Shading effects of *Pinus radiata* on productivity and feeding value of cocksfoot pasture in an agroforestry system.

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by

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Dedication

I dedicate this Master of Applied Science thesis to my late parents Mr Buddhi Raj Joshi and Mrs Gir kumari Joshi for the hard work they undertook to educate me in our mountain village of Khalte in Nepal; and to the Nepalese farmers with whom I worked to implement agroforestry practices.

Abstract of a thesis submitted in partial fulfilment of the requirement for the Degree of Master in Applied Science (Agroforestry)

Shading effects of *Pinus radiata* on productivity and feeding value of cocksfoot pasture in an agroforestry system

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The shading effects of radiata pine (*Pinus radiata* D. Don) trees on productivity and feeding value of nine-year-old cocksfoot (*Dactylis glomerata* L) plus clovers (*Trifolium spp*) pasture on Templeton silt loam of medium fertility was measured under four light regimes in a sub-humid temperate climate at the Lincoln University agroforestry experimental area over four seasons from February 1998. The experiment was a randomised split-plot design with three levels of shade under trees as main plots and ± water applied to cocksfoot cv Grasslands Wana pasture areas with or without sheep urine patches as sub-plots in each of three blocks. In an adjacent open pasture plot of the same age, four sub-plots were randomly assigned to each of three blocks.

Photosynthetic photon flux density (PPFD) measured under radiata pine trees was 18% of full sunlight at 650 trees ha^{-1}, 40% at 300 trees ha^{-1} and 67% at 200 trees ha^{-1} compared with the ambient PPFD of adjacent open cocksfoot pasture. Tree shade reduced soil temperature at 100 mm soil depth in summer by 0.9-1.9°C and increased it in winter by 0.5°C under moderate shade (40% to 67% PPFD) compared with open pasture with 20.5°C summer and 5.8°C winter mean temperatures. Likewise, volumetric water content (%) at 0-300 mm soil depth under 18% and 40% PPFD was significantly lower in late autumn, winter and spring seasons and higher during summer under 18% PPFD. Under 40% and 67% PPFD there was more soil water only in January compared with open pasture which had 30.9% and 9.8% soil moisture in June and January respectively. Partial irrigation reduced soil temperature significantly in late spring, summer and autumn and increased soil water content in summer under trees by only 1.3% and in open pasture by only 0.8% compared with unirrigated plots.

Botanical composition, expressed as percentage cover of nine-year-old Wana cocksfoot plus clover pasture along permanent transects in open pasture was 83% cocksfoot,

4% white clover, 1% subterranean clover, 5% weeds, 1% dead material and 6% bare ground compared with 74% cocksfoot, 3% white clover, 4% subterranean clover, 4% weeds, 5% dead material and 10% bare ground under trees with 67% ambient PPFD.

The five, 30 day production periods in March, June, September and November 1998, and February 1999 showed that cocksfoot pasture production at 18% PPFD was reduced by 55% even in irrigated urine and non-urine patches compared with open pasture. In this heavy shade, cocksfoot pasture productivity and feeding value was reduced by tree shade. However, under 40% and 67% PPFD pasture production without irrigation in urine and non-urine patches in the very dry 1998/99 season was reduced by 30% and 21% compared with open pasture which yielded 319 g DM/m^2 and by 16% and only 1% with irrigation (520 g DM/m^2 over the five months in irrigated open pasture).

The apparent feeding value of shaded cocksfoot pasture was reduced because of changes in grass morphology (longer and thinner leaves) of shaded pasture which resulted in reduced pasture bulk density which may reduce pasture intake through smaller bite size. This possible adverse effect on intake together with reductions in the nutritive value (digestible organic matter, nitrogen and metabolisable energy) of shaded pasture could result in reduced per head animal performance. However, the small (4%) increase of clover content and the decrease (29%) in reproductive tiller numbers under 40 to 67% PPFD may partially compensate these adverse effects in spring and early summer compared with open pasture.

Results showed that cocksfoot pastures under moderate shade (40% to 67% PPFD) were more stressed by water and nitrogen than by tree shade because the addition of water and nitrogen (urine) under moderate shade gave large increases in pasture production, pasture bulk density and nutritive value compared with the nil treatment pasture areas.

Key words: *Agroforestry, botanical composition, cocksfoot, feeding value, nutritive value, palatability, pasture bulk density, productivity, radiata pine trees, silvopastoralism, solar radiation, subterranean clover, tree shade and white clover.*

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CHAPTER ONE

Introduction

1.1 Background

Agroforestry in New Zealand is an integrated land use system where trees and pastures are grown together to provide diversification of farm income from the sale of timber and animals, and shelter for understorey pastures and livestock from cold and hot winds, and snow. This concept of modern agroforestry was started in the late 1850s with the introduction of Californian *Pinus radiata* to Mount Peel Station, Canterbury, New Zealand (Mortimer and Mortimer, 1984). In 1915, the New Zealand Forestry Branch of the Department of Lands and Survey started to plant trees for stabilisation of sandy areas (Hocking, 1997a). Barr (1984) reported that pre-war plantations in New Zealand were established mainly for shelter against winds, for firewood and for fencing timber. After that the development of plantations were driven by markets through large forest companies and joint ventures. Hawke (1997) reviewed the status of agroforestry in New Zealand and concluded that the emergence of large forest companies in New Zealand has brought many marginal pastoral lands under forestry plantations. In this situation, livestock were used as an opportunity for the utilisation of understorey pastures and for protection of plantations from ground fire.

Cossens (1984) and Percival *et al.* (1984a) reported pasture production under radiata pine trees from Invermay, in the southeast of the South Island, and Tikitere, in the northeast of the North Island. Shelter belt management systems have also received research attention in the 1970s and 1980s and a coordinated programme for shelterbelt/agroforestry research commenced in 1991 (Hawke, 1997). The papers of Devkota *et al.* (1997) and Devkota *et al.* (1998) show that Massey University has also played a significant role in agroforestry research with broad leaf species such as alder trees in the North Island of New Zealand. On the Canterbury plains, Lincoln University established an agroforestry experimental area in 1990 to study the competition between radiata pine trees and understorey pasture species in a sub-humid temperate climate (Mead *et al.,* 1993).

The main aims of these studies are to provide basic information about tree and understorey pasture interactions to farmers and investment companies, because they are currently planting woodlots, shelterbelts and other agroforestry plantations at a rate of 60,000 to 100,000 hectares per year (Hawke, 1997). About 90% of these plantations are established with radiata pine trees (Lane, 1995a). These plantings are established for shelter to conserve soil from wind and water erosion, to protect livestock and crops from winds and snow, to establish amenity plantations, to improve the surrounding environment and to generate income from the sale of timber (Mead, 1995a; Hawke, 1997; and Wilkinson, 1996 and 1997). Jarvis and Perley (1990) reported that the main objectives of silvopastoral systems are to maintain as high a pastoral production as possible for as long as possible under trees. This involves growing and tending fewer trees per hectare by planting widely-spaced trees over pasture, and grazing livestock under woodlot stands, shelterbelts and shade trees. However, the specific concept of wide-spaced tree agroforestry as developed in New Zealand appears to have a limited future because wide spaced plantations produce unsatisfactory timber quality and total pasture production over the life of trees under radiata pine trees is reduced compared with open pasture (Hawke, 1997).

The main reasons for the reduction of pasture production under trees are the competition between trees and pastures for solar radiatation, water, nutrients and growing space. Knowles *et al.* (1999) reported that light is a limiting factor for understorey composition and production in temperate regions of New Zealand. In addition, roots of both radiata pine trees and understorey pastures during early stages of growth compete with each other for moisture, nutrients and space (Mead *et al.*, 1993; Pollock *et al.*, 1994 and Yunusa *et al.*, 1995b). Competition at the Lincoln University agroforestry experiment resulted in a 25% reduction in tree height and a 45% reduction in the diameter of two year old trees in phalaris plus clover and lucerne treatments compared with trees in the bare ground treatment (Mead *et al.*, 1993). Cocksfoot plus clover pasture production in the first three years at the Lincoln University agroforestry experiment was reduced by 26% compared with the adjacent open pasture but much of this difference may be attributed to the space occupied by trees in their herbicide treated areas (Pollock *et al.*, 1994). The competitive advantage in this silvopastoral system shifted in favour of pine trees against pasture after the first three years (Pollock *et al.,* 1994). However, the cocksfoot pasture under radiata pine trees at the Lincoln University agroforestry experimental area after nine years has persisted well and is weed free with a very small proportion of bare ground compared with ryegrass, phalaris and lucerne pastures.

Generally most grasses and legumes do not persist well under trees, because their morphology changes and productivity is usually decreased. Smith (1982) reported that the changes in red and far-red ratios of solar radiation perceived by understorey plants through the phytochrome system may change the morphogenetic characters in plants growing in heavy shade. Evans *et al.* (1992) reported that grass and legume plants etiolate and grow taller in medium to heavy shade in order to better access the available light energy. In this situation, leaves become longer and thinner. Wong (1991) concluded that tiller numbers, leaf, stem, stubble and root production in grasses are mostly reduced at low light intensity. However, under light shade or shelter, productivity of understorey pastures may be enhanced. For instance tree shelter in North Otago increased pasture production by 20-30% and agriculture crop yields by 20% (Simpson, 1983).

A further adverse effect of tree and understorey pasture competition is the change in pasture composition. Cossens (1984) and Percival *et al.* (1984a) reported that the white clover content at both Invermay and Tikitere resesearch centres declined with increasing tree age and tree density. In addition, Mitchell (1956) found a 50% reduction in total dry matter production of white clover under 50% shade. On the other hand, the productivity of shaded cocksfoot pasture in South Korea was greatest up to 25% shade, but dry matter yield decreased as shade was increased (Seo *et al.*, 1989). Cossens (1984) reported a 19% reduction in dry matter production from mixed pastures under eight year-old radiata pine with 200 trees ha^{-1} in south Otago, New Zealand but he did not report the shade level.

The reduction of pasture production under shade and the changes in the morphology of shaded pastures result in low pasture bulk density, which may reduce pasture intake through smaller bite sizes by animals. The adverse effect on the pasture intake due to the reduction of pasture bulk density together with reductions in nutritive value of shaded pasture due to less clover content together with ingestion of tree leaf litter could result in per head animal performance being less than could be expected from the pasture dry matter produced. However, the nitrogen content of grasses in shaded pasture is increased in some cases. For example van Garderen (1997) reported 3.8% nitrogen content in cocksfoot herbage under 60% shade compared with 3.4% N in open pasture in October harvest.

The presence of darker green higher yielding urine patches in the Lincoln University agroforestry experiment pastures suggests that these shaded grass dominant pastures are usually deficient in nitrogen and that an increased supply of nitrogen would improve their total productivity and nutritive value. van Garderen (1997) recorded a 40% increase of cocksfoot dry matter yield in urine patches compared with non-urine areas at the Lincoln University agroforestry experiment. Marriott *et al.* (1987) reported that the nitrogen content in ryegrass herbage grown in urine patches was 4.3% which was 1.72 times higher than in non-urine areas. Water is another critical factor for pasture production. McBride (1994) reported an 80% increase in pasture production by ryegrass-white clover pasture at Winchmore on the Canterbury plains with irrigation applied whenever soil moisture content of the top 100 mm soil reduced to 20% during summer.

Therefore, it is difficult to allocate relative values to the various influences which shade and other tree effects have on the productivity and feeding values of pastures in silvopastoral systems. Further research on the interactions between radiata pine trees and understorey cocksfoot pasture for light, water and plant nutrients is needed to improve our understanding of silvopastoral systems in association with *Pinus radiata* in New Zealand.

1.2 Research objectives

This research was conducted from February 1998 to July 1999 to investigate the hypothesis that the productivity and feeding value of Wana cocksfoot pasture under trees is less than the same pasture type without trees. The specific objectives were:

- to measure the annual pattern of photosynthetic photon flux density (PPFD), soil moisture and temperature under three levels of tree shade and in adjacent open pasture.

- to measure the productivity of Wana cooksfoot under different levels of shade, water and plant nutrients (sheep urine) during four seasons from February 1998.

- to measure, during four seasons, the components of feeding value such as pasture mass, canopy height, sward density, vegetative and reproductive tiller number, leaf length and width, botanical composition and nutritive value (digestible organic matter, nitrogen and metabolisable energy contents) and grazing preferences of sheep in a cocksfoot pasture growing under three levels of tree shade and in open pasture.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

Agroforestry in New Zealand is an integrated land use system where trees and pastures are grown together to provide diversification of farm income from the sale of timber as well as other crops. Shelter from trees also protects agricultural crops/pastures, and livestock from cold and hot winds, frost and snow. Trees on pastoral farms are planted to meet these main objectives. The majority of silvopastoral plantations are established with radiata pine because this is a remarkable exotic species from coastal California which grows much faster in New Zealand than in its home range and produces reasonably high quality timber in a shorter period than other species (MacLaren, 1993).

Percival *et al.* (1984c) reported that the livestock carrying capacity in the Tikitere agroforestry experiment declined as pasture production decreased under radiata pine trees. This was attributed primarily to tree shade but also tree leaf litter which can smother pasture and reduce feeding value by covering pastures. There was also less clover and ryegrass under trees. The pasture bulk density and nutritive value of shaded pastures were also reduced compared with open pastures.

The main aims of this chapter are to review the role of agroforestry systems in New Zealand and the performance of cocksfoot in shaded and open environments.

2.2 Agroforestry systems and practices in New Zealand

Pastoral farming is the basis of New Zealand agriculture. Therefore, sheep, beef and dairy farming are still considered as the main source of farm income. Mead (1995a) reported that the removal of agriculture subsidies in New Zealand has caused many farmers to question their traditional activities. This, coupled with farmers' desires to diversify farm income by selling timber in local and international markets has helped to motivate farmers towards tree planting. Agroforestry as an integrated land use option is being developed and expanded on New Zealand farms. The agroforestry systems which are practiced in New Zealand are discussed below.

2.2.1 Agrosilvicultural system

In the context of New Zealand, agrosilvicultural systems can be defined as the growing of trees on cropping farms. These trees provide shelter for agricultural crops and fruit trees. Sturrock (1988) stated that tree shelter is vital for many crops such as apples, and sub-tropical fruits such as kiwifruit, and can increase productivity of some crops by 10% or more. However, tree shade may reduce the yield of understorey crops. Mulligan (1986) noted that shading in grape production is a very critical factor. Therefore, shelter management should be focused on minimising shading and maximising the wind speed reducing effects of trees on understorey crops. Pruning, side trimming and topping are essential operations for the improvement of porosity and for the reduction of shading effects of trees on agricultural crops. Lee (1983) suggested that porosity of shelter trees should be maintained at 40-50% so as to reduce the amount of turbulence behind the shelterbelts in agrosilvicultural systems.

2.2.2 Silvopastoral system

Growing of trees with pasture and grazing animals is known as silvopastoralism. The main objective of this system is to diversify farm income and to maintain high pasture production for as long as possible, until the shading effects of mature trees suppress pasture production. This involves growing and tending fewer trees per hectare by planting elite trees more widely than usual into pasture, and /or grazing livestock under more closely planted woodlots (Jarvis and Perley, 1990). Shelterbelts, timberbelts and shade trees should also be regarded as components of silvopastoralism as the shelter and shade can enhance animal production and timber may also be produced. Tree planting on farms, either in woodlots, timberbelts or shelterbelts, are also established for the conservation of soil from wind and water erosion, and to reduce loss of soil moisture by evapotranspiration where hot winds are prevalent. Both pasture and livestock receive vital protection by trees from the adverse effects of hot and cold winds, frost and snow.

Some farmers plant large blocks of trees (up to 20 ha) as "stock havens" in central locations on their properties so that animals can be sheltered there when they are vulnerable, after shearing and at lambing or calving time. The negative effects of silvopastoral systems arise from the competition between trees and understorey pastures for light, moisture, nutrients and space. This has adverse effects on trees as well as on productivity and feeding value of understorey pastures. Trees and their roles in silvopastoral systems are discussed next.

2.2.3 Roles of trees in silvopastoral systems

The importance of trees in silvopastoral practices is well recognised and encouraged in New Zealand to meet the following roles of trees at both farm and national level (Figure 2.1).

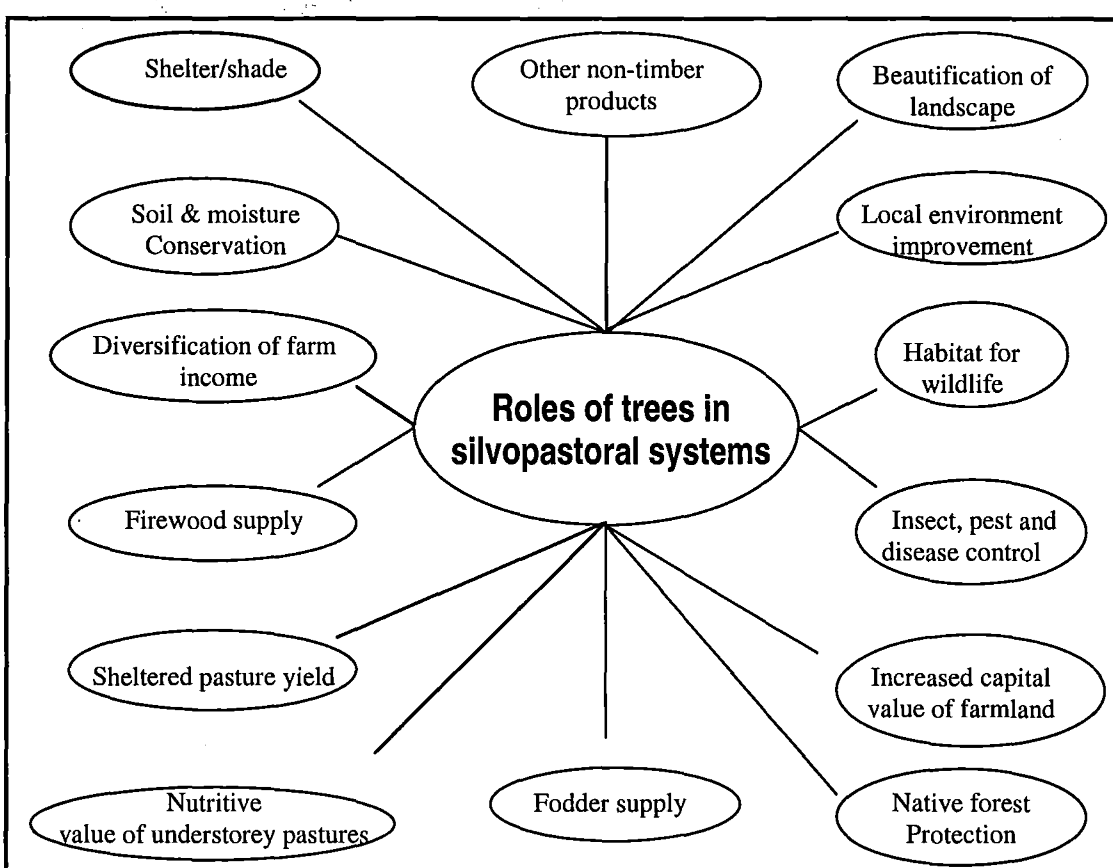

Figure 2.1. Roles of trees in silvopastoral systems at both farm and national level.

2.2.3.1 Trees for soil and moisture conservation

Wilkinson (1997) reported that 32% of North Island and 25% of South Island pastoral lands require farm woodlots and wide-spaced tree planting activities for soil conservation. For this purpose, radiata pine and eucalyptus species are used widely to stabilise coastal sand dune areas of New Zealand (Hocking, 1997a), whereas tree willows are effective in river bank protection because their roots stabilise soils. Poplars and willows are also suitable species for erosion control on hill pastoral lands (Wilkinson, 1997).

2.2.3.2 Tree shelter and shade

The drier parts of New Zealand have high evapotranspiration rates during summer due to the effect of high temperatures, and hot, dry winds. Tree shade and reduction in wind speed by tree shelter in this environment play an effective role in the reduction of evapotranspiration.

Wilkinson (1986) reported that shelterbelts should be as long as possible by connecting with existing shelter to obtain continuity and gaps should be avoided where possible because wind velocity is increased by 25% around ends and through gaps. Therefore, rows of trees or shrubs are established across the prevailing wind to provide shelter for agriculture crops and pastures, and to protect livestock and farm houses from hot and cold winds, frost, snow and sunshine. Tree shelter in silvopastoral systems conserves soil moisture during summer and creates a favourable environment for understorey growth.

2.2.3.3 Diversification of farm income

This is one of the most important roles of agroforestry in New Zealand. Some exotic species such as *Pinus radiata, Eucalyptus spp, Populus spp and Cupressus macrocarpa* are planted on pastoral farms for income diversification. Grazing the pastures gives regular income from milk, meat and wool, while trees provide income after long intervals (25-60 years). Firewood and pulpwood however, can be harvested in relatively short rotations compared to higher value timber. Hocking (1997b) reported that the financial return from radiata pine stands on the Rangitoto farm in the Manawatu shows that agroforestry can be a very profitable practice in the sand country of New Zealand (Table 2.1).

Table 2.1 Commercial returns from forestry in Rangitoto farm (adapted from Hocking, 1997b).

Year	Area clear felled (ha)	Age (yrs)	Prod^n thinned area (ha)	Income ($)
1992/93	0.6	28	4.0	48,000
1993/94	1.2	31	3.0	99,000
1994/95	1.7	28	2.0	88,000
1995/96	2.6	29	2.5	109,000

There are many difficulties in predicting forestry income in agroforestry systems. However, commercial returns from Rangitoto farm in the Manawatu shows that silvopastoral practices can be considered profitable and practicable in New Zealand farming systems.

2.2.3.4 Pasture yield

Tree shade and shelter play a vital role in conserving soil and soil moisture in silvo-pasture which in turn will help to increase pasture production. Simpson (1983) reported that tree shelter/shade in North Otago increased pasture production by 20-30% and agriculture crop yields by 20%. Therefore, tree shade is not always harmful to understorey crops. However, where trees are actually planted in the pasture rather than in shelter belts only, pasture production is reduced (Pollock *et al.*, 1994).

2.2.3.5 Nutritive value changes

The nutritive value of shaded pasture is mostly reduced compared to open pasture. This is partly because of the reduction of clover content in pasture (Percival *et al.*, 1984a). However, nitrogen content in shaded pasture at the Lincoln University agroforestry experiment was increased by 0.4% N compared with open pasture (van Garderen, 1997). Further information for nutritive value change in shaded pastures is presented in section 2.3.5.5.8.

2.2.3.6 Non-Timber Products

Another role of trees in silvopastoral systems is to produce non-timber products. For example, kamahi, manuka, willow (Wilkinson, 1997) and beech trees are encouraged on farmlands for honey production because these plants are a good source of nectar/honey dew and pollen for honey bees. Mead (1995a) reported that a growing number of people in Australia are planting trees to diversify their farm output with products such as nuts, fruit, honey, browse and essential oils. Some farmers in New Zealand also use poplars and willows for fodder production for livestock feeding during dry summer seasons.

2.2.3.7 Beautification of landscape

The amenity and aesthetic value of trees are another motivating factor for tree planting on farms because farmers are often aware that trees will not only improve their working conditions, but also enhance their whole enjoyment of life. Agroforestry plantations with ornamental species also provide enjoyment to the people living around the farm. Beautification of farmland is an important role of agroforestry plantations that is commonly adopted in New Zealand during the planning and implementation of agroforestry programmes.

2.2.3.8 Local environment improvement

Mead (1995a) reported that the environmental movement has increased awareness of the positive benefits from trees such as their ability to sequester carbon and produce oxygen by the photosynthesis process, and it also provides shade for protection from increased ultraviolet radiation. In addition, farm trees can also absorb dust and other air pollution. Another role of farm trees is to provide habitat for wildlife. Therefore, trees are essential for local environment improvement.

2.2.3.9 Insect, pest and disease control

Reid and Wilson (1985) reported that trees provide habitats for wildlife including birds, which will in turn, provide effective methods for insect, pest and disease control. It is often not economic to use pesticides on pastoral land and pesticide use is becoming less acceptable due to the long term ecological approach. Sometimes pests become a major source of farm animal diseases. Populations of such harmful pests will fluctuate over time, but if natural predators are encouraged, long term control will be cheaper and often just as effective. Trees are a vital component in habitat enhancement in the use of natural control methods against pests. The control of pest populations by natural predators will help create healthy environments for understorey pastures and grazing animals.

2.2.3.10 Increase the capital value of farmland

Simpson (1983) reported that trees planted on farm land increase the capital value of land because the potential income from timber will be included during the farm land valuation process.

2.2.3.11 Native forest protection

An indirect benefit of silvopastoral systems is the reduction of pressure on milling native forests for timber. In the past, these forests were degraded both in quality and quantity by extraction of timber and non-sustainable resource exploitation. Currently, pressure on New Zealand native forests is significantly reduced because about 98.5% of total logs produced in this country are extracted from planted forests (MOF, 1995 and Lane, 1995b). This will be helpful for the improvement of the condition of native forests which may be managed to supply limited quantities of hardwood and softwood for special purposes on a sustainable basis.

2.2.4 Interactions in silvopastoral systems

Research on tree and understorey pasture interactions show that when tree stocking is high in silvopastoral systems, the productivity and feeding value of understorey pastures are reduced dramatically compared with that in open pasture. The positive aspects of silvopastoral systems in relation to pasture production and general farming operations are summarised in Section 2.2.3 and the negative aspects are discussed below.

2.2.4.1 Change in soil chemical and microboial activities

The majority of plantations in New Zealand are established with radiata pine. This practice is known as monoculture. The monoculture of radiata pine has been viewed by foresters, farmers and researchers as a risky practice with respect to nutrient deficiencies in soils and vulnerability to pests and diseases. Mead (1995b) reported that New Zealand soils are often deficient in nitrogen, phosphorus and boron. A monoculture of radiata pine will further increase the problem of nutrient deficiencies in soils with repeated tree cropping. Hawke and O'Connor (1993) summarised the recent studies on soil chemical and microbial changes during radiata pine growth at the Tikitère agroforestry experiment in the central North Island and reported decreased soil pH, soil organic phosphorus and microbiological activity with increasing tree stocking.

2.2.4.2 Reduction of pasture productivity

Hawke (1997) reviewed the literature for New Zealand and concluded that pasture production under radiata pine agroforestry always declined relative to open pasture as tree stocking and tree age increased. This was attributed to the competition between trees and understorey pastures for environmental factors such as solar radiation, nutrients and moisture.

The reduction of pasture production under trees had a direct effect on livestock performance. Percival *et al.* (1984c) reported that the livestock carrying capacity and mean lamb birth weights at Tikitere declined as pasture production decreased under tree shade. They also reported that when tree density increased at Tikitere wool weight per sheep also decreased. The overall decrease of wool weight at 50 stems per hectare was an 8% decline, 12% at 100 stems per hectare and 16% at 200 stems per hectare. Gut examination of poorer condition ewes from under the trees at Tikitere and Waratah suggested that there may also be higher gastro-intestinal nematodes and parasites in silvopastoral plots. This is presumably because of greater survival of infective parasite larvae in the more humid shaded conditions under trees.

2.2.4.3 Increase weed percentage

Percival *et al.* (1984a) reported that there were more weeds in silvopastoral plots compared with open pasture. Most were associated with the slash that accumulates from successive pruning and thinning, and the inability of animals to graze or destroy the weeds which were protected under the slash.

2.2.4.4 Damage of wildlife to understorey crops

Trees provide habitats for birds, rabbits, hares, possums and other wild animals. Some bird species in agrosilvicultural systems can cause significant damage to agricultural crops, while possums, rabbits and hares in silvopastoral systems cause considerable destruction of understorey pastures and young trees.

2.2.4.5 Reduction of productive area

Reid and Wilson (1985) reported that the presence of trees on farm land will reduce the area of productive pasture near trees. Pollock *et al.* (1994) noted a 14% reduction in pasture area at the Lincoln University agroforestry experiment due to the use of herbicides to control weeds along tree rows. However, a progressive farmer, Mr Peter Smail has demonstrated that two row shelterbelts on the Canterbury plains will shelter most pasture areas and occupy only 2% of the total farm area. Furthermore, Mr Smail also showed that side trimming of the conifer species in shelterbelts modifies livestock behaviour so that sheep and cattle do not camp beside shelter belts. Hence pasture near the trees was not adversely affected.

2.2.4.6 Reduced work efficiency

Another disadvantage of trees on cropping farms is that trees may create problems in harvesting and other cultural operations because dead branches and twigs in crops lower the efficiency of mechanical harvesting etc. The presence of trees in pasture may increase the time required to muster sheep and cattle.

2.2.4.7 Long term investment

Forestry planting and maintenance includes land preparation, seedling purchase, plantation establishment, fencing, weeding and fertilising etc which require a large amount of expenditure and work, especially early in the life of trees. MacLaren (1993) reported that the income from radiata pine timber may not commence until 25 to 30 years after plantation establishment. In this situation, farmers have to wait a long time for income return on their investment. Farmers must compound the costs of forest establishment over time to obtain a realistic estimate of profitability. The interest rate paid on establishment costs has a large influence on final profits from the investment on trees.

2.2.4.8 Competition between trees and understorey pastures

Competition in silvopastoral systems for environmental factors will occur at both the interspecific and intraspecific level. The severity of competition in this system will be determined by tree stocking, tree age, silvicultural operations (pruning and thinning), tree and pasture species, growing season, climate and fertility status of soils.

Competition between trees and understorey pastures for environmental factors such as solar radiation, soil moisture and nutrients has adverse effects on both trees and pastures. Generally, understorey pasture affects the growth and development of trees during early stages of tree growth, while trees adversely affect pasture growth and development from the time trees are large enough to shade pasture to the time of harvesting. Mead *et al.* (1993) reported that the growth of radiata pine was reduced markedly due to pasture competition in the phalaris plus clover and lucerne treatments during the first few years at the Lincoln University agroforestry experiment. These two treatments resulted in a 25% reduction in height growth and a 45% reduction in the diameter of two year old trees. This reduction was assumed to be because of competition between trees and pastures for soil moisture and nutrients. However, if soil moisture and nutrients are in abundance, competition between young trees and understorey pastures will not occur because there are sufficient soil resources for each component of the system. If these resources are depleted and do not meet the demand, then competition will occur. The vegetative and reproductive processes of understorey pastures will be altered due to the competition. This may change plant size and plant populations. The most extreme effect of competition between trees and pastures for environmental factors is the elimination of a pasture species within a sward due to extreme shading.

In silvopastoral systems, solar radiation is the most important component in relation to pasture production because tree shade reduces the transmission of light energy to understorey pastures. Water and nutrients can be stored and supplied in soil reservoirs, but photosynthetically active radiation cannot be stored within a pool to be utilized at a later time. Light must be intercepted instantaneously by leaves during daylight for photosynthesis to occur. Donald (1961) stated that light competition would also occur between the leaves of an individual plant. The basal leaves are mostly shaded by upper leaves and the rate of photosynthesis in the lower canopy is suppressed. In extreme cases, shading may cause the death of lower leaves. Harper (1978) pointed out that this situation does not occur with competition for moisture and nutrients, as plants have the ability to redistribute these resources throughout the plant. In silvopastoral systems, trees will intercept the majority of solar radiation resulting in the reduction of pasture yield. In lower regions of pasture canopies where clover is mostly found, the light available for interception will be reduced dramatically due to the tree shade and the growth of understorey grasses above the legumes. The decrease of clover content in silvopastoral systems may therefore be attributed to the reduction of solar radiation under tree plus grass shade. Finally, tree cover not only reduces the light transmission to understorey pastures, but also affects the rainfall distribution below their canopy and consequently the moisture content in soils.

2.3 Cocksfoot and its performance in silvopastoral systems

Moloney (1993) stated that cocksfoot is the second most commonly sown temperate grass after perennial ryegrass (*Lolium perenne* L.) in New Zealand. This species seems to be well adapted to moderate soil fertility, low soil moisture areas and also where shading is common. Langer (1990) concluded that cocksfoot tends to become rather coarse and highly tufted if it is not grazed frequently and intensively. Coarse and highly tufted cocksfoot is not greatly acceptable to grazing animals. Grasslands Apanui was the first cultivar of cocksfoot developed in New Zealand. It was replaced in 1980 by Grasslands Wana and Grasslands Kara. These two cultivars are characterised by improved digestibility, rust tolerance, cool-season growth and greater persistence in regions with dry summers.

2.3.1 Genetic characteristics of cocksfoot

Moloney (1993) reported that relative to ryegrass, cocksfoot provides reliable leafy summer growth free of endophytes, with greater persistency in dryland and grass grub affected regions. Seed production of English varieties of cocksfoot began in 1853 on Banks Peninsula, but genetically improved cocksfoot cultivars were not developed in New Zealand until recently in contrast to the early development of commercial seed production. Langer (1990) reported that cocksfoot cultivars in New Zealand have been developed from seeds brought from European countries such as Denmark, Great Britain, Sweden, Spain and Belgium etc. The first cultivar developed in New Zealand, Grasslands Apanui, was used extensively during the 1960-70s. This cultivar gained the reputation for being erect and clumpy, and having poor palatability, high rust susceptibility and poor persistence under sheep grazing.

Rumball (1982b) reported that Grasslands Wana cocksfoot (G17) was developed in New Zealand from plants of lower altitude grassland near Arteijo in north-western Spain. Wana cocksfoot was introduced to the New Zealand agriculture sector in 1980. It is a semi-prostrate and densely tillered cultivar and was developed for dryland pastures of low soil fertility and heavy set stocking by sheep (Moloney, 1993). Grasslands Kara has low tiller density, an open structure and was developed for lowland, high soil fertility dairy pastures. The stem and stripe rust tolerance capacity is very high in Wana cocksfoot compared with other cultivars (Table 2.2). Saborto is another cocksfoot cultivar commercially available in New Zealand and its characteristics are similar to Grasslands Kara. Moloney (1993) stated that farmers have been disappointed with the dominance of Wana in lowland pastures of medium to high fertility where important companion grasses and clovers have been suppressed, leading to reduced pasture nutritive value and poor palatability.

Table 2.2. Features of cocksfoot cultivars commercially available in New Zealand (adapted from Moloney, 1993).

Parameter	Grassland Wana	Grassland Kara	Saborto
Growing habit	Semi-erect, short and fine leaves	Erect, tall and broad leaves	Very erect, tall and very broad leaves
Vegetative tillers	7000-11,000/m^2 and small size	1000-5,000/m^2 and large	Few and large
Rust tolerance	Very high	High	Moderate
Winter growth	Moderate to high	Very high	High
Early spring growth	Moderate	Very high	Very high

2.3.2 Morphology

Cocksfoot is a perennial pasture species that is strongly tufted and tall in growth habit. It is highly competitive in pastures over companion species for soil moisture and nutrients. Speeding and Diekmahus (1972) mentioned that vegetative tillers of cocksfoot are flattened in their morphology and display high rates of tiller production (up to 11,000/m^2). Grasslands Wana is more prostrate in morphology than other cocksfoot cultivars and shows greater persistence and ability to compete with weeds, companion pasture species than other cocksfoot cultivars. Langer (1990) reported that tolerance to grass grub and, once fully established, to Argentine stem weevil, as well as some resistance to stem and stripe rusts make Wana cocksfoot a valuable pasture plant in New Zealand. The common companion pasture species of cocksfoot are ryegrass and white clover, but Wana's aggressive nature can restrict the productivity of companion species (Moloney, 1993). Grasslands Wana provides higher summer yield and persistence in low fertility dryland environments with moderate to severe grazing pressure. The rooting system, tiller production, leaf formation and development, seasonal yield, reproduction and nutritive value of cocksfoot are presented in following section.

2.3.2.1 Root system

Cocksfoot has a thick, fibrous, highly branched, adventitious root system. Evans (1976) found that the roots of Apanui cocksfoot extended down to 140 cm with a uniform distribution of roots to lower depth. Barker *et al.* (1985) suggested that the nature of Wana's root system may be one of the main contributing factors which has led to its successful establishment, persistence and production in pasture systems grazed by sheep compared with other cocksfoot cultivars.

2.3.2.2 Tiller production

Moloney (1993) reported that Wana cocksfoot produces a larger number of tillers than other cocksfoot cultivars (7- 11,000 tillers/m^2), but usually these tillers are smaller than in Kara cocksfoot. The relative rate of tillering by cocksfoot is determined by temperature. Mitchell and Lucanus (1960) reported that cocksfoot plants produced 37% more tillers under 15.5°C day and 7°C night temperature compared with 15.5°C day and 2°C night temperature.

2.3.2.3 Leaf formation and development

The leaves of cocksfoot are hairless, with the older blades appearing harsh to touch, particularly along the keel on the lower surface. The upper surface of the blade has no ribs. The central vein is prominent and continues along the entire sheath, with the blades sharply folding along the central vein. Lambrechtsen (1992) found that the leaf blade length of cocksfoot ranges from 10-45 cm with a width of 2-14 mm. Rumball (1982b) reported that Wana cocksfoot has green to blue green leaves which appear shiny compared with other cocksfoot cultivars.

2.3.3 Seasonal yield of cocksfoot cultivars

Judd *et al.* (1990) reported that the advantage of cocksfoot over ryegrass in summer and autumn has been noted in Taranaki dairy pastures of New Zealand. This improvement in pasture production provides an opportunity for an improved supply of nutritious feed to animals in dry summer seasons. However, cocksfoot is an aggressive perennial grass which can reduce clover content in pasture. The reduction of clover content in pastures will lower the amount of nitrogen fixed and reduce the nutritive value of the pasture. In comparison to endophyte-infected Nui perennial ryegrass, the dry matter yield of cocksfoot cultivars in the Canterbury plain was also higher (Stevens *et al.*, 1992). This means cocksfoot can be considered as an alternative species to ryegrass in the warmer Argentine stem weevil affected areas of New Zealand. The seasonal yield of cocksfoot cultivars is presented in Table 2.3 which shows a slightly higher dry matter yield of Wana cocksfoot than other cultivars under a lax grazing system in Southland, New Zealand.

Table 2.3. Seasonal and annual dry matter yield of cocksfoot cultivars and white clover (WC%) content in Southland under infrequent grazing (adapted from Stevens *et al.*, 1992).

Cultivars	Spring		Summer		Autumn		Winter		Total	
	Yield	WC (%)	Yield	WC (%)	Yield	WC (%)	Yield	WC (%)	Yield	WC (%)
Kara	5110	15	4760	17	2380	5	1270	6	13520	13
Wana	5270	21	5330	22	2700	5	1260	10	14560	18
Apanui	5490	12	5170	12	2310	5	1160	7	14130	11
Saborto	5140	13	5110	15	2450	6	1140	11	13840	12

Table 2.3 shows that Wana cocksfoot may favour white clover growth (18%) compared with other cultivars.

2.3.4 Reproduction

The inflorescence of Wana cocksfoot forms a panicle, with lower branches being longer and heavier in seed. The panicle branches carry 2-5 spikelets which form in clusters. The seed is oblong in shape with mean length of 5-6 mm and a width of 1-1.5 mm. In comparison with other cocksfoot strains, Wana has slightly smaller seeds, flowers a few days earlier than Kara and yields more seeds. Rumball (1982a and b) stated that the seed of Kara (1.0 g/1000 seeds) is slightly larger than the seeds of Wana. However, annual seed yield of Wana reached up to 770 kg ha^{-1} in Palmerston North (Rumball, 1982b). Seed weight of Wana cocksfoot is less than half that of perennial ryegrass seed. Therefore, cocksfoot seedlings are smaller and slower to establish than ryegrass.

2.3.5 Factors affecting the performance of cocksfoot

Environmental factors such as soil moisture, nutrients, temperature and solar radiation have a great influence on the productivity and feeding value of pasture species. Harris (1990) reported that wind has an adverse effect on air temperature and moisture availability in soil. The decline of soil moisture due to the effect of hot and dry winds reduces the pasture yield during summer. Soil fertility is another factor which also influences the productivity and feeding value of pasture species. The major environmental factors and their effects on pasture yield are presented below.

2.3.5.1 Soil moisture

Canterbury is very cool in winter, warm and dry in summer with occasional prolonged droughts and high evapotranspiration rates in summer which can lead to severe soil moisture deficits on shallow soils. In silvopasture systems, soil moisture will further decrease due to tree competition. Yunusa *et al.* (1995a and b) reported lower soil moisture storage close to trees.

Irrigation is extremely important for pasture production in Canterbury. Thomson (1994) reported that Canterbury and North Otago are well suited to irrigation because there are large rivers with high summer flows, large plain areas with well drained soils, and moisture deficits for pasture production in summer. Irrigation in Canterbury is essential from September to April for maximum pasture production to be achieved. McBride (1994) concluded that irrigating pasture in Canterbury increased average yields by up to 80% with greatest responses in summer. However, the productivity of irrigated pasture may be determined by frequency and methods of irrigation. Rickard and McBride (1986) reported that pasture production would be decreased with excess irrigation. This was attributed to nutrient loss by leaching and the rise of the water table reducing the growth and development of roots. McBride (1994) reported that irrigation at 50% available soil moisture in the top 100 mm soil in Canterbury increased pasture yield from 6.7 tonnes to 11.9 tonnes ha^{-1}. However, the number and timing of irrigations determined the productivity of pasture species. McBride (1994) reported that pastures in Canterbury require frequent irrigation during summer compared with other seasons. If the number of irrigations is increased/decreased beyond the maximum /minimum limit, pasture yield would be decreased. McBride (1994) mentioned that the number of irrigations in Canterbury ranges from 2-11 per season and should be determined on the basis of evapotranspiration.

The seasonal yield of Kara cocksfoot in drier Canterbury sites shows that cocksfoot is one of the best drought tolerant grass species in New Zealand (Figure 2.2). This is assumed to be because of the deep rooting system of cocksfoot which can withdraw moisture from a greater soil depth. Evans (1976) reported that Apanui cocksfoot appeared to grow better at high soil moisture tension compared to endophyte-infected Nui ryegrass. However, this relative advantage of cocksfoot is dramatically reduced in high rainfall areas. This is probably because of the high water table and poorly drained wet soils which can reduce the growth and development of roots. Speeding and Diekmahus (1972) stated that herbage production of cocksfoot pasture in high water table soils decreased and forage becomes unpalatable to grazing animals, even when the forage is young.

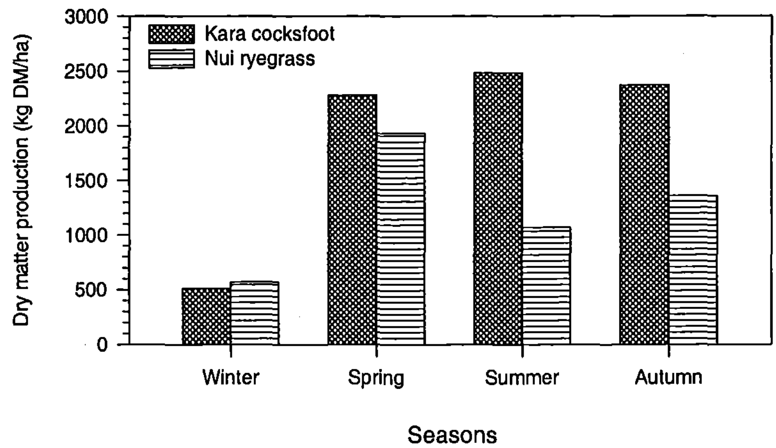

Figure 2.2. Seasonal dry matter yield of Kara cocksfoot compared with endophyte infected Nui ryegrass under lax grazing system in drier Canterbury site (adopted from Stevens *et al.*, 1992).

Figure 2.2 shows that Kara cocksfoot produced more than double the dry matter yield in a dry summer compared with Nui ryegrass.

2.3.5.2 Temperature

Temperature influences the photosynthesis process, respiration, reproduction (tillering, flowering and fruiting etc) and phenological development in plants. Temperature also affects the efficiency of water use by plants and mineralisation in soils. Gates (1993) reported that the net photosynthesis rate of a plant increases with temperature until a broad optimal temperature range is reached, but it drops off at higher temperatures. Seed germination involves metabolic activity that can be limited or enhanced by temperature. Lang (1965) reported that seeds in temperate regions germinate well between 8^0C to 25^0C. Temperatures below and above a plant's requirement will affect the plant's phenological, morphological and physiological development processes. In New Zealand, the most critical season for pasture production is winter. Daly (1990) reported that the mean winter temperature of the North and South Island of New Zealand is about 11^0C and 5^0C respectively. Table 2.4 shows the reduction in weight of cocksfoot tissue due to the low temperature.

Table 2.4. Relative change in weight of cocksfoot , white clover and subterranean clover tissue formed per day with different levels of temperature under controlled environments (adapted from Mitchell and Lucanus, 1960).

Day and night temperature	Relative growth		
	Cocksfoot	White clover	Subterranean clover
15.5°C day and 7°C night	100	100	100
15.5°C day and 2°C night	57	61	86
7°C day and 7°C night	37	35	58
7°C day and 2°C night	22	27	37

Table 2.4 shows that there was 63% less growth in cocksfoot with 7°C day and 7°C night temperature compared with cocksfoot under 15.5°C day and 7°C night temperature. Garnier and Roy (1988) reported that tree cover acted as a buffer for the understorey environment compared with open swards. Therefore, the monthly mean temperature of shaded cocksfoot pasture in France was 0.6°C higher in winter than in an adjacent open sward and 1.6°C lower in summer. The decline of summer temperature under tree shade will reduce the evapotranspiration rate during hot and dry periods, while the rise of winter temperature due to trees will improve pasture growth and development under tree shade. Korte *et al.* (1987) reported that when soil temperature is between 5.5-10°C during spring each degree soil temperature rise results in 8 kg DM/ha/d increase in temperate pasture production.

2.3.5.3 Urine patches and their effects on pasture yield

Soil nitrogen (N) is an essential element for plant growth and development and eventually for animal nutrition. Nitrogen in agricultural ecosystems is highly mobile due to its high rate of turnover and losses through the processes of volatilization, immobilisation, leaching, surface runoff and soil erosion. The nitrogen requirements of animals grazing pasture in New Zealand is mostly supplied by legumes and through animal urine return to grazed pasture grasses. Hoglund *et al.* (1979) reported that the annual nitrogen fixation by clover over a range of flat land in New Zealand ranged from 107- 392 kg N/ha/year. Addiscott *et al.* (1991) stated that more than 80% of nitrogen consumed by animals is returned to the soil in urine and dung form. Cameron (1992) reported that animal dung and urine usually have a high nitrogen concentration (5-10 g N litre^{-1} of urine) and their decomposition in the soil can release relatively large amounts of mineral nitrogen. Cows are estimated to urinate approximately 2 litres of urine over an area of 0.4 m^2, resulting in an application of between 400-1200 kg N /ha (Addiscott *et al.*, 1991). Levy (1970) reported that animal urine is rich in N, while dung is richer in phosphorus and potassium. Doak (1952) stated that sheep excrete 2.9 litres urine/day in New Zealand. Urine patches in grazed pastures are unevenly distributed, which promotes highly nitritious growth of pasture species in small discrete patches. Marriott *et al.* (1987) reported a 39% increase in the production of perennial ryegrass and van Garderen (1997) recorded 40% more cocksfoot dry matter yield in urine patches compared with non-urine areas. Marriott *et al.* (1987) in UK found a difference in nitrogen concentration in the herbage of perennial ryegrass grown in urine patches and non-urine patches. The urine patches had 4.3% N and non-urine patches 2.5% N. This means animal urine improved both productivity and nutritive value of pasture grasses. However, vigorous nitrogen or urine fertilised grasses usually reduce the clover content. Marriott *et al.* (1987) stated that white clover content in ryegrass-white clover pasture was reduced by 55% in urine patches compared with non-urine areas. Parsons *et al.* (1991) also recorded 20% reduction of clover content in urine patches compared to the adjoining non-urine patches.

2.3.5.4 Biotic stress

Brougham (1960) reported that old type cocksfoot cultivars such as Apanui are slow to establish, sensitive to severe grazing and treading, and more susceptible to stem rust (Lancashire and Latch, 1969). However, well established Wana cocksfoot can tolerate stem and stripe rust, grass grub and Argentine stem weevil (East *et al.,* 1982 and Moloney, 1993).

Rumball (1982b) noted that Grasslands Wana cocksfoot gives high summer yields and persistence in a low fertility dryland environment with moderate to severe grazing systems. The deep rooting system, aggressive growth and vigour, poor palatability and availability of other species in pasture swards will help to make cocksfoot pasture resistant to grazing stress and become dominant in mixed pastures. Moloney (1993) reported that long grazing rotations and long residuals can result in rank growth and high rust incidence in cocksfoot grass, resulting in poor feed quality and utilisation.

Under light grazing Wana tends to become less palatable, coarse and highly tufted. This is not greatly acceptable to grazing animals. Thus livestock prefer to graze other companion pasture species. This type of grazing pattern improves Wana persistence and vigour, but reduces the amount of preferred species such as clovers in the mixed pasture.

2.3.5.5 Silvopastoral environment

Cocksfoot (known as orchard grass in North America) has superior performance under tree shade. Wong (1991) defined shade tolerance as " the relative growth of pasture plants in shade compared to the full sunlight as influenced by regular defoliation. It embodies the attributes of both dry matter productivity and persistence". Trenbath (1976) reported that shade tolerant plants generally accommodate themselves in low photosynthetically active radiation by modifying their physiological, anatomical and morphological structures, and by reducing the rate of respiration, lowering root-shoot ratio, leaf area and leaf weight ratio.

When solar radiation passes through a tree canopy its quality will be altered because tree leaves absorb the light in the 400-700 mm waveband. Holmes (1981) reported that blue and red light are reduced compared with green and far-red under tree shade. Because of differential absorption of red and far-red light by trees, the ratio of red to far-red declines (Table 2.5). The changes in red and far-red ratio will be perceived by understorey plants through the phytochrome system which may change morphogenetic characters in plants (Smith, 1982). Plants become taller and thinner under shade compared with full sunlight in an effort to access the reduced solar radiation available.

Table 2.5. The red and far-red ratio of light in full sun and under tree shade (adopted from Wilson and Ludlow, 1991).

Full sunlight	Robber plantation		Old coconut trees	Mature rain forests
	Immature	Mature		
1.20	1.07	0.62	1.03	0.43

According to Sheehy and Peacock (1975), canopy saturation point for cocksfoot is about 330 W m^2 or 1518 μ moles/m^2/s (1 W m^2 = 4.6 μ moles/m^2/s). Above the point of saturation, the additional input of solar radiation serves only to increase transpiration, re-radiation and convection, and thermal stress. Under tree canopies, the photosynthetically active radiation levels reduce dramatically. The amount of photosynthetically active radiation is the most important component of solar radiation for the photosynthesis process. The amount of solar radiation reaching on understorey plants in mature rain forest is reduced by 64% compared with full sunlight (Wilson and Ludlow, 1991). The decrease of solar energy under shade not only affects the photosynthesis process and the accumulation of dry matter, but also reduces other development processes of understorey plants. Tree shade and its effects on understorey pasture species are discussed in following sections.

2.3.5.5.1 Dry matter production

Pasture production decreases steadily with increasing tree stocking and tree age because tree shade has a negative effect on the photosynthesis process of understorey pastures. Dennis and Woledge (1981) reported that the rate of photosynthesis of grasses and legumes was lowered with increased levels of shade. Mitchell (1956) found that under 50% shade total dry matter production of white clover was decreased up to 50%. Seo *et al.* (1989) stated that the highest cocksfoot yields were obtained in South Korea at 0 to 25% shade, but yields decreased as shade was increased beyond 25%. Cossens (1984) reported a 19% reduction in dry matter production from mixed pasture under 8 year-old radiata pine with 200 trees ha^{-1} in south Otago, New Zealand, but did not report shade levels. Reynolds (1995) stated that in general pastures growing in less than 30 to 40% light transmission have lower dry matter content (higher water content) in herbage.

2.3.5.5.2 Root formation and development

Wong *et al.* (1985) reported that the physiological, anatomical and morphological development of grass roots is often reduced at low light intensity. According to Burton *et al.* (1959), root and rhizome production of *Cynodon dactylon* at 28.8% light transmission in south-eastern USA was decreased markedly compared with full sunlight. Sillar (1967) found that a 74% reduction of light intensity reduced the dry matter production of *Stylosanthes humilis* roots by 44%.

In the case of legumes, root nodulation is an important biological process. This is adversely affected by tree shade. Chu and Robertson (1974) reported that the number of nitrogen fixing nodules on white clover was significantly decreased by shade (240 nodules /plant) compared to open pasture (395 nodules /plant). The reduction of nodule numbers in legumes under shade will reduce nitrogen inputs to soil and may cause nitrogen deficiency in plants. This may then result in reduced productivity and nutritive value of shaded pasture.

2.3.5.5.3 Leaf formation and development

The stems of all plants have nodes where leaves are attached that are separated by internodes. These internodes are extremely short in grasses. In some grasses, leaf formation and development is better under shade compared to open environments. Garnier and Roy (1988) concluded that open pasture cocksfoot in France had more tillers but fewer leaves per tiller compared with shaded cocksfoot pasture. They further added that under shade, leaf emergence, longevity and surface area of cocksfoot were greater than that in open pasture (Table 2.6).

Table 2.6. Comparison of cocksfoot leaf formation and development in opened and shaded environments (adapted from Garnier and Roy, 1988).

Cocksfoot leaves	Open pasture		Shaded pasture	
	Winter	Summer	Winter	Summer
Leaf emergence rate (Leaves/day X 1000)	26	21	28	30
Leaf longevity (days)	82	78	93	75
Leaf surface area (cm^2)	0.7	0.9	1.3	1.0
Number of leaves/tiller	2.1	1.9	2.1	2.4

Wong (1991) reported that leaf formation and development in C_4 grasses are mostly reduced at low light intensity. However, the results of Table 2.6 show that leaf formation and development in C_3 temperate cocksfoot species was higher under shade compared with open pasture.

2.3.5.5.4 Tiller production

In grass species, tillers arise from buds in the axil of leaves. Evans *et al.* (1964) and Ludlow *et al.* (1974) reported that the rate of tillering is reduced by tree shade in grasses because the slower rate of leaf formation provides fewer leaf axils for tiller development. Garnier and Roy (1988) noted that the per plant tiller number of cocksfoot was decreased by 31% under trees compared with open pasture (Figure 2.3).

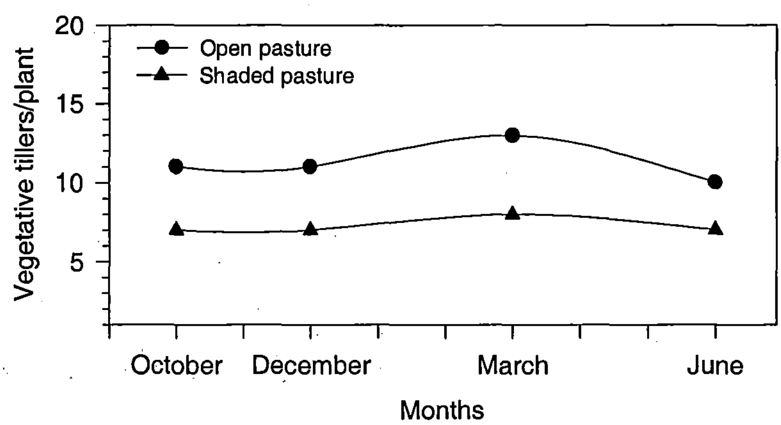

Figure 2.3. The number of cocksfoot tillers in open pasture and under *Quercus pubescens* trees in France (adopted from Garnier and Roy, 1988).

The reduction of tiller number per cocksfoot plant under shade is associated with fewer leaf axils under shade. Pastures having low tiller numbers are more susceptible to animal damage during hard grazing and in such pastures annual weeds are able to establish successfully.

2.3.5.5.5 Etiolation

Evans *et al.* (1992) stated that grass and legume plants will etiolate and grow taller in an effort to gain better access to the available light. In this situation, leaves become taller, narrower and thinner. Anderson (1978) found etiolation in cocksfoot was due to the cell elongation under shaded environments. This is responsible for the reduction of mechanical strength of cell walls. The result of this process in cocksfoot is increased susceptibility to lodging and fungal attack which will ultimately reduce the productivity and palatability of shaded cocksfoot plants. In the case of white and red clover, etiolation is a characteristic that enables them to be more competitive for solar energy in shaded environments. Percival *et al.* (1984a) noted that productivity of white clover in Tikitere declined with increasing tree density and tree age. While the etiolation ability of clovers is helpful to maintain productivity during competition for light between pasture species, difficulties arise under trees where the total available light above the pasture canopy would be much reduced.

2.3.5.5.6 Flowering and seed production

There are different stages in the reproduction of grasses, which are appearance of flower, pollination and fertilization, and maturation of seeds. Langer (1990) reported that the stem apex of grasses becomes entirely transformed in the course of time and bears floral structures that later become visible inflorescences (head or ear). The spike or branches of a panicle that occur in flower groups are called spikelets. The number of individual flowers per spikelet varies from 1 to 15 or more. Seed will develop in spikelets after pollination. Carbohydrates produced in the inflorescence itself and in the upper parts of the tiller continue to be deposited until the seed is mature, but reduced levels of light intensity under tree shade will affect the flowering, seed formation and maturation process in grasses because soluble carbohydrates would be expected to be less under shade (Wilson and Wong, 1982). Therefore, tree shade will affect flowering and seed production mechanisms of cocksfoot and other grasses and legumes.

2.3.5.5.7 Feeding value

An adverse effect of tree and understorey pasture competition is the change in pasture composition. Cossens (1984) and Percival *et al.* (1984a) reported that the white clover content at both Invermay and Tikitere resesearch centres declined with increasing tree age and tree density. Evans *et al.* (1992) stated that grass and legume plants will etiolate and grow taller in an effort to gain better access to the available light. This coupled with the reduction of pasture yield under shade will reduce pasture bulk density.

2.3.5.5.8 Nutritive value

Cocksfoot gives higher yields in summer than ryegrass, but its leaves are relatively low in soluble carbohydrates and higher in lignin content. Therefore, the high nutritive value of cocksfoot requires frequent grazing to maintain a leafy sward and ideal growing conditions. Barker *et al.* (1985) noted that the dry matter digestibility of Wana was 64.1% compared with Nui ryegrass recording 70.5% under the same conditions. In general, older leaves tend to be coarse, with a reduction in palatability. Young leafy cocksfoot herbage may have 68-78% dry matter digestibility. van Garderen (1997) reported 20.8% crude protein in cocksfoot herabge grown in January 1997 in sheep urine patches and 14.6% in non-urine areas, and 73.1% and 73.5% digestible organic matter in urine and non-urine patches respectively in the Lincoln University agroforestry experiment.

In shaded environments, the nutritive value of temperate grass/clover pasture declines because the percentage of clover is reduced compared with open pasture. The amount of soluble carbohydrate concentrations and percentage of digestibility in legumes are also decreased under shade. Thompson and Poppi (1990) reported that the digestibility of pasture species is influenced mainly by chemical composition of the carbohydrate fraction of the cell wall (cellulose and hemicellulose). The nutritive value of cocksfoot and white clover at the Lincoln University agroforestry experiment in a summer season are presented in Table 2.7.

Table 2.7. The nutritive value of Wana cocksfoot under full sunlight and 60% shaded condition in October (adapted from van Gaderen, 1997).

Environment	Organic matter digestibility (%)		Nitrogen (%)	
	Full sunlight	60% shade	Full sunlight	60% shade
Cocksfoot	77.8	75.9	3.4	3.8

Table 2.7 shows that digestible organic matter in cocksfoot under tree shade was reduced, whereas nitrogen content was greater under shade compared with open pasture. This decline in digestibility was in contrast to Jung and Russelle (1991) who concluded that the cellulose, hemicellulose and neutral detergent fibre in cocksfoot were reduced by 23 gm, 20 gm and 12 gm/kg respectively under a shaded environment.

This work of Jung and Russelle (1991) showed that under lower light intensities, the digestibility of cocksfoot plants was increased due to the decrease of cellulose, hemicellulose and other fibres.

2.3.5.5.9 Animal performance under tree shade

Percival *et al.* (1984c) reported that the livestock performance under radiata pine trees in Tikitere declined as pasture quality decreased under trees due to the reduction of clover content compared with open pasture. Hight *et al.* (1968) noted that under one quarter of full sunlight in ryegrass /white clover pasture, sheep grazed less dry matter (9-15%) than in full light. As a result of less dry matter consumption, live weight of sheep was decreased by 38%. Percival *et al.* (1984c) also found that lamb birth weight was reduced under radiata pines by 0.8 and 0.3 kg for the 400 trees per hectare flock compared with the open pasture flock at Tikitere Research Station in years 8 and 9 respectively after plantation establishment. When tree density increased at Tikitere per sheep wool weight also decreased. The overall effect in wool weight reduction at 50 stems per hectare was an 8% decline, 12% at 100 stems per hectare and 16% at 200 stems per hectare. There was similar pattern at Waratah Research Station under the older trees, the average loss being 25 %. They have further added that gut examination of poorer condition ewes under the tree shade at Tikitere and Waratah suggested that there might be higher gastro-intestinal nematodes and parasites in silvopastoral plots.

Geenty and Rattray (1987) reported the metabolisable energy requirements of ewe hoggets aged 6-12 months which is presented in Table 2.8.

Table 2.8. Metabolisable energy requirements (MJ ME/d) of ewe hoggets (adapted from Geenty and Rattray, 1987).

Liveweight gain (g/d)	Liveweight of ewe hoggets				
	20 kg	25 kg	30 kg	35 kg	40 kg
	ME requirements				
0	8.0	9.0	10.0	11.0	12.0
50	10.0	11.5	13.0	14.0	15.5
100	12.5	14.0	16.0	17.5	19.0
150	14.5	17.0	19.0	21.0	23.0
200	17.0	19.5	22.0	24.5	26.5

2.4 Grazing preference of sheep

The measurement of fresh grass and legume rate of intake by grazing animals is useful for the comparison and classification of herbages in relation to grazing preferences of animals. This is a complex task because the amount of consumption will be affected by several factors such as number and physiological state of animals (age, body condition, pregnancy and lactation etc), condition and composition of pastures and their digestibility, grazing behaviour of animals, and weather conditions etc. Leaver (1982) reported that sheep are more selective in their grazing behaviour than cattle. Poppi *et al.* (1987) suggested that the grazing behaviour of animals on pasture is complex, but it is partly determined by pre and post grazing pasture mass. Ultimately, these factors influence the bite size and weight, rate, depth, area and volume of ingestive behaviours of grazing animals (Burlison *et al.*, 1991). However, the pasture height had a greater influence on grazing behaviour of animals than pasture bulk density (Gong *et al.*, 1996a and b). Edwards *et al.* (1993) noted that sheep would preferentially graze urine patches first before non-urine patches due to some or all of the following: increased height, high proportion of green leaves, increased nutritional value and/or easy accessibility.

2.4.1 Measurement of grazing preference of animals

Hodgson (1982) reported that the choice of procedures for recording grazing behaviour of animals is strongly influenced by considerations of convenience, flexibility, comprehensiveness and cost. Meijs *et al.* (1982), on the other hand, have suggested that the grazing preference of animals can be estimated by measuring the height of grasses and legumes before and after grazing the pastures. Pasture species whose heights are reduced most during animal grazing are assumed to be the most preferred species. This method can also be used to compare the grazing preference of animals in shaded and open pasture. The measurement of pasture height should be done several times up to the end of a grazing trial to get reliable information on the rate of height decline. van Garderen (1997) at Lincoln University agroforestry experiment used this technique to measure the grazing preference of sheep on cocksfoot pasture grown under 60% shade and in the open. He found that sheep grazed more closely in open pasture in comparison to shaded pasture. This was probably due to the height of cocksfoot plants in open pasture being less than under trees at the start of grazing as well as at the end of the 5 days grazing periods.

2.5 Silvopastoral management techniques

In silvopastoral systems, tree shade affects both productivity and feeding value of understorey pastures. This effect of trees can be reduced by carrying out silvicultural operations such as pruning and thinning. The prescribed silvicultural regimes for radiata pine stands are discussed below.

2.5.1 Pruning

Cutting of tree branches off close to the trunk is known as pruning. The objectives of this operation are to reduce the danger of crown fires, to improve tree stands and understorey growth, to produce clearwood and to improve financial returns from both trees and understorey pastures in a silvopastoral system. Pruning schedules in radiata pine should be determined on the basis of trunk diameter over stubs (DOS) and tree height. Whiteside *et al.* (1989) suggested that timing of pruning as expressed by DOS affects both timber grades and values. Earlier pruning with a small DOS will increase the timber yield as well as understorey production by reducing the effects of tree shade. A 14 cm DOS gives the same economic return as a 17 cm DOS, while 20 cm DOS gives somewhat lower return (Whiteside *et al.,* 1989). Dominant, vigorous, well spaced, straight and erect trees with a single leader should be selected for pruning. After that, tree branches should be cut cleanly at right angles to the trunk and as near as possible to the nodal swelling without any damage to the stem or bark. Stem cones and epicormic shoots should also be removed for clearwood production. The pruning slash should ideally be removed from the field so that pasture production is not inhibited by shade from slash which may take several months to disintegrate.

2.5.2 Thinning

Thinning is an essential operation in radiata pine for the improvement of timber quality and understorey growth in silvopastoral systems by removing slow growing, malformed and diseased trees. It is also necessary to promote vigorous growth in trees by reducing competition for moisture, nutrients, solar radiation and space. This practice is also useful to increase wind firmness in trees, to reduce the amount of malformation and to create a favourable environment for understorey pastures. MacLaren (1993) suggested that thinning in radiata pine stands can be carried out in three stages of tree growth, which are in the early stages (at 3-6 years of age), late stages (at 10-16 years of age) and production thinning in the later stages. Early thinning is very cheap because trees are very small and easy to fell. In this operation, dead, dying, diseased and weak trees should be removed. However, early thinning well before pruning can be harmful to tree stands and understorey pastures, because this operation enhances branch growth. Therefore, early thinning and low pruning should be coordinated properly to reduce the branching problem in radiata pine trees.

Production thinning is also called thinning with extraction. Currently, thinning to waste is very common in New Zealand (MacLaren, 1993) because small logs have no potential market except near to pulp industries. Thinning to waste is harmful to understorey pastures because thinning slash inhibits pasture production by covering the ground. The risk of windthrow in radiata pine is very high after production thinning in those trees where tree height is greater than 18 meters (MacLaren, 1993). Therefore, production thinning should be carried out on the basis of tree form and height, and prevailing winds. The final stocking of radiata pine in silvopastoral systems should be determined on the basis of production objectives. If understorey pasture production is to be continued up to the end of forestry rotation, then 100-150 trees ha^{-1} should be left after thinning operations (Elliott, 1993). This will result in low timber production compared with 250-350 trees ha^{-1} final stocking. MOF and NZFRI (1996) reported that about 250-350 stems ha^{-1} final stocking at around age 26-28 years yielded between 500-750 m^3 ha^{-1} total volume.

2.5.3 Pasture management

Pine needles can smother parts of pasture areas and reduce productivity and feeding value of understorey pastures. Ideally pruning and thinning slash should be removed for better understorey growth and development. Another technique to improve pasture production under tree shade is to grow shade tolerant species. Devkota *et al.* (1997) reported that cocksfoot and subterranean clover are shade tolerant species compared with ryegrass and white clover.

Irrigation and fertisation are also equally important for the improvement of understorey production. However, these should not be applied in large amounts because radiata pine is susceptible to malformation and toppling in highly fertile soil. Animal grazing should be introduced in silvopastoral systems after 2-3 years of plantation establishment. Grazing is useful to control weeds, to improve access to the stand, to reduce fire hazards and to stimulate tree and pasture growth through recycling of plant nutrients. Percival *et al.* (1984a & c) and Percival *et al.* (1988) reported that improved grazing management and higher stocking rates improved the levels of dry matter productrion, but hard grazing usually changed the botanical composition of pastures by reducing the presence of preferred species such as clover. Korte *et al.* (1987) reported that grazing management must be focused to maintain pasture quality by avoiding extremes of pasture mass for long periods, especially over grazing following drought or allowing accumulation of rank pasture during spring and summer.

2.6 Summary

Agroforestry systems in New Zealand are practiced in both agricultural and pastoral farms. The main driving forces for this practice are the need for trees to protect agricultural and pastoral crops, livestock and farm houses from hot and cold wind, frost, snow and sunshine, and the diversification of income from the sale of timber. However, the future of silvopastoral systems in association with radiata pine is uncertain because pasture production under tree shade declines dramatically due to the reduction of pasture growth and development, and clover content. This is also responsible for the decline of livestock performance in silvopastoral systems.

Silvopastoral farming would be made more profitable by selecting appropriate pasture species, and by lowering the level of tree shade by adopting appropriate silvicultural regimes.

Cocksfoot seems to be an appropriate species in silvopastoral practice because this is a perennial grass suitable for pastures under tree shade in low to moderate soil fertility and low soil moisture. However, the productivity, feeding value and palatability of cocksfoot herbage is mostly affected by soil nutrients, water and grazing systems. Cocksfoot herbage becomes less palatable under lax grazing systems. When cocksfoot pasture is grazed lightly, the herbage becomes coarse and tufted which is less acceptable to grazing animals. Animals prefer to graze urine patches first due to the increase in height, green leaves, nutritional values and easy access.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This study was conducted in the Lincoln University agroforestry experimental area in Canterbury, New Zealand (43° 38'S and 172° 28'E). The area contains 36 plots of grasses and legumes, 18 in the understorey of radiata pine and 18 in open pasture (Appendix 3.1). For this study, the main experiment for the determination of pasture productivity and nutritive value was conducted in Plot 2A, Wana cocksfoot under radiata pine, and Plot 27 of cocksfoot in open pasture. The physical environment of these two plots was measured. Botanical composition of the nine-year-old cocksfoot pasture was assessed in Plots 2, 10 and 13 under radiata pine trees and Plots 24, 27 and 33 in open pasture. Supplementary studies compared dry matter production, nutritive value and grazing preference of sheep between urine and non-urine patches of Wana cocksfoot in Plots 2 and 2A of the agroforestry area, and in Plots 27 and 33 in open pasture.

3.1.1 Description of Lincoln University agroforestry experiment

The experiment design of the agroforestry study area is a split-plot randomised block design with six pasture species as the main plot treatment and five tree genotypes as the sub-plots (Mead *et al.,* 1993). The site was established in July 1990 to study the competition between radiata pine trees and understorey pasture species in a sub-humid temperate environment. The total area planted in trees is about 5.2 hectares (ha) with 18 plots of 42.0 x 46.2 m (0.194 ha) per plot. An additional adjacent 1 ha without trees has 18 pasture plots of 18 x 27.5 m. Trees were planted with 7 x 1.4 m initial spacing (1000 trees ha^{-1}) and were thinned to 200 stems ha^{-1} over the next 6 years. Tree rows were ripped to a depth of 50 cm before plantation establishment and hexazinone herbicide (Valpar at the rate of 2.5 kg a.i. per ha) was sprayed in a 1 m wide strip in the spring in 1990 and 1991. Pasture species were drilled on September 28 and October 2, 1990 (Table 3.1) in 6 m wide strips between tree rows.

Table 3.1. Pasture species combinations and radiata pine genotypes established at the Lincoln University agroforestry trial plot (from Mead *et al.*, 1993).

Main plots pasture species	Tree types of radiata pine sub plots
Maru phalaris (8 kg ha^{-1}) + clovers	Clone 1-Set 38/6 half sib of "850" clone 55
Wana cocksfoot (10 kg ha^{-1}) + clovers	Clone 2-Set 38/203 half sib of "850" clone 55
Yatsyn perennial ryegrass (13 kg ha^{-1}) + clovers	Clone 3-Set 11/8 full sib of "875" clones 7x 292
WL 320 lucerne (8 kg ha^{-1})	Clone 4-Set 38/9 half sib of "850" clone 55
Yatsyn perennial ryegrass (13 kg ha^{-1}) + clovers	Seedlings - "850" open pollinated seed (GF 14)

The five tree types differed in shape and size, but this did not result in obvious differences in shade patterns on pasture. Light and shade regimes on pasture under tree sub-plot treatments were therefore regarded as similar. Silvicultural operations altered the shading levels of the trees. Trees within the agroforestry experiment were thinned to 400 stems ha^{-1} in 1994 and pruned to maintain 3.5-4.0 m live crowns in January 1995. Trees were then thinned down to 200 stems ha^{-1} and pruned up to 6 m. However, the outer rows of radiata pine trees were not pruned or thinned. These unmanaged trees provided heavy shade to understorey pastures. Therefore, Plot 2A which is located in the agroforestry experiment was selected to study shading effects. Within this plot three levels of shade were identified: heavy (650 trees ha^{-1}), moderate (300 trees ha^{-1}) and light (200 trees ha^{-1}) shade shown in Plate 3.1.

3.1.2 Soil of the Lincoln University agroforestry experiment

Soil of the Lincoln University agroforestry experiment is classified as a Templeton silt loam (Haplustepts) which has 1-2 m of fine alluvial sediments over gravels. Kear *et al.* (1967) reported that this soil has medium to free drainage with a moderate capacity to retain moisture (320 mm in the top one meter). The soil becomes hard when dry. Yunusa *et al.* (1995b) reported high nutrient levels within the Lincoln University agroforestry experiment. The soil is considered as one of the most productive cropping soils in the Canterbury plains and is used for annual crops, ryegrass and white clover seed production and grazing. The Lincoln University agroforestry experiment area was cropped with peas (*Pisum sativa*) in the 1989/90 season.

3.1.3 Climate of the Lincoln University agroforestry experiment

The climate of the agroforestry experimental area is classified as a sub-humid temperate climate. The long term average rainfall was 666 mm with a winter maximum (Mead *et al.*, 1993). Weather conditions of this study site are described on the basis of meteorological data recorded at Broadfields meteorological station 3 km north of the site (Table 3.2). The potential evapotranspiration is almost twice the annual rainfall resulting in moisture limitations to pasture production in summer.

Table 3.2. Broadfields metrological data for rainfall, solar radiation, evapotranspiration, potential moisture deficit, air temperature, number of frosts and rainy days from January 1994 to December 1998.

Parameters	1994	1995	1996	1997	1998
Rainfall (mm)	535.9	540.2	555.9	557.3	382.0
Solar radiation ($MJ/m^2/yr$)	5219.1	5035.9	5258.4	5277.0	5331.0
Evapotranspiration (mm)	1037.3	997.3	1006.9	1023.3	1114.0
Moisture deficit (mm)	501.4	460.1	451.0	485.2	732.0
Mean of max. temp (°C)	16.6	16.5	16.5	16.6	17.7
Mean of min. temp (°C)	6.1	7.1	6.7	6.7	7.3
Mean of the year (°C)	11.1	11.5	11.4	11.3	12.3
Wind run (km/d)	314.9	322.7	305.3	309.5	314.4
Ground frost days	73	68	66	79	58
Screen frost days	42	37	28	38	26
Rainy days	138	141	146	125	121

During the experimental period from 9 February 1998 to 20 February 1999, rainfall was about 401 mm which was about 265 mm less than the long term mean. In addition, the potential evapotranspiration (1134 mm) was about 100 mm higher than in previous years. However, the number of frost days during the study period was less than average. The monthly climatic data of the Lincoln University agroforestry experiment is described in the following section.

3.1.3.1 Solar radiation and wind

The intense sunshine, and hot and dry northwest winds are responsible for the high evapotranspiration rate in the Canterbury plains during summer and early autumn (Figure 3.1). The prevailing wind direction is north-easterly but the drying winds come from northwest. In contrast, about 80% of rain bearing wind comes from the south or south-west direction.

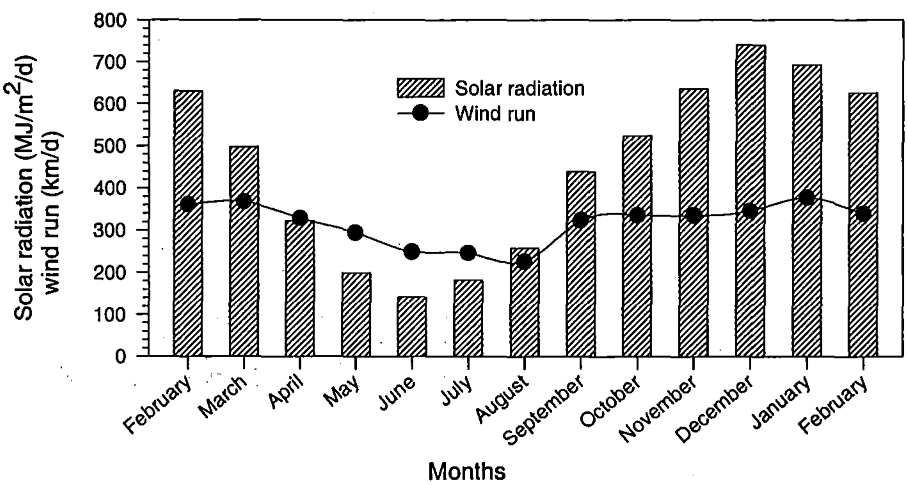

Figure 3.1. Solar radiation and wind run measured at Broadfields meteorological station at Lincoln from 1st February 1998 to 28th February 1999.

Both monthly solar radiation levels and daily wind run were lower between May, and August compared with other months.

3.1.3.2 Temperature

Mean winter (June, July and August) air and soil temperatures are about near the minimum required for growth of most pasture species (Figure 3.2). Both soil and air temperature influence a plant's growth and development. In the five coldest months from May to September, air temperature was about 0.5°C higher than soil temperature.

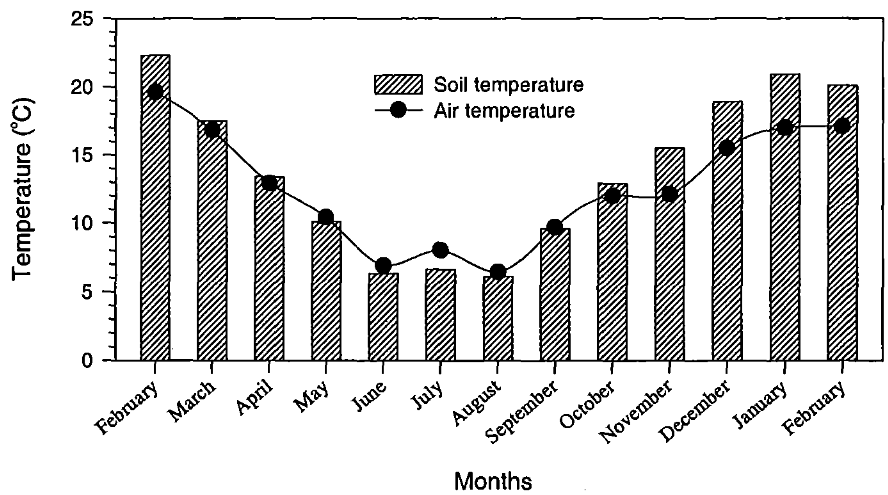

Figure 3.2. Mean soil temperature at 100 mm soil depth and air temperature measured at Broadfields metrological station at Lincoln from 1st February 1998 to 28th February 1999.

3.1.3.3 Potential moisture deficit

The monthly rainfall, evapotranspiration and potential moisture deficit recorded at Broadfields is presented in Figure 3.3.

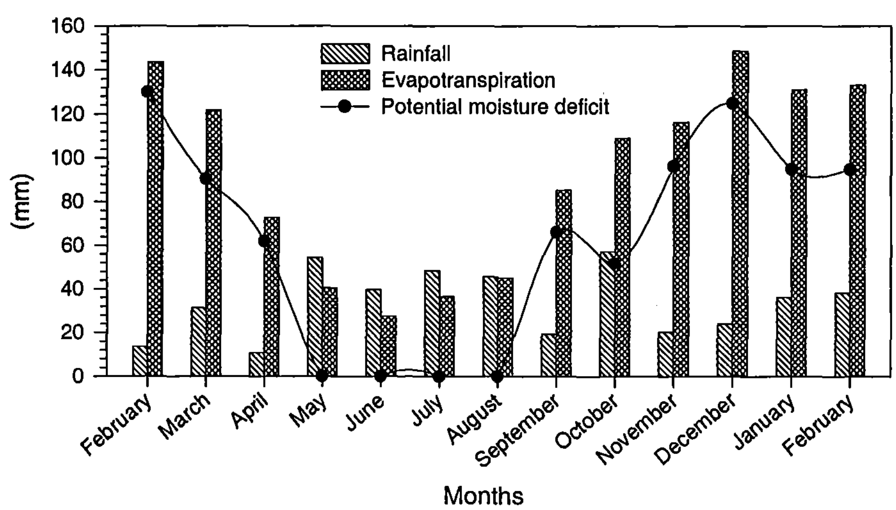

Figure 3.3. Rainfall, evapotranspiration and potential moisture deficit measured at Broadfields meteorological station from 1st February 1998 to 28th February 1999.

Figure 3.3 shows that there was a high potential moisture deficit in all months except in May, June, July and August. However, values for agroforestry site would differ from those reported because trees intercept rainfall, and shade disturbs the distribution of solar energy and reduces wind speed and evapotranspiration rates.

3.2 Experiment design

The experiment was randomised split-plot design with three levels of shade under trees as main plots and ± water applied to cocksfoot cv Grasslands Wana pasture areas with or without sheep urine patches as sub-plots in each of three blocks. In adjacent open cocksfoot pasture of the same age, four sub-plots were randomly assigned to each of three blocks. Measurements are described below.

3.2.1 Pasture productivity and nutritive value measurement

In agroforestry plot, measurements were made under three levels of shade and subplots supplied with ± water and ± sheep urine. In adjacent open cocksfoot pasture of the same age, four sub-plots (± water and ± urine) were randomly assigned to each of three blocks. Thus, within blocks there were four sub-plots in each of the three tree environments giving 12 sub-plots per block (Figure 3.4). The treatments were established as follows.

- Urine ± by visually selecting urine patches at least 2 or 3 weeks after grazing for each subsequent measurement period.

- Water ± (rainfall versus rainfall + irrigation to provide evapotranspiration replacement) at 7 day intervals depending on the potential evapotranspiration report from the previous week at Christchurch and Broadfields meteorological station. Rainfall data was recorded at the Broadfields meteorological station and Field Service Centre of Lincoln University (about 2 km from the site).

Block 1		Block2		Block 3	
650 trees ha^{-1}		**650 trees ha^{-1}**		**650 trees ha^{-1}**	
N	W	W	N	W	U+W
U	U+W	U+W	U	N	U
300 trees ha^{-1}		**300 trees ha^{-1}**		**300 trees ha^{-1}**	
N	W	U	U+W	W	N
U	U+W	N	W	U+W	U
200 trees ha^{-1}		**200 trees ha^{-1}**		**200 trees ha^{-1}**	
W	N	N	U+W	U+W	U
U+W	U	U	N	N	W
		Open pasture			
N	U+W	U	N	U+W	U
U	W	W	U+W	N	W

Figure 3.4. Layout of sub-plots under three levels of tree shade and in adjacent open pasture (N= Nil, U= Urine, W= Water and U+W= Urine plus water).

Groups of four sub-plots were selected for pasture uniformity, lack of weeds and strongness of urine patches for each of the five harvest periods. Grass in the sub-plot areas was then trimmed to about 15 mm height above the ground level by hand (Plate 3.2). The size of sub-plots was $0.1m^2$. These plots were marked by colour pegs for each treatment.

Water was applied by hand (watering can) as required to meet the potential moisture deficit. The amount of water applied in each treatment was calculated on the basis of 1 mm rain being equivalent to 1 litre of water on $1m^2$ (10 mm /$0.1m^2$) and is outlined in Table 3.3.

Plate 3.1. Three levels of tree shade: heavy, medium and light shade from left side to right sunny zone in Plot 2A at the Lincoln University agroforestry experiment illustrating the 18%, 40% and 67% PPFD environments.

Plate 3.2. Sub-plot (0.1 m^2) pre-trim establishment in open pasture on 1st November 1998.

Table 3.3. The evapotranspiration, rainfall, potential moisture deficit, water applied and number of irrigations during the five 30 day growing periods from February 1998 to February 1999.

Pasture production periods	Evapo-transpiration (mm)	Rainfall (mm)	Moisture Deficit (mm)	Water Applied (mm)	Number of irrigations
15 Feb-14 March	123	27	96	100	4
15 May-14 June	29	38	-	10	1
15 Aug-14 Sept	61	43	18	20	2
1-30 November	112	18	94	100	4
21 Jan–20 Feb.	147	22	125	130	4
Total	472	148	333	360	15

Water was applied at one week intervals on the basis of potential moisture deficit of the previous week. The potential moisture deficit of the last two days was not included for the calculation of required amount of water because potential moisture deficit data was not available for this period. In June, there was no moisture deficit, but 10 mm water was applied to cover moisture deficit of the first week of experiment establishment in May 15, 1998 and the evapotranspiration during that period was 9.1 mm. The herbage was harvested 30 days after plot establishment. After the first harvest, new positions were selected within each block for the next rotation rather than repeated harvests on the same sites. Methods used for the measurement are described in following section.

3.2.1.1 Dry matter production

The dry matter production of 30 days old cocksfoot herbage was determined from five harvests. A quadrat measuring 0.1 m^2 was used and herbage was cut at 15 mm above ground level and this dried for a period of 48-62 hours in a forced draft oven at 65^0C. Dry weight of herbage was recorded. Samples were bulked and stored for nutritive value analysis.

3.2.1.2 Cocksfoot canopy height

The canopy height of 30 day regrowth cocksfoot tillers was determined before herbage harvesting. A sward height stick and measuring scale (ruler) were used. While measuring tiller heights, the reproductive tillers were ignored. Height of ten randomly selected tillers was taken in each sub-plot and the mean value recorded.

3.2.1.3 Grass density

The mean density of cocksfoot grass was determined by dividing the dry matter production (mg/m^2) by its height.

$$\text{Mean pasture bulk density (mg DM/cm}^3) = \frac{\text{Dry matter production (mg/m}^2)}{\text{Pasture volume (cm}^3)}$$

$$= \frac{\text{g DM/m}^2 \times 1000}{(1\text{ m}^2 \times 10{,}000 \times \text{pasture height (cm)}}$$

3.2.1.4 Vegetative tiller population

The vegetative tiller number was counted within 7-10 days after each herbage harvest. A 0.025 m^2 quadrat was placed in the middle of 0.1 m^2 sub-plot and the tiller numbers counted.

3.2.1.5 Reproductive tiller population

Reproductive tiller numbers of Wana cocksfoot, both in the understorey of radiata pine and open pasture, were measured in November, 1998 by using a 0.1 m^2 quadrat on the plots established for the fourth harvest of herbage.

3.2.1.6 Cocksfoot leaf populations, shape and size

The shape and size of cocksfoot leaves grown under both agroforestry and open pasture were determined prior to the five harvests. The length and width of 10 first and second leaves were measured and the mean value recorded. The width of leaves were measured to the nearest mm at the mid-point of a leaf blade length. Leaves of 10 tillers were also counted and the mean value recorded. Pseudostem length of cocksfoot tillers was estimated from by subtracting leaf blade length from tillers heights. The leaf blade length was measured in March, June, September and November 1998 and February 1999 and tiller leaf populations and leaf width was measured in September and November 1998, and February 1999.

3.2.1.7 Nutritive value

Organic matter digestibility, nitrogen and metabolisable energy were determined for samples from each harvests. This work was undertaken by the Animal and Veterinary Science Group, Lincoln University, Canterbury New Zealand.

3.2.2 Physical environments measurements

The main aim of this part of the study was to quantify the shade levels and their effects on solar radiation distribution, soil temperature and moisture in agroforestry plots. These measurements were carried out in Plot 2A agroforestry and in Plot 27 open pasture. The photosynthetic photon flux density (PPFD), soil temperature and moisture were measured for one year starting from July and August 1998. Tree height and diameter, and soil nutrients were measured only in February 1999.

3.2.2.1 Tree height and diameter

Tree height and crown length were measured by a hypsometer, while diameter at 1.4 m height was measured with diameter tape.

3.2.2.2. Soil nutrients analysis

Soil samples from trial plots were analysed to determine the effect of trees and pastures on soil nutrient availability. 12 to 24 soil cores to 75 mm depth were taken from the trial areas depending on plot size. Cores in three levels of tree shade areas (Plot 2A) were taken at random. Cores in other 6 plots were taken along the line transects used for the seasonal measurement of pasture cover. The stock camps near the road in open pasture (Plot 24 and 33) were not sampled. Soil samples were taken at 2 m intervals along the line transects and tested in the New Zealand Pastoral Agriculture Research Institute Limited at Ruakura for pH, Ca, K, P, Mg, Na and S (Table 3.4).

Table 3.4. Soil nutrient levels of experimental sites.

Environments	pH	Ca	K	P	Mg	Na	S
Plot 2A heavy shade	5.8	6	24	12	24	14	9
Plot 2A medium shade	5.9	7	18	14	28	10	5
Plot 2A light shade	5.8	6	16	18	23	13	6
Plot 2 agroforestry	5.7	6	22	16	19	10	6
Plot 10 agroforestry	5.8	8	19	16	27	13	6
Plot 13 agroforestry	5.8	8	27	20	22	12	9
Plot 24 open pasture	5.8	10	7	11	28	12	3
Plot 27 open pasture	6.0	8	23	15	27	11	4
Plot 33 open pasture	6.0	10	17	8	30	14	4

Table 3.4 shows that sulphur under trees appears greater than in open pasture. Phosphorus is in satisfactory level in all plots except in Plot 33 open pasture. Potassium is high in all plots except Plot 24 open pasture. Calcium and pH levels are marginally higher in open pasture than under trees. Magnisium and sodium levels are satisfactory in all plots.

3.2.2.3 Photosynthetic photon flux density

The ambient photosynthetic photon flux density of the three shade zones in Plot 2A agroforestry and Plot 27 open pasture was measured using a Decagon linear quantum sensor ceptometer (Plate 3.3). This work was carried out at one month intervals over a year during clear sunny days. In May, June, July and August, the PPFD was recorded from 9 am to 4:30 pm, in September and April from 8 am to 5 pm and in other months from 8 am to 6 pm at one hour intervals. While measuring the PPFD, four readings were taken from each block of a shade zone and the average value recorded. The daily PPFD (moles/m^2/s) was calculated as the area under PPFD vs time of day (measured in seconds) curve. Thus,

$$\text{Daily PPFD} = \frac{\text{Mean PPFD } (\mu \text{ moles/m}^2\text{/s}) \times \text{hours of daylight} \times 3600}{1000{,}000}$$

3.2.2.4 Soil temperature

Soil temperatures of both agroforestry and open pasture under irrigation and unirrigated environments were measured by using an electrical resistance meter. Wave guide stainless steel wires were installed permanently at 100 mm soil depths in each block of three shade levels under trees (Plate 3.4) and in open pasture. The soil temperature was measured once a day at two week intervals. The first reading for the month was taken between 11 to 11:30 am and the second between 3 to 3:30 pm. The mean monthly values were calculated. Irrigation was applied on the basis of per week potential moisture deficit measured in Broadfields meteorological station (Table 3.5) to measure the effect of irrigation on soil temperature.

Table 3.5. Water applied to meet per week potential moisture deficit in irrigated cocksfoot pasture where soil temperature and moisture was being measured at 14 days intervals from August 1998 to July 1999.

Months	Evapotranspiration (mm)	Rainfall (mm)	Potential moisture deficit (mm)	Water applied (mm)
August	43	46	0	20
September	95	19	76	70
October	118	57	61	37
November	116	20	96	96
December	142	24	118	118
January	129	14	114	114
February	133	38	95	120
March	107	56	52	85
April	60	36	24	20
May	70	23	47	45
June	29	69	-	-
July	27	135	-	5

Plate 3.3. Photosynthetic photon flux density being measured under 200 trees ha^{-1} zone in August 1998.

Plate 3.4. Permanent plots (0.1 m^2) for soil temperature and moisture measurement in Plot 2A agroforestry. Black tubes indicate location of permanent measurement sites in 18% and 40% PPFD environments.

3.2.2.5 Soil moisture

The volumetric water content in soil, expressed as a percentage of both agroforestry and open pasture under irrigation and non-irrigated environments at 300 mm soil depth, was measured by Time Domain Reflectometry (TDR). A model 6050X1 Trase system was employed and gave a volumetric water content in the soil. Metal wave guides, made up of stainless steel were permanently installed in each replicate (3 in each zone) of agroforestry shade zones (Plate 3.4) and in open pasture to measure soil moisture. The amount of water applied to irrigated plots is presented in Table 3.5. The soil moisture was assessed at two week intervals 3-4 days after irrigation. The first reading for the month was taken between 11 to 11:30 am and the second between 3 to 3:30 pm. The mean monthly values were calculated and presented.

3.2.3 Botanical composition measurement (% cover)

The cocksfoot plus clover pasture cover was measured in three replicates both in agroforestry and open pasture. This was assessed using permanent line transects (3 lines per plot) in April (autumn), July (winter), October (spring) and December (summer) 1998. The aim was to describe the cover of nine-year-old cocksfoot plus clover pastures grown under radiata pine (Plots 2, 10 and 13) and in open pasture (Plots 24, 27 and 33) over four seasons. The components of pasture cover recorded were cocksfoot, white clover, subterranean clover, weeds, dead material, including pine needles, and bare ground. This study was carried out by visual estimation within 0.025 m^2 circular quadrats placed at 1 m intervals along the transect lines. The line transects ran in a north-south direction under trees and east-west in open pasture. The first sub-plot was established by leaving 1 meter in each boundary line of the main plot. Tree lines were 28 m long with 26 points recorded for each of three row sub-plots and open pasture line was 18 m long with 16 points of measurement.

3.2.4 Supplementary study

A supplementary investigation aimed to measure pasture production, nutritive value and grazing preference of sheep in cocksfoot pasture of 32 and 52 days regrowth grown as an understorey of radiata pine or in the open. This study was conducted in July, October and December, 1998. The experiment design was randomised split-plot design with two plots in both agroforestry (Plot 2 and 2A) and open pasture (Plot 27 and 33). In both agroforestry and open pasture, ten urine patches and corresponding adjacent areas designated "non-urine patches" were selected randomly by using 0.025 m^2 quadrat. Sward height was measured prior to all harvests by using a sward height stick and measuring scale (ruler). Out of 10 urine and corresponding non-urine patches, five patches in both urine and non-urine patches were harvested for the measurement of dry weight and nutritive value before grazing started. The sward height of the remaining five urine and five non-urine patches were measured daily during grazing for the determination of grazing preference by sheep.

3.2.4.1 Dry matter production

Dry matter productivity of five urine and non-urine patches of 32 (July) and 52 days regrowth of Wana cocksfoot grown on understorey of radiata pine and open pasture was determined as described in Section 3.2.1.1.

3.2.4.2 Cocksfoot canopy height

Height of cocksfoot sward in both urine and non-urine patches grown under radiata pine and in open pasture was measured by using a sward height stick and ruler as described in Section 3.2.1.2.

3.2.4.3 Analysis of nutritive value

Samples for dry matter measurement were used for analyses nutritive value. These samples were ground and bulked urine and non-urine samples seperately. Reproductive tillers and flowers were also ground with the sample to determine how the reproductive tillers and flowers affect the nutritive value of cocksfoot. Chemical analysis of organic matter digestibility, nitrogen and metabolisable energy were performed. This work was undertaken by the Animal and Veterinary Science Group, Lincoln University, Canterbury, New Zealand.

3.2.4.4 Grazing preference of sheep

The study of grazing preference by sheep on urine and non-urine patches was carried out in 1998 (July for 4 days, October for 9 days and December for 8 days). The first measurement from Plot 2A agroforestry and Plot 27 open pasture, while the second and third grazing used Plots 2 and 2A agroforestry and Plots 27 and 33 open pasture. Sward height was assessed prior to the introduction of sheep into pasture plots. The number of sheep was calculated on the basis of pasture mass of each grazing plot. In the first grazing five 11 month old ewe hoggets were allocated to Plot 27 open pasture and 11 sheep in Plot 2A agroforestry. In the second experiment, five 13 month old sheep were grazed in Plot 27 and five grazed in Plot 33 in open pasture, while 16 sheep grazed Plot 2 and 8 grazed Plot 2A agroforestry. The third grazing was carried out with 15 month old sheep, 8 sheep in open pasture and 37 in agroforestry plots. The decline of pasture height was measured daily using sward height stick and measuring scale (ruler) at 4 to 5pm in July and 7 pm in October and December on each day.

3.3 Statistical analysis

Data from this study was analysed by using the linear model routines in Genstat 5 4.1. Mean values of each treatment within and between harvests were used for the comparison of productivity and nutritive value of Wana cocksfoot grown in understorey of radiata pine and open pasture. Standard error of means (SEM) or standard error of differences (SED) and least significant difference (LSD) values were calculated to find out significant differences between means of different treatments, shading levels and harvests. Similar statistical procedures were used to analyse data collected from physical environment measurements, botanical composition assessment of nine-year-old cocksfoot plus clover pasture and supplementary study on productivity, feeding value and grazing preference of sheep in 32 and 52 day regrowth urine and non-urine patches grown on understorey of radiata pine and open pasture. In the case of nutritive value, there was no replicate due to bulking of samples. Therefore, higher-order interaction terms were used as an estimate of the residual mean squares.

CHAPTER FOUR

RESULTS

4.1 Introduction

Section 4.2 describes the measurement of the physical environment of the experimental site. Section 4.3 deals with the botanical composition of the nine-year old cocksfoot plus clover pasture and Sections 4.4, 4.5 and 4.6 present data of the cocksfoot pasture productivity, nutritive value and grazing preference of sheep, respectively. A summary of the statistical analyses showing p-values of main effects and interactions is presented in Appendix 4.1. The tables of means and least significant difference values used to compose figures in this chapter are presented in Appendix 4.2.

4.2 Experimental site

Data of tree height and diameter, solar radiation, soil temperatures and moisture levels were used to quantify the four physical environments where cocksfoot dominant pastures were assessed.

4.2.1 Tree populations

Tree height was not affected by the tree population nine years after planting (Table 4.1). However, tree diameter, measured at a tree height of 1.4 meters above ground, was reduced ($p < 0.01$) in the 650 trees ha^{-1} compared with the 200 and 300 trees ha^{-1}.

Table 4.1. Tree height, diameter and crown length under different tree populations in February 1999.

Measurements	Zone 1	Zone 2	Zone 3	SED	lsd at $p < 0.05$
Trees/zone	19	7	14	--	--
Area (m^2)	292	233	700	--	--
Trees ha^{-1}	650	300	200	--	--
Tree height (m)	11.11	11.42	11.43	0.500	1.390
Tree diameter (m)	0.19	0.24	0.25	0.012	0.033
Pruning height (m)	No pruning	5.91	6.12	0.390	1.678
Crown length (m)	10.41	5.51	5.31	0.280	0.777

Crown length of the trees at 650 trees ha^{-1} was significantly higher than the crown length of the trees at 300 and 200 trees ha^{-1}. In this heavily shaded zone, the effect of tree shade on light interception, soil temperatures and soil moisture content was large compared with the other two agroforestry zones. Details of these differences are given in Sections 4.2.2, 4.2.3 and 4.2.4.

4.2.2 Photosynthetic photon flux density

There was a seasonal variation in solar radiation transmission under radiata pine trees and in the open pasture and the interaction between months and tree shade was significant (Figure 4.1). The lowest PPFD in open pasture was measured in July and under trees in June, and the highest was in December in all shade levels.

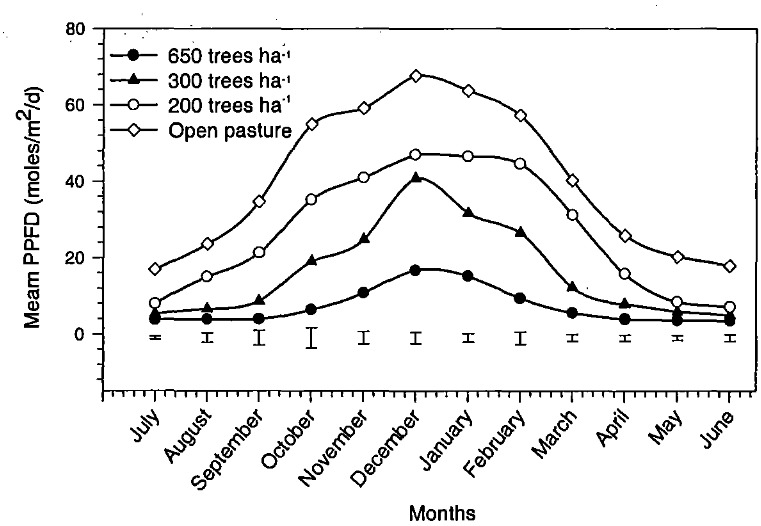

Figure 4.1. Photosynthetic photon flux density (PPFD) under three levels of tree shade and in the adjacent open pasture from July 1998 to June 1999 (Bars = lsd for interaction: months x shade p <0.05).

The PPFD in all shade regimes rose from September, with a peak in December. Open pasture in September intercepted 34.6 moles/m^2/d PPFD which was 9.6, 4.5 and 1.7 times higher than in 650, 300 and 200 trees ha^{-1}. In December the PPFD was 4.0, 1.7 and 1.4 times more in open pasture (67.7 moles/m^2/d) than in 650, 300 and 200 trees ha^{-1}, respectively. After February, the ambient PPFD under 650, 300 and 200 trees ha^{-1} and in open pasture declined to be 3.5, 5.0, 7.2 and 17.9 moles/m^2/d respectively in June. Table 4.2 shows the differences ($p < 0.001$) in the mean daily solar energy transmission caused by tree shade, giving four distinct light environments (18, 40, 67 and 100% of PPFD in open pasture.

Table 4.2. Mean daily photosynthetic photon flux density (PPFD) under four shade levels from July 1998 to June 1999.

Research plots	PPFD (moles/m^2/d)	% compared with open pasture
650 trees ha^{-1}	7.2	18
300 trees ha^{-1}	16.2	40
200 trees ha^{-1}	26.8	67
Open pasture	40.2	100
SED	1.44	--
lsd at $p < 0.05$	4.58	--

The daily PPFD transmission pattern in three levels of tree shade and in open pasture for cocksfoot pastures on 18th November is presented in Figure 4.2. Under 650 and 300 trees ha^{-1} the highest PPFD was intercepted at 3 to 4 pm compared with between 12-2 pm for the open pasture and the 200 trees ha^{-1} zone. In addition, light transmission in the 650 and 300 trees ha^{-1} environments was negligible until about mid-day.

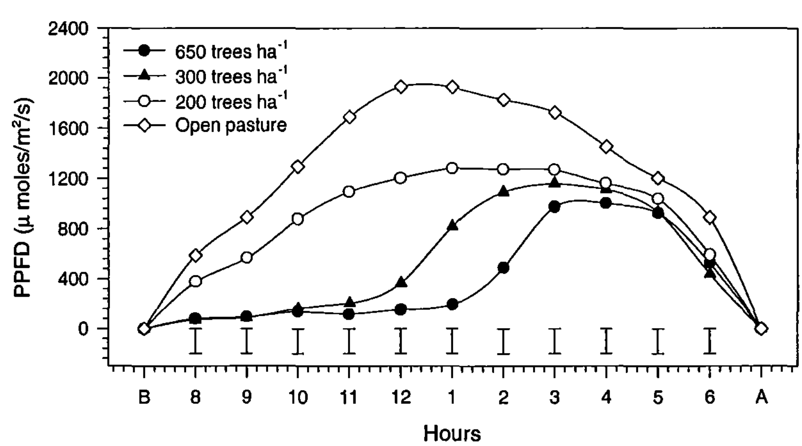

Figure 4.2. Photosynthetic photon flux density (PPFD) under three levels of tree shade and in open pasture on 18th November 1998 from before sunrise (B) and after sunset (A): Bars = lsd at $p < 0.05$.

The daily PPFD measured from July 1998 to June 1999 is presented in Appendix 4.3. This shows the open pasture intercepted more than 1500 µ moles/m^2/s PPFD from October to February from 11 am to 3 or 4 pm. In contrast, the level was only exceeded from December to February from 2 to 3 pm in the 200 and 300 trees ha^{-1}.

4.2.3 Soil temperature

Season had the greatest effect on soil temperature at 100 mm soil depth in all light regimes (Figure 4.3). For example, the highest soil temperature was measured in January in unirrigated plots which was 16.6°C under 18% PPFD, 19.1°C under 40% PPFD, 20.5°C under 67% PPFD and 21°C in open pasture. In contrast, the lowest soil temperature was measured in August 1998. This was less than 5°C in all PPFD pastures under both irrigated and unirrigated plots. The monthly mean soil temperature under 18% and 40% PPFD was significantly lower from October to March than in open pasture in both the irrigated and unirrigated plots.

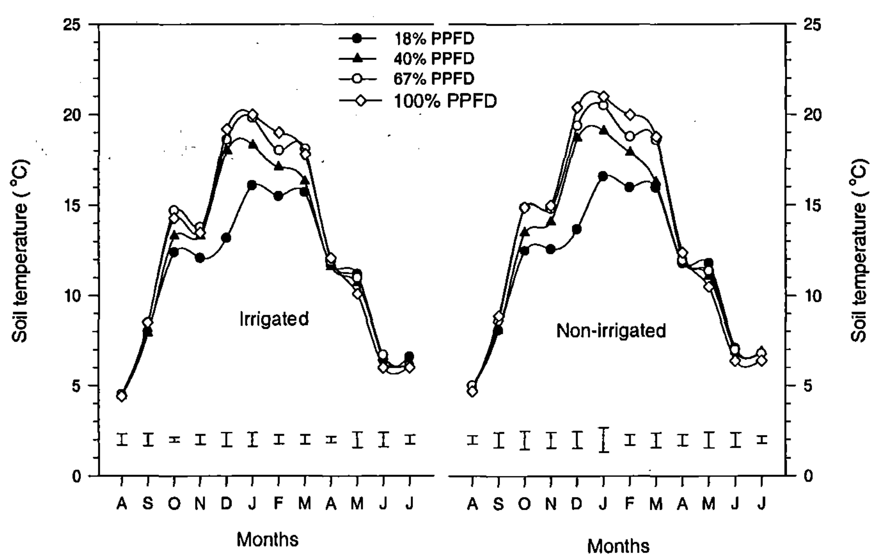

Figure 4.3. Mean soil temperature at 100 mm soil depth under four light regimes from August 1998 to July 1999 (Bars = lsd at <0.05).

Compared with open pastures, soil temperature in non-irrigated areas under 18%, 40% and 67% PPFD was 5.1°C, 1.9°C and 0.9°C less in summer (December to February) and 0.5°C, 0.4°C and 0.5°C higher in winter (June to August), respectively. The mean soil temperature under irrigation was always less than the non-irrigated and a significant difference was found ($p < 0.01$) from November to February in both open pasture (1.2°C less) and under moderate tree shade (0.8°C less).

4.2.4 Soil moisture

Figure 4.4 shows the greatest effect of season ($p < 0.001$) on soil moisture at 0-300 mm soil depth under the four light regimes. The volumetric water content (VWC) under 18% PPFD was lower than in other light regimes from April to November in irrigated and non-irrigated conditions. Also from December to February, VWC at 18% PPFD was higher than in open pasture. Under 40% to 67% PPFD VWC was higher (0.8-1.4%) in December and January, but lower (1.4°C) in March to May than in open pasture.

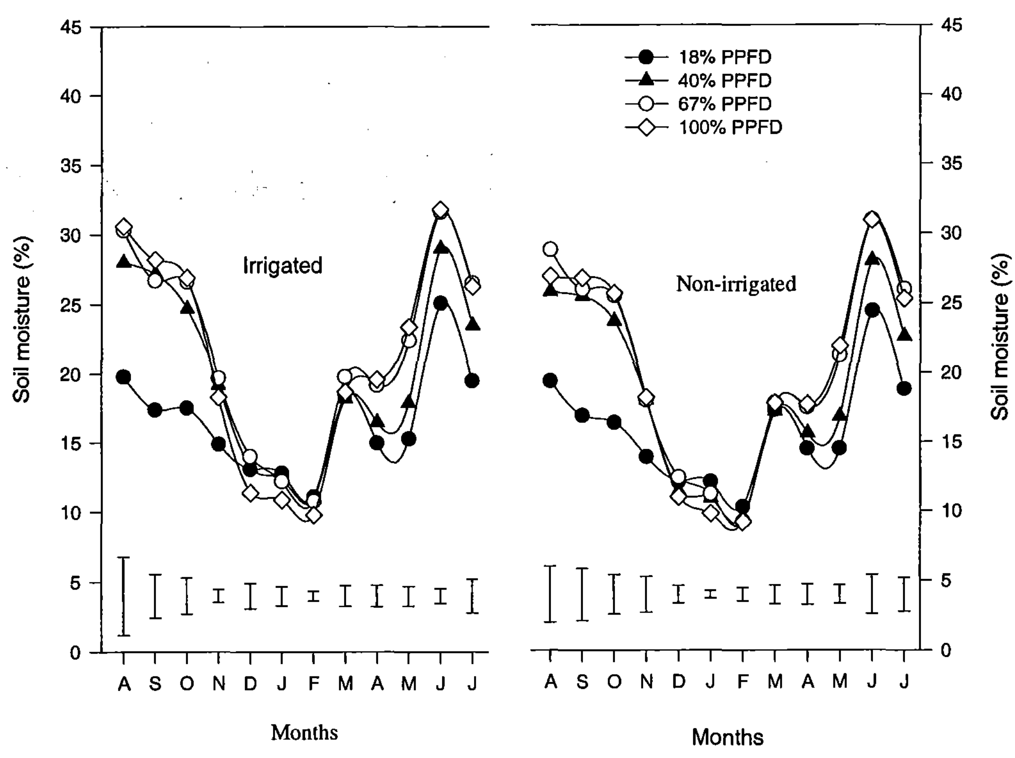

Figure 4.4. Soil moisture at 0-300 mm soil depth under four light regimes from August 1998 to July 1999 (Bars = lsd at p <0.05).

The highest VWC was recorded in June in all shade regimes and was 24.4% under 18% PPFD, 28.0% under 40% PPFD, 30.9% under both 67% and 100% PPFD. The lowest VWC (<11.1%) was found in February in both irrigated and non-irrigated conditions. Irrigation to meet current potential moisture deficits in summer (December to February) under 40% to 67% PPFD increased the soil moisture by 1.3% and in open pasture by 0.8% compared with non-irrigated plots.

4.3 Botanical composition

The mean botanical composition (% cover) of open and agroforestry pastures over four seasons was over 74% cocksfoot (Figure 4.5). The cocksfoot content, expressed as percentage cover, was 9% more ($p < 0.001$) in open pasture than in the main agroforestry treatment (67% PPFD). In contrast, the clover cover under trees and in open pasture was less than 7%. The subterranean clover cover was higher ($p < 0.05$) under trees compared with in full sunlight. Within a 1 m radius of trees both cocksfoot and clover cover on the north side was 7% and 2% less respectively compared with the south side of the trees.

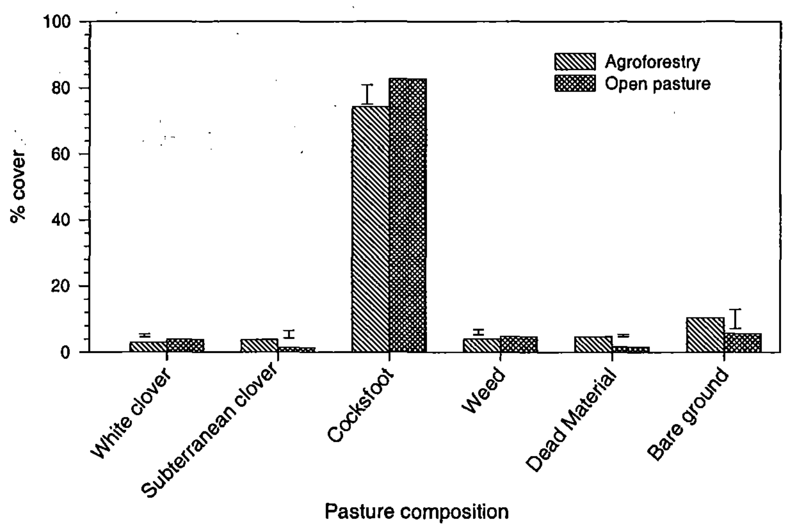

Figure 4.5. Mean botanical composition and bare ground cover % over four seasons in cocksfoot plus clover pasture under trees and in adjacent open pasture (Bars = lsd at p < 0.05).

Bare ground was 4% higher under trees compared with open pasture (6%). Both annual and perennial weeds were recorded in the agroforestry plots and in open pasture. These included *Poa annua*, *Viola arvensis* (field pansy), *Rumex obtusifolius* (dock), *Polygonum aviculare* (wireweed), *Achillea millefolium* (yarrow) and *Agropyron repens* (couch). Finally, the open pasture had 2% dead material cover compared with 5% dead material under trees.

4.3.1 Seasonal changes in pasture composition

All components of pasture cover varied with seasons both in agroforestry and open pasture (Table 4.3). The combined white and subterranean clover content ranged from 2% in April to 11% in October and December under 67% PPFD (20% clover cover in Plot 2 main agroforestry plot in October). Cocksfoot cover under 67% PPFD was about 74% in all seasons compared with 83% in open pasture.

Table 4.3. Seasonal changes in pasture composition in both agroforestry (AF) and open pasture (OP).

Covers	Areas	April (%)	June (%)	October (%)	December (%)	SED	lsd at $p < 0.05$
Cocksfoot	AF	73.7	76.3	73.1	74.2	1.19	2.59
	OP	81.3	83.0	83.7	83.0	1.19	2.59
White clover	AF	1.0	2.0	4.0	4.7	0.29	0.63
	OP	2.0	3.0	5.3	5.0	0.29	0.63
Subterranean clover	AF	1.0	1.0	6.9	6.1	0.67	1.46
	OP	1.0	1.0	1.6	1.7	0.67	1.46
Weeds	AF	2.0	4.0	5.3	4.7	0.78	1.70
	OP	3.7	6.7	4.7	4.0	0.78	1.70
Dead material	AF	7.7	5.0	2.7	3.3	0.62	1.35
	OP	2.3	1.0	1.0	2.3	0.62	1.35
Bare ground	AF	14.6	11.7	8.0	7.0	1.09	2.37
	OP	9.7	5.3	3.7	4.0	1.09	2.37

In April and June, the dead material content in the agroforestry pasture was higher ($p < 0.05$) due to the increase in pine needles and dead cocksfoot leaves compared with October and December. Weed cover was higher in June in open pastures compared with other months, but more bare ground in both agroforestry and open pasture was noted in April.

4.4 Pasture production

There was an interaction between seasons, shade and treatments (± water and ± urine) for cocksfoot dry matter production (Figure 4.6). In February, March and June, cocksfoot pasture production was not affected by light levels for the nil and urine treatments. However, there was an increase in dry matter production when light levels increased from 18% to 40% PPFD in the water and urine plus water treatments. There was no further increase from 40% to 100% PPFD. In contrast, the dry matter production response to increased light was generally linear from 18% to 100% PPFD in September and November.

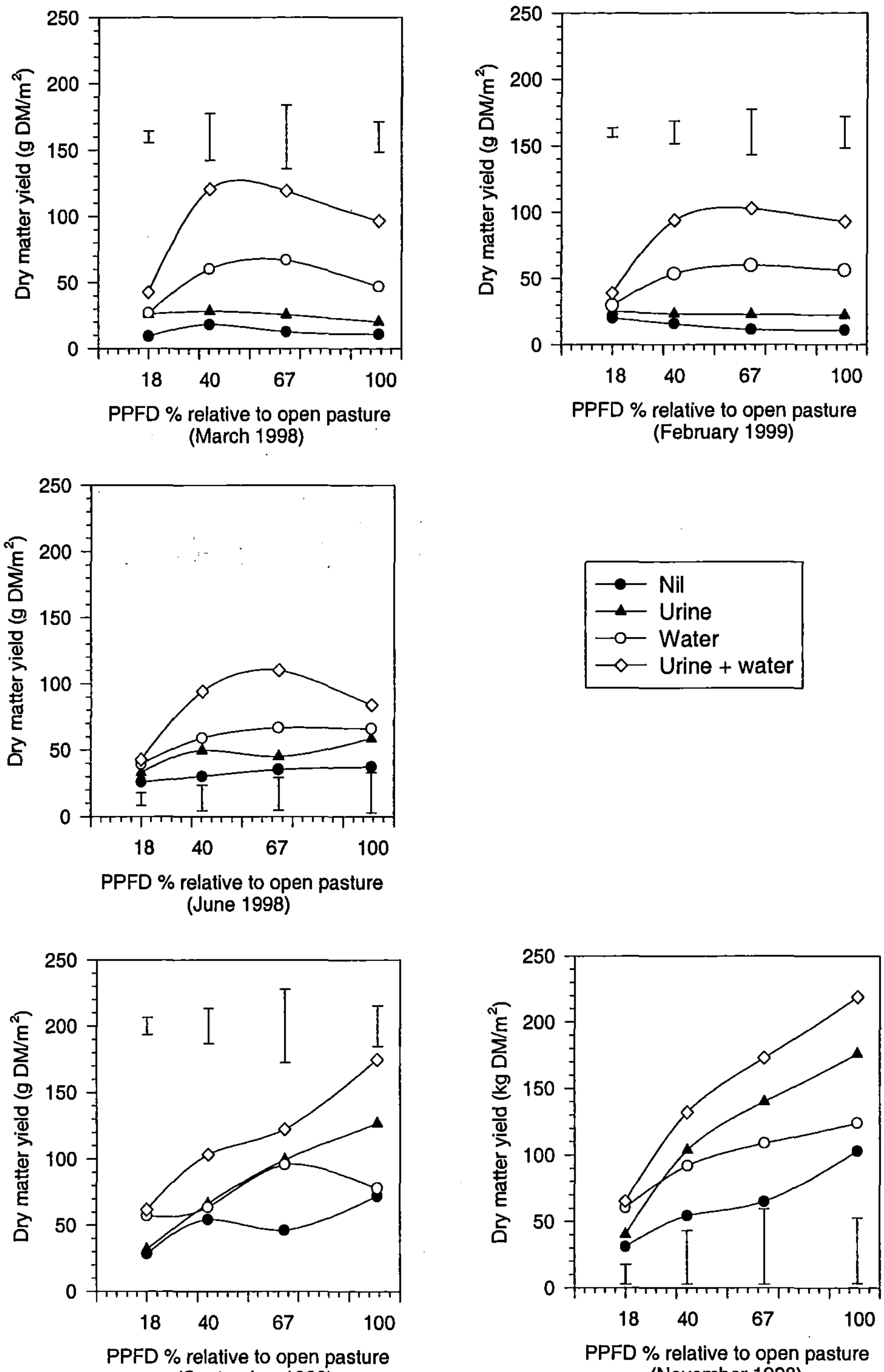

Figure 4.6. Mean dry matter yield of Wana cocksfoot pasture from five harvests under four light regimes in four treatments (Bars = lsd for interaction: seasons x shade and treatments p <0.04).

In all seasons, pastures receiving both urine and water produced the highest dry matter yield (Plate 4.1) and the nil treatment the lowest yield. However, in March, February and June the water only treatment out yielded the urine only treatment with the reverse true in November at 40 to 100% PPFD. Thus, the highest yield (219 g DM/m^2) was achieved for spring pasture receiving urine plus water in the open and the lowest (9 g DM/m^2) from the nil treatment in March under 18% PPFD.

The mean pasture production rate in open pasture from five harvests in non-irrigated urine and non-urine patches was 2.13 g DM/m^2/d which was 57%, 30% and 21% higher than under 18%, 40% and 67% PPFD. Under irrigation, this was 3.47 g DM/m^2/d, which was 55%, 16% and 1% higher than in 18%, 40% and 67% PPFD zones respectively. The differences were significant between open pasture, and under 18% and 40% PPFD zones.

4.4.1 Vegetative tiller population

There was an interaction between seasons, shade and treatments (± water and ± urine) for vegetative tiller population in cocksfoot pastures (Figure 4.7). In all seasons, the number of tillers increased with increasing light levels. However, for the nil treatment in September and November the increase only occured between the 18% and 40% PPFD light levels. The number of vegetative tillers produced was highest for the urine only, water only, and combined urine plus water treatments in 100% PPFD pasture in September or November. The maximum for the nil treatment was about 5000 tillers/m^2 in open pasture in all seasons. The minimum number of vegetative tillers (3200 tillers/m^2) was similar for all treatments under 18% PPFD in March, June and February.

Finally, the mean vegetative tiller population of open pasture from five measurements under four treatments was 5500 tillers/m^2, which was 39%, 18% and 12% higher than under 18%, 40% and 67% PPFD zones.

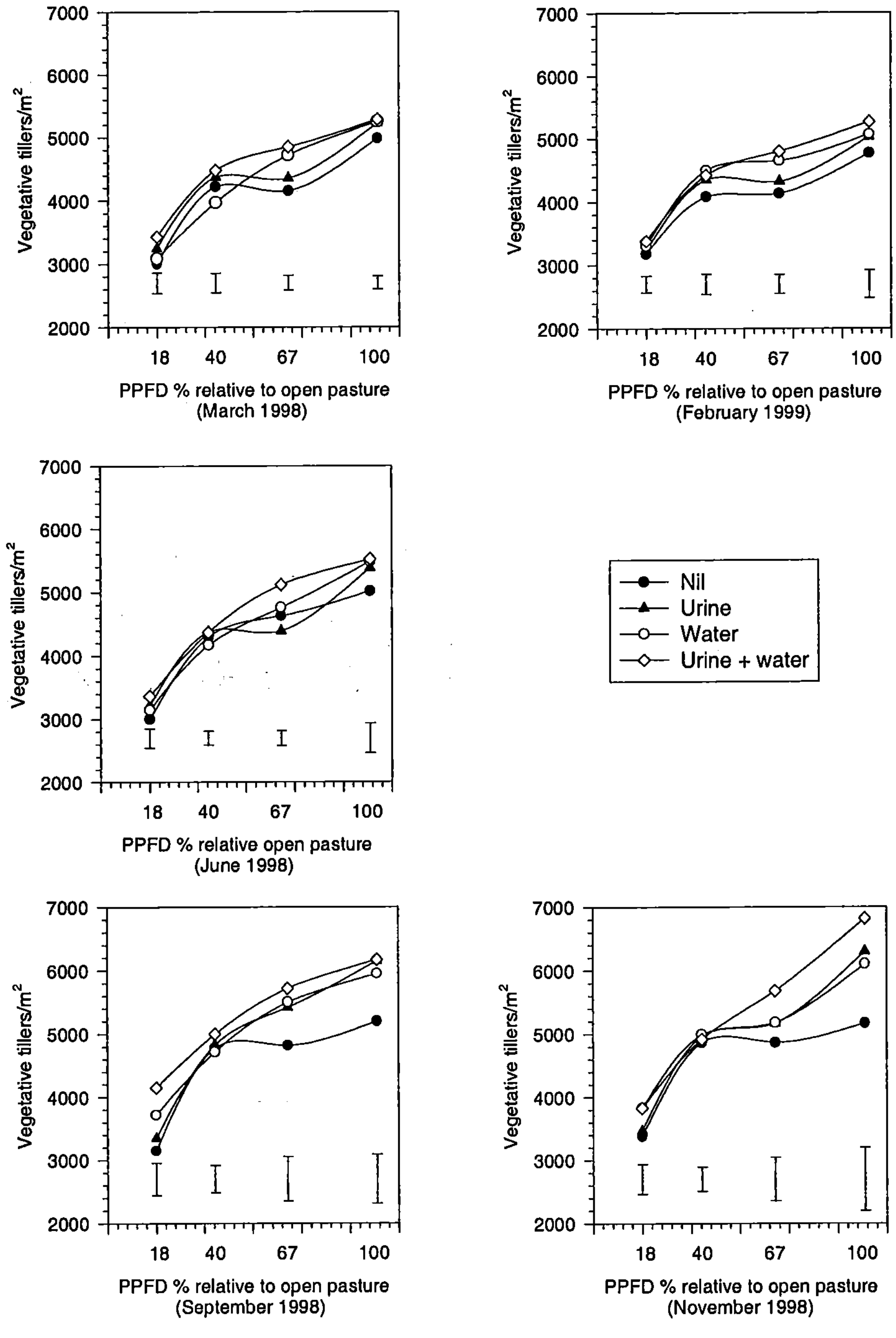

Figure 4.7. Number of cocksfoot vegetative tillers per m^2 for five harvests under four light regimes in four treatments (Bars = lsd for interactions: seasons x shade x treatments $p < 0.001$).

4.4.2 Reproductive tiller population

Cocksfoot reproductive tiller populations measured after 30 days regrowth in November showed an interaction ($p < 0.01$) between shade and treatments (± water and ± urine). The number of reproductive tillers increased between 18% and 67% PPFD and then plateaued to 100% PPFD in all treatments except the nil treatment where the only increase occured between 67% and 100 PPFD (Figure 4.8).

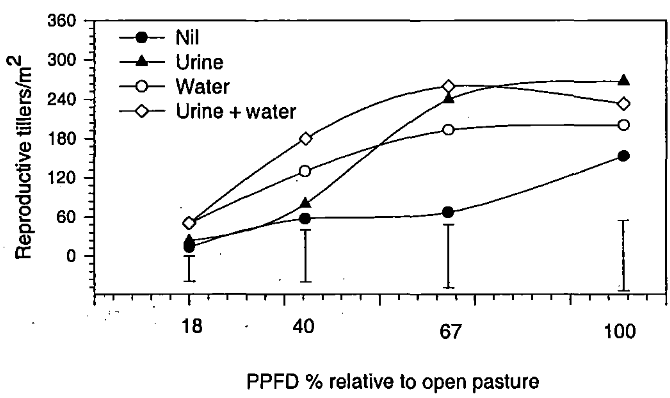

Figure 4.8. Reproductive tiller populations of Wana cocksfoot under four treatments (Bars = lsd for interaction: shade x treatments p = 0.013).

The mean reproductive tiller population of open pasture from four treatments was 213 tillers/m^2, which was 84%, 47% and 11% higher than under 18%, 40% and 67% PPFD zones.

4.4.3 Cocksfoot canopy height

The interaction between seasons, shade and treatments (± water and ± urine) for cocksfoot canopy height was significant (Figure 4.9). For most treatments, canopy height increased between 18% and 40% PPFD, but declined from 67% to 100% PPFD in all seasons. The response was most pronounced for November which also produced the tallest canopy for all treatments. The exceptions were the nil and urine treatments in February which had stable canopy height across all light levels. In each season, the canopy height increased from the nil to the urine treatment and from the urine to the water treatment and was highest in the urine plus water treatment. The exception was the open pasture where both urine only and water only treatments produced similar canopy height.

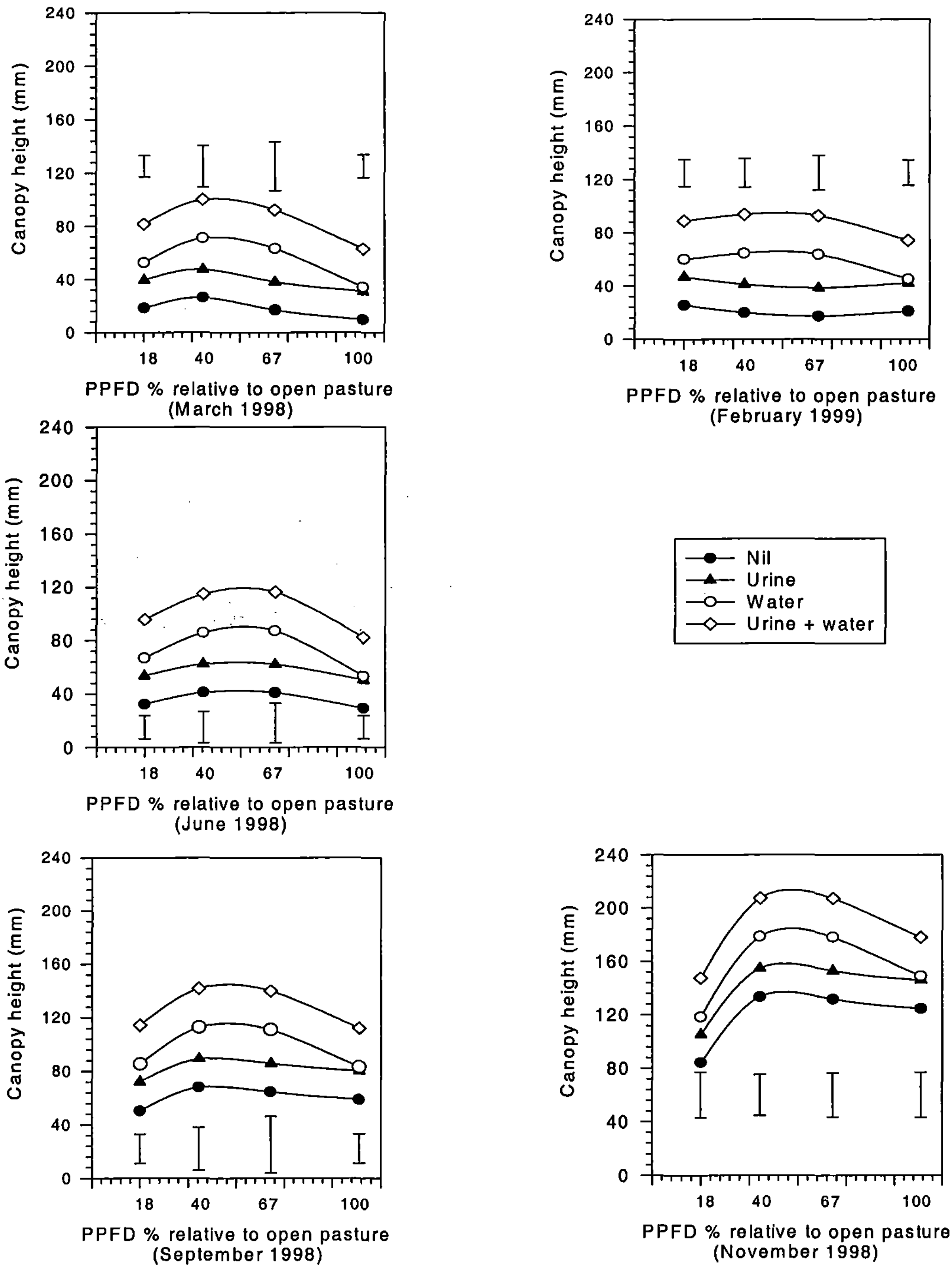

Figure 4.9. Cocksfoot canopy height form five measurements under four light regimes in four treatments (Bars = lsd for interaction: seasons x shade x treatments p <0.01).

The cocksfoot tillers grown under moderate tree shade (40% to 67% PPFD) etiolated more and produced a 91 mm mean canopy height. This was 21% and 20% taller than under 18% PPFD and in open pasture (100% PPFD) respectively.

4.4.4 Pasture bulk density

There was an interaction between seasons, tree shade and treatments (± water and ± urine) for the cocksfoot pasture bulk density (Figure 4.10). In most seasons, the cocksfoot pasture bulk density increased linearly with the increasing PPFD, to be at a maximum in the open pasture. In March, June and September treatment effects were minimal in all light levels except in open pasture in September. However, bulk density in the February 1999 season was similar across all light levels for the nil and urine only treatments. Pasture bulk density increased from 18% to 40% PPFD in the water only and water plus urine and was then stable for the water only treatment but continued to increase to be highest in the open pasture supplied with urine plus water. Overall, the highest pasture bulk density (1.61 mg DM/cm^3) occurred in September for the urine plus water plots in open pasture and the lowest was in November under 18% PPFD in the treatment nil plots (0.38 mg DM/cm^3).

The mean pasture bulk density of open pasture was 1.17 mg DM/cm^3, which was 52%, 35% and 25% higher than under 18%, 40% and 67% PPFD.

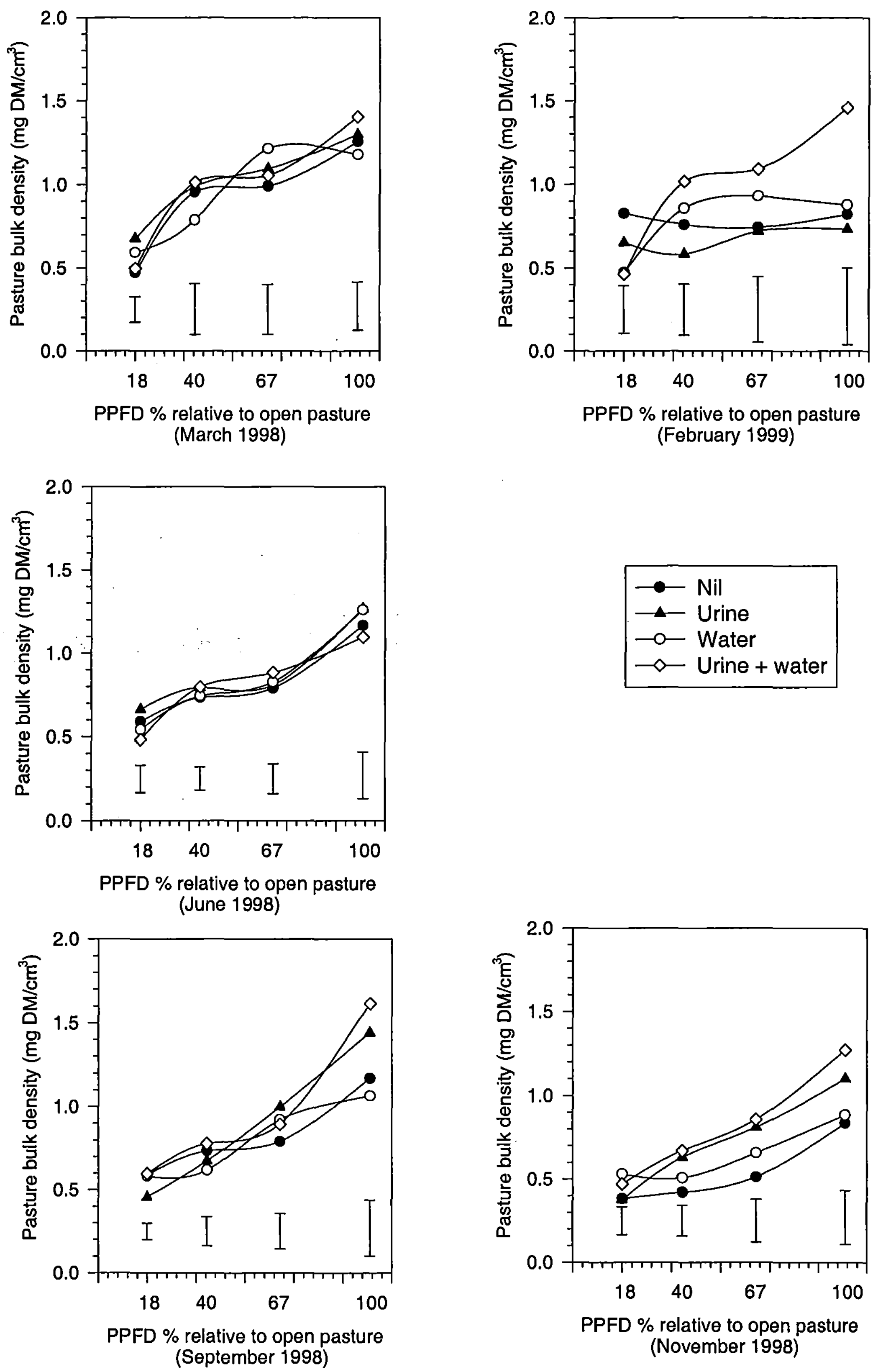

Figure 4.10. Cocksfoot pasture bulk density under four light regimes in four treatments from five harvests (Bars = lsd for interaction: seasons x shade x treatments p <0.01).

4.4.5 Leaf number per tiller

Season had the greatest effect (p <0.001) on leaf populations in cocksfoot tillers in all light regimes (Figure 4.11). The lowest number of leaves/tiller was found in February for each treatment. In most cases, pastures in the nil, urine and water treatments had similar leaf populations across all four light regimes and the highest leaf numbers were achieved in the urine plus water treatment under 67% PPFD in September. Light intensity had little influence on leaf number except under 18% PPFD in September.

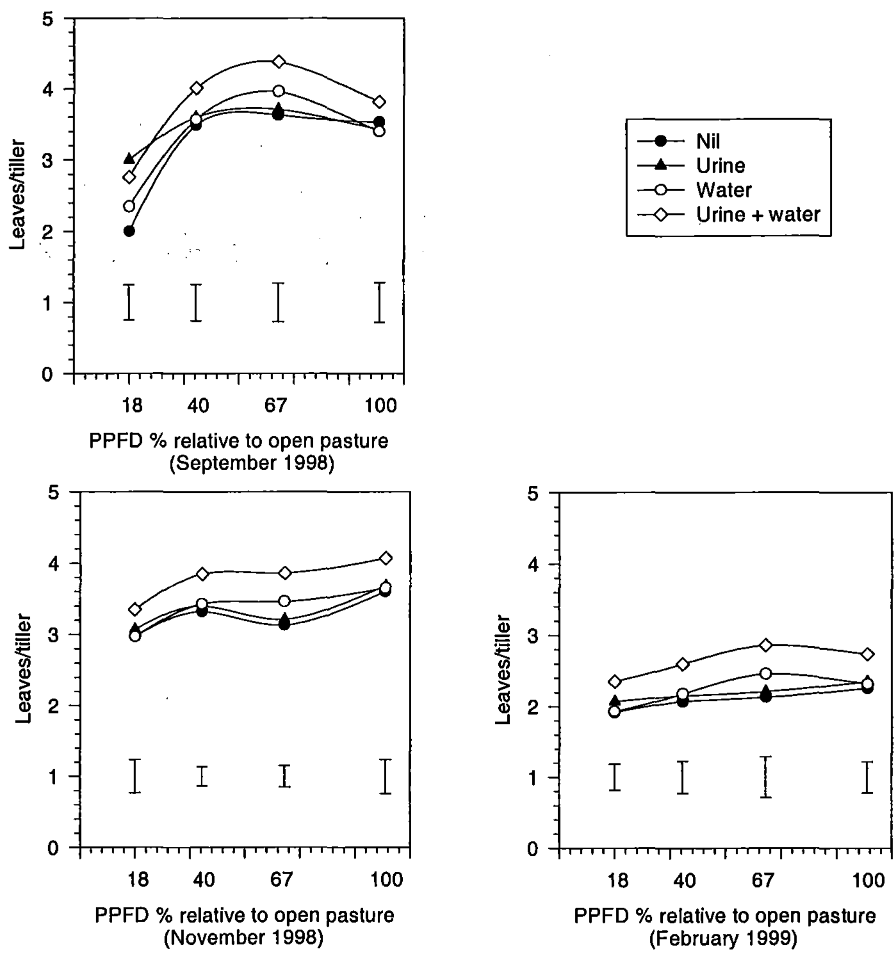

Figure 4.11. Cocksfoot leaf populations under four light regimes in three measurements from four treatments (Bars = lsd at p <0.05).

4.4.6 Leaf blade length

The interaction between seasons, shade and treatments (± water and ± urine) for cocksfoot leaf blade length was significant (Figure 4.12). Leaf blade length increased between 18% and 40% PPFD for most treatments, but declined from 67% to 100% PPFD in all seasons. The response was most pronounced for November which also produced the longest leaves for all treatments. The exceptions were the nil and urine treatments in March and February which had stable leaf lengths across four light regimes.

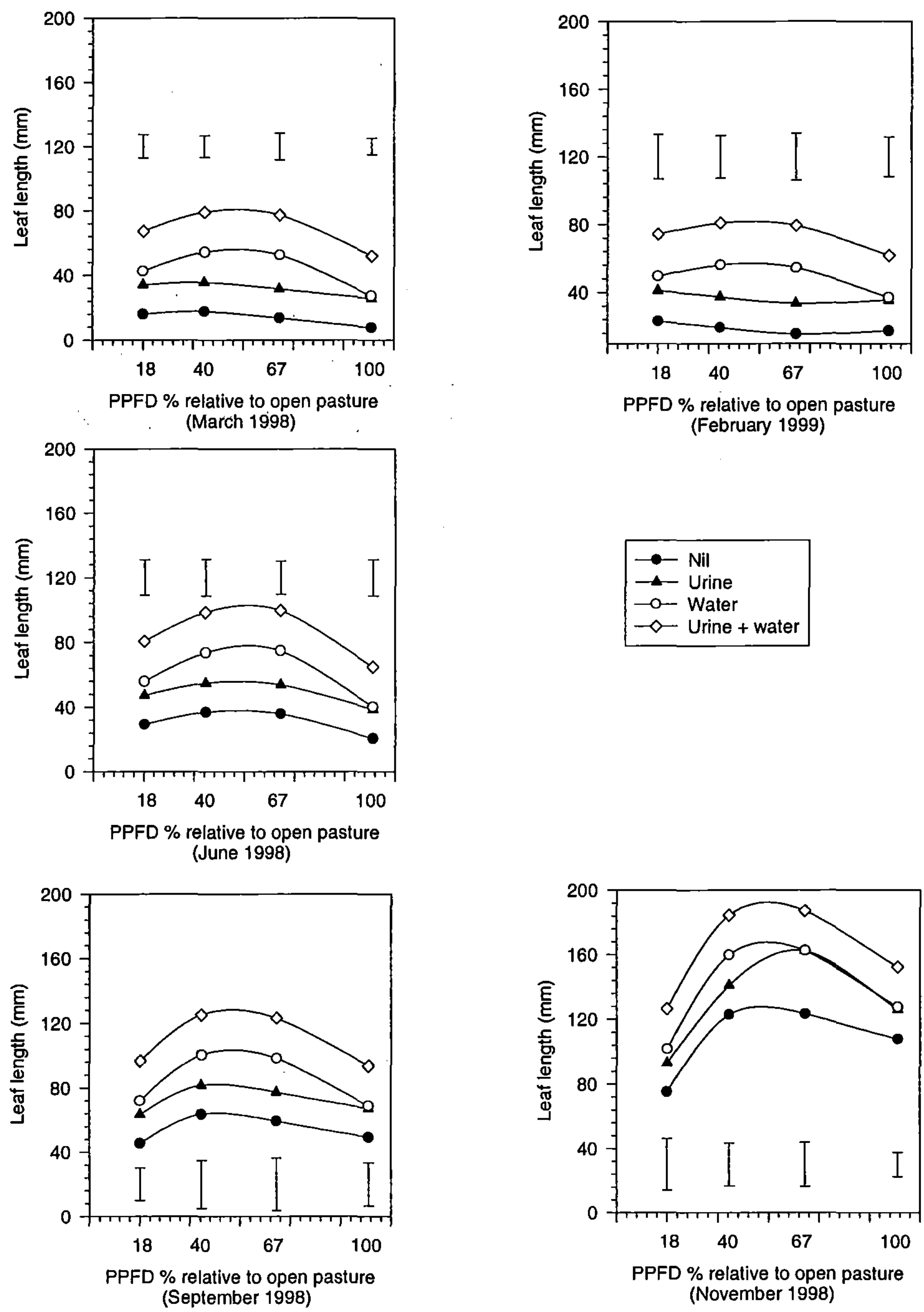

Figure 4.12. Cocksfoot leaf blade lengths under four light regimes from five harvests in four treatments (Bars = lsd for interaction: seasons x shade x treatments p<0.01).

In all seasons, the cocksfoot leaf blade lengths increased from the nil to the urine treatment and from water to urine plus water to be highest in the urine plus water treatment. The exception was the open pasture where both the urine only and the water only treatments produced similar leaf lengths.

4.4.7 Leaf width

Figure 4.13 shows that the cocksfoot leaf widths increased (p <0.001) with increasing PPFD in all treatments in September and November but in February it was stable from 40% to 100% PPFD. In addition, cocksfoot leaf widths in the nil and urine treatments were similar in all months under all four light regimes.

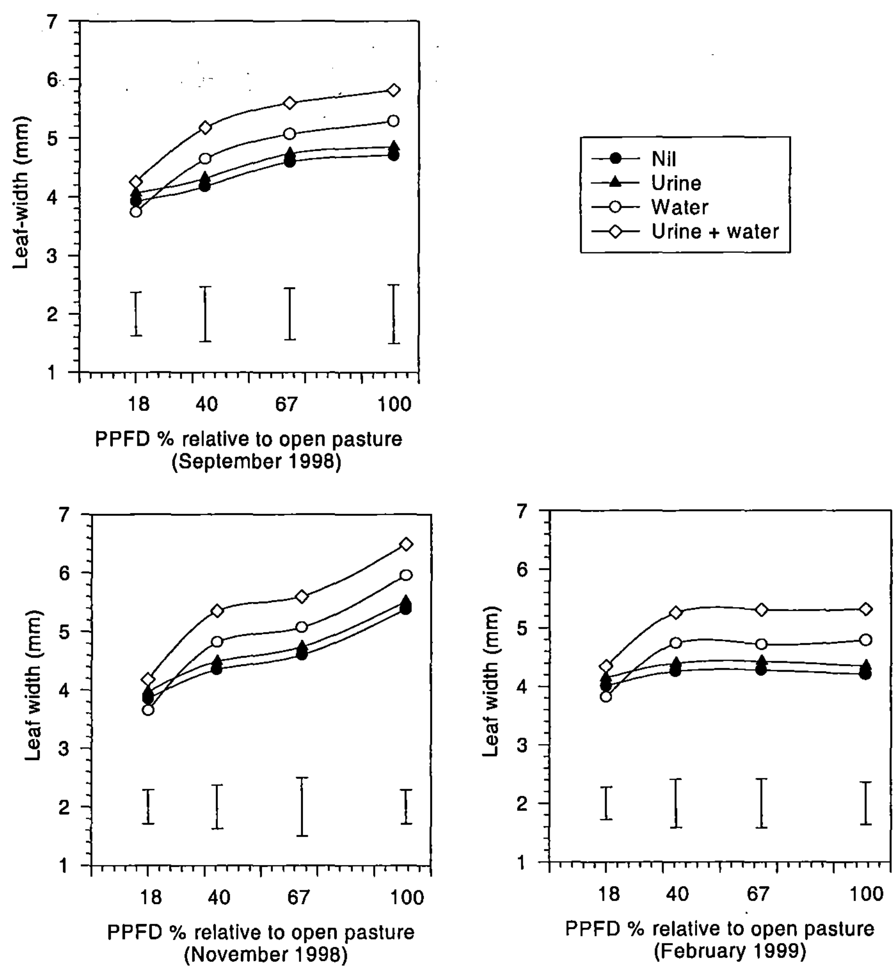

Figure 4.13. Cocksfoot leaf width under four light regimes in three measurements from four treatments (Bars = lsd at p <0.05).

Pastures that received water and urine plus water produced wider ($p < 0.001$) leaves in all light levels except under 18% PPFD compared with the nil and urine treatments. The open cocksfoot pasture in November under urine plus water had greatest leaf width (6.49 mm) and the least (3.65 mm) was under 18% PPFD in the water only treatment in the same November measurement.

4.4.8 Length of cocksfoot pseudostems

There was an interaction ($p < 0.01$) between seasons, tree shade and treatments (± water and ± urine) for cocksfoot pseudostems (Figure 4.14). In June, September and February pseudostem length was relatively constant across light levels. In contrast, the pseudostem length increased from 18% to 40% PPFD in March to be lowest in open pasture for each treatment. The opposite occured in November with an increase between 67% and 100% PPFD. In March, the nil treatment produced the shortest pseudostems and the water plus urine treatment gave the lowest pseudostem in open pasture than under trees.

The longest cocksfoot pseudostem (25.6 mm) was measured in November under full sunlight with urine plus water treatment and the shortest (1.5 mm) in February under 40% PPFD in the nil treatment plots.

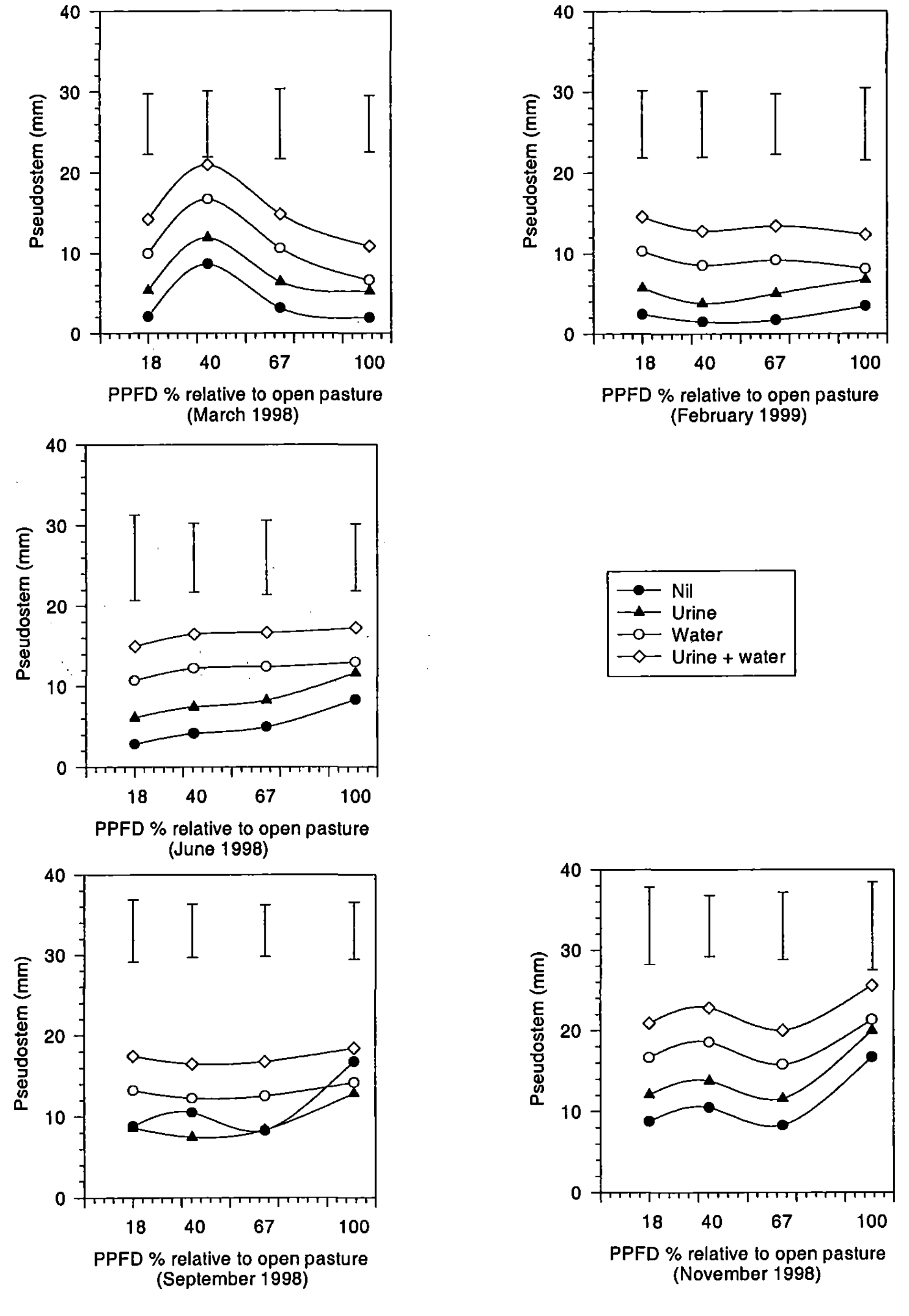

Figure 4.14. Pseudostem length of cocksfoot for five harvests under four light regimes in four treatments (Bars = lsd for interaction : seasons x shade x treatments p <0.05).

4.5 Feeding value

The components of feeding value of cocksfoot pasture grown under four shade levels were indicated by the pasture composition, pasture canopy height, pasture bulk density and the nutritive value of the cocksfoot herbage. Pasture composition, cocksfoot canopy height and bulk density have been described in earlier sections. The nutritive value of cocksfoot herbage grown under four light regimes is presented below.

4.5.1 Nitrogen content

Treatments (± water and ± urine) had the greatest effect on nitrogen (N) content in cocksfoot herbage (Figure 4.15). As expected the N% was higher in the urine and urine plus water treatments than in the other two treatments. The nitrogen content in 30 day regrowth cocksfoot was similar across all light levels in each month, except June but the mean value differed between months. The lowest mean nitrogen percentage in all treatments occured in November at about 2.4% compared with about 3.9% in September and 3.0% in March, June and February. The exception was the open pasture in June which also averaged about 4.0% N.

Finally, the mean nitrogen content in the open cocksfoot herbage was 3.19%, whereas the cocksfoot grown under 18%. 40% and 67% PPFD had 2.95%, 3.03% and 2.97% N, respectively.

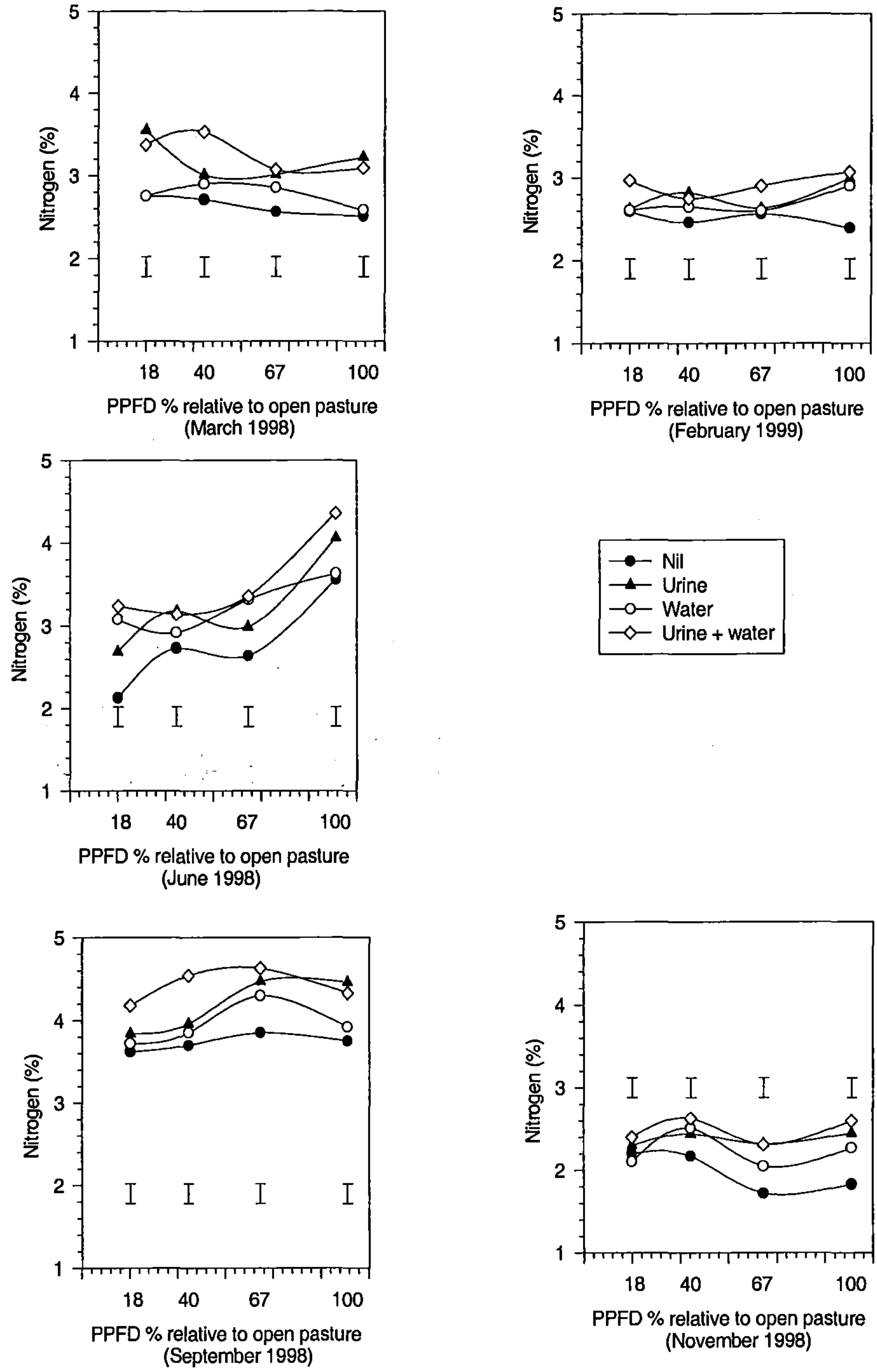

Figure 4.15. Nitrogen content in cocksfoot herbage under four light regimes in four treatments from five harvests (Bars = sem).

4.5.2 Digestible organic matter

The digestible organic matter content in 30 day regrowth cocksfoot herbage increased ($p < 0.001$) with increasing PPFD (Figure 4.16). For most treatments, the digestible organic matter content increased between 18% and 67% PPFD in all months, but was almost stable from 67% to 100% PPFD in September and November. In June, there was a generally linear response where DOM% in cocksfoot dry matter increased with light levels in all four treatments.

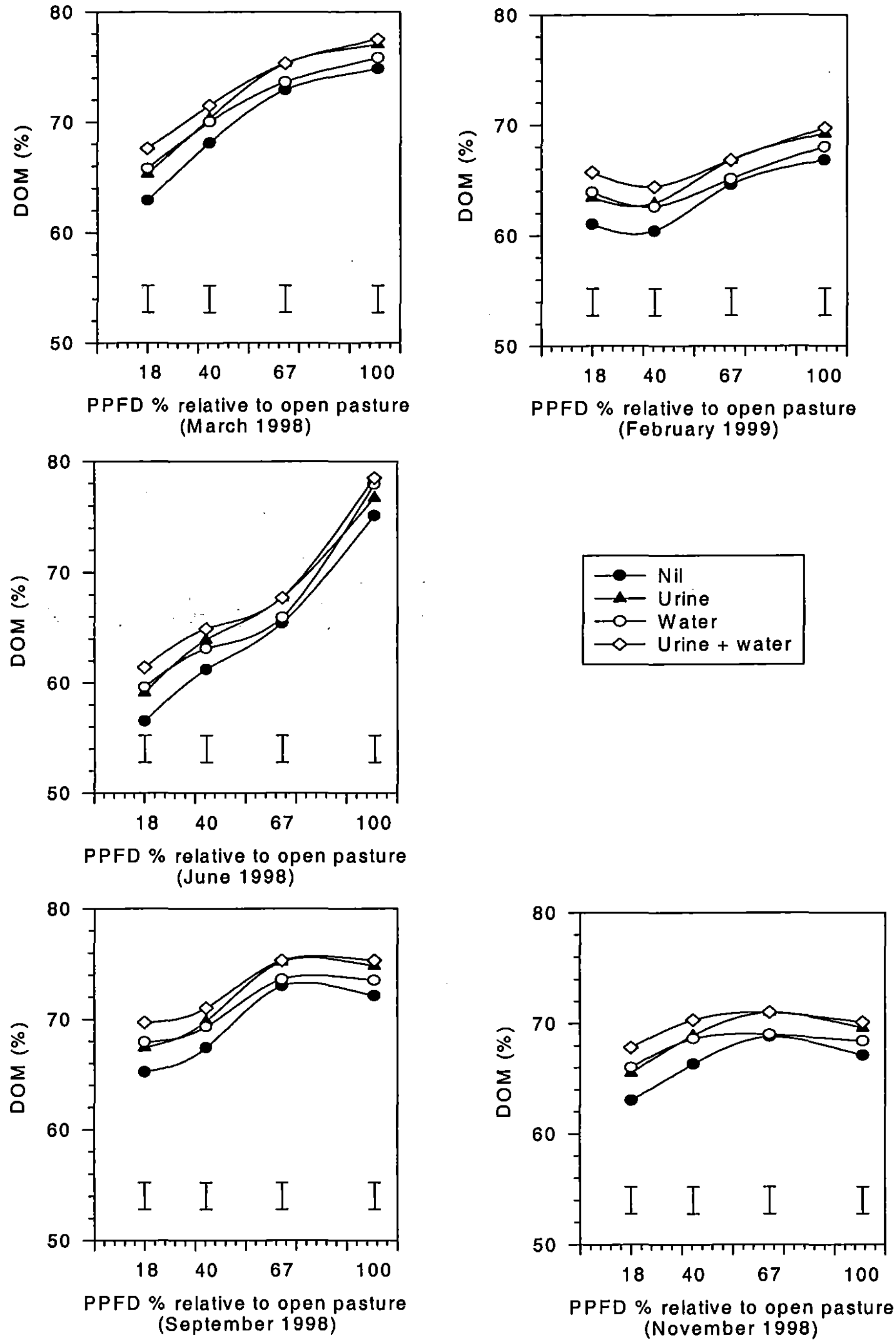

Figure 4.16. Digestible organic matter (DOM) in cocksfoot under four light regimes from five harvests in four treatments (Bars = sem).

The cocksfoot pastures receiving both urine and water gave the highest DOM and the nil treatment the lowest DOM in all seasons across the four light regimes. Thus, the highest DOM (78.5%) was achieved for the winter pasture (June) receiving urine plus water in the open and the lowest (56.5%) from the nil treatment under 18% PPFD in the same harvest. In June, the cocksfoot pasture under trees in non-urine areas was more affected by the *Rhynchosporium* fungus. This appeared to have a direct effect on the DOM content in shaded nitrogen deficient cocksfoot pastures.

The mean DOM value for open cocksfoot herbage was 72.3% DOM, whereas this under 18%, 40% and 67% PPFD was 64.2%, 66.8% and 70.2%, respectively.

4.5.3 Metabolisable energy

There was a great effect of PPFD on the metabolisable energy content (M/D value) in 30 day regrowth cocksfoot herbage (Figure 4.17). In most seasons, the M/D value increased with increasing light levels although the magnitude of response was greater in June than in other months. Similarly, the response of PPFD was greater in March than in September, November and February where the M/D value was about 10 MJ ME for all treatments under 67% and 100% PPFD. In all seasons, the M/D value of the nil treatment was lowest with small differences among the remaining treatments.

The open cocksfoot pasture receiving both urine and water had the highest M/D value (11.65 MJ ME/kg DM) in the March and the lowest (7.81 MJ ME/kg DM) was in the nil treatment plots under 18% PPFD in the June harvest. This was probably due to the fungal disease present in the agroforestry plots. Finally, the mean M/D value of open cocksfoot herbage was 10.67 MJ ME/kg DM, whereas under 18%, 40% and 67% PPFD the M/D mean values were 9.23, 9.58 and 10.08 MJ ME/kg DM.

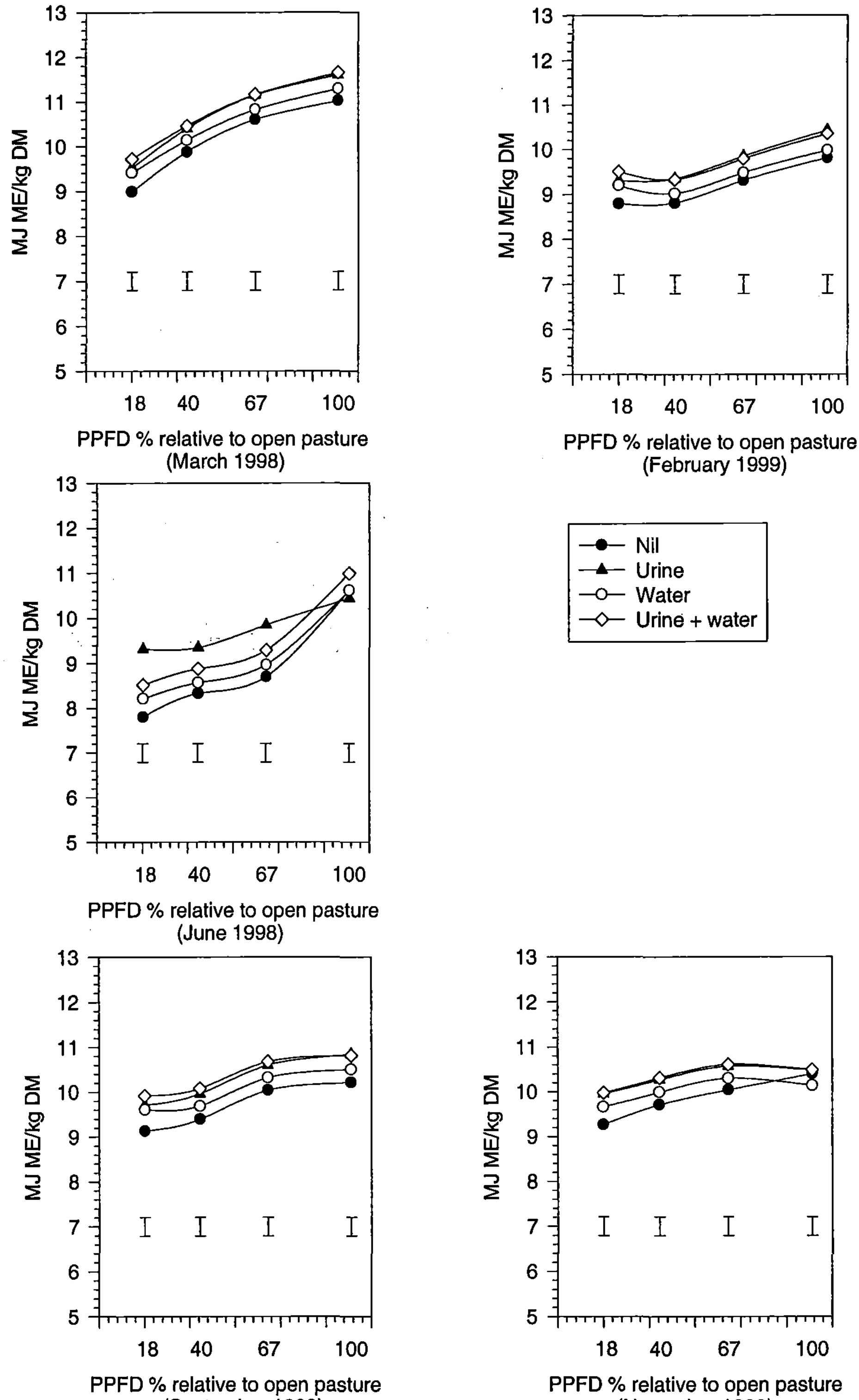

Figure 4.17. Metabolisable energy (MJ ME/kg DM) in cocksfoot herbage under four light regimes form five harvests in four treatments (Bars = sem).

4.6 Supplementary study

During the sheep grazing experiment, dry matter yield, cocksfoot canopy height and nutritive value of urine and non-urine patches of 32 day regrowth herbage in July, and 52 day regrowth in October and December under 200 trees ha^{-1} (67% PPFD) and in open pasture were measured. Results of these measurements are presented below.

4.6.1 Dry matter production

Table 4.4 shows higher ($p < 0.001$) dry matter yield in urine patches under trees and in open pasture compared with the non-urine areas. Tree shade significantly reduced the dry matter yields in urine patches of 32 day regrowth cocksfoot herbage in July compared with the dry matter yields of urine patches in open pasture, but in October and December there was not any effect of tree shade on the dry matter yield of 52 day regrowth cocksfoot herbage.

Table 4.4. Mean dry matter yield (g DM/m^2) of urine and non-urine patches during sheep grazing in July, October and December 1998 (lsd at $p < 0.05$).

Yield (g DM/m^2)	Months	Agroforestry		Open pasture		SED	lsd
		Urine	Non-urine	Urine	Non-urine		
DM yield	July	90	54	98	55	2.41	5.90
DM yield	Oct.	267	232	272	228	18.07	44.21
DM yield	Dec.	372	310	395	324	20.69	50.61

Table 4.4 shows greater ($p < 0.001$) dry matter yield of December harvest compared with October and July harvests in both agroforestry and open pasture.

4.6.2 Cocksfoot canopy height

Table 4.5 shows higher ($p < 0.001$) cocksfoot canopy height in urine patches compared with in non-urine patches in October and December in both agroforestry and open pasture. The canopy height of cocksfoot pasture under trees was also significantly higher in October and December than in open pasture.

Table 4.5. Mean cocksfoot canopy height (mm) of urine and non-urine patches during sheep grazing in July, October and December 1998 (lsd at $p < 0.05$).

Canopy height	Months	Agroforestry		Open pasture		SED	lsd
		Urine	Non-urine	Urine	Non-urine		
Height (mm)	July	72	64	68	63	2.23	5.46
Height (mm)	Oct.	277	189	195	168	9.20	22.51
Height (mm)	Dec.	302	278	278	252	7.06	17.27

Canopy height of the December harvest was greater ($p < 0.001$) than in October and July harvests in both agroforestry and open pasture.

4.6.3 Nutritive value of 52 day regrowth (20th October to 8th December) cocksfoot herbage

Nutritive value of 52 day regrowth cocksfoot herbage in the reproductive growth stage determined during sheep grazing in December shows that sheep urine increased ($p < 0.05$) only the M/D value of shaded cocksfoot compared with the M/D value of cocksfoot grown in the same environment in non-urine areas (Table 4.6).

Table 4.6. Digestible organic matter, nitrogen content and metabolisable energy content in 52 days regrowth cocksfoot herbage in December grown under radiata pine trees and in open pasture.

Environment	Nutritive value	Non-urine	Urine	SED	lsd at $p < 0.05$
Under trees	DOM%	67.60	69.40	1.890	5.246
(67%PPFD)	N%	1.56	2.05	0.189	0.525
	M/D value	10.00	10.50	0.160	0.444
Open pasture	DOM%	64.20	67.80	2.120	5.885
	N%	1.42	1.59	0.190	0.527
	M/D value	9.70	10.20	0.210	0.583

Table 4.6 shows that the nutritive value of cocksfoot grown under full sunlight during the reproductive growth stage in December 1998 was reduced compared with under trees, but these reductions were non-significant ($p = 0.543$ for DOM, $p = 0.460$ for N and $p = 0.310$ for M/D value).

4.6.4 Grazing preference of sheep

Results of July, October and December grazing experiments show that the palatability of cocksfoot herbage was determined by the growing season and growth periods of cocksfoot grass, tree shade, disease and nitrogen from sheep urine. The grazing preferences of sheep on urine and non-urine patches of cocksfoot grown under radiata pine shade and in open pasture are described below.

4.6.4.1 Sheep grazing on 32 day regrowth herbage

The July sheep grazing experiment conducted in 32 day old regrowth of Wana cocksfoot herbage grown under 200 trees ha^{-1} (67% PPFD) and in open pasture showed no effects of tree shade on grazing preferences of sheep because the cocksfoot canopy height decline in both shaded and unshaded pasture was similar (Figure 4.18).

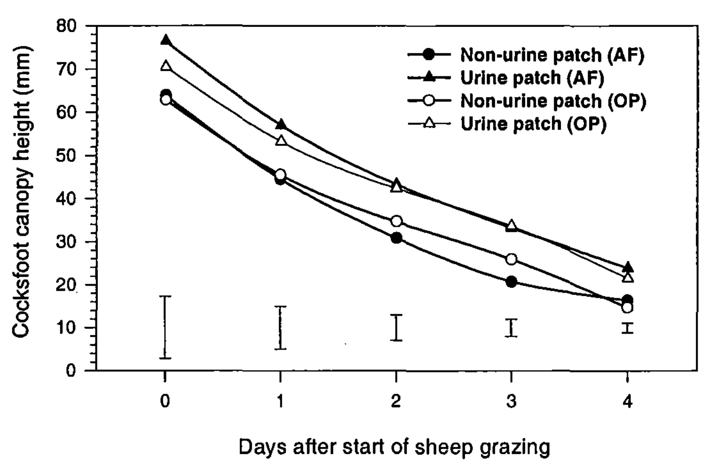

Figure 4.18. Cocksfoot canopy height during sheep grazing from 23-27 July 1998 under radiata pine trees (AF) and in open pasture (OP): Bars = lsd at $p < 0.05$.

Figure 4.18 shows that both the urine and non-urine patches were grazed equally by sheep, but lower initial cocksfoot canopy height in non-urine patches had resulted significant reduction in cocksfoot canopy height in non-urine patches at the end of four day grazing trial compared with in urine patches in both shaded and unshaded pastures.

4.6.4.2 Sheep grazing in 52 day regrowth herbage

The second grazing experiment conducted in October on 52 day regrowth of Wana cocksfoot pastures grown under tree shade and in open pasture showed the effect of tree shade and treatments (± urine) on cocksfoot canopy height decline during sheep grazing (Figure 4.19). On the first day of grazing, the cocksfoot height in urine patches under trees declined by 60 mm and in non-urine patches by 25 mm, whereas in open pasture the decline was 51 and 22 mm respectively. On the second day, the decline was 38 and 31 mm under trees and 24 and 18 mm in open pasture.

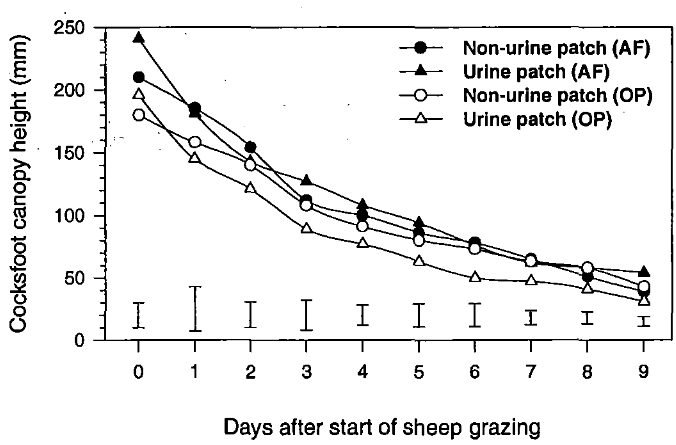

Figure 4.19. Cocksfoot canopy height during sheep grazing from 5-14 October 1998 under tree shade (AF) and open pasture (OP): Bars = lsd at p < 0.05).

By the end of the nine day grazing period, the cocksfoot canopy height in non-urine patches under trees was less ($p < 0.001$) than in urine patches due to the initial cocksfoot canopy height in non-urine patches which was also significantly lower than in urine patches. In contrast, canopy height of urine patches in open pasture declined more compared with non-urine patches due to the fungal disease (Plate 4.2) in non-urine areas under full sunlight.

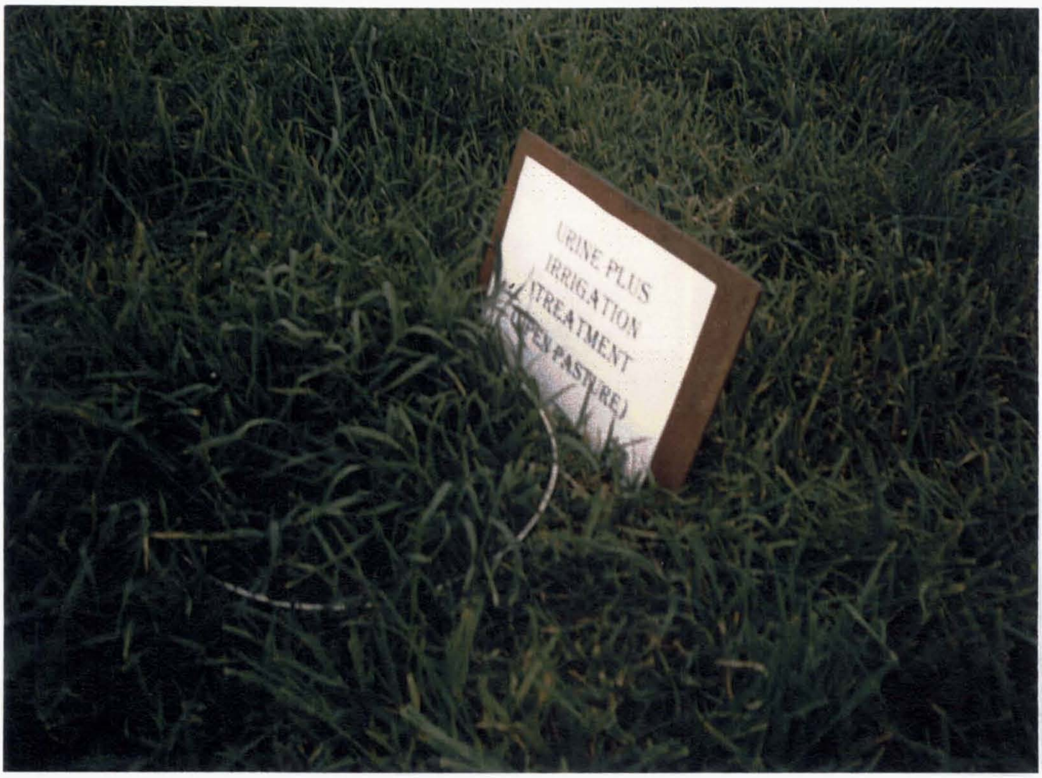

Plate 4.1. Urine plus water treatment sub-plot in open pasture on 14th September 1998. The browning of leaf tips of cocksfoot grass showing fungal infection (*Rhynchosporium orthosporum*).

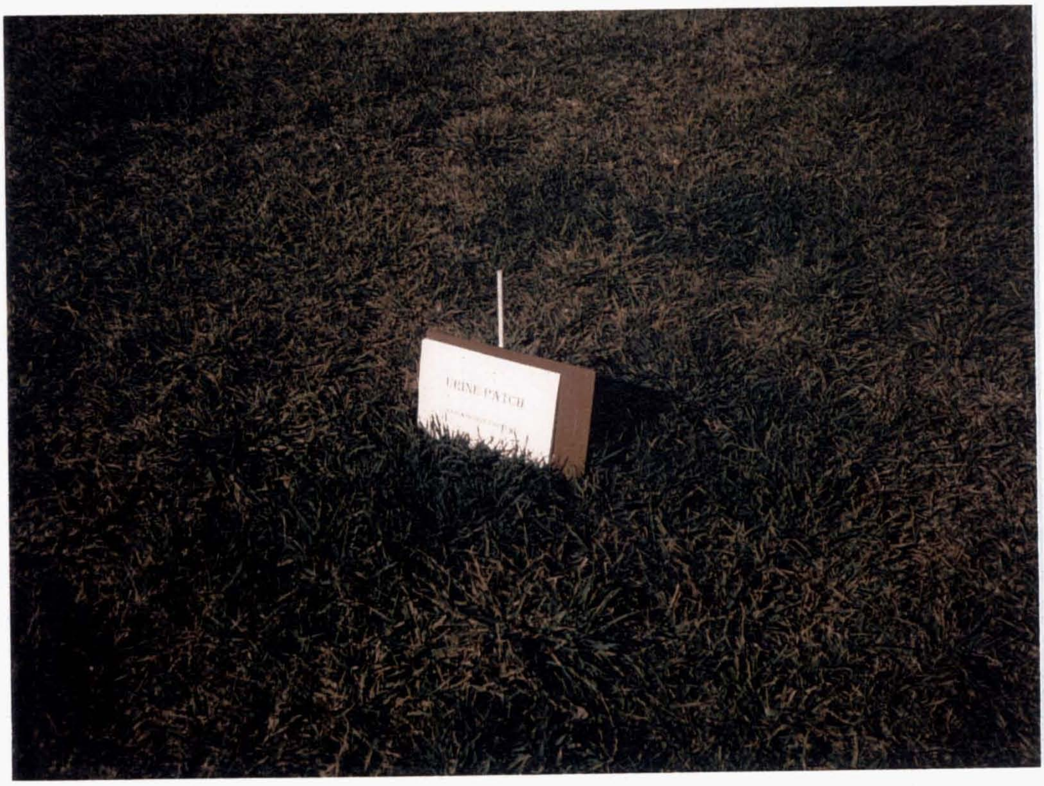

Plate 4.2. Fungal disease (scald) caused by *Rhynchosporium orthosporum* on 25th September 1998 in open pasture. Infection is much more severe on grass without urine.

Figure 4.20 shows the grazing preferences of sheep on urine and non-urine patches of 52 day regrowth cocksfoot pasture in December under radiata pine trees and in open pasture. Up to the third day of the grazing experiment, ewe hoggets grazed more urine patches compared with non-urine areas especially in open pasture. After that the canopy height of cocksfoot grown in non-urine areas started to decline more in both shaded and unshaded pastures. By the end of the eight day grazing period, the cocksfoot canopy height in non-urine patches under trees and in open pasture was less ($p < 0.001$) than in urine patches due to the initial cocksfoot canopy height in non-urine patches which was also significantly less than in urine patches.

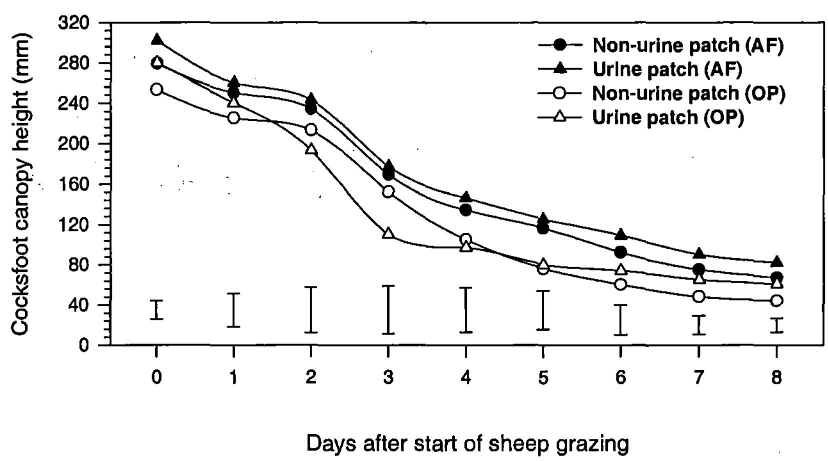

Figure 4.20. Cocksfoot canopy height during sheep grazing from 8-15 December 1998 under tree shade (AF) and open pasture (OP): Bars = lsd at p < 0.05.

An interesting observation found in the October and December grazing experiments, was the complete disappearance of clover herbage and green leaves grown in urine patches within 2-3 days of sheep grazing (Plates 4.3 and 4.4).

Plate 4.3. Clover cover under radiata pine trees in Plot 2 in first day of grazing experiment in October 1998.

Plate 4.4. Clovers and green leaves of cocksfoot in urine patches disappeared after three day of nine days grazing experiment in October 1998.

4.7 Summary

Radiata pine trees influenced light interception, soil temperatures and moisture content in soil which in turn reduced pasture productivity and feeding value of cocksfoot under 18% and 40% PPFD compared with open pasture. All components of the feeding value such as pasture production rate, tiller populations, pasture bulk density, DOM%, N% and M/D value were reduced with decreasing ambient PPFD levels. Cocksfoot leaves under 40 to 67% ambient PPFD were longer and narrower than in open pasture. However, there was a small increase of clover cover and a decrease in reproductive tillers under trees compared with in adjacent open pasture.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

The first part of this chapter discusses the effects of trees on understorey PPFD, soil temperature and moisture levels, and their impact on the productivity and feeding value of cocksfoot pasture. The second part refers to the grazing preference of sheep on urine and non-urine patches of cocksfoot pasture grown under trees and in the open.

5.2 Tree density and their effects

The diameter, at 1.4 m height, of unpruned radiata pine trees in 650 trees ha^{-1} zone was reduced by 21% and 24% compared with trees in the 300 and 200 trees ha^{-1} zones respectively. The main cause for this has been competition between trees for moisture (Goldberg, 1996), nutrients and space. This result suggests that competition in silvopastoral systems for environmental factors occurred at both interspecific and intraspecific levels. However, the severity of competition is usually determined by the tree density and canopy length. This is discussed below.

5.2.1 Effects of trees on PPFD transmission

The PPFD under the 300 trees ha^{-1} was 40% of that of open pasture. This may have been partly due to the trees grown in the 650 trees ha^{-1} zone being on the north side of the 300 trees ha^{-1} zone. Before midday (12:00 pm), tree shade from the unpruned 650 trees ha^{-1} would have shaded the 300 trees ha^{-1} zone (Plate 3.1). The PPFD level under 200 trees ha^{-1} pruned to 6 m height was 67% of open pasture. Therefore, the silvicultural operations adopted for the management of trees impacted on solar energy transmission in this silvopastoral system.

Cossens (1984) and Percival *et al.* (1984a) reported the pasture production under different radiata pine tree densities, but they did not mention the solar radiation levels under the different tree densities. On the other hand, Devkota *et al.* (1998) reported the PPFD (17%, 27% and 77%) under alder trees that were measured on three occasions (7 February, 19 March and 14 April 1997) on clear sunny days between 1200 to 1300 hours using a Licor Quantam Sensor. On the basis of present study, the PPFD transmission pattern under trees is also affected by season and time of day in which understorey pastures received solar energy. Figure 4.1 shows that the PPFD in winter was reduced by 73%, 83%, 78% and 69% under 650, 300 and 200 trees ha^{-1} and in open pasture respectively compared with the PPFD value in summer. This result suggests that the season had a great effect on the transmission of solar energy to understorey pastures.

The time of day in which understorey pastures received solar radiation changed the level of the PPFD. For example, cocksfoot pasture under 300 trees ha^{-1} in November (Figure 4.2) received 78% less PPFD in the morning (8-9 am) and 16% more in the late afternoon (6 pm) than at midday (12:00 pm). Finally, the seasonal and daily variation in availability of solar radiation also impacted on the understorey soil temperature and moisture levels, which affected the growth and development of understorey cocksfoot pastures.

5.2.3 Soil temperature

The trees in the agroforestry system created microclimates that reduced soil temperatures at 100 mm soil depth in summer, autumn and spring seasons, but increased it in winter compared with open pasture (Figure 4.3). In the moderate shade (40 to 67% PPFD) of 200-300 trees ha^{-1}, the soil temperature in summer was reduced by 0.9-1.9°C compared with open pasture. This result is similar to that reported by Percival *et al.* (1984b) who measured the reduction in soil temperature at 300 mm soil depth on the Tikitere Forest Farming Research Area under 400 stems ha^{-1} site of 0.6-1.5°C in summer and autumn seasons compared with the open pasture. Furthermore, Garnier and Roy (1988) reported a 1.6°C lower air temperature for cocksfoot pasture grown under trees in the summer in France. The reduction of soil temperature under trees in summer is attributed to tree shade reducing the interception of solar radiation and creating a cool microclimate in summer.

In winter, the soil temperature under trees was 0.5°C more than in open pasture. Garnier and Roy (1988) also reported a 0.6°C higher air temperature under trees in winter in France and attributed this to tree cover creating a warm environment and thus reducing the intensity of frost damage to pasture plants. In September (early spring), the soil temperature under 300 to 650 trees ha^{-1} was 8.1°C which was 0.8°C less than in open pasture. Korte *et al.* (1987) reported that when soil temperatures are between 5.5-10°C during spring, each degree of soil temperature increase results in a 8 kg DM ha^{-1} day^{-1} increase in pasture production. Therefore, this temperature reduction under trees may have reduced pasture production in the spring.

Soil temperatures measured after three to four days of irrigation show that the soil temperature under irrigation was always less than in unirrigated plots, with greatest reductions between November to February in all shade levels. In winter, 25 mm of water was applied on irrigated plots, which reduced soil temperatures under trees and open pasture by 0.5°C and 0.4°C respectively. Rainfall or irrigation in cool seasons may reduce pasture production because low temperature is the main limitation for pasture production in winter in New Zealand (Barrs *et al.*, 1990).

5.2.4 Soil moisture

Trees in silvopastoral systems also reduced the volumetric water content (VWC) of soils in autumn, winter and spring, but increased the VWC in summer compared with open pasture. The increase of soil moisture (0.8-1.4%) under moderate tree shade in summer compared with open pasture is attributed to tree shelter reducing the evapotranspiration from understorey pastures during hot and dry periods. However, the VWC in autumn (0.3-2.6%) and spring (0.4-1.2%) under moderate shade (200-300 trees ha^{-1}) was reduced compared with open pasture. The reductions in VWC under trees may have resulted from the rain shadow effect of trees and the interception of rainfall and transpiration of soil water by the tree canopies. Belsky (1994) reported that usually roots of both trees and understorey pastures are located in the same soil horizons, with the fine roots of trees extending into pasture areas and resulting in increased absorption of soil moisture. Gautam (1998) found more fine roots of radiata pine trees in the 100-300 mm soil depth at the Lincoln University agroforestry experiment compared with in 0-100 mm soil depth. This was attributed to the higher soil moisture content in the 100-300 mm soil depth.

Figure 4.4 shows that soil moisture was lower for the cocksfoot pastures in summer (December to February) and early autumn. During this four month period, 437 mm of water was used in irrigated areas to meet the current potential moisture deficit, and soil moisture was usually measured three to four days after irrigation. Irrigation during this hot and dry period (Table 3.3) increased soil moisture by only 1.3% under 200-300 trees ha^{-1} and 0.8% in open pasture compared with non-irrigated plots. This apparent small increase in soil moisture due to irrigation had a great effect on cocksfoot pasture growth and development in summer and early autumn compared with winter and early spring. This was shown by the increased pasture production during this dry period under 200 trees ha^{-1} (81%) and in open pasture (79%) compared with non-irrigated plots.

Figure 4.4 shows that irrigation to meet the current potential moisture deficit was not effective in increasing the volumetric water content in soils. There are several possible explanations for this.

- Irrigated VWC measurement sites were small (0.1 m^2) and were irrigated using a watering can. During irrigation, there was some runoff of water from the actual plots. In addition, some of the irrigation water may have been lost through cracks and macropores in the soil and run below the rooting zone of the plots.

- All pasture areas were hard and compact at all 24 permanent VWC measurement sites. In addition, the soil moisture readings were taken from permanent plots throughout the year. Sometimes, these small plots were irrigated during the sheep grazing time as well. Therefore, the surface soil of these plots was hard and compact due to the trampling effects of the sheep. In these plots more surface runoff and less infiltration of water could have been occurred.

- The amount of water applied during dry summer months (December to February) was about 30 mm at weekly intervals. During this period the evapotranspiration rate was about 32 mm per week. Therefore, some or most of the irrigation water may have been lost by soil evaporation and some transpired by pasture plants.

- During this study period, soil moisture was measured after 3-4 days of irrigation. During that 3-4 days, irrigation water may have been lost or may have been used by pasture plants.

- The soil moisture was measured at 0-300 mm soil depth. All water from the limited irrigation in sheep grazing pastures would not penetrate down to 300 mm due to surface runoff and poor infiltration. Thus the VWC measurement was integrated over a depth that was unlikely to have been fully wetted by the irrigation treatments.

- In the case of the shaded pastures, some of the irrigation water may have been absorbed by the tree roots and lost by transpiration.

- In future, this kind of study should be carried out with trickle irrigation, where water is applied at a much slower rate rather than by using a watering can. In addition, plots should be bigger in size so that the runoff problem can be minimised. Furthermore, irrigation at weekly intervals to meet the potential moisture deficit appears to have been appropriate during summer months when the evapotranspiration rate is high.

Finally it must also be noted that VWC measurement does not relate directly to the four actual pasture productivity and feeding value measurement subplots (± urine and ± water) because:

- soil water was measured at 24 fixed positions (4 PPFD zone x ± irrigation x 3 blocks) and therefore differed from the temporary sub plots where pasture productivity and feeding values were measured.

- more water in total was applied to fixed VWC sites (730 mm in twelve month) than to the temporary subplots (360 mm during five 30 day production periods in March, June, September and November 1998 and February 1999). The amount of water applied to both studies was determined by the previous weeks' evapotranspiration.

- hence during periods of low rainfall /high evapotranspiration sub-plots were often irrigated at suboptimal rates. Pasture in these irrigation sub-plots would therefore be likely to have responded by producing more dry matter than was measured.

5.3 Pasture production

Total pasture production under 650 trees ha^{-1} was reduced by 55% in irrigated urine and non-urine patches compared with irrigated areas of open pasture (Section 4.4). This result shows that pasture production under heavy shade (18% PPFD) was mainly reduced by tree shade rather than by soil moisture or nutrient stress. However, an interesting result with regard to silvopastoralism was the relatively small reduction in cocksfoot dry matter yield under 40% and 67% PPFD from pruned nine-year-old pine trees between 300 and 200 trees ha^{-1}. In this environment pasture production in non-irrigated plots (nil and urine only treatments) was decreased by 30% and 21%, and in water only and urine plus water treatments by 16% and only 1% compared with open pasture. This result was consistent with Cossens (1984) who reported a 19% reduction in dry matter production from mixed pasture under eight-year-old radiata pine with 200 trees ha^{-1} at a humid cool site in south Otago, New Zealand. The results of cocksfoot pasture production under 200 and 300 trees ha^{-1} show that the cocksfoot pastures under these intermediate shade levels were more stressed by lack of water and nitrogen than by tree shade. The moisture stress under trees was probably caused by the combination of a rain shadow effect of trees (Gautam, 1998) and competition for soil moisture between trees and pastures.

Figure 5.1 shows the effects of PPFD, soil temperature and moisture over four seasons on cocksfoot dry matter yield. The indication is that pasture production in February and March was limited by soil water stress because the field capacity of this experimental site would be 28% volumetric water content. So the maximum available water content would be about half of this (14%). From December to February the VWC was below 14% (Figure 4.4). Therefore, cocksfoot pasture under trees and in open was under moisture stress in summer season. However, there was some evidence that tree shade helps to conserve soil moisture during summer and early autumn, because in these harvests pasture production in moderate shade (40% to 67% PPFD) was 15% more than in open pasture and there was 0.5% more soil moisture content under wide spaced trees than in open pasture.

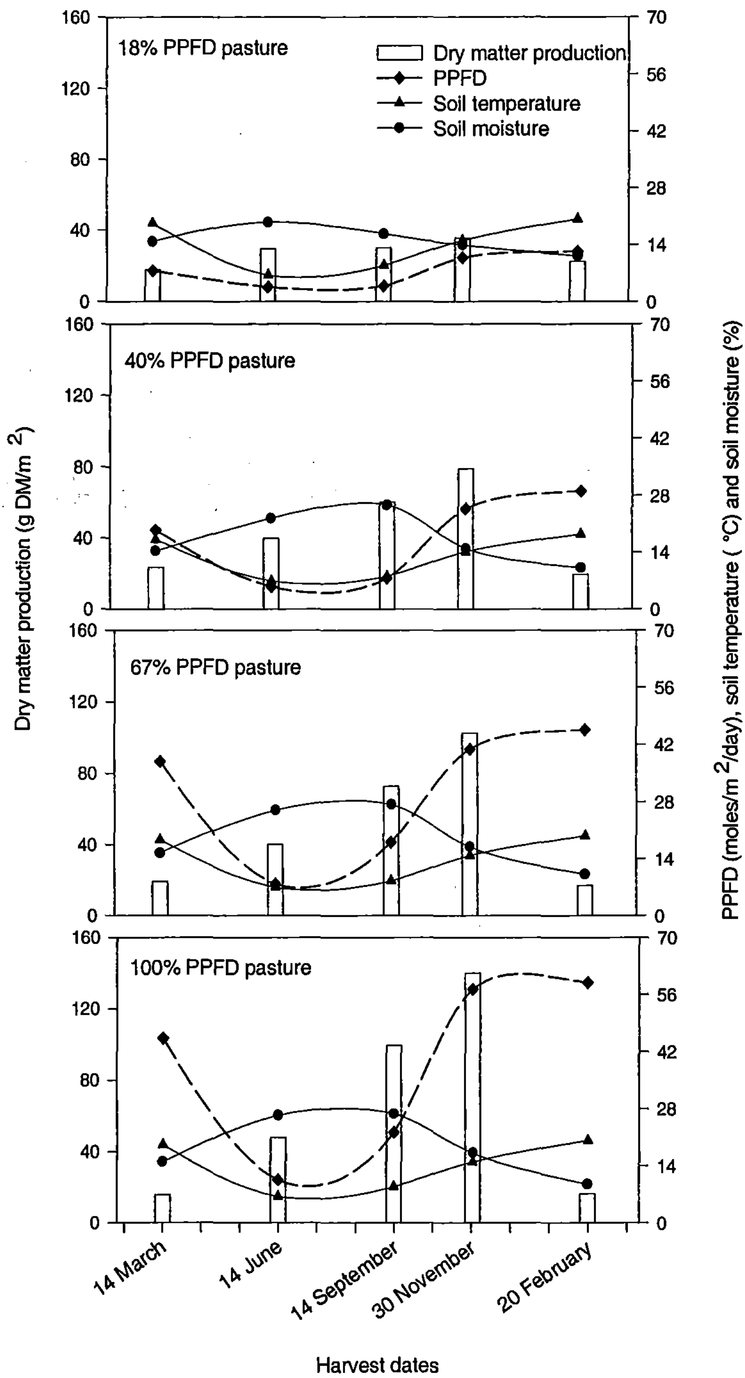

Figure 5.1. Dry matter production, photosynthetic photon flux density (PPFD), soil temperature and moisture in cocksfoot pasture over 30 days before harvest dates in unirrigated areas.

In winter (June), cocksfoot dry matter yield was greater than during drought conditions, but lower than in spring. The lower productivity of cocksfoot pasture in June in open pasture was assumed to have been caused by low soil temperature (<6.4°C in open pasture), and under trees from low soil temperature (<6.9°C under shade) and low PPFD. Korte *et al.* (1987) reported that low levels of solar radiation does not appear to limit plant growth in winter as low temperature is the major problem for pasture production. However, trees reduced light intensity (Figure 4.1) greatly in winter compared with in other seasons.

Fungal infection (*Rhynchosporium orthosporum*) on cocksfoot grown under trees was also severe during early June and did not diminish until faster grass production rates in spring. It was clear from field observations that faster growing cocksfoot in urine patches had lower levels of *Rhynchosporium* infection (Plate 4.2).

In spring (September and November harvests), soil temperatures and VWC were both at satisfactory levels for cocksfoot pasture production. It seems likely that the level of light energy was the dominant factor that limited pasture production. During these two harvests soil temperature and moisture under 200 trees ha^{-1} (67% PPFD zone) decreased by 0.3°C and 0.5% respectively, but cocksfoot dry matter yield was reduced by 21% compared with open pasture. The main reason for the reduction of cocksfoot pasture production under 200 trees ha^{-1} compared with open pasture in September was probably lower PPFD (Figure 4.1). In November, the difference could be due to the lower PPFD and reproductive tiller populations which was 11% less under trees than in open pasture. Korte *et al.* (1987) also reported an increase in growth rates of grass dominated pastures in mid and late spring which was attributed to their reproductive development that increased dry matter production rates.

Table 5.1 shows the summary of the cocksfoot pasture production rate under four light regimes from four treatments. These rates were 55%, 68%, 73% and 65% greater in the urine plus water treatment than the nil plots for successive increments in light levels from 18% to 100% PPFD. In constrast, there was only a 15% increase in cocksfoot pasture production under full sunlight compared with moderate (40 to 67% PPFD) shade treatments. These results show that soil moisture and nutrient (nitrogen) were more important for cocksfoot pasture production under moderate tree shade than solar radiation in this sub-humid environment. The implication was that cocksfoot pasture can be grown successfully in this agroforestry environment when it is not stressed for water and nutrients.

Table 5.1. Dry matter production rate of Wana cocksfoot (g DM/m^2/d) under four light regimes from means of five harvests and the percent higher for urine, water and urine plus water treatments than in nil treatment.

	PPFD relative to open pasture							
	18%		40%		67%		100%	
Treatments	DM	%	DM	%	DM	%	DM	%
Nil	0.76	-	1.15	-	1.14	-	1.56	-
Urine	1.04	27	1.81	36	2.22	47	2.69	42
Water	1.42	46	2.19	47	2.65	57	2.48	37
Urine + water	1.68	55	3.63	68	4.18	73	4.45	65

5.3.1 Irrigation and its effects on pasture production

During five 30 day production periods, 360 mm water was applied in ± urine to overcome the current potential moisture deficit. Irrigation in non-urine patches increased cocksfoot dry matter yield by 46%, 47% and 57%, and 37% in five harvests from 18% to 100% PPFD respectively compared with nil treatment pastures. The increase in cocksfoot dry matter yield from irrigation was consistent with the result of McBride (1994) who reported a 44% increase of pasture production on the Canterbury plains by irrigation at 50% available moisture in the top 100 mm of soil. The greater responses of shaded cocksfoot pasture to the addition of water suggests that tree shade in sub-humid environments may improve the efficiency of limited irrigation.

The net increase of cocksfoot dry matter shown in Figure 5.2 was estimated by substracting the dry matter yield of nil treatment from water only treatment, and urine only treatment from urine plus water treatment. The net increase of cocksfoot dry matter yield from irrigation which was greater in urine patches than in non-urine areas. This result suggests that cocksfoot dominant pasture was deficient in both water and nitrogen. However, the response of cocksfoot dry matter yield to irrigation under 18% PPFD was small in all harvests because the heavy tree shade in this zone limited the growth and development of cocksfoot rather than moisture or nutrients.

In March and February harvests, irrigation in non-urine patches under 40% and 67% PPFD, and in open pasture increased cocksfoot dry matter yields by 70%, 81% and 79% respectively compared with the nil treatment plots. This result was consistent with McBride (1994) and Rickard *et al.* (1986) who reported a 80% and 79% increase in pasture production by ryegrass-white clover pasture at Winchmore on the Canterbury plains with irrigation at 20% soil moisture content of the top 100 mm soil during summer.

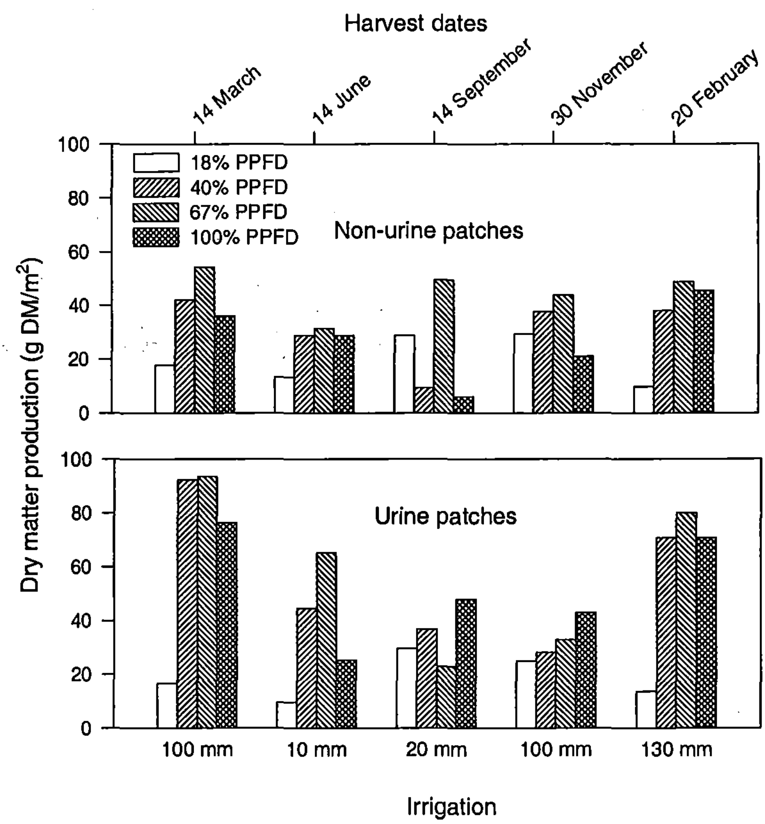

Figure 5.2. The net increase of cocksfoot dry matter yield from irrigation under four light regimes.

These figures show that the effect of irrigation on cocksfoot pasture production under four light regimes was high in hot and dry periods and less in winter and spring. Therefore, irrigation in sub-humid Canterbury plains under both shaded and unshaded environment will be more useful for pasture production from mid summer to early autumn (January to March).

5.3.2 Sheep urine

The presence of darker urine patches in grazed pastures in all seasons indicates the typical state of nitrogen stress in grass dominated pastures. Addiscott *et al.* (1991) reported that more than 80% of nitrogen consumed by animals is returned to the soil in the form of urine and dung. Figure 4.6 shows that sheep urine only (nitrogen) stimulated cocksfoot pasture growth in spring in all light levels during this study period with greatest responses under 67% PPFD and in open pasture. This stimulation increased total dry matter production under moderate shade and full sunlight by 42% compared with adjacent non-urine patches. This result was consistent with Marriott *et al.* (1987) who reported a 39% increase in the production of perennial ryegrass, and with van Garderen (1997) who recorded 40% increase of cocksfoot dry matter yield in urine patches compared with non-urine areas at the Lincoln University agroforestry experiment.

Figure 4.6 illustrates the seasonal effects of urine on cocksfoot dry matter yield which was very high in spring (September and November) compared with winter (June), late summer (February) and early autumn (March). These results suggest that the effectiveness of sheep urine to produce cocksfoot dry matter yield could be reduced by several factors depending on the seasons. In the open pasture, production was reduced low soil temperatures in June (<5.8°C) and low soil moisture in summer, while low soil temperature (<6.3°C) and reduced PPFD level, and inadequate soil moisture in summer (<11.5%) and early autumn (<15%) at times of high evapotranspiration demand (>120 mm/month) reduced production in the agroforestry areas.

The study was conducted during a dry year with only 401 mm rainfall compared with the 666 mm long-term mean. Therefore it was expected that the responses of water on cocksfoot dry matter yield in urine patches would be large. The mean dry matter yield of cocksfoot pasture under moderate tree shade and open pasture with urine plus water was 48% and 40% more respectively than with sheep urine only. This result indicates that when water was limiting, soil nitrogen (urine) alone did not bring dramatic changes in pasture production in the sub-humid environment of the Canterbury plains.

5.4 Vegetative tiller population

An effect of trees on understorey cocksfoot pasture was the reduction of the vegetative tiller population (Figure 4.7). The reduction of cocksfoot tillers under heavy shade was consistent with the result of Garnier and Roy (1988) who reported a 36% reduction of cocksfoot tiller population in France under tree shade compared with open pasture. However, they did not report the level of shade. Ludlow *et al.* (1974) reported that leaf formation under low light intensity is reduced, which provides fewer leaf axils for tiller development in C_4 grass species. It seems likely that the same mechanism was responsible for the reduction of tillers in the C_3 cocksfoot.

During this study period, there was a distinct seasonal pattern in cocksfoot tiller population with highest tiller numbers in spring and lowest in late summer and early autumn. This result indicates that the high level of PPFD during summer and early autumn which increased soil temperatures and reduced soil moisture content in soils may have a direct effect on the vegetative tiller populations in cocksfoot pasture. The addition of water and nitrogen in cocksfoot pasture increased the mean tiller populations of cocksfoot pastures by only 10% under trees and by 12% in open pasture compared with the nil plots during hot and dry periods. The main reasons for the small increase of cocksfoot tiller populations under urine plus water could be the relatively short study period (30 days) from application of water to the final counting of cocksfoot tillers. The irrigation to meet potential moisture deficit may not have been sufficient to stimulate additional growth and development of tillers in this pasture. Finally, the open pasture under urine plus water treatment in November had 6820 tillers/m^2 which was at the lower end of the range (7,000-11,000 cocksfoot tillers/m^2) reported by Moloney (1993) for humid areas in the North Island of New Zealand. The reduction of cocksfoot tiller populations at the Lincoln University agroforestry experiment compared with the result of Moloney (1993) is attributed to the soil moisture, nutrient stress and possibly less frequent grazing compared with pastures observed by Moloney (1993).

5.5 Reproductive tiller population

Solar radiation and soil temperature had a direct effect on the reproductive development of 30 day regrowth cocksfoot pasture in November. The cocksfoot pasture with 40% to 67% ambient PPFD had 29% less reproductive tillers compared with open pasture. This may be due to reduced soluble carbohydrate under shade (Wilson and Wong, 1982) or a change in the red to far-red ratio. Only 4% of total tillers in open pasture and 67% PPFD were reproductive tillers. Under 18% and 40% PPFD was only 1% and 2% of total tillers were reproductive.

Figure 4.8 showed that urine, water and urine plus water increased the reproductive tiller population of cocksfoot in open pasture and under 67% PPFD compared with under 18% and 40% PPFD. The decrease in reproductive tillers under shade may partially improve animal performance in late spring and early summer compared with open pasture because reproductive tillers reduce the nutritive value of cocksfoot herbage. However, the best way to reduce the problem of nutritive value reduction by reproductive tillers is by grazing management. Korte *et al.* (1987) reported that grazing can modify the time of flowering, with close and frequent grazing delaying stem development and reducing reproductive tiller populations.

5.6 Cocksfoot leaves and their shape and size

A summary of cocksfoot leaf formation and development under four light regimes is presented in Table 5.2. The reduction in leaf population under 40% PPFD was similar to results from Garnier and Roy (1988) who reported an 8% reduction in cocksfoot leaf number per tiller in spring (October) and early summer (December) under trees compared with their open sward. However, there was no difference in leaf populations between open pasture and 67% PPFD pasture in this current study.

The leaf blade length of open pasture was 24% less than the leaf length of cocksfoot grown under 40% to 67% PPFD. This was attributed to the etiolation of cocksfoot leaves under moderate shade. Anderson (1978) found that etiolation in cocksfoot was due to cell elongation under shade. Under heavy tree shade (18% PPFD) cocksfoot pasture was affected by moisture and nutrient stresses. Therefore, leaf numbers, leaf blade length, leaf-width and leaf surface area were all suppressed under this heavy tree shade treatments compared with open pasture.

Table 5.2. Cocksfoot leaf dimensions under four light regimes from means of five measurements and four treatments.

	PPFD relative to open pasture			
Cocksfoot leaves	18%	40%	67%	100%
Leaf blade length (mm)	61.7	81.2	79.7	61.0
Leaves/tiller	2.56	3.14	3.25	3.22
Leaf-width (mm) at mid leaf length	4.00	4.67	4.89	5.22
Leaf surface area (mm^2)	247.0	379.0	390.0	318.0
Cocksfoot pseudostem length (mm)	10.1	11.6	10.3	12.2
Leaf/stem ratio on length basis	6:1	7:1	8:1	5:1

Table 5.2 shows that leaf/stem ratio decreased under full sunlight compared with shaded pastures because cocksfoot grass in open pasture had shorter leaf blades and slightly longer pseudostems.

The leaf number per tiller, leaf blade length and leaf width of cocksfoot were all increased with the application of water, urine and urine plus water in all light regimes (Figures 4.11, 4.12 and 4.13). These results illustrate the changes in morphology of the cocksfoot dominant pastures in the Lincoln University agroforestry experiment caused by water and nitrogen stress during the 1998-99 season. Of note from this response of cocksfoot grass to the addition of water and nitrogen was the increase of pseudostem length. The implication was that cocksfoot pasture under high soil nitrogen and water produced longer pseudostems, which will have a tendency to reduce the feeding value of cocksfoot herbage.

5.7 Feeding value

Reasons for the feeding value of heavily shaded cocksfoot pasture being reduced more than under moderate shade (40% to 67% PPFD) and compared with open pasture are discussed in this section.

5.7.1 Botanical composition

The fact that there were no major differences in pasture cover between open and tree shaded pasture demonstrates the tolerance of cocksfoot to dry and/or shaded environments. The pasture cover categories which were increased under trees were bare-ground and dead material due to the presence of pine needles. This increase in bare-ground and dead material was probably related to the reduced productivity and tiller number of the cocksfoot under the trees.

The cover of clovers in both shaded and unshaded pasture was low (<11% clover cover even in October) due to the cocksfoot growth. Pollock *et al.* (1994) also reported that after the third year of the Lincoln University agroforestry experiment clovers tended to be dominated more by cocksfoot than by ryegrass. However, the most interesting result found during this botanical composition study was 4% more clover cover in spring (October) under 67% PPFD (Plate 4.3) compared with open pasture. This was attributed partially to subterranean clover which is moderately shade tolerant (Lodge, 1996 and Devkota *et al.* 1997) and had about 3% more cover than white clover under trees, and partially to sulphur content (Table 3.4) in soil which was in satisfactory level under trees than in open pasture. The small increase of clover cover under trees may partially improve the feeding value of shaded pasture in spring and early summer compared with open pasture.

Some weeds species appear to tolerate smothering from slash and litter more than sown pasture species. However, the weed population under trees was low compared with open pasture. Percival *et al.* (1984a) reported that the weed cover on humid warm Tikitere pasture tended to be more in silvopastoral plots compared with open pasture. Most of these weeds were associated with the slash and leaf litter that accumulates from successive pruning and thinning, and leaf fall. In the Lincoln University agroforestry experiment, pruning and thinning slash was removed, but the accumulation of pine needles in mid autumn and early winter had increased dead material cover by 3% compared with open pasture. In early winter and mid summer, more dead cocksfoot leaf cover was found under trees compared with open pasture.

This was attributed to the fungal disease in cocksfoot in early June 1998 and moisture stress in January 1999.

5.7.2 Cocksfoot canopy height

Cocksfoot canopy under 40 to 67% PPFD etiolated by 20% compared with grass in full sunlight. This result was similar to van Garderen (1997) who reported a 25% increase in cocksfoot canopy height under radiata pine trees. Evans *et al.* (1992) described grass etiolation as a response by grasses growing in shade attempting to gain better access to available light. However, during the 1998-99 twelve month study period, cocksfoot canopy height under 18% PPFD was only 1% more than in open pasture. This result indicates that the cocksfoot under very low PPFD did not etiolate. This lack of etiolation may have been caused by the low soil moisture level under 650 trees ha^{-1} treatment. Figure 4.9 shows that cocksfoot height under four shade levels in February 1999 did not differ. During that period moisture content in soil was less than 11.5% in all light regimes. The cocksfoot canopy height with urine plus water treatment was more than double that of the nil treatment cocksfoot pastures of all light regimes in all months (Figure 4.9). This result shows the elongation of cocksfoot tillers was only possible with adequate soil moisture and nutrients.

5.7.3 Pasture bulk density

The main effect of grass etiolation under moderate tree shade was the reduction of pasture bulk density compared with open pasture. The mean pasture bulk density of open cocksfoot pasture was 1.17 mg DM/cm^3, whereas under 18%, 40% and 67% PPFD this was 0.56, 0.75 and 0.88 mg DM/cm^3 respectively. This result was consistent with Gong *et al.* (1996a) who reported 1.0 mg DM/cm^3 pasture bulk density of cocksfoot pasture during vegetative growth and 0.72 mg DM/cm^3 during the reproductive stage. The reduction of pasture bulk density under shade was attributed to the decrease in dry matter yield and increase in cocksfoot canopy height under trees. A similar result was also found by Percival *et al.* (1988) who reported reductions in pasture bulk density under radiata pine trees compared with open pasture.

Pasture bulk density reduction under trees could result in a smaller mean bite size which would lead to reduced animal intake and growth rates (Percival *et al.,* 1988). In contrast, more recent work by Gong *et al.* (1996b) showed that pasture bulk density had little influence on the ingestive behaviour of sheep grazed in cocksfoot pasture compared with sward height. The bite rate of sheep generally declined in cocksfoot pasture in response to increasing height, but bite depth and bite volume of sheep were greater with increasing sward height (Gong *et al.*, 1996b). Their results illustrated the relationships between canopy height on bite rate, bite depth and bite volume as well as dry matter intake by animals during grazing. However, at low bulk densities, bite size may be more influential than canopy height. For example mean bulk density at 18% PPFD was 0.56 mg DM/cm^3 in the present study but the lowest value tested with sheep by Gong *et al.* (1996a) was 0.72 mg DM/cm^3.

5.7.4 Nutritive value

The nutritive value of 30 day regrowth Wana cocksfoot grown under four light regimes at the Lincoln University agroforestry experiment shows that the DOM%, N% and M/D value of shaded pasture were reduced compared with unshaded cocksfoot pasture (Figures 4.15, 4.16 and 4.17). In June, this was mainly caused by dead material due to *Rhynchosporium* fungus on cocksfoot plants. However, the nutritive value of 52 day regrowth cocksfoot during the reproductive stage in early December was marginally higher under trees compared with open pasture. Therefore, tree shade had a marginal effect on the possible increases and decreases of nutritive value of cocksfoot. These small differences are discussed below.

5.7.4.1 Nitrogen content

The nitrogen content under radiata pine trees was only reduced greatly in the June harvest compared with open pasture (Figure 4.15). This may be partially attributed to the greater incidence of fungal disease in cocksfoot grown under trees. In September harvest, the N content under 67% PPFD pasture was 4.35% which was 0.24% higher than in the open. This result was consistent with van Garderen (1997) who reported 0.40% greater nitrogen content under 60% shade in October compared with open pasture. In the November and February harvests, the mean nitrogen content in cocksfoot herbage grown in both shaded and unshaded pastures was less than 3% N. This was attributed to the rapid expansion of reproductive tillers in November and moisture stress in February. The addition of water and nitrogen to cocksfoot pasture under four light regimes increased the N content in the grass dry matter by an average of 0.62% in open pasture and 0.57% under 67% PPFD compared with nil treatment.

5.7.4.2 Organic matter digestibility

Compared with open pasture, the digestible organic matter content in 30 day regrowth cocksfoot was reduced in most harvests under 18% and 40% PPFD (Figure 4.16). The seasonal patterns in digestibility have been studied by Hunt (1971) who found digestibility declined to a minimal level in February. He attributed this to warmer and drier conditions, resulting in an increase in fibrous herbage. However, the greatest reduction in DOM under trees during the 1998-99 study was found in the June harvest compared with open pasture. This was attributed to both fungal disease to cocksfoot plants under trees and reduced light intensity. In November harvest, the DOM content was marginally greater under 67% PPFD compared with open pasture because reproductive tillers under trees were decreased by 11%.

The overall decrease of DOM% under 67% PPFD in unirrigated plots ± urine patches was 2.5% of DOM units compared with open pasture. van Garderen (1997) also noted a 1.9% reduction in DOM under radiata pine trees in October compared with open pasture. Thompson and Poppi (1990) reported that the digestibility of pasture species is influenced mainly by the chemical composition of the carbohydrate fraction of the plant. This is because of the cell wall fraction such as cellulose and hemicellulose should be higher under trees than in the open.

5.7.4.3 Metabolisable energy

The average energy (M/D value) levels of cocksfoot under trees was reduced by 5-14% compared with open pasture (Figure 4.17). The main reason for the reduction was probably fungal disease in the June harvest. The M/D value under 67% PPFD was higher in the November harvest compared with open pasture. This was attributed to the decrease of reproductive tillers under trees compared with open pasture. Cocksfoot pasture grown in urine patches with or without water resulted in more metabolisable energy under 67% and 40% PPFD and in open pasture compared with treatment nil plots. It follows that grass dominant cocksfoot pastures in the sub-humid climate of Canterbury, which are normally deficient in both water and nitrogen are likely to be of low M/D value in summer.

Geenty and Rattray (1987) reported that the metabolisable energy requirement of ewe hoggets aged 6-12 months weighing 25, 30, 35 and 40 kg liveweight was 10.0, 11.5, 13.0 and 14.0 MJ ME/d respectively for 50 g per head per day liveweight gain. The metabolisable energy of 67% PPFD plot and open pasture was higher than 10.0 MJ ME and below 11.0 MJ ME. Therefore, if young sheep of 25 kg liveweight eat 1 kg DM per day there would be sufficient metabolisable energy to achieve this modest target weight gain.

5.8 Grazing preference of sheep

Results of three grazing experiments suggest that the palatability of cocksfoot herbage may be determined by season, growth periods, shade, disease and soil nitrogen (urine). In all grazing experiments, the canopy height of cocksfoot pasture before the start of grazing was 6-14% more under trees than in open pasture. Similarly, urine patches had 8-16% more canopy length in both shaded and unshaded pastures compared with adjacent non-urine patches.

In the first three days of the grazing experiments, the ewe hoggets grazed 12% more urine patches in October and 18% in December compared with corresponding non-urine areas in both shaded and unshaded pastures. This result was similar to van Garderen (1997) who also reported a greater cocksfoot canopy height decline in urine patch compared with non-urine patches in the second day of sheep grazing experiment at the Lincoln University agroforestry experiment. Reasons for this could be the greater height of cocksfoot grass and/or the greater crude protein/nitrogen content in urine patches than in adjoining non-urine areas. Edwards *et al.* (1993) also found similar results and reported that sheep would preferentially graze urine patches either due to the greater canopy height, higher proportion of green leaves and or increased nutritional value (N%). However, by day four of grazing in July, day nine in October and day eight in December, the grazing preference of sheep shifted from urine patches to non-urine areas because most of the green leaves in the urine patches had been removed and only pseudostems remained. More reduction of cocksfoot tillers height in non-urine patches was also attributed to the initial cocksfoot canopy height which was lower in non-urine patches compared with urine patches. In October, the canopy height of urine patches in open pasture reduced at a faster rate compared with non-urine areas possibly because the open cocksfoot pasture grown in non-urine areas was infected by *Rhynchosporium* fungus which had reduced the palatability of cocksfoot herbage grown in non-urine areas.

Plates 4.3 and 4.4 demonstrate the effect of clover species on grazing behaviour of sheep because most of the clover herbage disappeared from the field within first two to three days of grazing experiment in October. This demonstration of sheep having a strong preference for clover was also reported by Edwards *et al.* (1993).

Sheep grazed 32 day regrowth cocksfoot herbage more closely compared with 52 day regrowth in October and December. This may be the result of cocksfoot grass maturity. Korte *et al.* (1987) reported that the palatability of grasses decreased with the increase in plant maturity. The reproductive tillers may also affect the grazing pattern of sheep in December when there were 11% more in open pasture compared with under trees.

Finally, more precise work would be required to compare ± tree pasture preference by testing ± tree swards offered to caged sheep.

5.9 Supplementary study

5.9.1 Pasture production

Table 4.4 shows that there was not any difference in cocksfoot dry matter yield between shaded and unshaded pastures in 52 day regrowth herbage in October and

December. This is partially attributed to the fungal disease in October in open pasture and more soil moisture content (1.4%) under 200 trees ha^{-1} in December compared with open pasture. In 32 day regrowth cocksfoot herbage in July dry matter yield in urine patches was higher in open pasture compared with under trees. This is probably due to the effect of higher PPFD in open pasture. The cocksfoot dry matter yield of shaded and unshaded pastures in 52 day regrowth herbage was higher in December than in October. This was attributed to the reproductive growth in cocksfoot in December.

5.9.2 Cocksfoot canopy height

The cocksfoot canopy height in October and December was higher under trees compared with open pasture. This is attributed to the etiolation of cocksfoot tillers under 67% PPFD.

5.9.3 Nutritive value

The DOM%, N% and M/D values of 30 day old cocksfoot herbage were higher under full sunlight (Figures 4.15, 4.16 and 4.17), while those in 52 day old herbage in December were higher under radiata pine trees (Table 4.6). This result indicates that pastures in silvopastoral systems with cocksfoot and radiata pine trees require appropriate grazing management techniques for the improvement of the nutritive value of grazing pastures. This would involve frequent grazing to keep grass leafy, improved legume content by sowing subterranean clover and fertiliser to encourage legumes (phosphorus, sulphur, lime etc). Korte *et al.* (1987) suggested that the first aim of grazing management is to maintain pasture quality by avoiding extremes of pasture mass for long periods, especially by over-grazing following drought, or allowing accumulation of rank pasture during spring or summer.

5.10 Summary

Radiata pine trees in an agroforestry system created microclimates by reducing the transmission of PPFD on understorey pasture that reduced soil temperatures at 100 mm soil depth in summer, autumn and spring, but increased it in winter compared with open pasture. Likewise, the volumetric water content of soils at 0-300 mm soil depth reduced in autumn, winter and spring seasons, but increased the VWC in summer compared with open pasture.

Pasture production under moderate shade (40% to 67% PPFD) reduced compared with open pasture but this reduction was minimal when pasture was not stressed for water and nutrients (nitrogen). Cocksfoot plants under moderate shade were taller but leaf width, tiller numbers and in particular pasture bulk density were all less than in open pasture. Digestible organic matter, nitrogen content and metabolisable energy in cocksfoot herbage under moderate shade were marginally reduced compared with open pasture. The nutritive value of shaded pasture was only reduced greatly in the June harvest. This may be partially attributed to the greater incidence of fungal disease in cocksfoot grown under trees.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSION

6.1 Introduction

Section 6.2 deals with the environmental factors and their impact on pasture productivity and feeding values. Section 6.3 describes the limitations of this research project. Sections 6.4, 6.5 and 6.6 highlight silvopastoral system management practices, future work for temperate, sub-humid agroforestry research and conclusion, respectively.

6.2. Pasture production

Trees in silvopastoral systems create microclimates which influence light interception, water balance, soil temperature and soil properties, which in turn influence the growth and development of understorey pasture compared with open pasture. Figure 6.1 illustrates the relationship between the total annual pasture production rate and intercepted PPFD under different soil moisture and nutrient levels.

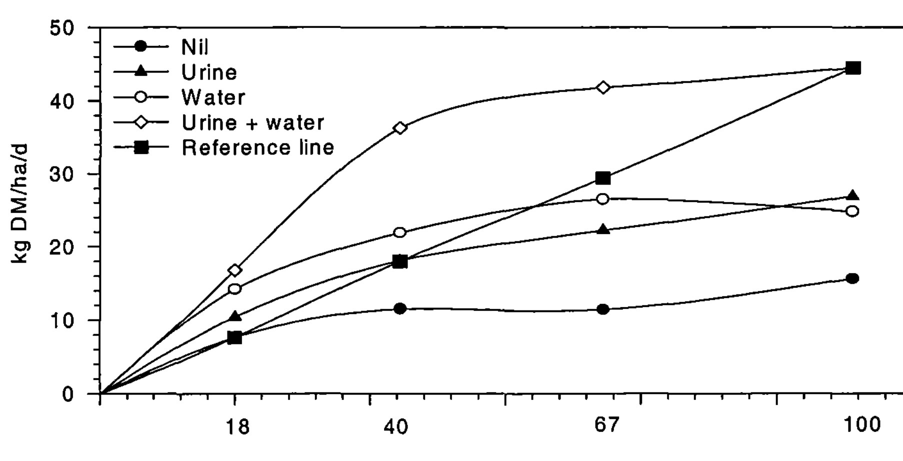

Figure 6.1. Pasture production rate under four light regimes in four different treatments from means of five harvests.

The reference line refers to the assumption that pasture production should be proportional to light energy or PPFD at the levels of soil moisture, nutrients and temperature. The four curves show the actual dry matter production rate of cocksfoot dominated pasture under the four light regimes at different water and nutrient levels during five 30 day harvest periods during the 1998-99 experimental period.

Figure 6.1 strongly suggests that cocksfoot pasture under trees used intercepted PPFD more efficiently and produced more dry matter in relation to the quantity of intercepted PPFD compared with open cocksfoot pasture. The main reasons for this are:

- According to Faurie *et al.* (1996), the photosynthetic efficiency of plant leaves appears to decrease continuously with increasing irradiance. Above the point of saturation, further increments of solar radiation give no increase in the rate of net photosynthesis. The additional input of solar radiation serves only to increase transpiration, re-radiation and convection, and thermal stress. Sheehy and Peacock (1975) reported that the canopy saturation point for cocksfoot is about 330 W/m^2 or 1518 μ $moles/m^2/s$ PPFD (1 W m^2 = 4.6 μ $moles/m^2/s$). Between March and September none of the PPFD levels of pasture grown under the four light regimes exceed the canopy saturation point for cocksfoot (Appendix 4.3). However, the saturation point for cocksfoot was exceeded from October to February between 11 am to 3 or 4 pm in open pasture, and under 40% and 67% PPFD during summer months (December to February) from 2 to 3 pm.

- Hay and Walker (1989) reported that environmental stress such as hot and dry summers limit the efficiency of intercepted PPFD for photosynthesis. During this study period, there was only 401 mm rainfall and 1134 mm evapotranspiration, which caused moisture stress for pasture production and would have reduced the efficiency of cocksfoot conversion of PPFD into dry matter.

- Duru *et al.* (1995) reported that the radiation use efficiency of cocksfoot and tall fescue decreased with the reduction in soil nitrogen. The presence of darker urine patches and production responses in all seasons showed the nitrogen deficiency in the cocksfoot dominant pastures. Grass nitrogen content under moderate shade (40% to 67% PPFD) was similar to open pasture (Figure 4.15) and there was no consistent pattern between seasons in nitrogen content in cocksfoot herbage. The pasture production data (Table 5.1) clearly show that increased nitrogen availability, especially with irrigation would give large increases in pasture production at all levels of PPFD.

- Hay and Walker (1989) stated that photosynthesis in temperate climates can be limited by low temperatures in winter and by water deficits in summer. During the 1998-99 study periods, soil temperature under trees in winter was 0.5°C higher than in open pasture, but pasture production between open pasture and under trees did not differ perhaps partly due to the fungal disease under trees. On the other hand, volumetric water content in soil in summer under moderate shade was 0.8% more than in open pasture. This possibly increased the cocksfoot dry matter yield under 40% to 67% PPFD by 16% in February 1999 harvest in the nil treatment plots compared with similar plots in open pasture.

- During this study period, the leaf area index (LAI) of cocksfoot pasture grown under four light regimes was not measured, but the surface area of individual cocksfoot leaves grown under four shade levels was determined. The area of individual leaves was 14% more under 40 to 67% PPFD than in cocksfoot leaves grown without shade. This may have some influence on the photosynthetic activities in the grass. However, the reduced (15%) tiller number in moderate shade probably countered the increase in individual leaf areas.

This discussion shows that environmental factors such as solar energy, temperature, water and nutrients are equally important for the growth of understorey pastures. Therefore, the possible effects of these factors on pasture production are discussed.

6.2.1 Tree shade

Tree shade disturbs the distribution of solar energy, and reduces wind run and consequently the evapotranspiration rate. During the 1998-99 study period, the ambient PPFD measured above the pasture canopy was 18% of full sunlight under 650 trees ha^{-1}, 40% at 300 trees ha^{-1} and 67% at 200 trees ha^{-1}. The components of pasture productivity and feeding value, such as pasture composition, tiller populations, leaf number, leaf length and width, and pasture production were all reduced with the decreasing ambient PPFD, and cocksfoot canopy height under 40 to 67% PPFD was increased by 20% compared with open pasture. Anderson (1978) found etiolation in cocksfoot was due to cell expansion under shaded environment. Similarly, Casal *et al.* (1985) noted etiolation in cocksfoot and attributed this to low red/far-red ratio.

The changes in the morphology of shaded pasture resulted in reduced pasture bulk density under moderate shade (46%-67% PPFD) by 30% which may reduce pasture intake through smaller bite size. This possible adverse effect on intake, together with reductions in the nutritive value under moderate shade, would result in a reduced per head animal performance. However, the small (4%) increase in clover content and the decrease (29%) in reproductive tillers under moderate shade may partially improve animal performance in spring and early summer.

In late summer and early autumn (February and March), tree shade created an improved environment for pasture production. During this period, dry matter yield under moderate shade was increased by 15% compared with open pasture. This result shows tree shade may enhance pasture production in the Canterbury plains during hot and dry periods.

6.2.2 Temperature

The main function of temperature is to enhance the photosynthesis process, respiration, reproduction and phenological development in pasture plants. During this study period, tree shade in summer reduced soil temperature by 0.9-1.9°C under 40% to 67% PPFD and in winter increased temperature by 0.5°C compared with open pasture. In addition, the air temperature in winter was also higher than previous five years (Table 3.2). The increase of temperature in winter usually reduces the frost damage to pasture plants and the reduction of summer temperature minimises the evapotranspiration rate. The increase of pasture production under 67% PPFD during winter, summer and early autumn could be the result of those factors. However, the reduction of soil temperature (1-2.9°C) under 300 to 650 trees ha^{-1} in spring due to tree shade may have resulted in the significant descrease in pasture production under 18% to 40% PPFD compared with open pasture. It follows that in an agroforestry system the combination of low light and low soil temperature affect winter and spring pasture growth.

6.2.3 Soil moisture

Pastures in this sub-humid climate are usually water deficient in summer. During the 1998/99 the site received 401 mm rainfall compared with the rainfall for the last four years which was at least 530 mm. In addition, the evapotranspiration rate (1134 mm) and potential moisture deficit (733 mm) were much higher than previous years (Section 3.1.3). Therefore, severe moisture deficits occured during the study period. However, moderate tree shade in summer increased the soil moisture content by 0.8% compared with open pasture. This may have contributed to improved pasture production under moderate shade by 15% compared with in the open. In autumn, winter and spring, soil moisture content under 18% and 40% PPFD was reduced, probably due to root competition and the rain shadow effect of trees which directly affected pasture production (Figure 4.6). During this study period, about 360 mm water was applied to investigate the effect of irrigation on pasture production. Under 40% to 67% PPFD, irrigation improved pasture production in non-urine patches by 54% with a high response in summer and early autumn compared with non-irrigated plots. The effect of this limited irrigation on pasture production was less in open pasture (Table 5.1) compared with under trees. On the basis of this study, irrigation between November to April, especially January to March would be the best practice for pasture production in the Canterbury plains.

6.2.4 Soil nutrients

The presence of darker urine patches in grazed pastures in all seasons indicates the typical state of nitrogen stress in grass dominated pastures. The nitrogen requirement of this study site is mostly supplied by sheep urine and some from clovers. Animal depositions such as urine and dung provide nitrogen, phosphorus, potassium, sulphur, magnesium and calcium to the soil and pasture. Urine from animals grazing pastures promote highly nutritious patchy growth of pasture grass species. Pastures growing in areas of sheep urine deposition had increased DOM (3%), N (0.3-0.6%) and M/D value

(0.4-0.6 MJ ME/kg DM) under moderate shade and in open pasture compared with non-urine areas.

van Garderen (1997) found 40% more cocksfoot dry matter yield in urine patches compared with adjacent non-urine patches. During this later study period, sheep urine under full sunlight and moderate shade increased cocksfoot dry matter yield by 42%. However, the area covered by urine patches was 8% in open pasture and 5% under trees and the effect of urine patches on total production and pasture feeding value is therefore small. Figure 4.6 showed that the addition of water in urine patches gave a further response of 40% more pasture yield under full sunlight and 48% under moderate shade compared with urine only patches.

Marriott *et al.* (1987) reported a disadvantage of animal urine was the reduction of white clover content in ryegrass-white clover pasture by 55% compared with non-urine areas. Parsons *et al.* (1991) also recorded a 20% reduction of clover content in urine patches. This was attributed to the vigorous growth of grasses in urine patches. Table 3.4 shows that open cocksfoot pasture had low level of sulphur and phosphorus compared with in agroforestry plots. This would have further reduce the competitiveness of clovers in open cocksfoot-clover swards. The application of phosphorus and sulphur fertiliser may improve clover vigour and hence pasture production in open cocksfoot pasture and under radiata pine trees. Nitrogen fertiliser would certainly increase grass production.

6.2.5 Reproductive growth

High solar radiation and temperature in November in 30 day regrowth cocksfoot pasture under full sunlight gave 29% more reproductive tillers compared with under moderate shade (40 to 67% PPFD). During this period, dry matter yields of open pasture was 30% more than under moderate shade. de Montard *et al.* (1999) also found a 45% increase in cocksfoot pasture production in France in the reproductive stage than in the vegetative stage. This result suggests that the increase of pasture production under full sunlight in November could be an effect of reproductive development.

6.2.6 Fungal disease

All cocksfoot pastures were affected by fungal disease during period of cool temperatures and hence slowed production rate. Under trees in early June and in October in open pasture cocksfoot was badly affected by the fungus (*Rhynchosporium orthosporum*). This infection was low in urine patches compared with non-urine patches. The disease reduced productivity and nutritive values of cocksfoot herbage in June under trees.

6.3 Experimental design

The experiment design was a randomised split-plot design with three levels of shade under trees as main plots and ± water applied to cocksfoot cv Grasslands Wana pasture areas with or without sheep urine patches as sub-plots in each of three blocks. In adjacent open cocksfoot pasture of the same age, four sub-plots were randomly assigned to each of the three blocks. This design was the most practical design for studying the light treatments. However, there were some problems relating to data collection and explanation of collected data.

- The selection of new urine patches for each of the five 30 day harvest periods was a problem after grazing the pasture because two or three weeks passed before new patches could be identified. Therefore, pasture productivity and feeding value could not be measured continuously or at regular intervals to obtain full season data for pasture production and nutritive value. Hence the five harvest periods are windows into important segments of each season, but do not provide a complete picture.

  The main plots under trees (eg 292 m^2 under 650 trees ha^{-1}), and subplots (0.1 m^2) both under trees and in open pasture were small in size giving limited scope for observation of the overall effects of trees on pasture and animal production. However, care was taken to avoid bias in sub-plot selection. The sub-plots were selected for pasture uniformity, lack of weeds and strongness of urine patches. In addition, new positions were chosen for each 30 day production period rather than repeated harvests on the same sites.

- The shading effects of trees on understorey cocksfoot pasture productivity and feeding value was carried out in Plot 2A agroforestry and in adjacent Plot 27 open pasture. Soils of both agroforestry and open pasture were assumed to be similar and no fertiliser or lime has been applied since 1989. The entire area was cropped with peas before plantation and pasture establishment in 1990. Currently, both agroforestry and open pasture have nine-year-old cocksfoot pasture. In open pasture, four sub-plots were randomly assigned to each of three blocks as in the three levels of tree shade (Figure 3.4), but these plots could not be randomised with and without trees. The main aim of this study was to compare the productivity and feeding of cocksfoot pasture grown under full sunlight and three levels of tree shade. The variations found between open pasture and under trees were the accumulated effects of radiata pine trees over the nine-year period.

- In the original proposal for this study it was also proposed to measure the effects of ± shade, ± urine and ± water on alkaloid levels (lolitrem B, ergovaline and peramine) in endophyte infected ryegrass in autumn. The ryegrass content in the ryegrass pasture treatments at the Lincoln University agroforestry experiment was depleted. Therefore, this study could not carried out. However, the PPFD, soil temperature and moisture levels of cocksfoot pasture grown under four shade regimes were carried out in detail. These physical measurements were conducted for a full 12 months period. This was started five month after the main experiment for pasture productivity and nutritive value measurement. This delay was because of time constraints and instrument problems. However, the data collected from these physical measurements can be related to cocksfoot pasture productivity and feeding value.

6.4 Silvopastoral system management practice

The silvopastoral system in New Zealand is a widely accepted land use option. This system is practiced for shelterbelts for sustainable agriculture, soil and water conservation, and land stabilisation (Wilkinson, 1997), improvement of the aesthetic value of landscape (Mead, 1995a), flexibility for livestock management (Percival *et al.*, 1984c), diversification of farm income, and national forest protection by reducing timber pressure. Because of these benefits of the silvopastoral system, every year about 80,000 hectares of farm and other lands is planted with trees (Hawke, 1997). Among them, radiata pine occupies about 90% area. Hawke in his 1997 review stated that pasture production under radiata pine trees at Tikitere is greatly reduced compared with open pasture. However, the results of this study show that pasture production under 40 to 67% PPFD was reduced by 26% in non-irrigated plots and only 9% under irrigation compared with in open pasture. Most of these reductions were recorded in the November harvest. The increase of pasture yields under full sunlight in November is attributed to reproductive growth which was 29% higher in open pasture than under moderate shade. Cossens (1984) and Percival *et al.* (1984a) reported the reduction of white clover under trees which can have great impacts on both the nutrient status of soils and the diet for grazing animals. Therefore, farmers and forestry companies should adopt the following management practices for profitable use of silvopastoral systems with appropriate grass and legume combinations under trees.

6.4.1 Pasture management

This includes discussion of the selection of shade tolerant pasture species, irrigation, fertilisation and grazing management.

6.4.1.1 Selection of species

According to Cossens (1984) Percival *et al.*, (1984a), the use of radiata pine in association with ryegrass-white clover is a common practice in New Zealand. However, the performance of these two species under radiata pine shade has been demonstrated to be unsatisfactory. Ryegrass was the least persistent grass in the Lincoln University agroforestry experiment. Percival *et al.* (1984a) and Cossens (1984) reported that the white clover production under radiata pine was greatly reduced in their experiment at Tikitere, Warataha and Invermay. On the other hand, Devkota *et al.* (1998) stated that tree shade affected perennial ryegrass more than cocksfoot cultivars, especially at the low PPFD. Seo *et al.* (1989) also showed that cocksfoot is a shade tolerant grass and persisted well under pine trees in South Korea. Devkota *et al.* (1997) found that cocksfoot, Yorkshire fog (*Holcus lanatus* L.) and lotus (*Lotus uliginosus*

Schkuhr) were the most shade tolerant pasture species. They tested 10 different species at Massey University, Palmerston North. Lodge (1996) reported subterranean clover as being shade tolerant. Devkota *et al.* (1997) found subterranean clover as a moderately shade tolerant species. This study on the shading effect of nine-year-old radiata pine trees on productivity and feeding values of nine year-old cocksfoot pasture confirmed that subterranean clover did better than white clover with cocksfoot grass under radiata pine trees. Therefore, further research on subterranean clover and cocksfoot in association with radiata pine trees should be continued and extended to appropriate New Zealand farms.

6.4.1.2 Irrigation

During the 1998-99 twelve month study periods, irrigation under moderate shade of 200 to 300 trees ha^{-1} to meet current potential moisture deficit improved the annual pasture yield by about 54% with greatest response in summer and early autumn. McBride (1994) also reported that irrigation in Canterbury increased pasture yield by up to 80% with the highest response in summer. Thomson (1994) noted that Canterbury and North Otago are well suited to irrigation because there are large rivers with relatively high summer flows, large areas of plains with well drained soils and high moisture deficits for pasture production in summer and early to mid autumn. The study on the shading effects of trees on understorey cocksfoot pasture shows that irrigation during summer and early autumn is extremely important in the Canterbury plains for the improvement of pasture production and nutritive value. During this study, irrigation increased DOM and N by 1.6% and 0.3% under full sunlight compared with non-irrigated non-urine patches. The amount and frequency of irrigation should be confirmed by other research because irrigation to meet potential moisture deficit during this study period was inadequate to achieve maximum pasture production.

6.4.1.3 Fertilisation

The presence of darker urine patches in all seasons, the reduction of clover composition in cocksfoot dominant pasture and the increment of cocksfoot dry matter yield in irrigated sheep urine patches indicate the need for fertiliser to improve pasture production. Table 5.1 shows that nitrogenous fertiliser with irrigation could be used to improve pasture production by up to 71% under moderate shade and 65% in open pasture. In places where irrigation is not avalable farmers can use nitrogenous fertiliser in March-April (autumn) when rainfall starts. This would be least harmful to clovers and would encourage nutritious grass production for winter feed. This nitrogen boosted cocksfoot would be especially valuable for agroforestry stock havens during southerly storms and specially for ewes after pre-lamb shearing.

Phosphorus and sulphur will play a vital role for growth and development of both grass and clover species. Barker *et al.* (1999) reported that the application of superphosphate (40 kg P/ha) on hill country Wana cocksfoot pasture increased bull beef returns from NZ$ 397.84/ha to $ 715.20/ha.

6.4.1.4 Grazing management

Korte *et al.* (1987) reported that grazing management must be focused to maintain pasture quality by avoiding extremes of pasture mass for long periods, especially over grazing following drought or allowing accumulation of rank pasture during spring and summer. On the other hand, the legume content in pastures improves pasture quality and animal performance, and soil nitrogen. Therefore, pasture management must also focus on the maintenance of high legume content. Due to the shading effects of trees, selective grazing behaviour of sheep, aggressive growth of Wana cocksfoot and the effect of urine, clover content at Lincoln University agroforestry experiment was depleted.

The nutritive value of mature cocksfoot herbage in December under full sunlight (Table 4.6) in non-urine patches was reduced compared with the 30 day regrowth herbage in November (Figures 4.15, 4.16 and 4.17). Langer (1990) reported that cocksfoot tends to become rather coarse and highly tufted under light grazing systems. The coarse and highly tufted herbage is not greatly acceptable to grazing animals. Therefore, animal grazing should be frequent to maintain the sward in a vegetative state.

6.4.2 Tree management

Silvicultural operations such as pruning and thinning should be aimed for tree shade reduction and clear wood production so that maximum profitability may be obtained from the silvopastoral production systems. Table 6.1 describes the silvicultural regime for clear wood production so that understorey growth and development is also improved. These operations are recommended for the establishment and management of new agroforestry plots, and improvement of existing stands.

Table 6.1. Pruning and thinning operations for radiata pine trees (MOF and NZFRI, 1996).

Age (yrs)	Average (ht)	DOS (cm)	Operations
0	0	0	plant 500-1000 trees ha^{-1}
4-6	6-7 m	15-20	prune 300-400 trees ha-1 by leaving 3.5-4 m green crown.
4-6	6-7 m		thin to 300-400 trees ha^{-1}
6-8	8-9 m	15-20	prune 250-350 trees ha^{-1} by leaving 4 m green crown.
8-10	10-12 m	15-20	prune 250-300 trees ha^{-1} by leaving 4 m green crown.
8-10	10-12		thin to 250-300 trees ha^{-1}
25-30	30-40		harvest

The dominant, vigorous, well spaced, straight and erect trees with a single leader should be pruned by cutting branches at right angles to the trunk and as near as possible to the nodal swelling without any damage to the stem or bark. Stem cones and epicormic shoots should also be removed for clear wood production. Pruning of trees may be beneficial to understorey pastures by reducing both solar radiation interception and transpiration by the overstorey trees. Thinning, on the other hand, reduces the competition for light, moisture, nutrients and space between trees, and trees pastures in silvopastoral systems. Ideally, the pruning and thinning slash should be removed from the field for maximum benefit to the understorey pastures.

Production thinning at 17-18 years after plantation establishment could be carried out. Elliott (1993) reported that when understorey pasture production should be continued up to the end of forestry rotation, then 150 trees ha^{-1} should be left after production thinning. However, care should be given to do production thinning when tree height is above 18 m. Maclaren (1993) reported that the risk of windthrow in radiata pine trees is very high after production thinning in those trees whose height is greater than 18 m. Therefore, production thinning should be carried out on the basis of tree form and height and the prevailing wind.

6.5 Future work

Results of this experiment brought up the following issues which should be addressed in future research work to study the shading effects of radiata pine trees on productivity and feeding value of understorey pastures.

- The main aim of pasture establishment and production is to provide feed for livestock. This is the common concept of pastoralists because the final value of pastures is measured in terms of animal productivity. Therefore, a grazing experiment should be focused to measure liveweight gain from shaded and unshaded cocksfoot pastures for an estimation of the reduction in feeding value of shaded pasture.

- Artificial urine should be prepared and used to study the effect of nitrogen on pasture productivity and feeding value rather than waiting for the identification of real sheep urine patches. In addition, sheep urine patches are usually small (0.1 m^2) in size.

- The main plots and sub-plots for the 1998/99 experiment were small in size. Therefore, trees in the heavily shaded zone also influenced the PPFD level of the 300 trees ha^{-1} zone. In this situation, both main and sub-plots should be apart and larger in size to reduce the shading effects of neighbouring trees.

- Each experiment should be started and finished within a season to investigate the seasonal effects on pasture productivity and feeding value more satisfactorily.

6.6 Conclusion

Conclusions of this study of cocksfoot dominant pasture grown under four light regimes in a sub-humid area with dry warm and moist cool seasons are:

- Productivity of cocksfoot pasture is not directly proportional to tree shade because the PPFD measured in clear sunny days during this study periods from July 1998 to June 1999 indicated that open cocksfoot pasture was light saturated from October to February between 11 am to 3 or 4 pm, and under moderate shade (40% to 67% PPFD) from December to February in between 2 to 3 pm.

- The cocksfoot pasture under moderate shade was more stressed by water and nitrogen deficiencies than by tree shade because cocksfoot pasture production in this zone was only marginally reduced in irrigated urine and non-urine patches compared with open pasture.

- Trees cause grass etiolation under moderate shade but leaf width, tiller numbers and in particular pasture bulk density were all less than in open pasture.

- Components of the nutritive value of cocksfoot herbage such as digestibility, nitrogen content and M/D value under moderate shade were marginally reduced compared with open pasture.

- The application of water and nitrogen (urine) increased cocksfoot pasture production and feeding value (pasture bulk density and nutritive value) greatly in all light regimes except pasture bulk density under heavy shade (18% ambient PPFD).

- The aggressive competitive ability of cocksfoot resulted in low clover content in both shaded and open pasture. This coupled with the larger response of cocksfoot production under urine patches shows that cocksfoot dominant pasture was more stressed by nitrogen deficiency than by shade.

- The performance of subterranean clover in spring suggested that this species is better suited to silvopastoral systems in sub-humid environments compared with white clover.

- Trees created microclimates which increased soil temperature under moderate shade in winter by 0.5°C and decreased temperature in summer by 0.9-1.9°C compared with open pasture.

- Competition for water between trees and understorey pastures decreased soil water content more under trees in all seasons except during the dry summer than in the open pasture.

- Studies of grazing preference for cocksfoot by sheep were inconclusive and require further study to separate the influences of soil nitrogen, sheep urine, sward height, tree shade, pasture bulk density, clover content and fungal disease on grazing behaviour of sheep.

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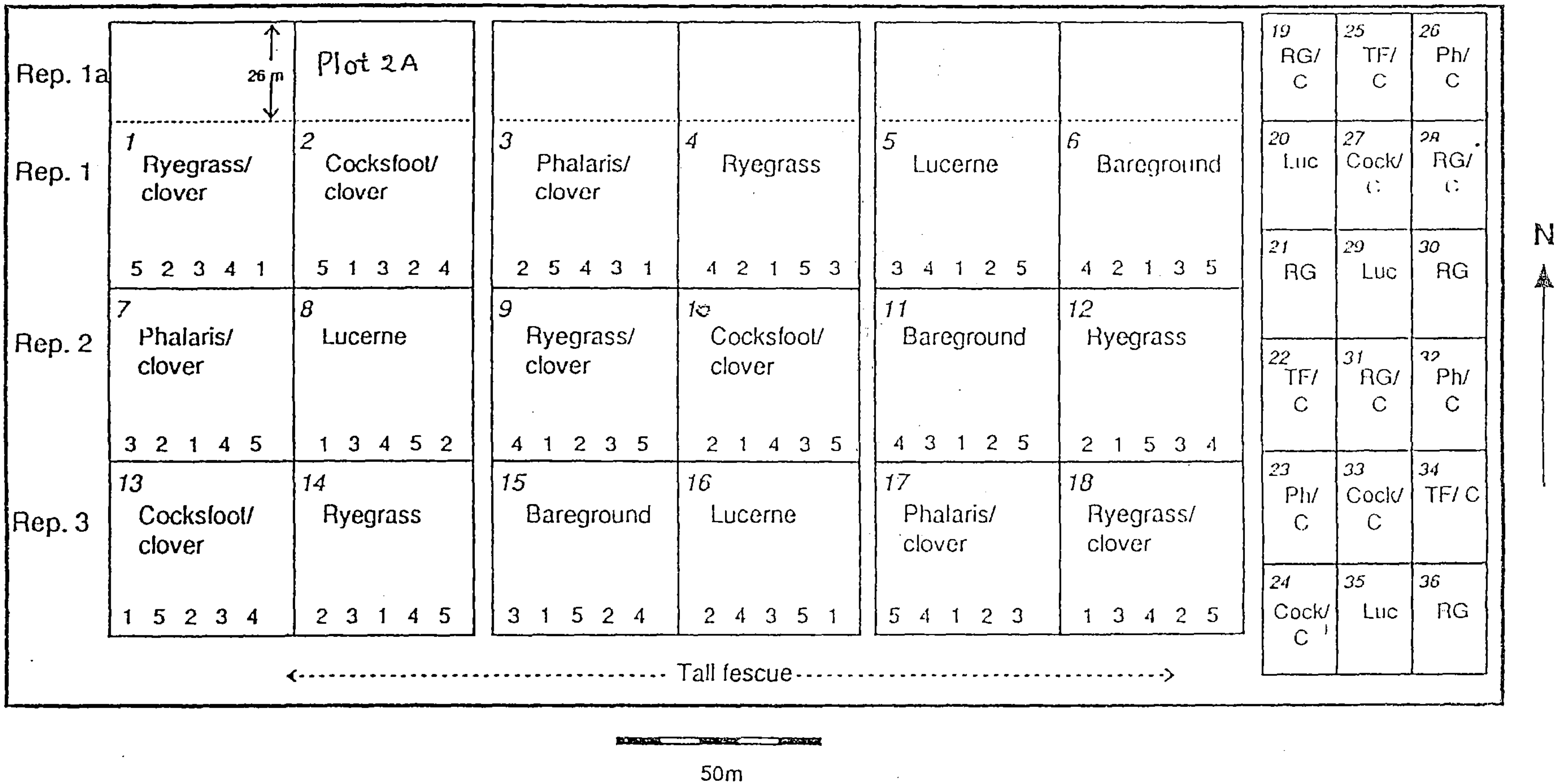
Appendix 3.1



LINCOLN UNIVERSITY AGROFORESTRY EXPERIMENT
Established July 1990

Main Plots (*1 - 18*): 42.0 x 45.0m (0.189 ha)
Open pasture (*19-36*): 18.2 x 27.0m (0.05 ha)
Initial spacing: 7 m x 1.4 m (1000 sph)
1,2,3,4,5: *Pinus radiata* genotypes
Thinned: 1992 (800 sph)
1993 (600 sph)
1994 (400 sph)
Pruned: Nov./Dec. 1994 (to 10 cm caliper)

Rotational grazing commenced Spring 1993
Separate flocks for each pasture treatment
Pasture mass pre- and post-grazing estimated
Seasonal botanical analyses
No fertiliser or irrigation
Red, white and sub. clovers sown

Appendix4.1

Summary of statistical analyses
(Analysis of variance)

Summary of statistical analyses for tree height and diameter, photosynthetic photon flux density (PPFD), soil temperature, soil moisture, botanical composition, pasture productivity, tiller population, reproductive tiller population, cocksfoot grass canopy height, pasture bulk density, shape and size of cocksfoot leaves, nutritive value and grazing preference of sheep is presented in following table.

Parameters	Variates	p-value
Tree height & diameter	Tree height x zone	0.710
	Diameter x zone	0.009
	Pruning height x zone	0.046
	Crown length x zone	<0.001
PPFD	Shade	<0.001
	Shade x months/measures	0.050
Soil temperature	Shade	<0.001
	Treatment (± water)	<0.001
	Shade x treatment (± water)	0.034
	Shade x measure/months	<0.001
	Shade x treatment x months	<0.938
Soil moisture	Shade	<0.001
	Treatment (± water)	<0.001
	Shade x treatment (± water)	0.463
	Shade x measures/months	<0.001
	Shade x treatment x months	1.000
Botanical composition	Cocksfoot	
	Shade	0.016
	Measure	0.037
	Shade x measure	0.416
	White clover	
	Shade	0.056
	Measure	< 0.001
	Shade x measure	0.923
	Subterranean clover	
	Shade	0.042
	Measure	< 0.001
	Shade x measure	0.003

	Weeds	
	Shade	0.237
	Measure	0.036
	Shade x measure	0.130
	Dead material	
	Shade	0.032
	Measure	0.041
	Shade x measure	0.070
	Bareground	
	Shade	0.091
	Measure	<0.001
	Shade x measure	0.514
Pasture production	Shade	<0.001
	Treatment (± water & ± urine)	<0.001
	Shade x treatment (± water & ± urine)	<0.001
	Shade x harvests	<0.001
	Shade x treatment x harvests	0.044
Tiller population	**Vegetative tillers**	
	Shade	<0.001
	Treatments (± water & ± urine)	<0.001
	Shade x treatment	<0.001
	Shade x measure	<0.001
	Shade x treatment x measure	<0.001
	Reproductive tillers	
	Shade	< 0.001
	Treatment (± water & ± urine)	< 0.001
	Shade x treatment (± water & ± urine)	0.013
Pasture canopy height	Shade	<0.001
	Treatment (± water & ± urine)	<0.001
	Shade x treatment (± water & ± urine)	0.001
	Shade x measure	<0.001
	Shade x treatment x measure	<0.01
Pasture bulk density	Shade	<0.001
	Treatment (± water & ± urine)	0.001
	Shade x treatment (± water & ± urine)	<0.001
	Shade x measure	<0.001
	Shade x treatment x measure	<0.01
Shape and size of leaves	**Leaf number**	
	Shade	<0.001
	Treatment (± water & ± urine)	0.002
	Shade x treatment (± water & ± urine)	0.703
	Shade x measure	<0.001
	Shade x treatment x measure	<0.254

	Leaf length	
	Shade	<0.001
	Treatment (± water & ± urine)	<0.001
	Shade x treatment (± water & ± urine)	0.031
	Shade x measure	<0.001
	Shade x treatment x measure	<0.010
	Leaf-width	
	Shade	<0.001
	Treatment (± water & ± urine)	<0.001
	Shade x treatment (± water & ± urine)	0.703
	Shade x measure	<0.02
	Shade x treatment x measure	0.254
	Cocksfoot pseudostem length	
	Shade	0.004
	Treatment (± water & ± urine)	<0.001
	Shade x treatment (± water & ± urine)	<0.041
	Shade x measure	<0.001
	Shade x treatment x measure	0.048
Nutritive value	**Digestible organic matter**	
	Shade	<0.001
	Treatment	<0.001
	Shade x treatment (± water & ± urine)	0.380
	Shade x harvests	<0.001
	Wald statistic	
	Shade	213.9
	Treatment	27.7
	Shade x treatment	10.9
	Shade x harvests	91.9
	Nitrogen content	
	Shade	<0.001
	Treatment	<0.001
	Shade x treatment (± water & ± urine)	0.234
	Shade x harvests	<0.001
	Wald statistic	
	Shade	19.3
	Treatment	72.6
	Shade x treatment	11.7
	Shade x harvests	82.9

	Metabolisable energy Shade Treatment Shade x treatment (± water & ± urine) Shade x harvests Wald statistic Shade Treatment Shade x treatment Shade x harvests	 <0.001 <0.001 0.359 <0.001 200.5 21.3 10.5 64.4
Grazing preference of sheep	**July** Shade Treatment (± urine) Shade x treatment (± urine) **October** Shade Treatment (± urine) Shade x treatment (± urine) **December** Shade Treatment (± urine) Shade x treatment (± urine)	 0.954 <0.001 0.073 <0.001 0.411 <0.001 <0.001 <0.001 0.444

Appendix 4.2
Tables of means and lsd/sem values used to compose figures in chapter four

Table 4.2.1 Photosynthetic photon flux density (moles/m^2/d) from July 1998 to June 1999 (from figure 4.1).

Months	650 trees ha^{-1}	300 trees ha^{-1}	200 trees ha^{-1}	Open pasture	lsd at p <0.05
July	3.80	5.30	8.00	16.90	0.806
August	3.90	6.60	15.00	23.60	2.500
September	3.90	8.60	21.40	34.60	3.854
October	6.40	19.00	35.50	54.90	5.240
November	10.80	24.70	40.90	59.10	3.304
December	16.73	40.80	46.90	67.70	2.948
January	15.13	31.60	46.50	63.70	2.312
February	9.53	26.60	44.60	57.30	3.268
March	5.60	12.20	31.40	40.20	1.720
April	4.00	7.90	15.80	25.80	1.578
May	3.63	5.90	8.40	20.20	1.234
June	3.53	5.00	7.20	17.90	1.740

Table 4.2.2 PPFD level (μ moles/m^2/s) under three levels of tree shade and in open pasture on 18th November 1998 (From figure 4.2).

Hours	650 trees ha-1	300 trees ha-1	200 trees ha-1	Open pasture	lsd at p <0.05
8:00 am	81	72	377	588	100.0
9:00 am	94	88	566	891	102.0
10:00 am	136	160	878	1296	140.0
11:00 am	118	205	1096	1692	238.0
12:00 pm	153	367	1205	1933	294.0
1:00 pm	195	819	1281	1929	270.0
2:00 pm	493	1094	1275	1830	246.0
3:00 pm	975	1160	1270	1726	254.0
4:00 pm	1002	1113	1160	1454	286.0
5:00 pm	928	934	1040	1204	254.0
6:00 pm	525	438	591	890	218.0

Table 4.2.3 Soil temperature (^{o}C) at 100 mm soil depth from August 1998 to July 1999 with or without irrigation (from figure 4.3).

(a) Without irrigation

Months	18% PPFD	40% PPFD	67% PPFD	100% PPFD	lsd at p <0.05
August	5.0	4.9	5.0	4.7	0.466
September	8.1	8.1	8.6	8.9	0.806
October	12.5	13.5	14.9	14.9	1.008
November	12.6	14.1	14.8	15.0	0.864
December	13.7	18.7	19.4	20.4	0.914
January	16.6	19.1	20.5	21.0	1.360
February	16.0	17.9	18.8	20.0	0.552
March	16.0	16.3	18.6	18.8	0.796
April	11.8	11.9	12.0	12.4	0.598
May	11.8	11.1	11.4	10.5	0.864
June	7.1	6.9	7.0	6.4	0.796
July	6.8	6.9	6.8	6.4	0.388

(b) With irrigation

Months	18% PPFD	40% PPFD	67% PPFD	100% PPFD	lsd at p <0.05
August	4.5	4.4	4.5	4.4	0.628
September	8.0	7.9	8.5	8.5	0.678
October	12.4	13.3	14.7	14.3	0.266
November	12.1	13.3	13.8	13.5	0.324
December	13.2	18.0	18.6	19.2	0.760
January	16.1	18.3	19.8	20.0	0.768
February	15.5	17.1	18.0	19.0	0.480
March	15.7	16.3	18.1	17.8	0.492
April	11.7	11.6	11.9	12.1	0.344
May	11.2	10.7	11.0	10.1	0.854
June	6.4	6.6	6.7	6.0	0.804
July	6.6	6.1	6.1	6.0	0.482

Table 4.2.4 Soil moisture (% by volume) at 0-300 mm soil depth from August 1998 to July 1999 with or without irrigation (from figure 4.4).

(a) Without irrigation

Months	18% PPFD	40% PPFD	67% PPFD	100% PPFD	lsd at p <0.05
August	19.4	25.8	28.8	26.9	4.002
September	16.9	25.5	26.0	26.8	3.730
October	16.4	23.7	25.5	25.7	2.818
November	13.9	18.0	18.0	18.2	2.562
December	12.1	11.4	12.4	11.0	1.266
January	12.1	10.9	11.2	9.8	0.552
February	10.3	9.4	9.2	9.2	0.940
March	17.3	17.2	17.8	17.8	1.340
April	14.5	15.6	17.5	17.9	1.470
May	14.5	16.8	21.2	21.9	1.316
June	24.4	28.0	30.9	30.9	2.778
July	18.8	22.6	26.0	25.3	2.406

(b) With irrigation

Months	18% PPFD	40% PPFD	67% PPFD	100% PPFD	lsd at p <0.05
August	19.8	28.0	30.3	30.6	5.600
September	17.4	27.2	26.7	28.2	3.112
October	17.5	24.7	26.6	26.9	2.588
November	14.9	19.2	19.7	18.3	0.916
December	13.1	13.2	14.0	11.5	1.808
January	12.8	12.4	12.2	10.9	1.356
February	11.1	10.9	10.8	9.9	0.682
March	18.5	18.2	19.8	18.9	1.473
April	15.0	16.5	19.2	19.6	1.510
May	15.3	17.9	22.4	23.4	1.404
June	25.1	29.0	31.6	31.8	1.054
July	19.5	23.5	26.5	26.3	2.412

Table 4.2.5 Botanical composition (% cover) of nine-year-old cocksfoot plus clover pasture grown under tress and in open (from figure 4.5).

Components	Under trees	Open pasture	lsd at p <0.05
White clover	2.92	3.83	0.934
Sunterranean clover	3.75	1.33	2.268
Wana cocksfoot	74.33	82.75	5.782
Weeds	4.00	4.75	1.498
Bare ground	10.33	5.67	5.842
Dead material	4.67	1.67	0.624

Table 4.2.6 Mean dry matter yield (g DM/m^2) of Wana cocksfoot for five harvests under four light regimes in four treatments (from figure 4.6).

PPFD	Treatments	Harvests				
		March	June	Sept.	Nov.	Feb.
18%	Nil	9.3	26.0	28.3	31.0	20.0
	Urine	26.0	33.0	32.0	40.3	25.3
	Water	27.0	39.3	57.0	60.3	29.7
	Urine + water	42. 7	42.7	61.7	65.3	39.0
lsd at p <0.05		8.88	9.25	13.02	14.93	7.10
40%	Nil	18.3	30.3	54.3	54.3	15.7
	Urine	28.4	49.7	66.3	103.7	23.3
	Water	60.3	59.0	63.7	92.0	53.7
	Urine + water	120.7	94.3	103.3	132.0	94.0
lsd at p <0.05		35.36	19.36	26.65	46.10	17.15
67%	Nil	12.7	35.3	46.3	65.0	11.3
	Urine	25.7	45.0	99.3	140.0	22.7
	Water	67.0	66.7	95.7	108.7	60.0
	Urine + water	119.3	110.3	122.3	173.0	102.7
lsd at p <0.05		47.86	24.57	55.57	60.88	34.16
100%	Nil	11.0	37.3	72.0	103.0	10.7
	Urine	20.3	58.7	126.7	176.0	22.3
	Water	47.3	66.0	78.0	124.0	56.3
	Urine + water	96.7	84.0	174.7	219.0	93.0
lsd at p <0.05		23.00	30.42	38.54	49.41	22.83

Table 4.2.7 Vegetative tillers populations (tillers/m²)of cocksfoot from five harvests under four light regimes in four treatments (from figure 4.7).

		PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	3000	4220	4150	4980
	Urine	3250	4370	4350	5220
	Water	3083	3970	4720	5250
	U + water	3430	4480	4850	5280
lsd at p <0.05		324.1	305.8	230.1	210.0
June	Nil	3000	4300	4630	5020
	Urine	3220	4380	4390	5380
	Water	3150	4170	4760	5480
	U + water	3370	4370	5120	5520
lsd at p <0.05		306.1	220.1	235.1	470.0
September	Nil	3150	4780	4820	5200
	Urine	3350	4830	5420	6150
	Water	3720	4720	5500	5950
	U + water	4150	5000	5720	6170
lsd at p <0.05		506.9	438.9	704.6	780.0
November	Nil	3380	4870	4870	5170
	Urine	3470	4970	5170	6300
	Water	3830	4990	5180	6100
	U + water	3830	4920	5680	6820
lsd at p <0.05		470.6	280.2	689.9	977.7
February	Nil	3180	4080	4130	4770
	Urine	3230	4350	4320	5030
	Water	3300	4500	4650	5070
	U + water	3380	4420	4800	5270
lsd at p <0.05		257.9	320.4	299.2	440.8

Table 4.2.8 Reproductive tillers populations (tillers/m²)of cocksfoot in November 1998 (from figure 4.8).

PPFD	Treatments				
	Nil	Urine	Water	Urine + water	lsd at p <0.05
18%	13	23	50	50	38.74
40%	57	80	130	180	79.70
67%	67	240	193	260	96.10
100%	153	267	200	233	108.20

Table 4.2.9 Cocksfoot canopy height (mm) for five harvests under four light regimes in four treatments (from figure 4.9).

PPFD	Treatments	Harvests				
		March	June	Sept.	Nov.	Feb.
18%	Nil	18.06	32.15	50.18	83.97	25.56
	Urine	39.31	53.39	72.06	105.22	46.81
	Water	52.45	66.53	85.20	118.37	59.95
	Urine + water	81.52	95.60	114.27	147.43	89.02
lsd at p < 0.05		15.94	17.47	22.12	34.25	20.23
40%	Nil	26.26	41.01	67.84	133.51	19.93
	Urine	47.51	62.26	89.09	154.76	41.18
	Water	71.08	85.83	112.67	178.33	64.75
	Urine + water	100.15	114.90	141.73	207.40	93.82
lsd at p < 0.05		30.66	23.33	31.96	30.71	21.50
67%	Nil	16.69	40.78	64.44	131.69	17.28
	Urine	37.94	62.03	85.69	152.94	38.53
	Water	63.15	87.23	110.90	178.15	63.73
	Urine + water	92.22	116.30	139.97	207.22	92.80
lsd at p , 0.05		40.53	29.42	42.31	32.95	25.68
100%	Nil	9.49	28.91	58.74	124.66	20.91
	Urine	30.74	50.16	79.99	145.91	42.16
	Water	33.68	53.10	82.93	148.85	45.10
	Urine + water	62.75	82.17	112.00	177.92	74.17
lsd at p < 0.05		17.23	17.25	22.04	23.62	18.77

Table 4.2.10 Pasture bulk density (mg DM/cm^3) of cocksfoot pastures from means of four treatments (from figure 4.10).

Harvests	Treatments	PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	0.473	0.953	0.990	1.255
	Urine	0.677	0.987	1.099	1.297
	Water	0.590	0.787	1.213	1.177
	Urine + water	0.497	1.013	1.053	1.403
lsd at p <0.05		0.154	0.306	0.302	0.290
June	Nil	0.793	0.757	0.783	1.050
	Urine	0.663	0.793	0.807	1.267
	Water	0.543	0.743	0.827	1.260
	Urine + water	0.483	0.797	0.883	1.097
lsd at p <0.05		0.162	0.138	0.178	0.278
September	Nil	0.590	0.733	0.790	1.167
	Urine	0.457	0.673	0.997	1.440
	Water	0.580	0.617	0.920	1.060
	Urine + water	0.597	0.777	0.893	1.613
lsd at p <0.05		0.098	0.176	0.212	0.338
November	Nil	0.383	0.420	0.513	0.833
	Urine	0.377	0.630	0.810	1.100
	Water	0.530	0.507	0.657	0.883
	Urine + water	0.470	0.670	0.857	1.270
lsd at p <0.05		0.166	0.184	0.258	0.324
February	Nil	0.827	0.760	0.743	0.820
	Urine	0.653	0.583	0.720	0.730
	Water	0.473	0.857	0.930	0.877
	Urine + water	0.463	1.017	1.090	1.457
lsd at p <0.05		0.288	0.306	0.392	0.464

Table 4.2.11 Cocksfoot leaf population (per tiller) under four treatment and four light regimes in different three months (from figure 4.11).

	PPFD	Treatments				lsd at p <0.05
		Nil	Urine	Water	Urine + water	
September	18%	2.00	3.00	2.35	2.76	0.499
	40%	3.49	3.60	3.57	4.01	0.516
	67%	3.63	3.71	3.96	4.38	0.540
	100%	3.35	3.43	3.40	3.82	0.560
November	18%	2.97	3.07	2.97	3.35	0.469
	40%	3.32	3.40	3.43	3.85	0.267
	67%	3.13	3.21	3.46	3.86	0.303
	100%	3.60	3.68	3.65	4.07	0.483
February	18%	1.92	2.07	1.93	2.35	0.369
	40%	2.07	2.15	2.18	2.60	0.455
	67%	2.13	2.21	2.46	2.86	0.577
	100%	2.26	2.35	2.32	2.74	0.442

Table 4.2.12 Cocksfoot leaf blade length under four light regimes from five harvests in four treatments (from figure 4.12).

Harvests	Treatments	PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	15.98	17.61	13.58	7.63
	Urine	33.93	35.56	31.52	25.58
	Water	42.48	54.34	52.54	27.16
	Urine + water	67.29	79.16	77.36	51.97
lsd at p <0.05		14.412	13.550	16.710	10.180
June	Nil	29.31	36.86	35.82	20.63
	Urine	47.26	54.81	53.77	38.58
	Water	55.81	73.59	74.79	40.16
	Urine + water	80.63	98.41	99.61	64.79
lsd at p <0.05		21.760	22.620	20.450	22.486
September	Nil	45.47	63.69	59.41	49.29
	Urine	63.42	81.64	77.36	67.24
	Water	71.97	100.42	98.37	68.82
	Urine + water	96.79	125.24	123.19	93.64
lsd at p <0.05		20.160	29.960	32.646	26.72
November	Nil	75.14	123.02	123.41	107.96
	Urine	93.09	140.97	141.36	125.91
	Water	101.64	159.76	162.37	127.49
	Urine + water	126.46	184.57	187.19	152.31
lsd at p <0.05		32.060	26.801	27.480	15.122
February	Nil	23.06	19.44	15.57	17.46
	Urine	41.01	37.39	33.52	35.41
	Water	49.56	56.18	54.54	36.99
	Urine + water	74.38	80.99	79.36	61.81
lsd at p <0.05		26.170	25.082	27.760	23.491

Table 4.2.13 The treatment effect on cocksfoot leaf width (mm) under four light regimes from means of three measurement (from figure 4.13).

PPFD	Months	Treatments				lsd at p <0.05
		Nil	Urine	Water	U + water	
18%	September	3.93	4.07	3.74	4.26	0.743
40%		4.18	4.32	4.65	5.18	0.942
67%		4.60	4.74	5.07	5.60	0.881
100%		4.71	4.85	5.29	5.82	1.008
18%	November	3.65	3.97	3.65	4.18	0.577
40%		4.35	4.49	4.82	5.35	0.745
67%		4.60	4.74	5.07	5.60	0.998
100%		5.38	5.51	5.96	6.49	0.577
18%	February	4.01	4.15	3.82	4.35	0.553
40%		4.26	4.40	4.74	5.26	0.822
67%		4.28	4.43	4.72	5.31	0.837
100%		4.21	4.35	4.79	5.32	0.724

Table 4.2.14. The cocksfoot pseudostem length (mm) under four light regimes in four treatments from five harvests (from figure 4.14).

PPFD	Treatments				SED	lsd at p <0.05
	Nil	Urine	Water	Urine + water		
March						
18%	2.08	5.38	9.97	14.23	3.050	7.463
40%	8.65	11.95	16.74	20.99	3.330	8.148
67%	3.11	6.42	10.61	14.86	3.530	8.637
Open pasture	1.86	5.16	6.52	10.78	2.830	6.925
June						
18%	2.84	6.13	10.72	14.97	4.340	10.619
40%	4.15	7.45	12.24	16.49	3.490	8.540
67%	4.96	8.26	12.44	16.69	3.790	9.274
Open pasture	8.28	11.58	12.94	17.20	3.390	8.295
September						
18%	4.71	8.64	13.23	17.48	3.180	7.781
40%	4.15	7.45	12.25	16.49	2.735	6.692
67%	5.03	8.33	12.53	16.78	2.632	6.440
Open pasture	9.45	12.75	14.11	18.36	2.910	7.120
November						
18%	8.83	12.13	16.73	20.97	3.930	9.616
40%	10.49	13.79	18.57	22.83	3.090	7.561
67%	8.28	11.58	15.78	20.03	3.430	8.393
Open pasture	16.7	20.00	21.36	25.61	4.480	10.962
February						
18%	2.50	5.80	10.39	14.64	3.390	8.295
40%	1.49	3.79	8.57	12.83	3.320	8.124
67%	1.71	5.01	9.19	13.44	3.050	7.463
Open pasture	3.45	6.75	8.11	12.36	3.630	8.882

Table 4.2.15 Nitrogen (%) content in cocksfoot herbage under four light regimes for four treatments in five harvests (from figure 4.15).

Harvests	Treatments	PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	2.75	2.71	2.56	2.51
	Urine	3.55	3.01	3.01	3.22
	Water	2.75	2.90	2.85	2.58
	Urine + water	3.37	3.53	3.07	3.09
Standard error		0.119	0.119	0.119	0.119
June	Nil	2.31	2.73	2.64	3.56
	Urine	2.69	3.18	2.99	4.06
	Water	3.08	2.92	3.32	3.63
	Urine + water	3.24	3.14	3.36	4.36
Standard error		0.119	0.119	0.119	0.119
September	Nil	3.62	3.70	3.85	3.75
	Urine	3.84	3.96	4.47	4.46
	Water	3.72	3.85	4.30	3.92
	Urine + water	4.18	4.54	4.63	4.33
Standard error		0.119	0.119	0.119	0.119
November	Nil	2.20	2.17	1.72	1.83
	Urine	2.30	2.44	2.32	2.45
	Water	2.10	2.51	2.05	2.27
	Urine + water	2.40	2.63	2.31	2.60
Standard error		0.119	0.119	0.119	0.119
February	Nil	2.59	2.46	2.56	2.39
	Urine	2.62	2.72	2.63	2.99
	Water	2.61	2.65	2.60	2.90
	Urine + water	2.97	2.75	2.90	3.07
Standard error		0.119	0.119	0.119	0.119

Table 4.2.16 Digestible organic matter content in cocksfoot herbage under four light regimes from five harvests in four treatments (from figure 4.16).

Months	Treatments	PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	62.9	68.1	72.9	74.5
	Urine	65.3	70.3	75.3	77.0
	Water	65.8	70.0	73.6	75.8
	Urine + water	67.6	71.5	75.3	77.5
Standard error		1.220	1.220	1.220	1.220
June	Nil	56.5	61.2	65.1	75.1
	Urine	59.1	63.9	67.7	76.7
	Water	59.6	63.1	65.9	77.9
	Urine + water	61.4	64.9	67.7	78.5
Standard error		1.220	1.220	1.220	1.220
September	Nil	65.0	67.4	73.0	72.1
	Urine	67.4	69.8	75.2	74.8
	Water	67.9	69.3	73.6	73.5
	Urine + water	69.7	71.0	75.3	75.3
Standard error		1.220	1.220	1.220	1.220
November	Nil	63.0	66.3	68.8	67.1
	Urine	65.5	68.9	71.0	69.6
	Water	66.0	68.6	69.0	68.4
	Urine + water	67.8	70.3	71.0	70.1
Standard error		1.220	1.220	1.220	1.220
February	Nil	61.0	60.4	64.2	66.8
	Urine	63.4	62.9	66.8	69.2
	Water	63.9	62.6	65.1	68.0
	Urine + water	65.7	64.4	66.8	69.7
Standard error		1.220	1.220	1.220	1.220

Table 4.2.17 M/D value (MJ ME/kg DM) of cocksfoot herbage under four light regimes from five harvests in four treatments (from figure 4.17).

Months	Treatments	PPFD relative to open pasture			
		18%	40%	67%	100%
March	Nil	8.99	9.88	10.60	11.02
	Urine	9.52	10.40	11.15	11.60
	Water	9.41	10.14	10.82	11.29
	Urine + water	9.72	10.46	11.16	11.65
Standard error		0.207	0.207	0.207	0.207
June	Nil	7.81	8.33	8.7	10.60
	Urine	8.45	8.88	9.28	11.12
	Water	8.21	8.57	8.97	10.60
	Urine + water	8.52	8.88	9.29	10.98
Standard error		0.207	0.207	0.207	0.207
September	Nil	9.13	9.39	10.04	10.20
	Urine	9.71	9.96	10.60	10.83
	Water	9.61	9.69	10.32	10.49
	Urine + water	9.92	10.08	10.68	10.80
Standard error		0.207	0.207	0.207	0.207
November	Nil	9.28	9.71	10.04	10.40
	Urine	9.79	10.27	10.57	10.48
	Water	9.68	9.99	10.30	10.14
	Urine + water	9.99	10.31	10.61	10.49
Standard error		0.207	0.207	0.207	0.207
February	Nil	8.81	8.81	9.31	9.81
	Urine	9.32	9.35	9.85	10.43
	Water	9.21	9.02	9.48	9.98
	Urine + water	9.52	9.33	9.79	10.35
Standard error		0.207	0.207	0.207	0.207

Table 4.2.18 Decline of cocksfoot height (mm) during sheep grazing experiment in July 1998 (from figure 4.18).

Days	Agroforestry		Open pasture		
	Non-urine	Urine patch	Non-urine	Urine patch	lsd at $p < 0.05$
0	64	76	63	71	14.50
1	45	57	46	53	9.92
2	31	43	35	42	5.96
3	21	33	26	34	4.08
4	16	24	15	22	2.27

Table 4.2.19 Decline of cocksfoot height (mm) during sheep grazing experiment in October 1998 (from figure 4.19).

Days	Agroforestry		Open pasture		
	Non-urine	Urine patch	Non-urine	Urine patch	lsd at $p < 0.05$
0	210	241	180	196	20.16
1	185	181	158	145	35.76
2	154	143	140	121	20.46
3	112	127	108	89	24.20
4	100	108	91	77	16.58
5	86	94	80	63	18.46
6	78	76	73	50	18.32
7	65	62	63	47	11.52
8	51	58	48	41	9.56
9	39	54	43	31	7.66

Table 4.2.20 Decline of cocksfoot height (mm) during sheep grazing experiment in December 1998 (from figure 4.20).

Days	Agroforestry		Open pasture		
	Non-urine	Urine patch	Non-urine	Urine patch	lsd at $p < 0.05$
0	279	302	253	280	17.96
1	250	260	225	240	33.02
2	234	243	213	193	45.40
3	169	177	152	110	47.40
4	134	146	105	97	44.20
5	116	125	76	80	38.46
6	92	109	60	74	29.96
7	75	90	48	65	18.66
8	67	82	44	61	14.01

Appendix 4.3
Photosynthetic photon flux density (μ moles/m²/s)
(July 1998 to June 1999)

Months	Trees ha^{-1}	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
20 July	650 trees	-	160	176	182	192	78	76	75	42	-	-
	300 trees	-	87	88	306	325	272	169	131	104	-	-
	200 trees	-	91	120	339	446	404	345	311	136	-	-
	Open pasture	-	340	538	582	615	540	471	436	315	-	-
22 August	650 trees	75	113	119	100	145	77	56	52	49	-	-
	300 trees	55	62	134	158	199	120	112	75	77	-	-
	200 trees	69	188	241	460	585	635	536	129	132	-	-
	Open pasture	301	624	861	1006	1063	1043	912	544	206	-	-
19 September	650 trees	76	114	124	153	111	67	66	61	128	114	-
	300 trees	62	79	118	177	184	210	215	460	484	151	-
	200 trees	121	230	537	1026	1091	1096	815	346	179	161	-
	Open pasture	422	811	1115	1399	1443	1424	1238	846	560	214	-
23 October	650 trees	42	60	84	71	85	99	114	228	526	433	285
	300 trees	65	70	109	131	305	752	975	1238	887	378	261
	200 trees	370	548	875	1057	1194	1161	1119	1162	793	727	356
	Open pasture	581	877	1280	**1604**	**1865**	**1828**	**1801**	**1659**	1384	1152	554
18 November	650 trees	81	94	136	118	153	195	493	975	1002	928	525
	300 trees	72	88	160	205	367	819	1094	1160	1113	934	438
	200 trees	377	566	878	1096	1205	1281	1275	1270	1160	1040	591
	Open pasture	588	891	1296	**1692**	**1933**	**1929**	**1830**	**1726**	1454	1204	890
19-20 December	650 trees	52	106	125	150	152	160	238	380	636	870	715
	300 trees	166	380	485	674	1117	1375	**1562**	**1764**	1507	957	636
	200 trees	306	599	873	1087	1355	1440	**1580**	**1565**	1429	1060	766
	Open pasture	629	973	1360	**1700**	**1902**	**2175**	**2088**	**1923**	**1655**	1367	1043

Months	Trees ha^{-1}	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
25-26 January	650 trees	47	109	72	73	66	125	225	318	641	871	714
	300 trees	159	142	153	96	348	1102	**1565**	**1601**	1403	902	655
	200 trees	303	597	871	1064	1303	1458	**1584**	**1571**	1399	1080	806
	Open pasture	645	999	1276	**1568**	**1896**	**1939**	**1944**	**1936**	**1639**	1354	1045
20 February	650 trees	43	49	56	65	67	72	213	292	631	830	689
	300 trees	51	68	92	90	109	764	**1567**	**1531**	902	901	674
	200 trees	399	566	656	1229	1299	1317	**1561**	**1529**	1260	1045	786
	Open pasture	568	899	1156	**1522**	**1639**	**1760**	**1814**	**1801**	**1610**	1367	942
19-20 March	650 trees	55	72	69	74	73	89	128	167	305	404	280
	300 trees	41	72	78	83	85	177	220	475	748	740	409
	200 trees	104	274	694	891	1086	1162	1102	1083	1045	760	413
	Open pasture	230	538	908	1149	1400	1505	1401	1322	1155	921	496
21 April	650 trees	100	177	184	125	103	52	60	88	135	80	-
	300 trees	43	51	62	79	74	64	215	325	398	110	-
	200 trees	51	87	182	239	601	960	902	698	558	110	-
	Open pasture	189	432	788	986	1196	1040	928	797	603	208	-
18 May	650 trees	102	167	211	267	212	152	100	70	51	-	-
	300 trees	43	58	86	88	98	98	199	411	272	-	-
	200 trees	45	50	55	73	163	200	595	536	255	-	-
	Open pasture	198	365	629	715	748	760	695	590	302	-	-
17-18 June	650 trees	-	102	167	207	175	145	102	74	47	-	-
	300 trees	-	43	58	86	98	102	201	407	278	-	-
	200 trees	-	45	50	55	163	200	598	516	298	-	-
	Open pasture	-	188	365	629	679	725	705	569	316	-	-

Note: PPFD levels written in bold numbers are above light saturation point for cocksfoot.