and legumes has been reported elsewhere to increase herbage production from two to many times that of resident vegetation (McLean et al. 1978; McLean and Clark 1980; Vavra et al. 1980; Vaughn and Murphy 1982; Krueger 1983; McLean 1983; Wallace 1983), as is the case here. Grazing, in many instances, also stimulates production of grasses and forbs (Whitehead 1970; Curll and Wilkins 1983; Reid 1983; Ruess 1984; Berendse 1985; Robinson and Rorison 1985). Average forage production varied among years ($p < 0.05$). Lowest production was in 1983, the year of pasture establishment. Forage production was about 1000 kg ha⁻¹ higher in 1984, a wet year, than in 1985, an unusually dry year. The greatest difference in production between grazed and ungrazed plots occurred in 1983 and 1984, two years with greater than average precipitation. It appears that seeded pastures were more able to respond to greater moisture availability than were unseeded areas. There was no effect ($p > 0.05$) of tree planting pattern on pasture production (Table I.2). Lack of forage response to tree presence in our young plantation is not surprising as canopy cover has little influence on forage until cover reaches 20-30% (Krueger 1981).

Newly established pastures in 1983 were dominated by subclover with strong components of tall fescue and annual

Table I.1. Mean annual forage production (kg dry matter ha⁻¹) of grazed and ungrazed treatments during 1983-1985. Data are $\bar{X} \pm$ S.E.

Year	Grazing Management		Yearly \bar{x}
	Grazed	Ungrazed	
1983	6120±540 ^a	2540±160 ^b	4330±600 ^x
1984	8680±450 ^a	3910±220 ^b	6290±760 ^z
1985	6390±370 ^a	4210±330 ^b	5300±400 ^y
3-yr. \bar{x}	7060 ± 370 ^a	3550 ± 220 ^b	

Grazing management means within year or yearly \bar{x} not sharing a common letter differ ($p < 0.05$).

Table I.2. Mean annual forage production (kg dry matter ha⁻¹) of tree planting pattern treatments during 1983-1985. Data are $\bar{X} \pm$ S.E.

Year	Tree Planting			Yearly \bar{x}
	Cluster	Grid	Open	
1983	4270±890	4540±1460	4180±1010	4330±600 ^x
1984	6310±1520	6030±1030	6540±1710	6290±760 ^z
1985	5450±870	5070±880	5370±490	5300±400 ^y
3-yr. \bar{x}	5340±640	4980±630	5370±680	

Yearly \bar{x} not sharing a common letter differ ($p < 0.05$).

Tree planting pattern means within a row do not differ ($p > 0.05$).

grass also present (Table I.3). In contrast, forage produced on unseeded areas was mostly tall fescue and annual grass (predominately Aira caryophyllea and Festuca myuros). All plots displayed a trend of increasing tall fescue and decreasing annual plants (both annual grass and subclover) during 1983-84. Although no species composition data were collected during 1985, field observations suggest that this trend continued during 1985-86 on ungrazed plots. Grazing management designed to favor clover over perennial grass appeared to be successful in stabilizing 1985-86 subclover content of grazed plots near 1984 levels. There was no apparent effect ($p > 0.05$) of tree planting pattern on species composition in 1983 or 1984 (Table I.4). However, field observations in 1985 suggest that the subclover component in grid plots was lower than that on cluster or open plots. While stocking rates seem to have little influence on the proportion of subclover in a pasture, the frequency of defoliation is important since clover does not tolerate shading (Whitehead 1970). Decline in the amount of forage consumed between 1984 and 1985 combined with no grazing on grid plots in summer 1985 likely resulted in shading-out of subclover by tall fescue.

Average yearly forage consumption by sheep generally followed trends in forage production (Table I.5). Approximately 62% of the total herbage produced was consumed by sheep in both 1984 and 1985. Only 35% of forage production was consumed by sheep in 1983, largely due to

Table I.3. Percent understory species composition (dry weight basis) of grazed and ungrazed treatments in Summer 1983 and 1984. Data are $\bar{X} \pm$ S.E.

Species Class	Grazing Management/Year			
	1983		1984	
	Grazed	Ungrazed	Grazed	Ungrazed
Tall fescue	15.9 \pm 3.6 ^a	64.9 \pm 4.5 ^b	66.8 \pm 5.0 ^b	83.9 \pm 3.3 ^c
Annual grass	6.2 \pm 2.0 ^a	21.4 \pm 3.9 ^a	3.1 \pm 1.0 ^a	6.6 \pm 1.4 ^a
Misc. forbs	2.4 \pm 0.9 ^a	8.4 \pm 1.5 ^a	1.5 \pm 0.7 ^a	6.6 \pm 1.4 ^a
Subclover	75.6 \pm 5.4 ^c	0.3 \pm 0.3 ^a	29.2 \pm 5.0 ^b	0.3 \pm 0.2 ^a

Means in a row not sharing a common letter differ ($p < 0.05$).

Table I.4. Percent understory species composition (dry weight basis) of tree planting pattern treatments in Summer 1983 and 1984. Data are $\bar{X} \pm$ S.E.

Class/Year	Tree planting		
	Cluster	Grid	Open
1983			
Tall fescue	48.3 \pm 16.2	43.8 \pm 15.6	36.6 \pm 16.4
Annual grass	15.5 \pm 3.3	10.4 \pm 6.4	15.4 \pm 6.9
Misc. forbs	2.9 \pm 1.0	8.0 \pm 2.7	5.4 \pm 1.8
Subclover	33.4 \pm 20.2	37.8 \pm 22.0	42.7 \pm 24.1
1984			
Tall fescue	72.3 \pm 10.3	74.3 \pm 6.3	79.4 \pm 2.9
Annual grass	2.5 \pm 0.6	5.5 \pm 1.9	6.6 \pm 1.7
Misc. forbs	4.7 \pm 3.1	6.8 \pm 3.5	4.7 \pm 3.0
Subclover	20.6 \pm 12.2	14.4 \pm 8.5	9.3 \pm 5.3

Means in a row do not differ ($p > 0.05$).

Table I.5. Mean annual forage consumption (kg dry matter ha⁻¹)
by sheep on tree planting pattern treatments of
grazed plots during 1983-1985. Data are $\bar{x} \pm$ S.E.

Year	Tree Planting			Yearly \bar{x}
	Cluster	Grid	Open	
1983	1250 \pm 60 ^a	1080 \pm 210 ^a	2290 \pm 350 ^b	1540 \pm 260 ^x
1984	4220 \pm 380 ^b	3090 \pm 190 ^a	4650 \pm 210 ^b	3980 \pm 320 ^z
1985	4990 \pm 370 ^c	1460 \pm 590 ^a	3480 \pm 20 ^b	3310 \pm 670 ^y
3-yr. Total	10460 \pm 2190 ^b	5630 \pm 1290 ^a	10420 \pm 1320 ^b	

Tree planting pattern means within year or yearly \bar{x} not sharing a common letter differ ($p < 0.05$).

the late commencement of grazing that year. In spite of similar forage production, three-year total forage consumption on grid plantations was only approximately half that achieved on open pasture. Cluster plantations, however, were similar to open pasture in both forage production and consumption over the three years studied. Other authors have noted similar trends of forage production and utilization by sheep in young conifer plantations compared to silvopastoral systems or traditional pasture management (Tustin et al. 1979; Batini et al. 1983; Anderson and Batini 1984). Silvopastoral systems are often planted with fewer total trees than are intensive commercial timber plantations. Presumably, tree density affects differences among treatments in forage production and use, through effects on both tree-pasture competition and ease of livestock management. Lower tree density in our cluster plantations (840 trees ha⁻¹) than in grid plantations (1600 trees ha⁻¹), together with grouping of trees into clumps, provided wide alley-ways between trees. Livestock management in these open alleys was similar to that practiced in open pasture, providing levels of forage consumption which generally equalled (1984) or exceeded (1985) those achieved on open pasture. Wide alley-ways between cluster units provided more options in livestock management. We found that strip grazing in these alley-ways, using portable fencing, permitted easy

livestock management. The high levels of use we obtained with this practice appeared to improve pasture performance and eliminated impacts on the tree crop by livestock. Dense planting of trees in grid plantations maximized the area covered by tree foliage and provided only narrow alley-ways between trees, thus making animal management difficult. This problem increased as trees grew, as indicated by the rapid decline in forage consumed on grid plantations between 1984 and 1985.

Conclusions and Implications

In our silvopastoral system, twice the amount of forage was produced in seeded, grazed plots as compared to unseeded, ungrazed plots. Intensive grazing management achievable in cluster plantations allows for the manipulation of the pasture to maintain the desired species composition, quality, quantity, and palatability for use by livestock. The presence of tree clusters seems to have little influence over pasture production or composition early in rotation. Our observations suggest that intensive pasture/livestock production may be practiced concurrently with silviculture during the early years of a timber rotation using a cluster planting. There is little loss of pasture/livestock production compared to similarly managed open pasture provided that trees are planted in such a manner that they do not interfere with animal management within the plantation. Conventional, high density grid

planting of Douglas-fir trees, however, is not recommended for silvopastoral systems because livestock management is difficult in the narrow spaces between trees in such plantations.

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CHAPTER II

GROWTH OF DOUGLAS-FIR TREES AND NITROGEN CYCLING IN A
SILVOPASTORAL SYSTEM

GROWTH OF DOUGLAS-FIR TREES AND NITROGEN CYCLING IN A
SILVOPASTORAL SYSTEM

Abstract

A two-crop silvopastoral system using a Douglas-fir (Pseudotsuga menziesii) tree crop and subclover (Trifolium subterraneum) as a nitrogen-fixing forage crop was investigated near Corvallis, Oregon, during 1983-1985. Treatments included all possible combinations of three tree planting patterns (no trees, trees planted 2.5 m apart in a grid, and clusters of five trees each with clusters 7.7 m apart) and two grazing/understory management systems (seeded to subclover and grazed by sheep or unseeded and ungrazed).

There was no apparent effect of grazing management on tree growth. Differences in height and diameter growth between grid and cluster planting patterns were primarily a function of planting density and initial tree size at the beginning of the study. Three-year average height and diameter growth of trees was 98.3 cm and 16.44 mm, and 74.2 cm and 13.20 mm for cluster and grid trees, respectively. Grazed plots received an average of 34 kg N ha⁻¹ yr⁻¹ from livestock urine. This was associated with slightly higher N content of Douglas-fir foliage on grazed compared to ungrazed plantations. However, N contents of trees in both grazed and ungrazed plantations were well within the normal range.

Introduction

Where domestic grass seeding and livestock grazing are combined with forest production, forest managers have been concerned with effects on tree survival and growth during the establishment phase of the system. Some believe that permanent reductions in tree growth may result from early grazing impacts or intense competition between seedling and understory plants (Youngberg 1959; Cleary 1978). However, few follow-up growth studies on established or mature trees are available to ascertain the impact of early grazing influences on later tree growth. Findings from young (under 12 years of age) multi-use plantations show that on average to good site qualities seeding and grazing have little effect on tree growth unless poorly managed (Anonymous 1974; McLean et al. 1978; Sharrow and Leininger 1983; Heinz 1984; Leininger 1984). Where site quality is limited by one or more factors, proper grazing and understory management have the potential of improving conditions for tree growth (DeBell and Miller 1979; Eissenstat and Mitchell 1983; Krueger and Vavra 1984; Sands and Nambiar 1984; Waring and Snowdon 1985).

Soils of the Pacific Northwest are low in nitrogen and phosphorus (Lavender and Walker 1979). Increased nutrient availability, especially of nitrogen, often improves growth of seedlings (Knight 1973) and established trees (Geist 1976; Miller and Fight 1979) where other factors are not

limiting. Use of nitrogen-fixing legumes in silvopastoral systems improves yield of associated plants on nitrogen-deficient sites (Dawson 1983; Reid 1983). While nitrogen fixed by legumes is not all readily available to associated plants (Heichel 1983), there is increased uptake of nitrogen by both grasses (Vaughn and Murphy 1982; Heichel 1983; Reid 1983) and trees (Anonymous 1978; Dawson 1983; Waring and Snowdon 1985) growing in association with nitrogen-fixing plants. Recycling of nutrients is hastened by grazing and by trampling of litter (Batini et al. 1983; Logan 1983; Heinz 1984). Animal excreta, particularly urine, is a significant source of readily available nutrients (Whitehead 1970; Watkin and Clements 1978; Ball et al. 1979; Gillingham 1983) that can be used by both the understory and the tree crop.

The objectives of this study were: 1) to evaluate the effects of grazing/understory management and pattern of tree planting on the growth of Douglas-fir trees, and 2) to estimate the amount of urinary nitrogen returned to the land by sheep.

Materials and Methods

The three hectare study site is located in the eastern foothills of the Coast Range approximately 16 km north of Corvallis, Oregon (Lat. $44^{\circ} 30'$, Long. $123^{\circ} 20'$). Soils are Jory Series (Xeric Haplohumults, Knezevich 1975) which have

average suitability for commercial timber production with a Douglas-fir site index of 145-165 (Knezevich 1975). Climate of the area is typically maritime with warm dry summers and cool moist winters. Average daily maximum summer temperature is 25° C while average daily winter temperature is 4° C. The frost-free period is 165-200 days. Mean annual precipitation is 110 cm, 70% of which falls from November to March (Knezevich 1975).

Two-year-old Douglas-fir trees (2-0 stock) were planted in two replications of two planting patterns in 1979: 1) grid = trees planted 2.5 m apart in a grid pattern (1600 stems ha⁻¹). and 2) cluster = 5 trees planted in each cluster with clusters 7.7 m apart (840 stems ha⁻¹). The entire site was rototilled in September 1982. The original plots (grid or cluster) together with adjacent pasture plots without trees (open) were split, and half of each plot was planted with 22 kg ha⁻¹ of inoculated subclover (Trifolium subterraneum var. Nangela) seed. Only clover-seeded plots were grazed. The resulting subplots were approximately 0.4, 0.1 and 0.1 ha in size for cluster, grid and open plots, respectively. A combination of ammonium sulfate and treble-superphosphate (10-24-0-12) fertilizer was applied to the entire area at a rate of 400 kg ha⁻¹ in October 1982. In addition, 1.1 kg ha⁻¹ of sodium molybdenate was applied at that time. Annual fall fertilizer applications were made to all plots to sustain

subclover production, following recommendations based upon N, P and K analysis of soil samples conducted by the Oregon State University Soil Testing Laboratory each year. Fertilizer applications were 150 kg ha⁻¹ of treble superphosphate (0-45-0-0) in 1983 and 180 kg ha⁻¹ superphosphate (0-25-0-10) plus 45 kg ha⁻¹ muriate of potash (0-0-60-0) in 1984.

Plots were individually fenced in March 1983. Grazing began in June 1983. A flock of dry ewes was rotated in random order through the plots, remaining in each plot until approximately 50% of the forage was consumed or until sheep began to consume tree foliage. Plots were grazed once each spring (April), summer (June-July) and fall/winter (November-January) seasons.

Tree height to the nearest cm and diameter at 0.5 m to the nearest mm were measured using a calibrated pole and a caliper, respectively, after commencement of rains in the fall each year. Sufficient soil moisture recharge at this time minimized variations in diameter associated with cambial shrinkage. The outer row/column of study trees in each plot was eliminated from analysis to avoid any "border effect."

Prior to grazing each season, moveable cages were randomly located in each plot (16 in cluster, 10 in grid and open plots). Immediately after sheep left each plot, one 0.2 m² circular plot was clipped within each cage (before) and a grazed plot (after), similar in composition,

was clipped nearby. Clipped vegetation was dried for 72 hours at 50° C and weighed. Forage consumption was calculated as the difference between the paired before and after plots. A prediction of the amount of pasture nitrogen recycled through sheep urine was calculated from forage consumption estimates, percentage forage N estimates presented for similar pastures by Sanders (1965), and estimated partitioning of consumed N in sheep urine and feces (Whitehead 1970; Gillingham 1983). The following formula was used: $\text{kg ha}^{-1} \text{ urinary N} = \text{kg ha}^{-1} \text{ forage ingested} \times \% \text{ forage N} \times 70\% \text{ of ingested N excreted in urine}$. Tree foliar samples were taken in December 1985 following collection techniques outlined by Lavender (1970). Needles were ground and analyzed for total nitrogen using micro-Kjeldahl techniques.

Data were analyzed as a split-split plot in time with tree planting treatments as main plots, grazing as subplots, and years as sub-subplots in a completely randomized design with two replications. Means, where appropriate, were separated using the Student-Newman-Kuels technique (Snedecor and Cochran 1980). Statistical significance was assessed at $\alpha=0.05$, unless otherwise specified.

Results and Discussion

Height growth varied by year (Table II.1). Height growth in 1983-84 was about 10 cm greater than in 1982-83 or 1984-85 ($p < 0.05$). Growth in 1983-84 probably reflected higher than average precipitation in the previous year when buds form and early during the growing period in 1984. Mean height growth increment during 1982-1985 was 32% greater ($p < 0.10$) on cluster than grid plantations. The difference between the annual height growth increment in clusters as compared to grids appeared to decrease over time, most likely related to tree size. Mean heights at the beginning of the experiment in 1982 were greater for clusters as compared to grids. By 1985, trees in grid plantations reached heights which were more comparable to trees in cluster plantations. There was no apparent effect ($p > 0.05$) of grazing management on height growth of Douglas-fir trees.

Average diameter growth was about 1-2 mm greater ($p < 0.05$) in 1982-83 than the following two years (Table II.2). While growth of grid trees was similar each year, cluster tree diameter growth decreased each year ($p < 0.05$). This may be a tree size related effect, or may show that the advantage of low density cluster planting lessens with time as trees grow and intraspecific competition becomes more intense. Trees in cluster plantations displayed 55% and 35% greater ($p < 0.05$) diameter growth than trees in grid

Table II.1. Mean heights and yearly mean height growth (cm \pm S.E.) of Douglas-fir trees in grazed and ungrazed treatments and in different tree planting pattern treatments from 1982-1985.

Year	Grazing Management		Tree planting		Yearly \bar{x}
	Grazed	Ungrazed	Cluster	Grid	
<u>Mean Height</u>					
1982	135.8 \pm 17.4 ^a	150.8 \pm 27.0 ^a	178.4 \pm 8.9 ^a	108.2 \pm 13.1 ^b	143.3 \pm 15.1
1985	385.3 \pm 37.8 ^a	418.9 \pm 52.6 ^a	473.2 \pm 16.9 ^a	331.0 \pm 26.8 ^b	402.1 \pm 30.1
<u>Yearly Mean Height Growth</u>					
1982-3	79.3 \pm 9.5 ^a	82.9 \pm 12.4 ^a	98.7 \pm 2.4 ^a	63.5 \pm 5.8 ^b	81.1 \pm 7.3 ^x
1983-4	88.8 \pm 6.6 ^a	97.1 \pm 7.5 ^a	104.2 \pm 3.1 ^a	81.7 \pm 4.3 ^b	93.0 \pm 4.9 ^y
1984-5	81.4 \pm 4.7 ^a	88.0 \pm 6.3 ^a	91.9 \pm 3.6 ^a	77.6 \pm 4.8 ^b	81.7 \pm 3.9 ^x

Tree planting pattern or grazing management means within year or yearly x not sharing a common letter differ (p < 0.05).					

Table II.2. Mean diameters and yearly mean diameter growth (mm \pm S.E.) of Douglas-fir trees in grazed and ungrazed treatments and in different tree planting pattern treatments from 1982-1985.

Year	Grazing Management		Tree Planting		Yearly \bar{x}
	Grazed	Ungrazed	Cluster	Grid	
<u>Mean Diameter</u>					
1982	16.9 \pm 2.7 ^a	18.8 \pm 4.2 ^a	23.5 \pm 1.4 ^b	12.2 \pm 1.6 ^a	17.9 \pm 2.4
1985	60.0 \pm 5.8 ^a	64.1 \pm 8.2 ^a	72.9 \pm 3.1 ^b	51.8 \pm 4.4 ^a	62.3 \pm 4.7
<u>Yearly Mean Diameter Growth</u>					
1982-3	16.2 \pm 1.9 ^a	16.6 \pm 2.7 ^a	19.9 \pm 0.5 ^c	12.9 \pm 1.5 ^a	16.4 \pm 1.5 ^y
1983-4	14.1 \pm 1.4 ^a	14.9 \pm 1.3 ^a	16.6 \pm 0.5 ^b	12.3 \pm 0.8 ^a	14.5 \pm 0.9 ^x
1984-5	13.5 \pm 1.0 ^a	13.7 \pm 1.0 ^a	12.8 \pm 1.0 ^a	14.4 \pm 0.8 ^a	13.6 \pm 0.7 ^x

Tree planting or grazing management means within year or yearly \bar{x} not sharing a common letter differ (p < 0.05).					

plantations in 1982-83 and 1983-84, respectively. Diameter increment of grid and cluster trees were similar in 1984-85 ($p > 0.05$). Similar to height, there was no effect ($p > 0.05$) of grazing management on tree diameter growth.

Grazed plots received an average of 34.1 kg of urinary N ha⁻¹ year⁻¹ during the three years of our study, based on our method of calculation. Cluster plantations and open plots received 13.9-19.7 kg ha⁻¹ greater ($p < 0.05$) urinary nitrogen addition than did grid plantations (Table II.3). Return of nitrogen varied among years, with 1983 receiving the least urinary nitrogen addition and 1984 the most ($p < 0.05$). Estimated nitrogen returned by sheep increased with succeeding years in cluster plantations. Grid and open plots had greatest urinary nitrogen inputs in 1984 ($p < 0.05$). Relatively low nitrogen inputs in all treatments in 1983 result from the low use of forage that year. Low urinary nitrogen deposited in grid plantations during 1985 reflects reduced forage production/grazing capacity as tree canopy increased.

Analysis of Douglas-fir needles for percent nitrogen content supports the contention that legumes in conjunction with grazing improves nitrogen status of associated trees. By 1985, conifer needles in grazed plots contained $1.54 \pm 0.03\%$ total nitrogen, which was higher than the $1.43 \pm 0.03\%$ contained in needles from ungrazed plots ($p < 0.10$). There was no difference in percent foliar nitrogen between cluster and grid trees.

Table II.3. Prediction of the amount of urinary nitrogen
(kg ha⁻¹) ± S.E.) returned to the land by grazing
sheep for different tree planting pattern treatments.

Year	Tree planting			Yearly \bar{x}
	Cluster	Grid	Open	
1983	11.7±0.5 ^a	10.2±1.9 ^a	21.6±3.2 ^a	14.5±2.5 ^x
1984	50.9±0.3 ^b	35.2±3.4 ^a	63.5±3.7 ^b	49.9±5.3 ^z
1985	57.1±5.7 ^c	18.8±8.6 ^a	38.2±0.3 ^b	38.0±7.5 ^y
3-yr. \bar{x}	39.9±8.8 ^{ab}	21.4±5.3 ^a	41.1±7.8 ^b	

Planting pattern treatment means within year or yearly \bar{x} not sharing a common letter differ (p < 0.05).

Lack of response of trees to nitrogen additions in grazing treatments may reflect the addition of fertilizer nitrogen to all plots in 1982, or may result from inherently adequate nitrogen status of our soils. Foliage nitrogen ranges from 0.6 - 2.3% of dry weight in Douglas-fir, the lower end representing deficiency levels (Lavender and Walker 1979). So while grazing plus legumes provides more available nitrogen for uptake by trees, there was no effect of improved nitrogen status on the growth of trees in grazed versus ungrazed plots since needles in both treatments were well within the normal range. Moreover, Douglas-fir is particularly resilient and well-adapted to soils which are low in available nutrients (Franklin and Waring 1979). Several multi-use studies have found no influence of seeding or grazing on seedling and tree growth (Anonymous 1974; McLean et al. 1978; Heinz 1984). It appears that on sites with moderate to high site indices for timber production, which our site represents, grazing and understory management have little effect on tree growth unless poorly managed.

Conclusions and Implications

There was no apparent effect of grazing management on tree growth in the first three years of the study. Grazed plantations are assumed to have had greater additions of

readily available nitrogen than did ungrazed plantations, due to both nitrogen fixation by legumes and deposition of forage nitrogen in urine and feces of grazing sheep. We expected that greater amounts of readily available nitrogen on grazed sites would enhance tree growth, but this did not occur. The difference in uptake of nitrogen by trees, as indicated by tree foliar nitrogen concentrations, is evidently not great enough to produce different growth responses. Tree growth was equivalent to that achieved by forest monocultures.

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CHAPTER III

DIRECT IMPACTS BY SHEEP ON DOUGLAS-FIR TREES IN A
SILVOPASTORAL SYSTEM

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Abstract

A silvopastoral system using a Douglas-fir (Pseudotsuga menziesii) tree crop and subclover (Trifolium subterraneum) as a nitrogen-fixing forage crop was investigated near Corvallis, Oregon, during 1983-1985. Treatments included all possible combinations of three tree planting patterns (no trees, trees planted 2.5 m apart in a grid, and clusters of five trees each with clusters 7.7 m apart) and two grazing/understory management systems (seeded to subclover and grazed by sheep or unseeded and ungrazed).

Utilization of forage by sheep ranged from 16-49%, depending on season and tree planting pattern. There was no apparent relationship between periodic utilization levels and animal impacts occurring each grazing period. Sheep removed about the same percentage of tree foliage during each grazing period (< 5%). About 15% of terminals were removed the first year, mostly by deer in the spring prior to stocking with sheep. The majority of trees were out of the reach of sheep and wildlife by 1985. Fewer than 5% of trees received substantial levels of breakage or debarking. Most impacts occurred on the smallest trees in each plantation, during the spring and summer grazing seasons.

Introduction

A concern of agroforesters and other natural resource managers is potential browsing and direct, mechanical impacts of grazing on tree regeneration and subsequent growth. Browsing impacts on radiata pine in Australia and New Zealand are insignificant if the terminal leader remains intact and if laterals are not completely stripped of needles (Tustin 1975; Gillingham et al. 1976; Tustin et al. 1979; Penaloza et al. 1985). Other direct impacts which may reduce growth of trees include breakage and debarking (Lewis 1980b; Lewis et al. 1984).

In general, it appears that high availability, palatability and variety of forage reduces browsing of trees by livestock (Borough 1972; Winward and Rudeen 1980; Batini et al. 1983; Penaloza et al. 1985). Higher forage use often results in higher use on trees (McLean and Clark 1980; Leininger 1984). However, where forage is plentiful, density of herbage is not necessarily a factor in damage to conifers (McLean and Clark 1980). Where low levels of grazing allow forage plants to become less palatable as they mature, livestock browsing of conifers may actually decrease as utilization increases (Monfore 1983).

The objectives of this study were to evaluate the nature and extent of impacts on Douglas-fir trees as a result of sheep grazing in young plantations planted in two different patterns.

Materials and Methods

The three hectare study site is located in the eastern foothills of the Coast Range approximately 16 km north of Corvallis, Oregon (Lat. $44^{\circ} 30'$, Long. $123^{\circ} 20'$). Soils are Jory Series (Xeric Haplohumults, Knezevich 1975) which have average suitability for commercial timber production with a Douglas-fir site index of 145-165 (Knezevich 1975). Climate of the area is typically maritime with warm dry summers and cool moist winters. Average daily maximum summer temperature is 25° C while average daily winter temperature is 4° C. The frost-free period is 165-200 days. Mean annual precipitation is 110 cm, 70% of which falls from November to March (Knezevich 1975).

Two-year-old Douglas-fir trees (2-0 stock) were planted in two replications of two planting patterns in 1979: 1) grid = trees planted 2.5 m apart in a grid pattern (1600 stems ha^{-1}), and 2) cluster = 5 trees planted in each cluster with clusters 7.7 m apart (840 stems ha^{-1}). The entire site was rototilled in September 1982. The original plots (grid or cluster) together with adjacent pasture plots without trees (open) were split, and half of each plot was planted with 22 kg ha^{-1} of inoculated subclover (Trifolium subterraneum var. Nangela) seed. Only clover-seeded subplots were grazed. The resulting subplots were approximately 0.4, 0.1 and 0.1 ha in size for cluster, grid and open plots, respectively. A combination of ammonium

sulfate and treble superphosphate (10-24-0-12) fertilizer was applied to the entire area at a rate of 400 kg ha^{-1} in October 1982. In addition, 1.1 kg ha^{-1} of sodium molybdenate was applied at that time. Annual fall fertilizer applications were made to all plots to sustain subclover production, following recommendations based upon N, P and K analysis of soil samples conducted by the Oregon State University Soil Testing Laboratory each year. Fertilizer applications were 150 kg ha^{-1} of treble superphosphate (0-45-0-0) in 1983 and 180 kg ha^{-1} superphosphate (0-25-0-10) plus 45 kg ha^{-1} muriate of potash (0-0-60-0) in 1984.

Plots were individually fenced in March 1983. Grazing began in June 1983. A flock of dry ewes was rotated in random order through the plots, remaining in each plot until approximately 50% of the forage was consumed or until sheep began to consume tree foliage. Plots were grazed once each spring (April), summer (June-July) and fall/winter (November-January) seasons. Prior to grazing each season, moveable cages were randomly located in each plot (16 in clusters, 10 in grid and open plots). Immediately after sheep left each plot, one 0.2 m^2 circular plot was clipped within each cage (before) and a grazed plot (after), similar in composition, was clipped nearby. Clipped forage was dried for 72 hours at 50° C and weighed. Forage utilization was calculated as the difference between paired before and after plots, divided by the total amount of

forage available each period.

Sheep grazed the plantations for three periods each during the 1983-84 and 1984-85 tree growth years, defined from budbreak in May to the following April. After budbreak each year, study trees were examined for sheep impacts. Tree condition was monitored just prior to and immediately after sheep grazed each plantation. For sheep-grazed plantations, difference in the status of trees prior to versus after sheep grazed was attributed to use by sheep. Any changes in tree status in the interim between grazing periods was attributed to use by wildlife.

Impacts were described in four ways: 1) percent of terminal shoots browsed, 2) optical estimation of the percent of current year's lateral branches per study tree which were browsed, 3) optical estimation of the percent of primary scaffold branches broken, and 4) percent and severity of debarking. The leader of each study tree was examined for animal damage. Sheep use of lateral branches was estimated using a class system with class mid-points of 0, 2.5, 7.5, 15, 30, 50, 70, and 90 percent of laterals browsed per tree. The distribution of trees in each class was used to generate a "mean browsing level" calculated as:

$$MBL = \frac{\sum_{i=0}^8 n_i m_i}{\sum_{i=0}^8 n_i}, \text{ where } n = \# \text{ of trees in class } i \text{ and } m = \text{midpoint of class } i.$$

This estimates periodic browsing by sheep for each plantation. When sheep browse a lateral branch, they generally consume one-half or less of the

available current year's needles. MBL therefore overstates the proportion of current year's tree foliage removed by sheep. Breakage of scaffold branches was expressed using a similar class system. Debarked trees were identified and the extent of circumference of cambial tissue removed was estimated. Damage by rodents was not observed on our site.

Data were analyzed as a split-split plot in time with tree planting treatments as main plots, grazing as subplots, and time (years, months, grazing periods) as sub-subplots in a completely randomized design with two replications. Means, where appropriate, were separated using the Student-Newman-Kuels technique (Snedecor and Cochran 1980). Statistical significance was assessed at $\alpha = 0.05$.

Results and Discussion

Percent forage utilization was generally moderate, ranging from 16% to approximately 49% of herbage produced. Forage utilization averaged about 18% greater ($p < 0.05$) for cluster plots than for grid plots (Table III.1). There is no apparent relationship between utilization levels each grazing period and browsing impacts by sheep. This is not surprising in light of the generally moderate to low levels of utilization achieved. The difference in the MBL between the beginning and end of each grazing period was the same on cluster and grid plantations, and did not differ ($p >$

Table III.1. Forage utilization levels (% dry matter) and livestock impacts on Douglas-fir trees in cluster and grid tree planting treatments for each grazing period in 1983-84 and 1984-85. Data are $\bar{x} \pm S.E.$

Season/Year	Cluster Tree Planting				
	% Util.	Change in MBL ¹	% Trees Terminals	% Trees Breakage	% Trees Debarking
<u>1983-84</u>					
Summer	23.6±5.8 ^b	1.6±1.2	4.5±3.0	8.7±0.4	4.2±1.8
Fall/Winter	28.4±0.6 ^c	1.8±1.5	0	0.5±0.3	0.8±0.1
Spring	49.2±2.3 ^f	5.3±1.9	0.4±0.4	2.7±0.4	0.4±0.4
<u>1984-85</u>					
Summer	29.7±9.4 ^c	3.2±0.8	1.2±1.1	5.6±2.7	1.5±0.7
Fall/Winter	29.1±7.3 ^c	4.6±0.8	0	0	0
Spring	39.2±6.0 ^e	2.8±0.2	0.8±0.7	7.0±0.7	0.8±0

Table III.1. Cont'd.

<u>Season/Year</u>	<u>Grid Tree Planting</u>				
<u>Period</u>	<u>% Util.</u>	<u>Change₁ in MBL¹</u>	<u>% Trees Terminals</u>	<u>% Trees Breakage</u>	<u>% Trees Debarking</u>
<u>1983-84</u>					
Summer	15.8±0.2 ^a	5.7±0.5	7.0±0.1	13.9±3.3	9.5±7.7
Fall/Winter	28.5±3.0 ^c	4.0±1.6	0	1.7±0.1	0
Spring	35.1±2.9 ^d	9.9±3.9	0.9±0.9	6.1±4.4	0
<u>1984-85</u>					
Summer	24.0±1.8 ^b	7.1±0.1	9.6±6.2	7.9±0.9	7.9±4.4
Fall/Winter	18.6±3.9 ^{ab}	4.1±1.9	0	0	0
Spring	21.3±8.1 ^b	3.3±1.3	0	5.2±1.9	0.9±0.9

Means in a column not sharing a common letter differ ($p < 0.05$).

¹ Mean Browsing Level

0.05) by grazing period or year (Table III.1). Sheep in Douglas-fir agroforests in southeast Oregon consumed some tree foliage regardless of season and browsed trees despite the availability of improved pastures (Logan 1983). This is consistent with our findings. Sheep browsing of Douglas-fir in the Coast Range, however, was highly seasonal with a noticeable tendency of sheep to consume brush and to avoid eating Douglas-fir during the summer months (Sharrow and Leininger 1984). More browsing is often observed in low versus high shrub density areas (Winward and Rudeen 1980). Lack of brush may help to explain why Douglas-fir is taken by sheep at all times of the year in agroforests. Our study site, typical of many improved pasture areas, had little shrub component. Sheep stripped small brush shoots in the spring. No encroachment of shrubs occurred on grazed plots, but some adjacent ungrazed plots had large brush species growing within some cluster units.

Sheep browsed trees during each of the grazing periods. This resulted in an increase in MBL after each grazing period over the grazing year. For grazed plantations, MBL averaged over two years was 10.8, 15.2, 18.8 and 24.1% for June (pre-grazing), July, January and April, respectively. The mean browsing level in June, the start of the tree growth year, is not 0 because of early browsing by wildlife. Deer contributed about 6% to MBL each year, and browsed an average of 89% of trees in each plantation.

In most cases, only severe browsing which removes more than 50% of the live tree crown has an effect on the growth of conifers (Lewis 1980b; Lewis 1980c; Neilsen 1981; Monfore 1983). Forest managers in Siuslaw National Forest in Oregon use 50% defoliation as the criterion to determine when sheep should be removed from forest plantations (Klingler 1985). The majority of trees in our study received only very light browsing by sheep. Assuming 50% defoliation to be the break where biological effect to the tree begins to appear, 13.7% of trees in clusters and 32.4% of trees in grids may have been adversely affected by browsing at the end of 1983-84 (Figure III.1), and 8.8% of trees in clusters and 23.6% of trees in grids may have been affected at the end of 1984-85 (Figure III.2). Heavily-browsed trees tended to be the smallest trees in each plantation. Trees browsed heavily in 1983-84 also tended to be those browsed heavily in 1984-85.

Removal of tree leaders not only immediately reduces tree height, but also can set back the tree's growth since a lag time occurs before a lateral will assume dominance. It has been suggested that sheep be removed when 10-20% of terminals have been taken to prevent significant growth reductions on a plantation as a whole (Tustin 1975). Trees taller than 1-2 m are relatively safe from terminal removal by sheep (Tustin et al. 1979). During the first two years, an average of 2% of trees had terminals browsed by sheep. By 1984-85 most tree terminals were out of the reach of

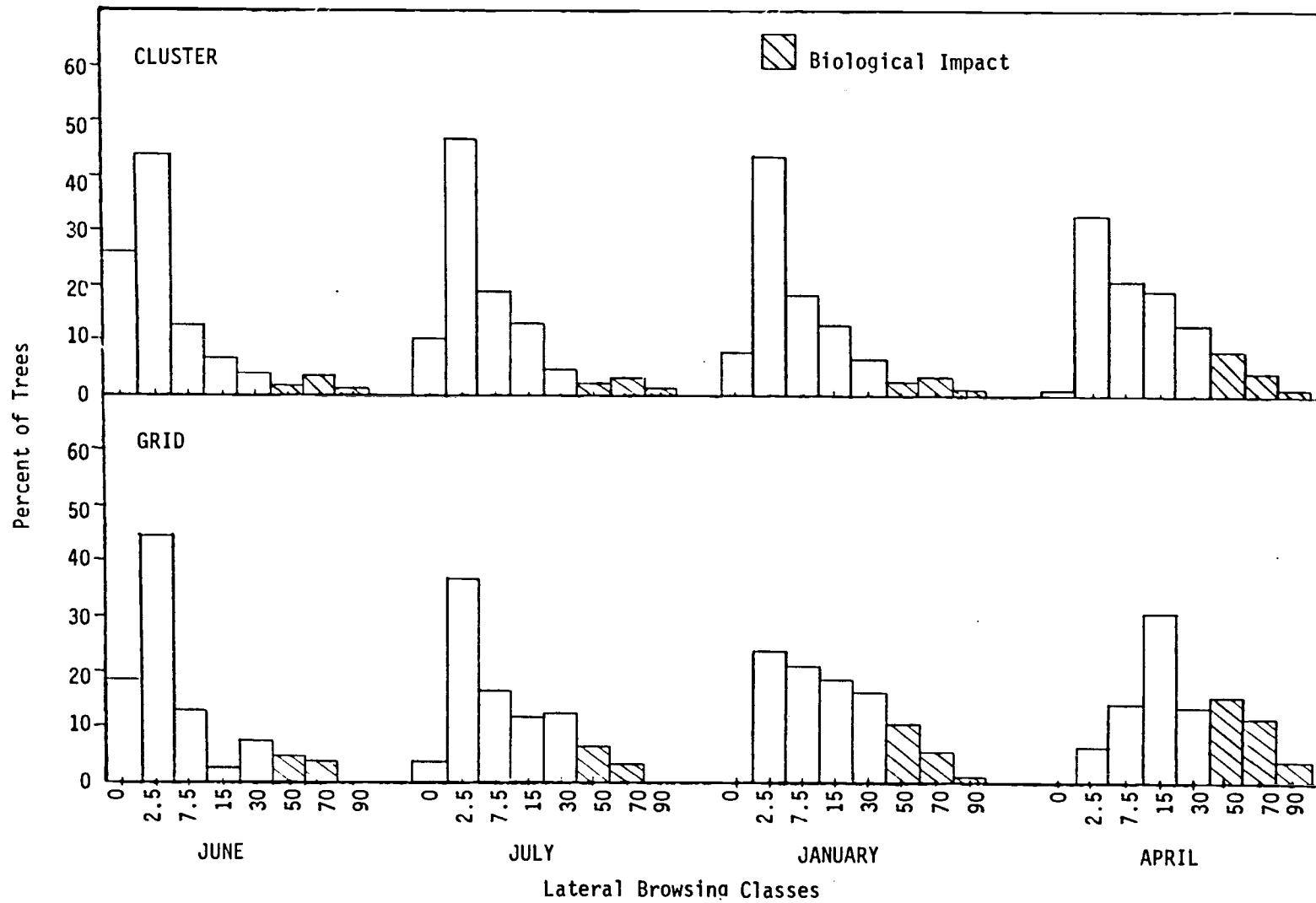


Figure III.1. Distribution of Douglas-fir trees into lateral browsing classes for cluster and grid plantations in 1983-84.

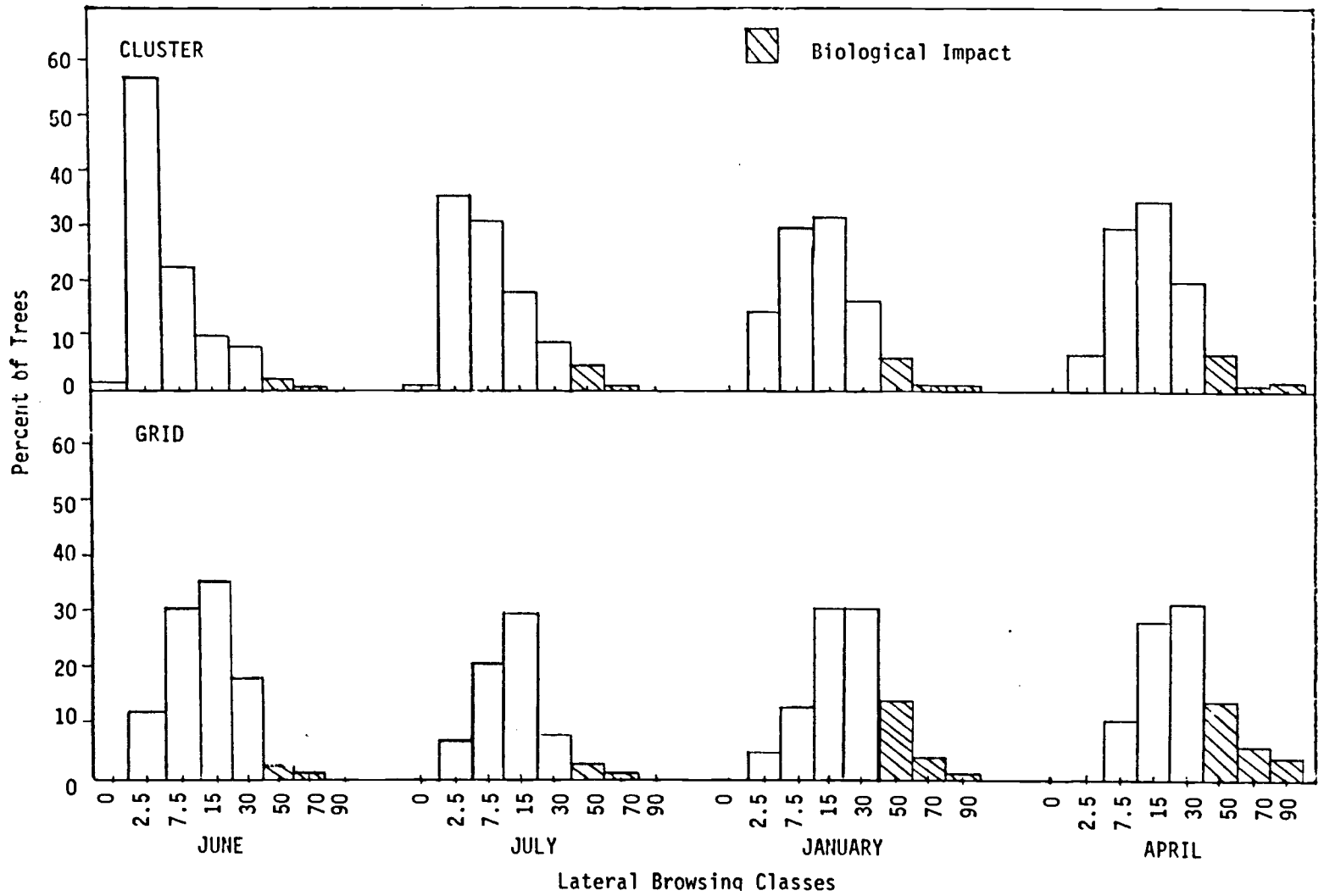


Figure III.2. Distribution of Douglas-fir trees into lateral browsing classes for cluster and grid plantations in 1984-85.

sheep. The majority of terminals were taken during the summer grazing periods in both cluster and grid plantations each year (Table III.1). Terminals removed by wildlife (predominately deer) averaged 13% in 1983-84 and 1% in 1984-85. In contrast to sheep browsing of terminals which was largely a summer phenomenon (Table III.1), browsing of terminals by deer occurred almost entirely in early spring prior to stocking with sheep.

Breakage of scaffold branches by sheep also occurred primarily during the summer grazing period (Table III.1). Breakage occurred to 10.3% of trees in summer, about twice that which occurred in spring ($p < 0.05$). Only 0.5% of trees had breakage which occurred in fall/winter. Most of the breakage occurred to lower branches, presumably during midday, when sheep rested directly beneath trees. No more than 5% of trees in any plantation had more than 50% of its branches broken (Figures III.3 and III.4). Trees with the highest number of broken branches were the smallest trees in each plantation and were frequently used as "scratching posts." Penaloza et al. (1985) felt that scratching by sheep was a minor problem, which appears to be the case here. Presumably, a strict external parasite control program would probably eliminate the more severe breakage problems.

Debarking occurred primarily in summer (Table III.1). The percent of trees receiving bark damage in the summer

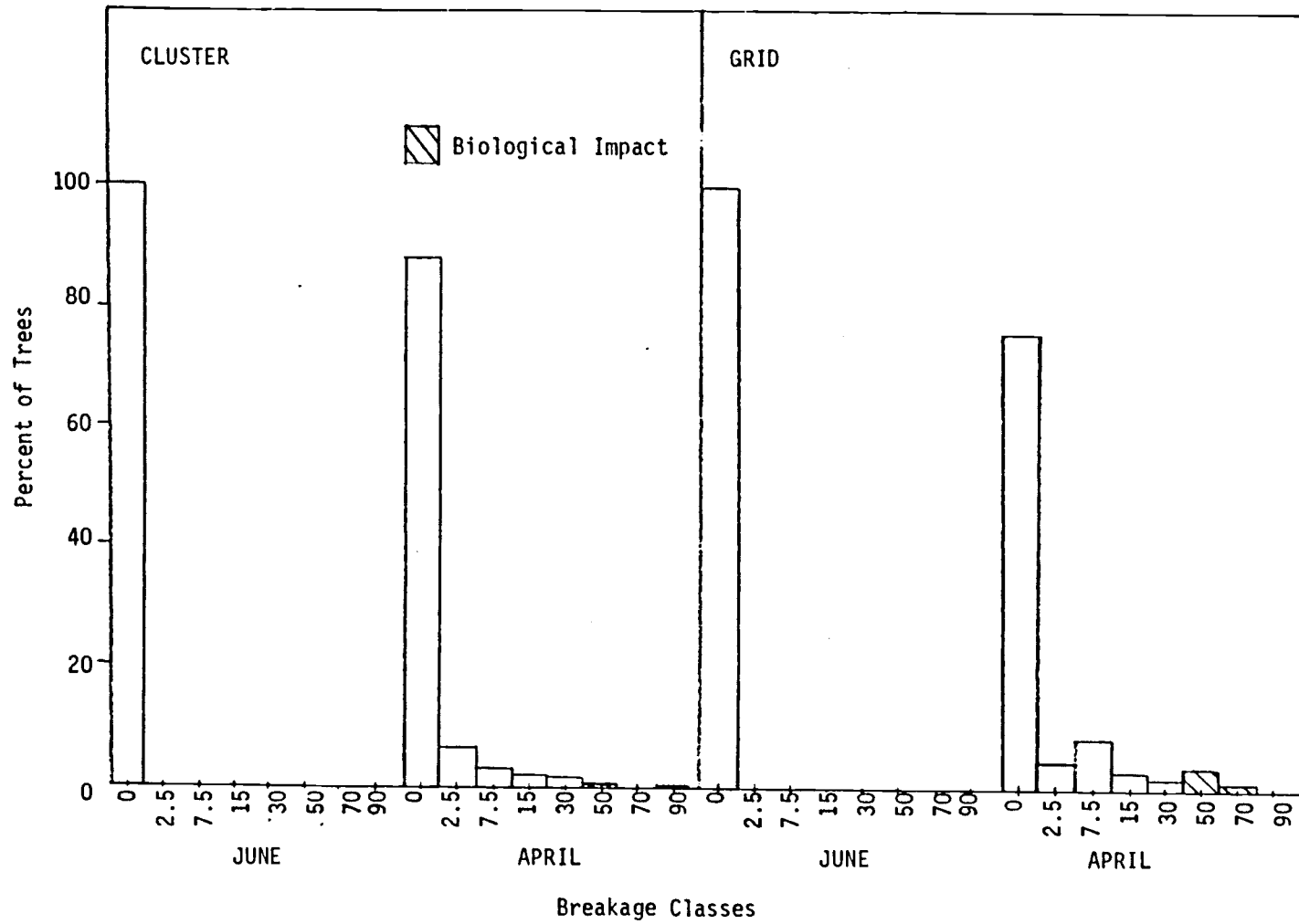


Figure III.3. Distribution of Douglas-fir trees into branch breakage classes for cluster and grid plantations in 1983-84.

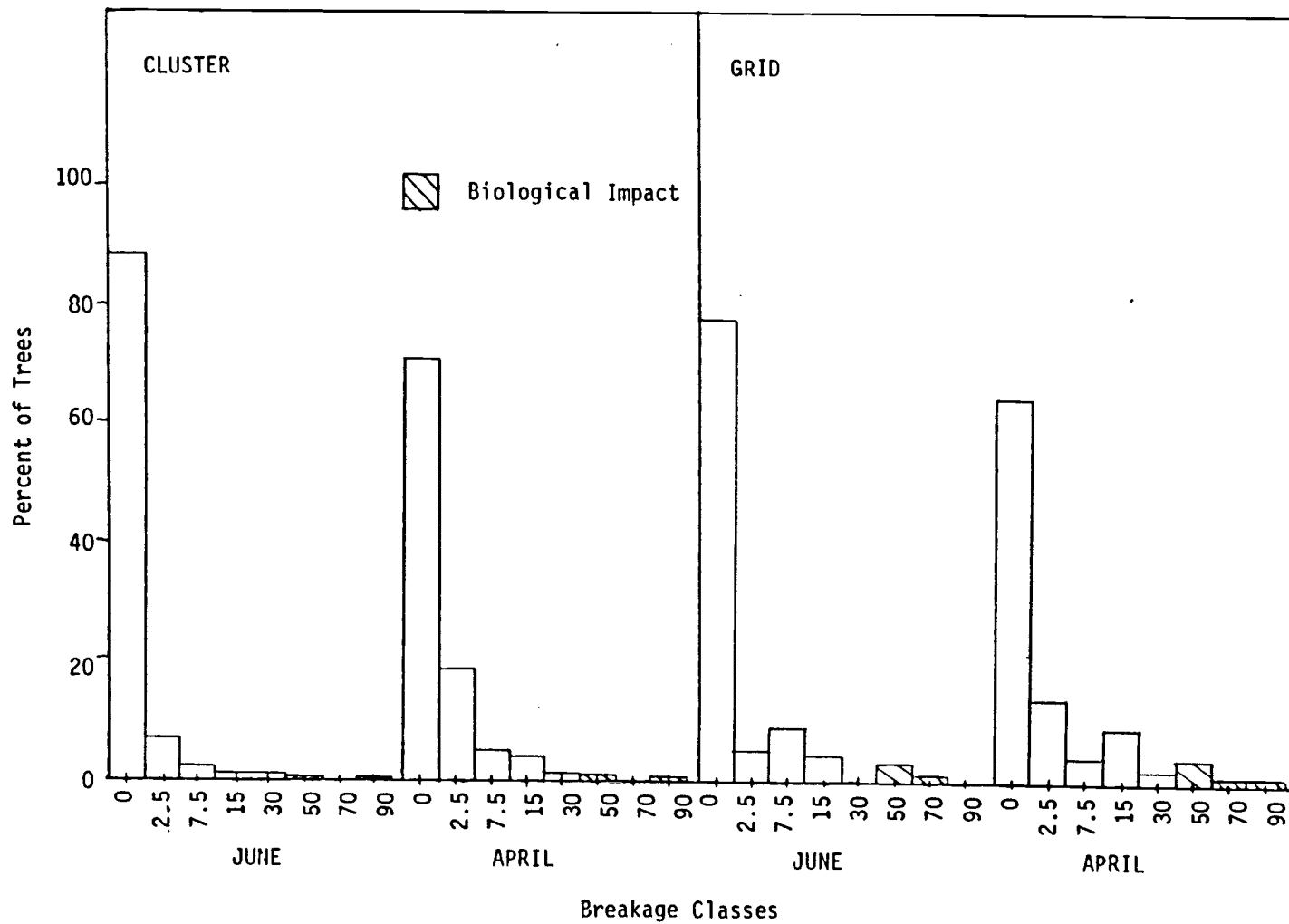


Figure III.4. Distribution of Douglas-fir trees into branch breakage classes for cluster and grid plantations in 1984-85.

grazing period was about 5% more ($p < 0.05$) than in fall/winter or spring. Debarking at this time was 6% greater in grid plantations ($p < 0.05$) than cluster plantations. Some authors suggest debarking is not damaging to trees unless it is a full girdle (Lewis 1980b; Brix and Mitchell 1985). However, a more conservative estimate is that there is no biological effect until more than one-half of the circumference is removed. Not more than 1.2% of trees in clusters and 4.4% of trees in grids received more than 50% bark removal by the end of 1984-85 (Figures III.5 and III.6). Anderson et al. (1985) found bark stripping occurred mostly in spring and summer to smaller trees. This is consistent with our findings. Overall, impacts occurred where sheep rest and were presumed to be a response to boredom (Anderson et al. 1985). Concentration of impacts may have been maximized by our small paddock size in grid plantations. The plantation sizes in this study ranged from 0.1- 0.4 ha in size. Impacts to trees in this study should therefore be considered a conservative, upper level expectation of impacts from proper grazing practices. Anderson et al. (1985) found that dense stands of trees received less debarking and lower needle consumption per tree than more open stands. They attributed this to less sheep pressure per tree, and felt that this ratio, more than any other factor, determined the extent of damage. In our study, grid plots with smaller more densely planted trees, were more heavily stocked than were clusters because

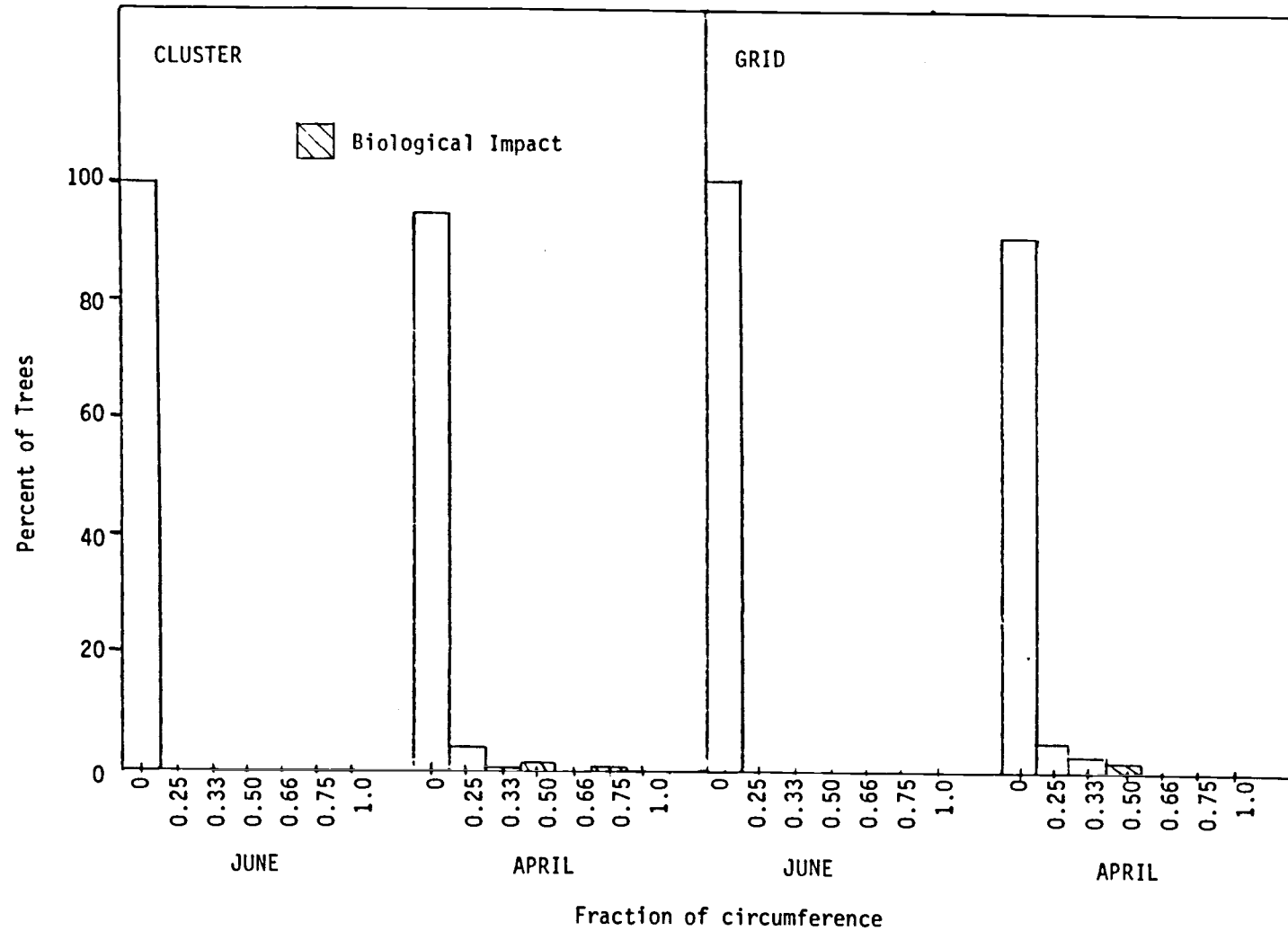


Figure III.5. Distribution of Douglas-fir trees into debarking classes (fraction of circumference debarked) for cluster and grid plantations in 1983-84.

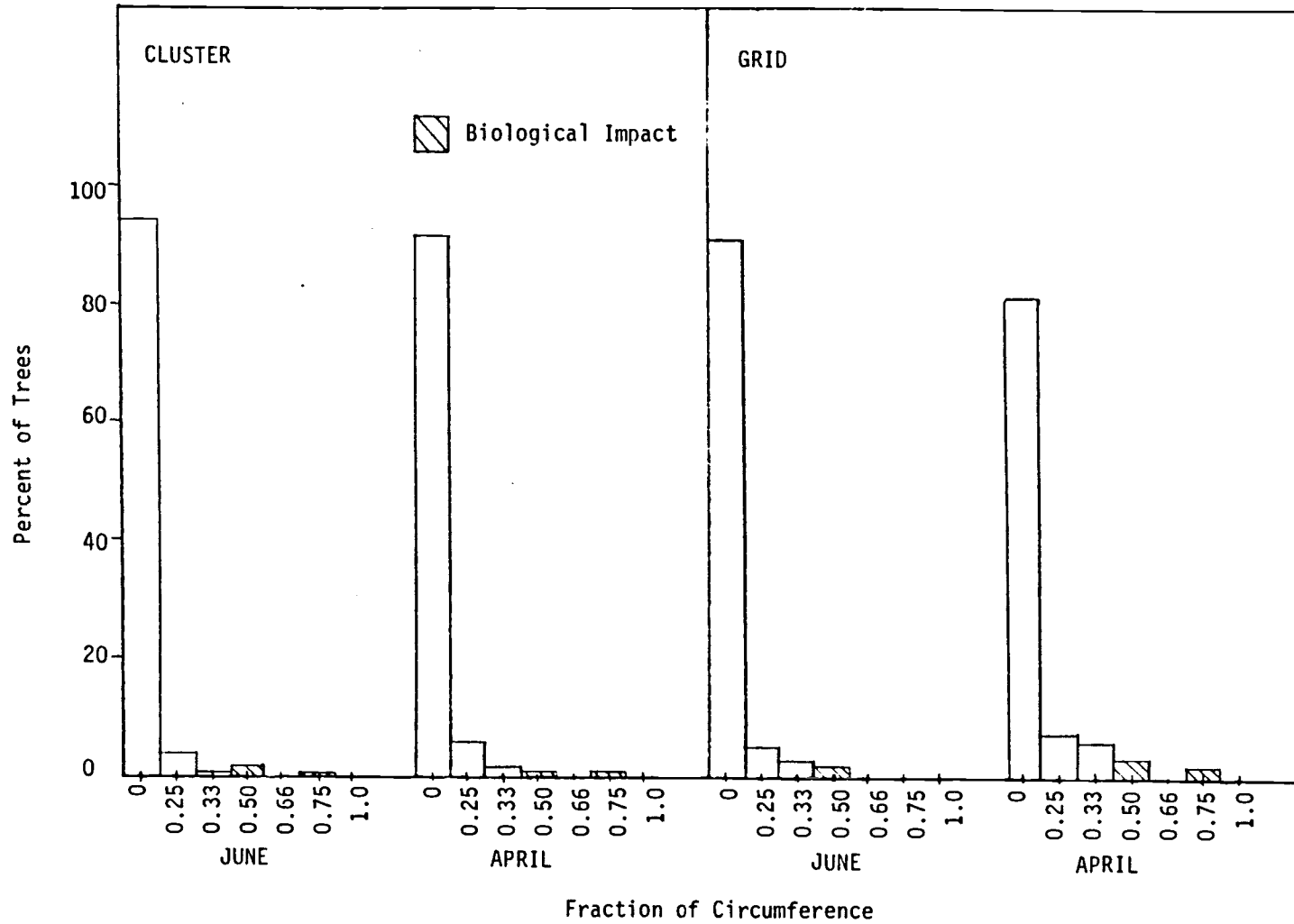


Figure III.6. Distribution of Douglas-fir trees into debarking classes (fraction of circumference debarked) for cluster and grid plantations in 1984-85.

Table III.2. Grazing schedules and stocking densities (animals per ha) on different tree planting treatments for each grazing period.

Season	Grazing Period	Stocking Density		
		Cluster	Grid	Open
Summer 1983	13 June- 15 July	79	504	393
Winter 1984	11 Jan.- 22 Jan.	48	305	238
Spring 1984	3 April- 29 April	55	351	274
Summer 1984	9 July- 26 July	143	534	417
Autumn 1984	2 Nov.- 14 Nov.	167	534	417
Spring 1985	2 April- 21 April	79	300	263

large flocks could not be easily divided (Table 2). The sheep-to-tree ratio was higher for grid plots, and this may explain why grid plots received more debarking and perhaps other impacts than did cluster trees. It may also be simply related to the smaller size of trees on grid compared to cluster plantations.

Conclusions and Implications

Only a small percentage of trees received a level of impact by animals which would be expected to produce a negative biological effect on their performance. On the whole, impacted trees were all the smallest ones in each plantation, and would normally be sacrificed to thinning in another 1-10 years.

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CHAPTER IV

PLANT AND SOIL WATER RELATIONS IN A SILVOPASTORAL SYSTEM

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Abstract

A silvopastoral system using a Douglas-fir (Pseudotsuga menziesii) tree crop and subclover (Trifolium subterraneum) as a nitrogen-fixing forage crop was investigated near Corvallis, Oregon, during 1983-1985. Treatments included all possible combinations of three tree planting patterns (no trees, trees planted 2.5 m apart in a grid, and clusters of five trees each with clusters 7.7 m apart) and two grazing/understory management systems (seeded to subclover and grazed by sheep or unseeded and ungrazed).

Trees experienced lowest water potentials in August and September in both 1984 and 1985. Mean twig xylem potential at pre-dawn in July, August and September was -0.56, -0.71, and -0.62 MPa, respectively. Trees were slightly less stressed where grazing occurred. July-September twig xylem potentials at pre-dawn and midday were -0.55 and -1.19 MPa for grazed, and -0.65 and -1.55 MPa for ungrazed plantations, respectively. Soil moisture was not affected by tree planting, but did vary by depth, month and year. Decrease in percent soil moisture from July to August was greater for ungrazed than grazed plots. Bulk density of the soil was also not affected by tree planting pattern. Bulk density at 0-3 cm was the same for grazed and ungrazed

plots, but at 3-15 cm bulk density was slightly higher on grazed plots.

Introduction

Drought has caused considerable seedling mortality in Douglas-fir plantations in the Pacific Northwest (Cleary 1971). Under drought conditions, competition occurs between plants for water, the limiting resource. Newton (1964) states that the rate of depletion of soil moisture is a direct function of the amount of vegetation in an area. Drought conditions may be exacerbated as the result of water use by herbaceous vegetation in a forest plantation. Contradictions concerning the competition between tree seedlings and the understory component can be found in the literature. Some studies have found that the understory, especially seeded domestic grasses, compete directly with trees for water, thus reducing tree survival and growth (Halls 1958; Youngberg 1959; Larson and Schubert 1969; Sands and Nambiar 1984). Other research has shown that tree seedlings do not compete with the understory for water to the detriment of tree stand establishment (Eissenstat and Mitchell 1983; Heinz 1984). On sites where the understory is competing with the tree for limited soil moisture, removal of herbaceous vegetation can greatly increase survival and vigor of conifer seedlings by increasing water availability (Newton 1964). Understory manipulation and removal through grazing can, therefore, improve conditions for tree growth. The role of grazing and understory management in the water relations of agroforestry systems,

however, has not been widely examined. How the components of a mixed crop system share the water resource, in space and through time, needs to be assessed in order to design better agroforestry management practices.

The objectives of this study were to evaluate the effects of grazing/understory management and tree planting pattern on 1) twig xylem potential and soil moisture during the dry summer months, and 2) bulk density of soils.

Materials and Methods

The three hectare study site is located in the eastern foothills of the Coast Range approximately 16 km north of Corvallis, Oregon (Lat. $44^{\circ} 30'$, Long. $123^{\circ} 20'$). Soils are Jory Series (Xeric Haplohumults, Knezevich 1975) which have average suitability for commercial timber production with a Douglas-fir site index of 145-165 (Knezevich 1975). Climate of the area is typically maritime with warm dry summers and cool moist winters. Average daily maximum summer temperature is 25° C while average daily winter temperature is 4° C. The frost-free period is 165-200 days. Mean annual precipitation is 110 cm, 70% of which falls from November to March (Knezevich 1975).

Two-year-old Douglas-fir trees (2-0 stock) were planted in two replications of two planting patterns in 1979: 1) grid = trees planted 2.5 m apart in a grid pattern (1600 stems ha⁻¹), and 2) cluster = 5 trees planted in each

cluster with clusters 7.7 m apart (840 stems ha⁻¹). The entire site was rototilled in September 1982. The original plots (grid or cluster) together with adjacent pasture plots without trees (open) were split, and half of each plot was planted with 22 kg ha⁻¹ of inoculated subclover (Trifolium subterraneum var. Nangela) seed. Only clover-seeded plots were grazed. The resulting subplots were approximately 0.4, 0.1 and 0.1 ha in size for cluster, grid and open plots, respectively. A combination of ammonium sulfate and treble superphosphate (10-24-0-12) fertilizer was applied to the entire area at a rate of 400 hg ha⁻¹ in October 1982. In addition, 1.1 kg ha⁻¹ of sodium molybdenate was applied at that time. Annual fall fertilizer applications were made to all plots to sustain subclover production, following recommendations based upon N, P and K analysis of soil samples conducted by the Oregon State University Soil Testing Laboratory each year. Fertilizer applications were 150 kg ha⁻¹ of treble superphosphate (0-45-0-0) in 1983 and 180 kg ha⁻¹ superphosphate (0-25-0-10) plus 45 kg ha⁻¹ muriate of potash (0-0-60-0) in 1984.

Plots were individually fenced in March 1983. Grazing began in June 1983. A flock of dry ewes was rotated in random order through the plots, remaining in each plot until approximately 50% of the forage was consumed or until sheep began to consume tree foliage. Plots were grazed once

each spring (April), summer (June-July) and fall/winter (November-January) seasons.

Twig xylem potentials of Douglas-fir trees were monitored with a Scholander pressure chamber. Pre-dawn and midday (1 p.m. Pacific Standard Time) measurements were taken at monthly intervals during the dry summer period (July- September) in 1984 and 1985. One randomly selected sunlit twig from each of five trees per plot was selected for evaluation. All measurement days were clear. Collection techniques followed those outlined in Kaufmann and Thor (1982). Pre-dawn samples were immediately placed on ice in plastic bags, then evaluated in the laboratory, approximately twenty minutes following collection. Midday twig xylem potential measurements were taken immediately on site.

Gravimetric determinations of soil moisture were made at monthly intervals from July- September in 1984 and July-August in 1985. Five soil samples per plot were collected with a bucket auger. Samples were taken at depths of 20, 50, and 100 cm below the soil surface, placed in metal cans, and immediately sealed. Soil cans were weighed and then dried at 50^o C for 72 hours.

Bulk density was assessed in the spring of 1985, two years following rototilling. Five samples of soil were collected from each plot with a bucket auger at 0-3 cm and 3-15 cm increments. These samples were dried at 50^o C for 72 hours, and weight per volume was calculated for each

sample.

Data were analyzed as a split-split plot in time with tree planting treatments as main plots, grazing as subplots, and time (time of day, month, year) as sub-subplots in a completely randomized design with two replications. Means, where appropriate, were separated using the Student-Newman-Kuels technique (Snedecor and Cochran 1980). Statistical significance was assessed at $\alpha = 0.05$, unless otherwise stated.

Results and Discussion

Annual precipitation at Corvallis, Oregon for 1984 was 120 cm, 15 cm above the 30 year average. In contrast, 1985 was an unusually dry year. Annual precipitation was 68 cm, 38 cm below the average (Figure IV.1). These yearly differences are reflected in the twig xylem potential data. Twig xylem potentials of trees in 1984 were -0.62 and -1.33 MPa at pre-dawn and midday, respectively. Trees in 1985 were more stressed ($p < 0.05$), with twig xylem potentials of -.60 and -1.62 MPa at pre-dawn and midday, respectively. Averaged over both years, trees in August and September were more stressed ($p < 0.05$) than in July (Table IV.1). Pre-dawn twig xylem potential was more negative in August and September than in July ($p < 0.05$), while midday twig xylem potential was more negative in August than in July or

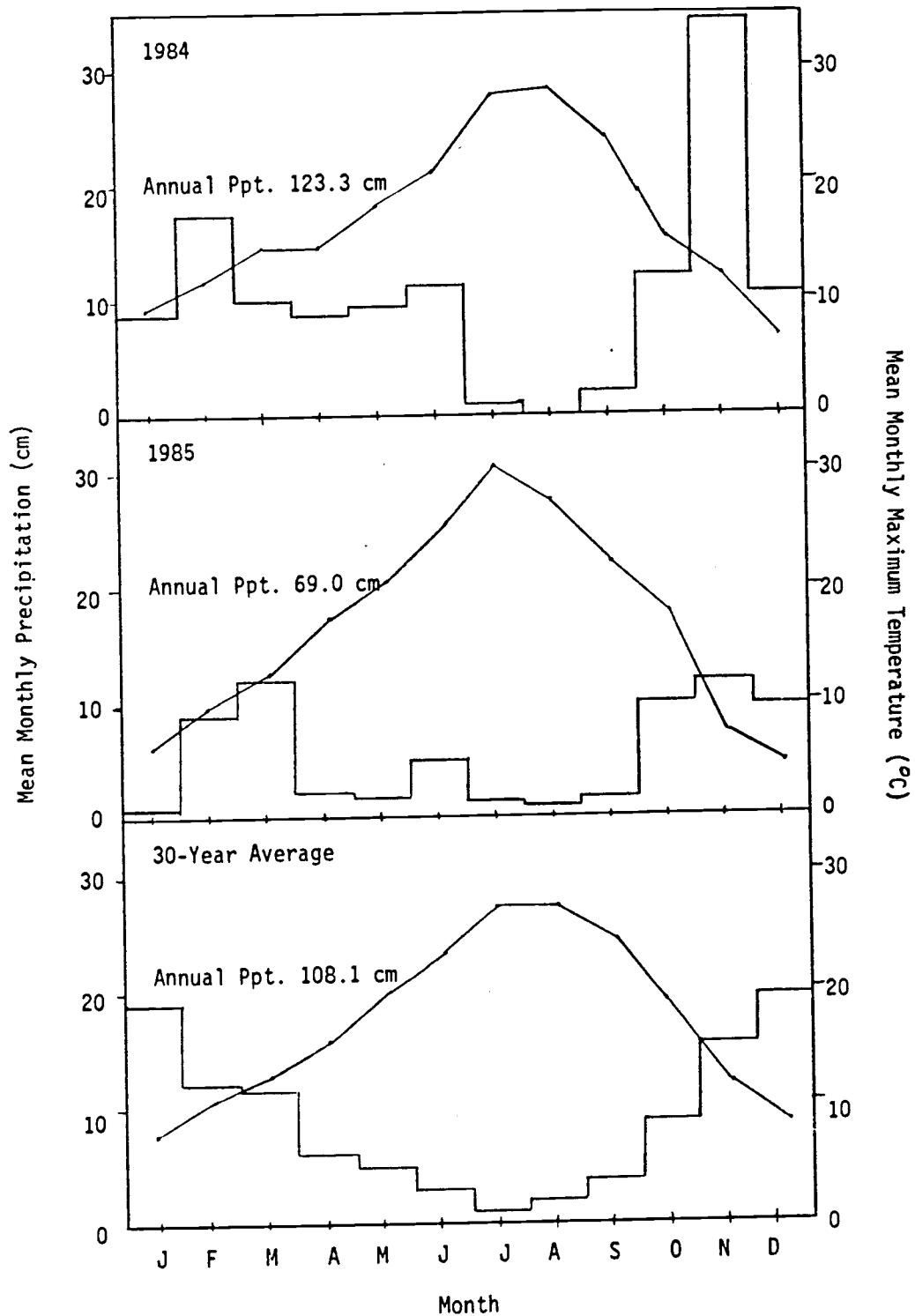


Figure IV.1. Mean monthly precipitation (bar graph) and mean monthly maximum temperature (line graph) for Corvallis, Oregon. Adapted from Anonymous 1986.

Table IV.1. Mean twig xylem potential (MPa) at pre-dawn and midday during July-September of 1984 and 1985. Data are $\bar{x} \pm S.E.$

Month	Time of Day	
	Pre-dawn	Midday
July	-0.49 \pm 0.02 ^a	-1.43 \pm 0.03 ^c
August	-0.71 \pm 0.04 ^b	-1.68 \pm 0.03 ^d
September	-0.61 \pm 0.03 ^b	-1.46 \pm 0.22 ^c

Means in a column not sharing a common letter differ ($p < 0.05$).

September ($p < 0.05$).

Two-year average twig xylem potential of grazed plantations at both pre-dawn and at midday was more ($p < 0.05$) than ungrazed plantations (Table IV.2). The difference in moisture stress between grazed and ungrazed at pre-dawn was twice the difference occurring at midday, perhaps because midday values were more variable. There was no difference in twig xylem potential between cluster and grid plantations at pre-dawn or at midday.

The critical water potential for stomatal closure is characteristic for each conifer species. Cleary (1971) found that Douglas-fir close their stomates at -1.5 MPa, while Running (1976) found -2.5 MPa to be the threshold for Douglas-fir where zero leaf conductance occurs. Waring and Cleary (1967) and Eissenstat and Mitchell (1983) found that established Douglas-fir trees with adequate soil moisture have summer pre-dawn water potentials of about -0.7 MPa and an afternoon low at 2 p.m. of about -1.9 MPa. These results are consistent with our findings. Another aspect of this study was to evaluate effects of grazing/understory management on the growth of Douglas-fir trees. No difference was found between growth of trees in grazed versus ungrazed plantations (Chapter II). There are several possible explanations for the lack of biological effect of treatment differences on trees. The majority of twig xylem potential values recorded in this study were at or above the threshold for Douglas-fir where zero leaf conductance

Table IV.2. Mean twig xylem potential (MPa \pm S.E.) of grazed and ungrazed treatments taken at pre-dawn and midday in 1984 and 1985.

Time of Day/ Year		Grazing Management	
		Grazed	Ungrazed
1984	Pre-dawn	-0.62 \pm 0.04 ^a	-0.63 \pm 0.03 ^a
	Midday	-1.29 \pm 0.17 ^c	-1.38 \pm 0.13 ^c
1985	Pre-dawn	-0.49 \pm 0.03 ^a	-0.68 \pm 0.07 ^b
	Midday	-1.70 \pm 0.11 ^d	-1.72 \pm 0.11 ^d
2 yr. x	Pre-dawn	-0.55 \pm 0.03 ^a	-0.65 \pm 0.03 ^b
	Midday	-1.49 \pm 0.08 ^c	-1.55 \pm 0.10 ^d

Grazing management means within a year not sharing a common letter differ ($p < 0.05$).

occurs. While seedlings commonly have twig xylem potential below -3.0 MPa during the summer (Cleary 1971), established trees usually have values one-half as severe as those experienced by seedlings (Waring and Cleary 1967). Also, twig xylem potential experienced during the main growth period (i.e. through July) is most important to the tree's performance, not the minimum twig xylem potential which is experienced in August or September (Cleary 1971). Twig xylem potential values for July in this study were rarely below the threshold for Douglas-fir, and generally occurred in the range that allows 70-98% maximum net photosynthesis (Cleary 1971). Eissenstat and Mitchell (1983) found no relationship between growth and water potential of Douglas-fir, but suggested that a significant nutrient x water interaction affects growth. Phenology of growth of trees and pasture plants in our system was different. Subclover dried off by mid-July, and perennial grasses were dormant during the summer. Trees made most of their growth from May to mid-August. Therefore, use of the water resource by each component differed in time. This may explain the small difference in moisture stress between trees in grazed and ungrazed plantations.

The percent soil moisture averaged over each year followed the same general pattern as twig xylem potential. Summed over all soil depths, soil moisture in 1984 was $30.8 \pm 1.2\%$, 3.4% higher ($p < 0.05$) than in 1985 ($27.4 \pm 1.3\%$),

which was the drier year. Averaged over the two years, there was less ($p < 0.05$) soil moisture available in August (27.0 ± 1.2) than in July ($31.1 \pm 1.2\%$). Soil moisture varied according to depth. The soil moisture contents for the 20, 50, and 100 cm depths were $20.1 \pm 0.5\%$, $25.5 \pm 0.6\%$, and $41.7 \pm 1.1\%$, respectively. Each is different from the others ($p < 0.05$). Percent soil moisture by depth, month and year is summarized in Table IV.3.

Soil moisture in grazed plantations was $30.8 \pm 1.8\%$ and $27.8 \pm 1.8\%$ in July and August, respectively. In ungrazed plantations, soil moisture was $31.5 \pm 1.7\%$ and $26.2 \pm 1.6\%$ in July and August, respectively. July figures for both grazed and ungrazed plots were higher than August percentages ($p < 0.10$). However, the decrease in soil moisture was greater for the ungrazed than the grazed plantations. This suggests that grazing (removal of herbage) is a water-saving scheme. Leininger (1984) found more soil moisture at lower depths with grazing, but a decrease in soil moisture near the surface as compared to ungrazed plantations. While the main grazing effect was insignificant in our study, the greater reduction of soil moisture at lower depths for the ungrazed plots in this study are consistent with Leininger's findings- that grazing is a water-saving enterprise. Diameter growth is particularly sensitive to soil moisture and Leininger suggested the increased diameter growth of trees on grazed sites in his study was possibly an effect of improved soil

Table IV.3. Climatological data¹, and mean twig xylem potential (MPa) and percent soil moisture summed over grazing management and tree planting treatments for July- September of 1984 and 1985. Measured data are $\bar{x} \pm \text{S.E.}$

Year	July	August	September
<u>1984</u>			
x pre-dawn xylem potential	-0.54 \pm 0.03 ^{ab}	-0.73 \pm 0.01 ^b	-0.60 \pm 0.02 ^{ab}
Soil moisture 20 cm	25.28 \pm 0.40 ^b	19.11 \pm 0.20 ^a	17.33 \pm 0.20 ^a
Soil moisture 50 cm	29.06 \pm 0.80 ^b	24.16 \pm 0.78 ^a	22.96 \pm 1.17 ^a
Soil moisture 100 cm	44.74 \pm 1.53 ^a	42.23 \pm 1.75 ^a	39.94 \pm 1.75 ^a
Total monthly ppt. (cm)	0.51	T	1.88
Ave. monthly temp. (°C)	19.0	18.5	16.1
Monthly evap. (cm)	21.1	18.8	11.6
<u>1985</u>			
x pre-dawn xylem potential	-0.43 \pm 0.03 ^a	-0.69 \pm 0.08 ^b	-0.63 \pm 0.07 ^b
Soil moisture 20 cm	19.21 \pm 0.29 ^b	16.63 \pm 0.36 ^a	----
Soil moisture 50 cm	25.64 \pm 1.12 ^a	22.96 \pm 1.06 ^a	----
Soil moisture 100 cm	42.66 \pm 2.64 ^b	37.08 \pm 2.30 ^a	----
Total monthly ppt. (cm)	1.37	1.22	1.98
Ave. monthly temp. (°C)	21.0	18.7	14.8
Monthly evap. (cm)	24.5	18.7	10.7

Means in a row not sharing a common letter differ ($p < 0.10$).

¹ Adapted from Anonymous 1986.

moisture relations. There was no apparent effect of tree planting pattern on soil moisture.

The soils on this study site were quite deep (100 cm) and had considerable water- holding capacities. The high percentages of soil moisture found in our study explain the relatively low levels of moisture stress experienced by trees during the summer. The small difference in moisture stress between grazed and ungrazed treatments is presumably a result of these low moisture stress levels, but may also reflect differences in rooting depths between trees and pasture plants. Subclover has a very shallow root system. While all plants have most of their roots in the top 5-15 cm of soil, perennial bunchgrasses usually have very deep rooting. Douglas-fir trees are shallow-rooted, but also have a moderate proportion of deep roots.

There were no effects of tree planting pattern treatments on bulk density ($p > 0.05$). However, the change from 3 cm to 15 cm is larger ($p < 0.10$) for the ungrazed than for the grazed plots (Table IV.4). Bulk density of soils at 0-3 cm was the same on grazed and ungrazed plots. At 3-15 cm, however, bulk density was slightly higher ($p < 0.10$) in grazed plots. The effect of rototilling on soil structure may have been reduced somewhat by the presence of livestock. Bulk density controls the movement and storage of water and thus influences the growth of trees. Linnartz, Hse and Duvall (1966) and Adams (1975) found that grazing

-3

Table IV.4. Bulk density ($\text{g cm}^{-3} \pm \text{S.E.}$) of soils at different depths in grazed and ungrazed treatments and in different tree planting treatments.

Depth	Grazing Management		Tree Planting		
	Grazed	Ungrazed	Cluster	Grid	Open
0-3 cm	1.18 \pm 0.01 ^c	1.20 \pm 0.02 ^c	1.19 \pm 0.01 ^Y	1.20 \pm 0.03 ^Y	1.17 \pm 0.03 ^Y
3-15 cm	1.02 \pm 0.01 ^b	0.98 \pm 0.01 ^a	1.01 \pm 0.01 ^X	1.00 \pm 0.02 ^X	0.99 \pm 0.03 ^X

Means within grazing management or tree planting not sharing a common letter differ ($p < 0.10$).

may impair the physical properties of forest soils. However, Skovlin et al. (1976) found no changes in bulk density on ponderosa pine- bunchgrass range due to stocking levels of livestock or grazing systems on forest or grassland soils. Proper stocking and timing of grazing in our study apparently had no adverse effect on bulk density.

Conclusions and Implications

Trees on grazed plots had slightly higher xylem water potentials than those on ungrazed plots. Our data are consistent with the contention that grazing may reduce water stress of trees during hot dry periods by reducing transpirational water use by the forage crop. Perhaps, due to the unusual depth and water holding capacity of the soils on this site, twig xylem potential differences experienced by trees in grazed versus ungrazed plantations were not sufficient to have an effect on tree growth. On marginal lands where the water resource is more in demand, it is expected that the water-saving scheme of removing herbage by grazing livestock may benefit the growth of trees, while also producing another marketable product.

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SUMMARY AND MANAGEMENT IMPLICATIONS

One of the most attractive aspects of agroforestry is the ability to produce different products at different stages of a tree crop rotation (Riitters et al. 1982). Production of saleable animal products can provide crucial intermediate income throughout the early years of a Douglas-fir plantation. In our silvopastoral system, twice the amount of forage was produced on grazed/seeded plots as on ungrazed, unseeded plots. Seeded forage was presumably more palatable and of higher quality for use by livestock and/or wildlife. Sheep maintained good animal condition from seeded pastures during all grazing periods. A substantial amount of forage was consumed by sheep on this small site. However, on grid plantations sheep consumed only about one-half as much forage as on either cluster plantations or open pastures.

Where density and planting pattern of trees do not interfere with proper livestock management, grazing can be used to: 1) manipulate the desired species composition, quantity and palatability of pasture for use by livestock by appropriate timing and frequency of grazing, and 2) to reduce competition between the young tree crop and understory vegetation. Increased pasture production on seeded, grazed plots was achieved without detriment to the tree crop. No moisture stress of Douglas-fir trees occurred in this study due to treatments. Grazing may actually

reduce water stress of trees during hot, dry periods by reducing transpirational water use of the forage crop.

There was no apparent effect of grazing management on tree growth. Differences in tree height and diameter growth between cluster and grid tree planting patterns were primarily a function of planting density and tree size. Mean heights and diameters of trees were greater for cluster plantations at the start of this study, presumably due to lower planting density in cluster than in grid plantations. By 1985, however, size of trees in grid plantations had become more comparable to those in clusters. Initial planting costs for cluster plantations were most likely less than those for grid plantations, and the cluster pattern is more compatible with pasture production and livestock management. Tree growth on cluster plantations was equivalent to or greater than that achieved by monocultures (unseeded, ungrazed plantations).

Only a small percentage of trees received a level of direct impact by sheep which may have reduced their performance. On the whole, trees with the highest levels of impacts were the smallest trees in each plantation, and would normally be sacrificed to thinning in 1-10 years. Use of larger pasture subdivisions, decreasing sheep-to-tree ratios through manipulation of stocking, and proper timing of grazing seem to have the greatest impact on reducing livestock impacts to trees. The most intensive livestock

management needs to be applied in spring and summer when the greatest amount of impacts occur.

Silvopastoral systems also provide additional benefits. Seeding legumes in combination with grazing can enhance nutrient status of soils and nutrient cycling on the site. The increase in nitrogen cycling by grazing animals can be quite substantial. From 1983-1985, grazed plots received 15-50 kg N ha⁻¹ yr⁻¹ from livestock urine. Increased uptake of available nitrogen by the tree crop may enhance growth of trees on nitrogen-deficient sites.

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APPENDICES

APPENDIX A: The Economics of Agroforestry

While agroforestry is by no means a new concept, it has received considerable attention in the last ten years. Results from current research indicate that these systems are technically feasible under appropriate management. Agroforestry is not likely to be considered as a viable alternative by land managers, however, unless it can be shown to be economically advantageous as well. Raintree (1983) states that the "adoptibility" attributes for a land use system are, among other things, a perceived advantage compatible with the local culture and low technical complexity. One of the perceived advantages of agroforestry is diversification of products (Anonymous 1974; Tustin and Knowles 1975; Logan 1983). Profits may be increased by diversifying into a new product which increases overall productivity (Anonymous 1974; Clawson 1983). There is, however, utilization of site resources by another crop besides the principal one. This incurs both direct and indirect costs, so the secondary crop must have value as well as benefit (DeBell 1979). This diversification offers flexibility, in management as well as in economics (Lundgren et al. 1983). It is this flexibility which makes agroforestry so promising for fragile ecosystems and marginal lands worldwide (Nair 1983). These land types have a history of degradation of soils and vegetation, as well as reduced production on both managed and natural sites (King 1979; Clawson 1983; Hall 1983). Such sites require

not only flexibility, but low-input (i.e. low technical complexity) systems, requiring little energy and capital investment (Dawson 1983; Nair 1983). Agroforestry thus integrates production with protection of the scarce natural resources (Harou 1983). The goal is to utilize inferior resources to provide the maximum net benefit (Clawson 1983). Thomas (1983) characterizes the trend of increasing intensity of management as resources become scarce. With a scarcity of resources, he emphasizes that cooperation and not confrontation is the key to success. In much of the United States' forested lands, however, land use decisions and understory management practices are still based on the single-use concept for timber production (Grelen 1978).

The "commodity" of agroforestry is the land-use system (Nair 1983). As with any system, an understanding of the biological components of production is needed to know how to allocate and manage resources to achieve specific objectives (Anonymous 1979). Physical and operational constraints need to be ascertained before economic constraints can be evaluated. Production functions are still poorly understood, especially when considering the widely differing time production cycles in most agroforestry systems. Production functions can be used to evaluate inputs of labor and capital and to determine optimal levels and mixes of inputs and outputs. These will vary according to associated costs and values. Production, costs and values are variable from year to year, and from

site to site (Clawson 1983).

There are no models of effects of physical interactions between two or more production activities, but some models have been designed to evaluate specific management practices when two outputs are considered (Riitters et al. 1982). Riitters et al. (1982) have designed a model to examine thinning intensity and rotation length of ponderosa pine when both forage and timber products are considered. In this model, grazing dominates the first thirty years, and in effect neutralizes stand regeneration costs. This allows for a shorter rotation time. They indicated that even if the relative values of timber increase with respect to grazing, the optimal solution still includes forage production because it occurs early in rotation and does not reduce timber production. In their simulation, grazing returned \$1586 per hectare, timber \$1405 per hectare, but a joint system generated \$2169 per hectare. Knowles and Percival (1983) developed a model to examine various final stem densities in relation to two outputs. They found that the maximum log volume was not the same as maximum profit. Profitability increased with lower final crop stockings at shorter rotations. This advantage in profitability doubled in comparison to higher tree densities when agricultural returns from grazing were included. Lundgren et al. (1983) examined different timber management situations with grazing in the southern United

States. While there was less initial investment and establishment costs for a thirty year rotation with no thinnings (therefore no grazing), this provided the lowest overall profit. Forty and sixty year rotations with intermediate thinnings to increase forage production and timber quality gave the best returns on investment. A similar model by Clary et al. (1975) showed that maximum economic profit came from combining 100 board feet of timber production per acre per year and 10.5 yearling days of grazing per acre per year. Two products do not have an equal substitution rate, so joint production often gives maximum profits. Costantoura (1985) found that using 2 x 14 meter row plantings provides 53% as much sawlog yield as a complete pine stand, and 65% of the agricultural production expected on open pasture. With 1.4 x 10 meter rows, he expected 93% of forest production and 42% of agricultural production. He also found that staggered tree plantings of 6% of the land base every three years provided similar returns as simultaneous plantings and provided a positive net return every year.

The diversity of products from agroforestry systems allows for diversity of investments and income sources. These models attempt to examine short term and long term investments, and associated returns, of agroforestry systems. Perhaps the most important economic advantage of agroforestry systems over traditional forestry is improving cash flow (Anderson and Batini 1983; Logan 1983).

Intermediate yields can be obtained from grazing, instead of only tree thinnings. Clary et al. (1975) analyzed thinning costs and returns from grazing and determined that the wood volume lost to grazing was less than the grazing value obtained. This interim income can come from sale of redmeat produced on private land, or from selling grazing permits on public lands (Monfore 1983; Hedrick 1975). Decreased initial costs of establishment can also be realized if fewer trees are planted at wider spacings (Anonymous 1974; Tustin and Knowles 1975).

Increasing long term net profits is possible with agroforestry systems, as shown through the models previously discussed (Beveridge et al. 1973; Tustin and Knowles 1975; Tustin et al. 1979). Combining products which have different time production cycles allows for maximum land use efficiency (McKinnell and Batini 1978). Combined systems on all sites were more profitable than single-use practices studied by Percival et al. 1984, with internal rates of return due to agroforestry at 11-12%. Batini et al. (1983) also concluded from their agroforestry study that income from grazing provides early financial returns and offsets the annual costs of timber growing. Internal rates of return were 12-20%, and were higher than for either single land use.

Raintree (1983) suggests that a component in the system can provide a product and/or have a service role.

Grazing in a multi-use system provides animal products, but can also provide a service to wood production (Kosco and Bartolome 1981; Hetzel 1983). To illustrate, studies show increased production on all site types from nitrogen fertilization (Miller and Fight 1979). These larger trees get higher stumpage prices from the mill. However, fertilization in young stands is often not a profitable investment because of the long period between fertilizer application and timber harvest (Cromack et al. 1979; Miller and Fight 1979; Batini et al. 1983). In many agricultural systems, fertilizer is a major cost of production (Gillingham 1983). Using nitrogen-fixing species to improve nitrogen status, coupled with grazing to increase nutrient cycling, has the potential to benefit the tree crop at a much lower initial cost than does fertilization (DeBell and Miller 1979; Logan 1983). Reid (1983) found a 59% savings on nitrogen application in pastures if clover was used. Seeding and grazing may also benefit the tree crop by reducing competition. In a study by Klingler (1982), non-seeded clearcuts required release treatments. Heinz (1984) showed that seeding plus fertilization cost \$63 per acre and grazing costs were \$11 per acre. These costs are comparable to the \$74 per acre cost of effective herbicide application. He concluded that seeding in combination with grazing was more favorable from an economic standpoint than herbicide or manual control because of the number of these applications required to get the same level of control.

Additional benefits were also noted.

Such secondary benefits, or costs, and other externalities of the system should also be considered (Hetzel 1983). These include: practices which reduce soil erosion (Klingler 1982; Hall 1983), rodent and animal control (Klingler 1982), improved habitat for wildlife (Klingler 1982; Hetzel 1983), support of watersheds and recreation (Hetzel 1983), reduced fire hazard (McKinnell and Batini 1978; Anderson and Batini 1983), and easier stand access (Tustin and Knowles 1975).

The objectives of future research in the economics of agroforestry systems should include identification of appropriate costs and benefits of each project, determination of what information is needed to measure these values, and establishment of criteria or methods to evaluate the economic efficiency of multi-use systems for use by decision makers and land managers.

APPENDIX B. Sheep-days of Use and Sheep Weights

-1
Table B.1. Sheep-days of use (SUD ha⁻¹ ± S.E.) in grazed plots
for forage years 1983-1985.

Tree Planting				

Year	Cluster	Grid	Open	Yearly \bar{x}
1983	525±103 ^a	1063±20 ^{ab}	1590±36 ^{bc}	1059±196 ^x
1984	1158±25 ^{ab}	1879±108 ^{bcd}	2462±285 ^{de}	1833±251 ^y
1985	2287±140 ^{cde}	1182±82 ^{ab}	2744±250 ^e	2072±303 ^y

Tree planting means within year or yearly \bar{x} not sharing a common letter differ ($p < 0.05$).

Table B.2. Sheep weights (lb.) before and after the spring grazing period in 1985.

Ewe No.	29 March	16 May	Gain/Loss
1060	125	127.5	2.5
290	124	137.5	14.5
176	141	161.5	21.5
278	166	174.5	9.5
820	169	177.5	9.5
2753	123	144.5	22.5
1824	179	195.5	17.5
6631	150	158.5	8.5
6163	166	173.5	8.5
1061	148	167.5	20.5
0827	136	139.5	4.5
No Tag	144	144.5	0.5
232	160	174.5	14.5
1064	155	161.5	7.5
1170	163	178.5	16.5
7140	174	185.5	12.5
QE	155	167.5	13.5
5392	149	154.5	6.5
67	167	172.5	6.5
1062	165	179.5	15.5
1063	180	178.5	-1.5
\bar{x}	154.9	164.5	11.2

APPENDIX C. Analysis of Variance Tables

Table C.1. Analysis of variance of annual forage production from 1983-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	84112.125	2	0.033	
Error	2576636.835	3		
Within Blocks				
Grazing (G)	111028368.281	1	80.060	0.002
P x G	54959.375	2	0.040	
Error	1386816.629	3		
Year (Y)	11593316.629	2	42.439	<0.001
P x Y	239369.750	4	0.876	
Error	273172.813	6		
G x Y	5072568.627	2	8.065	0.020
P x G x Y	1424007.376	4	2.264	0.177
Error	628935.271	6		

Table C.2. Analysis of variance of percent composition of perennial grasses in 1983 and 1984.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	10.826	2	0.123	
Error	87.809	3		
Within Blocks				
Grazing (G)	7586.370	1	69.170	0.002
P x G	118.825	2	1.083	0.443
Error	109.677	3		
Year (Y)	6321.260	1	64.018	0.003
P x Y	181.388	2	1.837	0.301
Error	98.742	3		
G x Y	2055.350	1	39.347	0.006
P x G x Y	126.425	2	2.420	0.236
Error	52.237	3		

Table C.3. Analysis of variance of percent composition of annual grasses in 1983 and 1984.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	19.920	2	0.362	
Error	55.027	3		
Within Blocks				
Grazing (G)	521.734	1	17.206	0.023
P x G	40.771	2	1.345	0.383
Error	30.322			
Year (Y)	476.150	1	28.568	0.011
P x Y	33.025	2	1.981	0.282
Error	16.667	3		
G x Y	205.920	1	3.948	0.140
P x G x Y	7.513	2	0.144	
Error	52.152	3		

Table C.4. Analysis of variance of percent composition of miscellaneous forbs in 1983 and 1984.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	26.889	2	0.971	
Error	27.706	3		
Within Blocks				
Grazing (G)	285.660	1	46.358	0.005
P x G	5.854	2	0.950	
Error	6.162	3		
Year (Y)	0.007	1	0.001	
P x Y	5.253	2	0.401	
Error	13.114	3		
G x Y	4.860	1	0.217	
P x G x Y	2.861	2	0.128	
Error	22.371	3		

Table C.5. Analysis of variance of percent composition of subclover in 1983 and 1984.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	2.400	2	0.122	
Error	19.636	3		
Within Blocks				
Grazing (G)	16276.042	1	582.369	<0.001
P x G	6.845	2	0.245	
Error	27.984	3		
Year (Y)	3234.082	1	30.448	0.010
P x Y	211.233	2	1.989	0.281
Error	106.216	3		
G x Y	3220.167	1	30.403	0.010
P x G x Y	207.228	2	1.957	0.285
Error	105.917	3		

Table C.6. Analysis of variance of forage consumption from 1983-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	2565753.580	2	23.123	0.014
Error	110959.583	3		
Within Blocks				
Grazing (G)	77880635.125	1	701.882	<0.001
P x G	2565753.580	2	23.123	0.014
Error	110959.645	3		
Year	4790612.971	2	53.301	<0.001
P x Y	819402.094	4	9.117	0.011
Error	89878.298	6		
G x Y	4790612.971	2	53.301	<0.001
P x G x Y	819402.094	4	9.117	0.011
Error	89878.231	6		

Table C.7. Analysis of variance of percent utilization of forage by sheep for each grazing period.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	568.220	2	18.932	0.019
Error	30.014	3		
Within Blocks				
Grazing (G)	18741.334	1	624.420	<0.001
P x G	568.220	2	18.932	0.019
Error	30.014	3		
Period (GP)	239.636	6	13.712	<0.001
P x GP	190.651	12	10.909	<0.001
Error	17.476	18		
G x GP	239.636	6	13.712	<0.001
P x G x GP	190.651	12	10.909	<0.001
Error	17.476	18		

Table C.8. Analysis of variance of sheep-use days from 1983-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	839965.590	2	101.257	0.001
Error	8295.380	3		
Within Blocks				
Grazing (G)	24641296.023	1	2970.478	<0.001
P x G	839965.590	2	101.257	0.001
Error	8295.397	3		
Year (Y)	841422.336	2	29.939	0.001
P x Y	258032.166	4	9.181	0.010
Error	28104.894	6		
G x Y	841422.336	2	29.939	0.001
P x G x Y	258032.166	4	9.181	0.010
Error	28104.874	6		

Table C.9. Analysis of variance of amount of urinary nitrogen returned by sheep from 1983-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	365.890	2	14.265	0.028
Error	25.650	3		
Within Blocks				
Grazing (G)	10465.290	1	408.004	<0.001
P x G	365.890	2	14.265	0.028
Error	25.650	3		
Year (Y)	972.916	2	82.234	<0.001
P x Y	120.028	4	10.145	0.008
Error	11.831	6		
G x Y	972.916	2	82.234	<0.001
P x G x Y	120.028	4	10.145	0.008
Error	11.831	6		

Table C.10. Analysis of variance of mean browsing level for each grazing period in 1983-4 and 1984-5.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	318.355	1	4.872	0.158
Error	65.344	2		
Within Blocks				
Grazing (G)	4720.034	1	72.234	0.010
P x G	318.355	1	4.872	0.158
Error	65.344	2		
Month (M)	127.124	3	32.471	<0.001
P x M	9.259	3	2.365	0.170
Error	3.915	6		
G x M	127.124	3	32.471	<0.001
P x G x M	9.259	3	2.365	0.170
Error	3.915	6		
Year (Y)	18.404	1	1.163	0.394
P x Y	1.334	1	0.084	
Error	15.823	2		
G x Y	18.404	1	1.163	0.394
P x G x Y	1.334	1	0.084	
Error	15.823	2		
M x Y	3.778	3	3.763	0.078
P x M x Y	2.755	3	2.774	0.135
Error	1.004	6		
G x M x Y	3.778	3	3.763	0.078
P x G x M x Y	2.755	3	2.774	0.135
Error	1.004	6		

Table C.11. Analysis of variance of percent of trees with terminal leaders removed by sheep during each grazing period in 1983-4 and 1984-5.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	9.542	1	1.589	0.335
Error	5.948	2		
Within Blocks				
Grazing (G)	49.005	1	8.239	0.102
P x G	9.452	1	1.589	0.335
Error	5.948	2		
Period (GP)	37.628	2	9.006	0.034
P x GP	10.133	2	2.425	0.204
Error	4.178	4		
G x GP	37.628	2	9.006	0.034
P x G x GP	10.133	2	2.425	0.204
Error	4.178	4		
Year (Y)	0.130	1	0.056	
P x Y	1.880	1	0.804	
Error	2.338	2		
G x Y	0.130	1	0.056	
P x G x Y	1.880	1	0.804	
Error	2.338	2		
GP x Y	0.034	2	0.008	
P x GP x Y	3.755	2	0.883	
Error	4.253	4		
G x GP x Y	0.034	2	0.008	
P x G x GP x Y	3.755	2	0.883	
Error	4.253	4		

Table C.12. Analysis of variance of percent of trees with branch breakage by sheep for each grazing period in 1983-4 and 1984-5.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	9.100	1	4.238	
Error	2.147	2		
Within Blocks				
Grazing (G)	291.560	1	135.799	0.005
P x G	9.100	1	4.328	0.176
Error	2.147	2		
Period (GP)	72.111	2	38.979	0.003
P x GP	3.111	2	1.682	0.295
Error	1.850	4		
G x GP	72.111	2	38.979	0.003
P x G x GP	3.111	2	1.682	0.295
Error	1.850	4		
Year (Y)	5.267	1	0.556	
P x Y	7.130	1	0.753	
Error	9.474	2		
G x Y	5.267	1	0.556	
P x G x Y	7.130	1	0.753	
Error	9.474	2		
GP x Y	9.813	2	3.113	0.153
P x GP x Y	0.961	2	0.305	
Error	3.152	4		
G x GP x Y	9.813	2	3.113	0.153
P x G x GP x Y	0.961	2	0.305	
Error	3.152	4		

Table C.13. Analysis of variance of percent of trees debarked by sheep each grazing period during 1983-4 and 1984-5.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	9.452	1	5.824	0.137
Error	1.623	2		
Within Blocks				
Grazing (G)	55.685	1	34.310	0.024
P x G	9.452	1	5.824	0.137
Error	1.623	2		
Period (GP)	38.904	2	50.656	0.002
P x GP	12.467	2	16.233	0.013
Error	0.768	4		
G x GP	38.904	2	50.656	0.002
P x G x GP	12.467	2	16.233	0.013
Error	0.768	4		
Year (Y)	1.235	1	0.109	
P x Y	0.460	1	0.041	
Error	11.297	2		
G x Y	1.235	1	0.109	
P x G x Y	0.460	1	0.041	
Error	11.297	2		
GP x Y	2.084	2	0.152	
P x GP x Y	0.023	2	0.002	
Error	13.739	4		
G x GP x Y	2.084	2	0.152	
P x G x GP x Y	0.023	2	0.002	
Error	13.739	4		

Table C.14. Analysis of variance of twig xylem potential at pre-dawn and midday from July-September in 1984 and 1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	2.581	1	0.780	
Error	3.307	2		
Within Blocks				
Grazing (G)	13.969	1	4.299	0.174
P x G	6.010	1	1.850	0.307
Error	3.249	2		
Time (T)	2025.293	1	3027.344	<0.001
P x T	1.485	1	2.220	0.275
Error	0.669	2		
G x T	1.293	1	28.109	0.030
P x G x T	1.416	1	30.783	0.027
Error	0.046	2		
Month (M)	46.690	2	53.728	0.002
P x M	0.957	2	1.101	0.417
Error	0.869	4		
G x M	2.776	2	2.687	0.182
P x G x M	0.216	2	0.209	
Error	1.033	4		
T x M	3.328	2	6.513	0.056
P x T x M	0.580	2	1.135	0.408
Error	0.511	4		
G x T x M	0.121	2	0.504	
P x G x T x M	0.833	2	3.471	0.134
Error	0.240	4		
Year (Y)	67.805	1	170.793	0.004
P x Y	1.127	1	2.839	0.235
Error	0.397	2		
G x Y	1.571	1	3.499	0.203
P x M x Y	0.000	1		
Error	0.449	2		
T x Y	102.507	1	96.796	0.007
P x T x Y	0.042	1	0.040	
Error	1.059	2		
G x T x Y	8.930	1	23.075	0.037
P x G x T x Y	0.360	1	0.930	
Error	0.387	2		
M x Y	101.395	2	248.517	<0.001
P x M x Y	0.235	2	0.576	
Error	0.408	4		
G x M x Y	3.930	2	6.084	0.062

Table C.14. Cont'd.

Source	MS	DF	F	Probability
P x G x M x Y	0.399	2	0.618	
Error	0.646	4		
T x M x Y	70.775	2	71.999	0.001
P x T x M x Y	0.224	2	0.228	
Error	0.983	4		
G x T x M x Y	1.295	2	6.080	0.062
P x G x T x M x Y	0.425	2	1.995	0.250
Error	0.213	4		

Table C.15. Analysis of variance of percent soil moisture at three different depths from July-September in 1984 and 1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	30.890	2	0.333	
Error	92.697	3		
Within Blocks				
Grazing (G)	5.417	1	0.029	
P x G	78.032	2	0.412	
Error	189.462	3		
Depth (D)	6075.815	2	151.117	<0.001
P x D	8.755	4	0.218	
Error	40.206	6		
G x D	19.397	2	0.249	
P x G x D	39.863	4	0.511	
Error	78.015	6		
Month (M)	596.703	1	343.327	<0.001
P x M	1.747	2	1.005	0.464
Error	1.738	3		
G x M	42.804	1	6.121	0.088
P x G x M	8.075	2	1.155	0.425
Error	6.993	3		
D x M	0.992	2	0.545	
P x D x M	1.293	4	0.710	
Error	1.820	6		
G x D x M	5.644	2	2.434	0.168
P x G x D x M	8.512	4	3.671	0.076
Error	2.310	6		
Year (Y)	416.194	1	181.903	<0.001
P x Y	2.695	2	1.178	0.420
Error	2.288	3		
G x Y	108.732	1	3.759	0.147
P x G x Y	10.513	2	0.363	
Error	28.929	3		
D x Y	11.903	2	2.693	0.146
P x D x Y	2.170	4	0.491	
Error	4.420	6		
G x D x Y	55.725	2	4.147	0.074
P x G x D x Y	5.126	4	0.381	
Error	13.439	6		
M x Y	7.475	1	0.494	
P x M x Y	7.985	2	0.527	
Error	15.139	3		
G x M x Y	5.097	1	1.246	0.346

Table C.15. Cont'd.

Source	MS	DF	F	Probability
P x G x M x Y	1.504	2	0.368	
Error	4.090	3		
D x M x Y	37.079	2	4.212	0.072
P x D x M x Y	5.553	4	0.631	
Error	8.804	6		
G x D x M x Y	5.133	2	1.115	0.388
P x G x D x M x Y	4.707	4	1.022	0.466
Error	4.604	6		

Table C.16. Analysis of variance of bulk density of soils at different depths.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	.000	2		
Error	0.001	3		
Within Blocks				
Grazing (G)	.000	1		
P x G	0.001	2		
Error	0.003	3		
Depth (D)	0.232	1		
P x D	.000	2		
Error	0.001	3		
G x D	0.008	1	8.000	0.065
P x G x D	0.004	2	4.000	0.143
Error	0.001	3		

Table C.17. Analysis of variance of tree height growth from 1982-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	3464.646	1	10.188	0.084
Error	340.072	2		
Within Blocks				
Grazing (G)	230.640	1	3.149	0.219
P x G	9.325	1	0.127	
Error	73.236	2		
Year	295.302	2	25.995	0.006
P x Y	224.052	2	19.723	0.010
Error	11.360	4		
G x Y	11.546	2	0.553	
P x G x Y	6.366	2	0.305	
Error	20.890	4		

Table C.18. Analysis of variance of diameter growth of trees from 1982-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	62.791	1	2.976	0.227
Error	21.097	2		
Within Blocks				
Grazing (G)	1.550	1	1.249	0.380
P x G	0.482	1	0.388	
Error	1.241	2		
Year (Y)	16.218	2	11.470	0.023
P x Y	39.150	2	27.687	0.006
Error	1.414	4		
G x Y	0.196	2	0.119	
P x G x Y	0.326	2	0.199	
Error	1.642	4		

Table C.19. Analysis of variance of standing volume of timber in 1982 and 1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	4.511	1	1.369	0.363
Error	3.296	2		
Within Blocks				
Grazing (G)	1.138	1	2.351	0.265
P x G	0.368	1	0.760	
Error	0.484	2		
Year (Y)	80.058	1	27.203	0.31
P x Y	3.316	1	1.127	0.400
Error	2.943	2		
G x Y	0.899	1	2.071	0.287
P x G x Y	0.259	1	0.597	
Error	0.434	2		

Table C.20. Analysis of variance of incremental volume growth of trees from 1982-1985.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	2.456	1	1.312	0.371
Error	1.872	2		
Within Blocks				
Grazing (G)	0.477	1	1.514	0.344
P x G	0.112	1	0.356	
Error	0.315	2		
Year (Y)	5.977	2	22.813	0.008
P x Y	0.089	2	0.340	
Error	0.262	4		
G x Y	0.014	2	0.255	
P x G x Y	0.002	2	0.036	
Error	0.055	4		

Table C.21. Analysis of variance of percent foliar nitrogen of Douglas-fir needles.

Source	MS	DF	F	Probability
Between Blocks				
Planting (P)	.000	1		
Error	.005	2		
Within Blocks				
Grazing (G)	0.028	1	9.333	0.092
P x G	0.003	1	1.000	
Error	0.003	2		