

Cocksfoot and lucerne productivity in a *Pinus radiata* silvopastoral system: a grazed comparison

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Abstract

Plant and animal production from cocksfoot pasture and lucerne under 10–11 year-old radiata pine trees (200 stems/ha) and from adjacent open pastures (without trees) were measured from the Lincoln University Silvopastoral Experiment. Light intensity under trees was 50–60% of the open pasture. Liveweight gain (LWG) from lucerne was 220 g/hd/d in the open and 158 g/hd/d under trees. On cocksfoot, LWG was 132 g/hd/d in the open and 100 g/hd/d under trees. When converted to LWG/ha, lamb production from open pastures was double that from shaded pastures for lucerne (5.1 and 2.5 kg/ha/d) and cocksfoot (3.4 and 1.7 kg/ha/d). Lucerne produced 11.2 t DM/ha in the open and 7.9 t DM/ha under trees which was 58% and 76% more than cocksfoot in the open and under trees, respectively. However, from September to November, when soil moisture was non-limiting, the lucerne DM production was 36% lower under tree shade than in the open. In comparison, the reduction was only 20% for cocksfoot, which confirms its greater 'shade tolerance'. The reduced lamb LWG produced from lambs on shaded pastures was attributed to the reduced pre-grazing pasture mass and pasture bulk density, leading to reduced apparent intakes. Crude protein and digestibility values were not influenced by shade, and clover content in cocksfoot pastures were low (<7%). It was concluded that: i) shaded pastures in silvopastoral systems limited animal production compared with open pastures owing to lower DM production rates which lowered pre-grazing pasture mass and reduced bulk density from the etiolated pasture; ii) the suitability of species for silvopastoral systems should be assessed from total plant and animal production and species persistence rather than 'shade tolerance', which only examines the relative decline in DM production under shade compared with unshaded situations.

Keywords: cocksfoot, *Dactylis glomerata*, lamb liveweight gain, lucerne, *Medicago sativa*, pasture production, *Pinus radiata*, shade tolerance, silvopastoralism

Introduction

The general aim of agro-silvopastoral systems is to maximise profitability from a given area of land using combinations of compatible trees and crops or pastures. Silvopastoralism in New Zealand with wide spaced conifers planted in resident pasture (mainly ryegrass–white clover pasture) has generally resulted in trees of reduced timber quality. The pasture species have been poorly adapted to tree competition (Hawke & Knowles 1997). There is however a large area of New Zealand where trees on pastoral farms can be profitable either directly from cash returns as timber or indirectly for stock shelter and soil conservation (Mead 1995). Studies on different understorey species will indicate ways to maximise animal production from pastures under the increasing area of trees on farms.

The Lincoln University Agroforestry Experiment was established in 1990 with the aim of investigating soil/tree/pasture/sheep/climate interactions. Five *Pinus radiata* genotypes and six understorey pasture treatments were included in a split-plot design. After 11 years, the two pasture species which stand out are lucerne (*Medicago sativa*) and cocksfoot (*Dactylis glomerata*) and it is clear that perennial ryegrass (*Lolium perenne*) (infected with *Neotyphodium lolii* endophyte) and white clover (*Trifolium repens*) are unsuited to silvopastoralism in the sub-humid Canterbury plains environment.

Plant production and morphology under shade can differ between temperate grasses and legumes (Devkota *et al.* 1997). Research with widely spaced *Pinus radiata* has indicated that cocksfoot is suitable for silvopastoral systems owing to its shade tolerance (Joshi *et al.* 1999; Peri *et al.* 2001a). However, Varella *et al.* (2001) reported that lucerne produced more dry matter (DM) than cocksfoot under moderate shade. Furthermore, the lack of clover and presence of obvious green urine patches in cocksfoot pastures indicated that cocksfoot pastures are frequently nitrogen stressed (Peri *et al.* 2001a).

Foliar nitrogen concentration often increases in shaded grasses but not in shaded legumes (Wong 1990; Varella *et al.* 2001), while many investigations have shown variable results for herbage *in vitro* digestibility from shaded environments (Wilson 1989; Varella *et al.*

2001). The effect of tree competition on sward characteristics, such as pasture mass, height, bulk density, reproductive development, botanical composition, and distribution of plant components within the canopy, may have an important influence on daily herbage intake and hence animal liveweight gain (Hodgson & Brookes 1999). Also, livestock performance is reduced with increasing tree age owing to decreased light transmission. Results from the Tikitere and Waratah agroforestry trials have shown that in most cases, ewe liveweights, wool production and lamb growth rates also decreased with increasing tree stocking (Percival *et al.* 1984).

The objective of this research was to compare pasture and animal performance of lambs grazing lucerne and cocksfoot pastures under 10–11 year-old radiata pine and in adjacent open sites from spring 1999 to autumn 2001.

Materials and methods

Experiment description

This experiment was conducted in a silvopastoral area located near Lincoln University, Canterbury, New Zealand. The pine trees were planted in July 1990 at 1000 stems/ha and have been periodically thinned to the present 200 stems/ha with 7 m between rows. All thinned and pruned material has been removed from the understory pasture. Tree rows were strip sprayed (1 m wide) with herbicide (hexazinone at 2.5 kg a.i./ha) to assist tree establishment. Plots with trees therefore, had only 86% of their area occupied by sown pasture. The Templeton silt loam soil consists of 1 to 2 m of fine alluvial sediments over gravels. The climate is temperate and subhumid with a long-term average rainfall of 660 mm. The average annual evaporation is about double the rainfall. Mean annual temperature is 11.4°C.

Cocksfoot ('Grasslands Wana') + clovers: 'Grasslands Pawera' red clover (*Trifolium pretense*) and 'Grasslands Huia' white clover (*T. repens*) and 'Wooenellup' subterranean (*T. subterranean*), and winter-dormant 'WL320' lucerne were sown in September 1990 in four 46 x 42 m (0.194 ha) main plots arranged in a completely randomised block design. At the same time, three cocksfoot and lucerne plots 27.5 x 18 m area were established in an adjacent open site with similar soil properties (Mead *et al.* 1993).

Herbage was cut and carried off the site for silage during the first 3 years but all plots were grazed by sheep from spring 1993. Neither fertiliser, lime nor irrigation has been applied to the experimental area since its establishment. Soil tests in September 1999 indicated low soil fertility with no differences between

cocksfoot and lucerne plots (Open: pH 6.0, Olsen P 7.0 µg/ml, S(SO₄) 3.0 ppm; Trees: pH 5.9, Olsen P 7.5 µg/ml, S(SO₄) 3.5 ppm).

Six new 'Grasslands Kaituna' lucerne plots were established (three in open and three under trees) in March 1999, replacing the 9-year-old phalaris (*Phalaris aquatica*) + clover plots. The 10-year-old "old" lucerne plots showed an average reduction of 50% in stem population compared with 1-year-old "new" lucerne in 2000. Also in 1999, three new cocksfoot plots were sown in the adjacent open site, one of these was used as the fourth plot to provide a four paddock rotation for lambs grazing cocksfoot in the open.

The current experiment ran from September 1999 to April 2001. Two flocks of shorn Coopworth ewe lambs (initial liveweight of 40±6 kg) were rotationally grazed for 7±1 days around either four cocksfoot (28 day rotation with 21±1 days regrowth) or six lucerne plots (42 day rotation with 35±5 days regrowth) under trees. Two smaller flocks of similar sheep were grazed in the same rotational pattern around cocksfoot or lucerne in the adjacent open pastures. All pastures were grazed from 15 September 1999 to 21 May 2000 (lucerne 5 May 2000) and from 21 September 2000 to 2 April 2001. The grazing in cocksfoot pasture was stopped during dry periods, from 16 March to 15 April 2000 and from 26 January to 8 March 2001, to allow pasture to accumulate a pre-grazing mass of approximately 2.0 t/ha.

Stocking rate during grazing periods, over 2 years, under trees and in open, averaged 21 lambs/ha for cocksfoot and 19 lambs/ha for lucerne and was adjusted when necessary after each liveweight measurement (37±5 day intervals). These adjustments resulted in similar pasture allowances for all four flocks (mean pasture allowance: 3.2 kg DM/hd/d for cocksfoot and 2.8 kg DM/hd/d for lucerne). Sheep parasites were controlled when necessary with anthelmintic drenches and pour-on dip.

Measurements

Environmental

Light intensity (photosynthetic photon flux density, PPFD) was monitored with quantum sensors installed below the tree canopy, but above pasture height. The level of light intensity under the 10–11-year-old trees was 60% of the open PPFD (100% transmittance) on a sunny day in summer and 50–55% over a sunny day in autumn and spring. Proportions of red (660 nm) to far-red (730 nm) wavelengths were measured in summer with a LI-COR spectroradiometer. The red to far-red ratio was 1.32 in the open and 0.54 under tree shade on sunny days.

The mean volumetric soil moisture content in the top 500 mm was measured every 7 days with Time Domain Reflectometry (TDR) and mean daily air temperature was also recorded. In spring, soil moisture was always above 24% and was always more than half the maximum available water content of the site (mean field capacity = 30%) indicating that the treatments were not moisture-stressed in spring. However, in both summers and autumn 2001, pastures were under water stress. Pastures under trees had 2.5% less soil moisture than open pastures owing to water extraction by tree roots. There was a small difference in mean daily temperature in the open (11.8°C) and under trees (12.0°C).

Biological

Pasture samples were cut prior to lambs grazing from each pasture. Pre- and post-grazing pasture masses were measured using a capacitance meter for cocksfoot pasture and by cuts in lucerne. The capacitance meter was calibrated against five dry matter cuts of both pre- and post-grazing pasture mass per treatment (open and under trees) in each 'pasture season' according to L'Huillier & Thomson (1988). Pre-grazing canopy height was measured using a sward stick and bulk density was derived from height and pre-grazing mass. Pre-grazing botanical composition in cocksfoot pastures was determined by dissecting a sub-sample from each pre-grazing cut. Pasture and animal production per hectare under trees was calculated on the basis of plot area, but pasture variates relating to grazing behaviour were expressed on the basis of sown pasture area (86%), to account for the sprayed area between trees.

Samples of cocksfoot and lucerne from the 0.2 m² quadrat cuts to 25 mm stubble heights were analysed for crude protein (CP) and organic matter digestibility (OMD). Cocksfoot samples consisted of green tillers with 85–90% leaf and 10–15% pseudostem. Lucerne samples collected for chemical analysis consisted of 44% leaf and 56% stem both in the open and under trees.

Liveweight gain/head and grazing days were recorded, and liveweight gain/ha calculated.

Statistics

Significant ($p < 0.05$) differences for pasture variables were determined by one-way analysis of variance according to the completely randomised block design. Standard deviation of means (SD) for animal variables were determined. Statistical analyses were carried out by using the Genstat statistical package (Genstat 5 1997).

Results

Liveweight gains and grazing days

Liveweight gain (LWG) per lamb was greater in open treatments than under trees (Figure 1). In both grazing years, lambs grew faster on lucerne than in cocksfoot (189 vs. 115 g/hd/d). The mean LWG per lamb was highest for lucerne in the open (220 g/hd/d) and under trees (158 g/hd/d) followed by cocksfoot in the open (132 g/hd/d) and under trees (100 g/hd/d) (Figure 1). The maximum LWG was in spring for animals on cocksfoot (mean of 177 in open and 127 g/hd/d under trees) and in early summer for lambs grazing lucerne (265 in open and 211 g/hd/d under trees).

The greater pre-grazing masses and growth rates in open plots allowed higher stocking rates than under trees and consequently more grazing days (Gd) per hectare. The mean Gd/ha for the grazing periods (mean of 37 days) of cocksfoot was 1004 in open and 603 under trees. For lucerne, the Gd/ha averaged 751 in open and 572 under trees.

These treatment differences were 25% greater when grazing days were used to calculate mean daily LWG per hectare (Figure 2). This doubled in open pastures (5.1 lucerne, 3.4 kg/ha/d cocksfoot) compared with under trees (2.5 lucerne, 1.7 kg/ha/day cocksfoot) and was greatest for cocksfoot in spring (4.5 in open and 2.9 kg/ha/d under trees) and for lucerne in spring/early summer (6.6 in open and 3.2 kg/ha/d under trees).

Pasture mass and intake

The mean annual total DM production of lucerne was 11.2 t DM/ha in open (15.2 new lucerne and 7.3 t DM/ha old lucerne) and 7.9 t DM/ha under trees (9.9 new lucerne and 5.8 t DM/ha old lucerne). The mean total DM production for cocksfoot was 7.1 in open and 4.5 t DM/ha under trees.

Differences in DM production resulted in the pre-grazing pasture mass being greater ($p < 0.05$) in open pastures than under trees (Figure 3). The mean cocksfoot pasture mass on offer was 2550 kg DM/ha in the open and 1650 kg DM/ha under trees. The weighted mean pre-grazing mass for lucerne pasture was 2570 in open (3370 new lucerne and 1610 kg DM/ha old lucerne) and 1720 kg DM/ha under trees (2210 new lucerne and 1290 kg DM/ha old lucerne).

In cocksfoot pasture, the total pre-grazing mass included obvious green urine patches covering 20–25% of the area. During spring (without water stress and temperatures non-limiting), the urine patches in open and under trees increased total DM production by 56% compared with adjacent non-urine patches and represented 35% of the total pre-grazing mass. However, in summer when soil moisture was 16–10%

Figure 1 Liveweight gain per lamb (g/hd/d) per grazing period from cocksfoot and lucerne treatments. Arrows indicate discontinuities in grazing from September 1999 to April 2001.

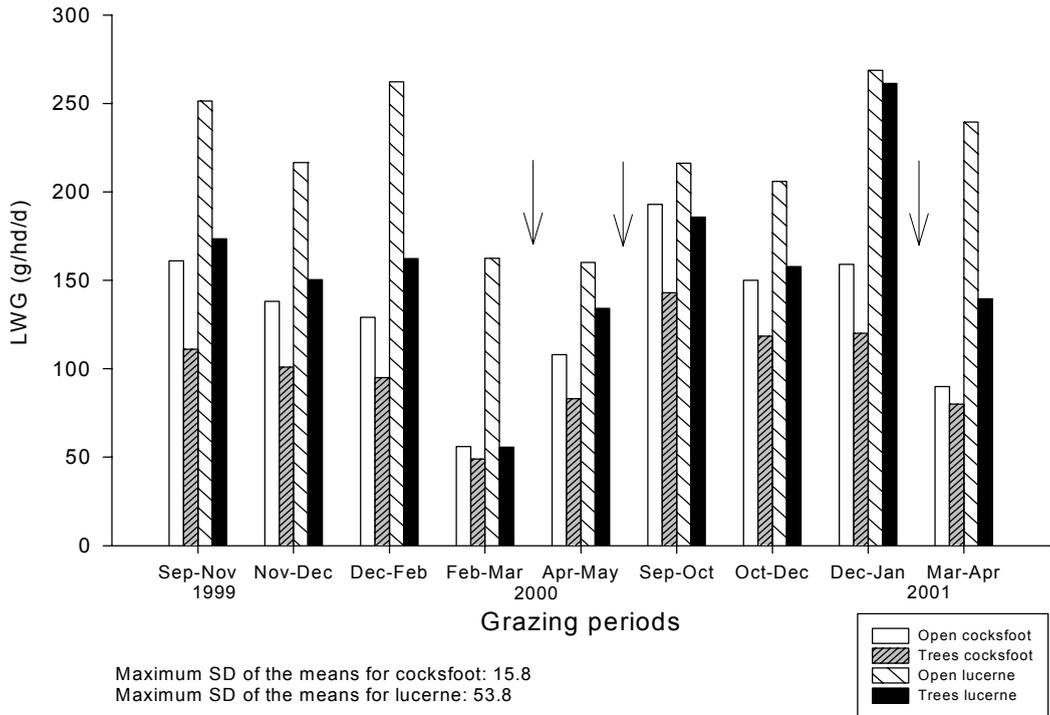


Figure 2 Liveweight gain per hectare (kg/ha/d) per grazing period from cocksfoot and lucerne treatments. Arrows indicate discontinuities in grazing from September 1999 to April 2001.

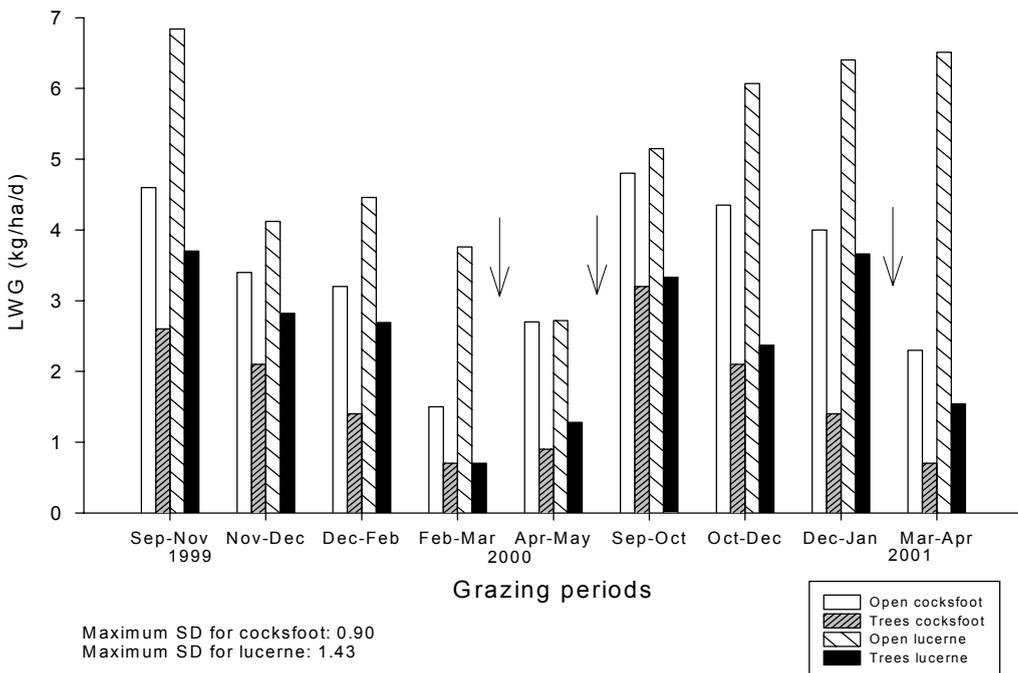
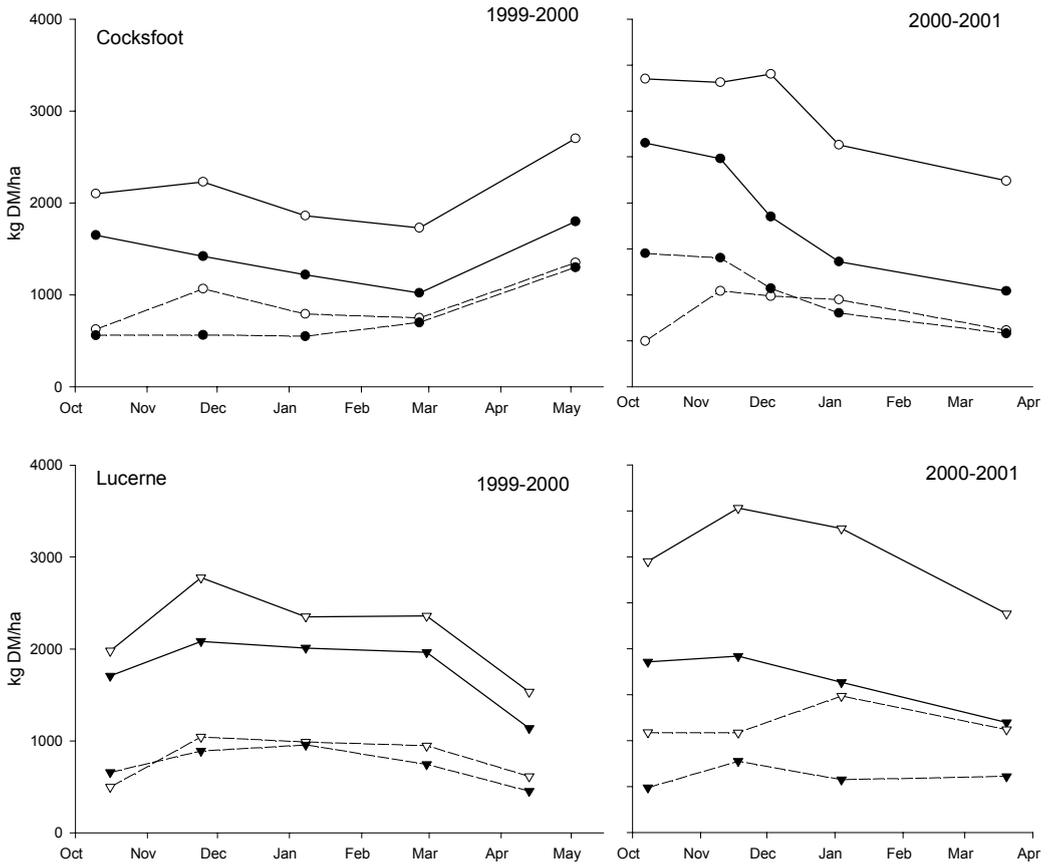
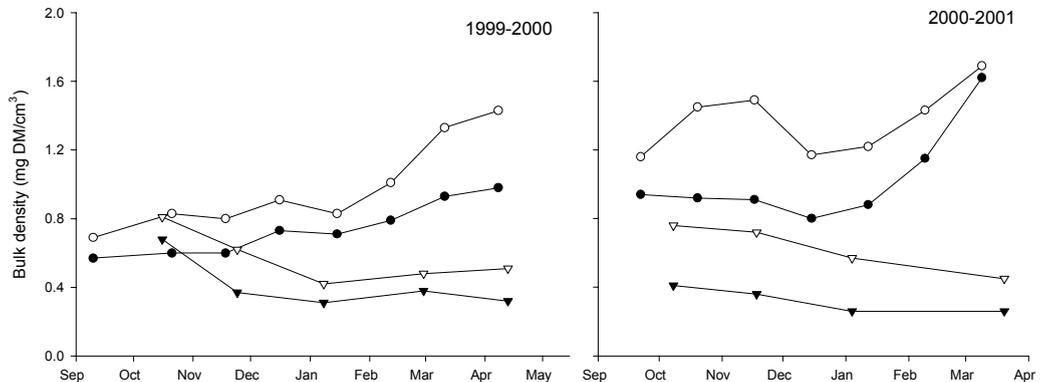


Figure 3 Pre- (—) and post-grazing (---) masses (kg DM/ha) from cocksfoot (○, ●) and lucerne (▽, ▼) pastures, from the open (○, ▽) and under trees (●, ▼). Data from lucerne represented the weighted mean values between new and old lucerne.



Maximum SE of the mean for cocksfoot: 340 and 260 for pre- and post-grazing masses, respectively.
 Maximum SE of the mean for lucerne: 280 and 330 for pre- and post-grazing masses, respectively.

Figure 4 Pre-grazing bulk density (mg DM/cm³) from cocksfoot (○, ●) and lucerne (▽, ▼) pastures, from the open (○, ▽) and under trees (●, ▼). Data from lucerne represented the weighted mean values between new and old lucerne.



Maximum SE of the mean for cocksfoot: 0.12 and for lucerne: 0.07.

the urine patches increased total DM by only 5–10%, and under severe water stress (soil moisture <10%) there was no effect of the N returned from sheep urine.

Post-grazing pasture mass was higher in open pastures and averaged 1270 kg DM/ha for cocksfoot and 990 kg DM/ha for lucerne compared with 890 kg DM/ha for cocksfoot and 680 kg DM/ha for lucerne under trees. In addition, the first year cocksfoot pasture was grazed harder (mean post-grazing mass of 825 kg DM/ha) than the second year (1350 kg DM/ha).

The pre- and post-grazing masses were used to calculate the mean apparent intake which was 1.6 kg DM/hd/d for cocksfoot in the open and 1.3 kg DM/hd/d under trees. The apparent intake was 10% higher in the second grazing season compared with the first. For lucerne, the mean apparent intake was 2.1 and 1.8 kg DM/hd/d in open and under trees, respectively. However, the apparent intake was higher in new lucerne (2.4 in open and 2.1 kg DM/hd/d under trees) compared with old lucerne (1.9 in open and 1.5 kg DM/hd/d under trees).

Pasture height, bulk density and nutritive value

The mean lucerne height in the open was 45 cm compared with 49 cm in the shade, and 15 cm for cocksfoot in the open and 17 cm under trees cocksfoot. Bulk density was greater ($p < 0.05$) in open pastures than in those under trees, and cocksfoot had double the bulk density of lucerne (Figure 4). The mean bulk density in open pastures was 1.17 mg DM/cm³ for cocksfoot and 0.60 mg DM/cm³ for lucerne, and under trees it was 0.89 mg DM/cm³ for cocksfoot and 0.37 mg DM/cm³ for lucerne. The bulk density in new lucerne (0.72 in open and 0.45 mg DM/cm³ under trees) was higher than in old lucerne (0.44 in open and 0.30 mg DM/cm³ under trees).

The mean CP% for cocksfoot plants under trees was 21.3% and 19.6% in open pastures when water was non-limiting (September–November). However, CP% decreased when water stress was severe (soil

moisture <17%). In contrast, tree shade had little effect on lucerne CP% (Table 2). In general, the weighted mean CP% (leaf/stem ratio) was similar between lucerne in open and under trees (18.7%) but values for lucerne leaf (28.1%) were more than double that of the stem (11.8%).

Shade had little effect on both lucerne and cocksfoot OMD (Table 2) but there was a fluctuating seasonal variation. Mean OMD values for lucerne leaf and stem were 81.6 and 58.8%, respectively and the weighted mean value was 68.4%. Cocksfoot mean OMD was 79.3 in open pastures and 77.8% under trees.

The mean clover content of the cocksfoot pasture for the two grazing seasons was 8% in open and 4% under trees. The maximum clover content was in spring (14% in open vs. 6% under trees).

Discussion

Animal performance

Lamb liveweight gain (LWG) under trees was less than would be expected solely from the difference in total DM production. While annual lucerne DM production and LWG/lamb under trees were both 72% of open, the LWG/ha under trees was only 49% of that in the open lucerne (Table 1). Cocksfoot results were similar but relatively more of the reduced LWG/ha under trees (50%) can be explained by the reduction in pasture production (63%) (Table 1). There is therefore an apparent reduction in pasture feeding value under trees, which is also contributing to the reduction in animal performance. Percival *et al.* (1984) reported that the effects of shade on sheep liveweight gain were minor at 100 stems/ha, but in some years at 400 stems/ha there was a net weight loss over a 12-month period.

One of the main differences between open and shaded pastures was in pasture production rate (Varela *et al.* 2001). This resulted in reduced pre- and post-grazing pasture masses in shaded pastures when

Table 1 Mean total DM production, sheep liveweight gains (per hectare and per lamb), pre- and post-grazing masses, apparent intake, grazing days, pre-grazing pasture height and bulk density from cocksfoot and lucerne, in open and under trees pastures for 2 grazing years (September 1999–May 2000 and September 2000–April 2001). Mean number of days grazed per year was 180. Standard error of means (SEM) for pasture variables and standard deviation of means (SD) for animal variables are given.

Treatments	Total DM (t DM/ha/yr)	LWG/ha (kg/d)	Pre-grazing mass (kg DM/ha)	Post-grazing mass (kg DM/ha)	Apparent intake (kg DM/hd/d)	LWG/lamb (g/d)	Grazing days/ha	Pasture height (cm)	Bulk density (mg DM/cm ³)
Open cocksfoot	7.1	3.4	2550	1270	1.6	132	1004	15	1.17
Trees cocksfoot	4.5	1.7	1650	890	1.3	100	603	17	0.89
SEM-SD	0.56	0.90	335.6	255.8	0.12	15.8	163.5	1.16	0.12
Open lucerne	11.2	5.1	2570	990	2.1	220	751	45	0.59
Trees lucerne	7.9	2.5	1720	680	1.8	158	572	49	0.37
SEM-SD	0.34	1.43	280.1	335.4	0.41	53.8	195.1	5.54	0.07

regrowth periods and pasture allowances were similar in open and under trees for each of the pasture types (Table 1). Apparent intakes were reduced by 0.3 kg DM/hd/d for lambs in both lucerne and cocksfoot flocks grazing pastures under trees (Table 1). Rattray & Clark (1984) reported that increasing pre-grazing mass per hectare resulted in increased sheep intake and liveweight gain over a range of pasture allowance.

The large reductions in shaded pre-grazing pasture masses were mainly owing to reductions in new lucerne stem (889 in open and 605 stems/m² under trees) and cocksfoot tiller (5400 in open and 4320 tillers/m² under trees) populations and their reduced individual dry weights (Peri P.L. & Varella A.C., unpublished). Plants also responded to shade by becoming etiolated mainly owing to the decrease in red to far-red ratio. When pasture bulk densities were calculated from pre-grazing mass and plant height, density decreased to 63% of open lucerne and 76% of open cocksfoot. Grazing animals therefore had greater potential intake in open pastures than under trees. For livestock grazing lower density pasture, the amount harvestable in a single bite is smaller (Gong *et al.* 1996b). Reduction in bite size leads to reduced daily pasture intake and LWG because the animal normally cannot sufficiently compensate by increasing the rate of biting or grazing time per day. Alternatively, long grazing rotations could be used under trees to provide time to accumulate sufficient pasture mass. However, problems from longer spelling times would be: i) taller pasture and increased reproductive development that result in reduced bulk density, and ii) older forage of lower nutritive value.

The clover content in open cocksfoot pasture was twice that under trees in all seasons but overall clover content was low (< 7%) and consequently unlikely to have influenced animal performance.

LWG in lucerne pastures was 38% (per head) and 32% (per hectare) greater than in cocksfoot pastures (Table 1). The superior CP% and OMD levels (mainly in leaves) and 15% greater apparent intake of lucerne contributed to this greater LWG in lucerne. However, the pasture bulk density was 52% higher in cocksfoot pastures which could have been expected to enhance pasture intake. An explanation for this apparent anomaly was provided by Gong *et al.* (1996a) who showed that, compared with grasses, legumes provided greater bite weights (1253 vs. 994 mg fresh matter), faster biting rate (28 vs. 24 bites/min), and hence greater intake rate by sheep. Gong *et al.* (1996a) suggested this was because there was a higher mass bulk density within the grazed horizon in legume swards than grasses. However, they did not include lucerne in the range of species studied.

Table 2 Mean crude protein content (CP%) and organic matter digestibility (OMD%) from cocksfoot and lucerne (leaf, stem and leaf/stem ratio), in open and under trees pastures for 2 grazing years (September 1999–May 2000 and September 2000–April 2001). Maximum standard deviations (Max. SD) of means are given.

Treatments	CP (%)	OMD (%)
Open cocksfoot	17.8	79.3
Trees cocksfoot	18.6	77.8
Max. SD	0.37	1.89
Open lucerne leaf	28.2	82.2
Open lucerne stem	12.1	59.4
Weighted mean leaf/stem ratio	19.2	69.4
Trees lucerne leaf	28.1	81.0
Trees lucerne stem	11.6	58.3
Weighted mean leaf/stem ratio	18.2	67.4
Max. SD	3.39	8.55

Pasture production

Cocksfoot was relatively more shade tolerant than lucerne when it was analysed during periods of non-limiting water and temperature (September–November). Lucerne DM production decreased 36% under moderate tree shade (55–60% PPF) and cocksfoot only 20%. However, when analysing the total annual DM production, results showed that lucerne produced 58% and 76% more than cocksfoot in open and under trees, respectively. The greater productivity of the light-responsive lucerne is mainly related to its deeper root system (drought tolerance), ability to fix nitrogen and the canopy structure which is efficient for capture of solar radiation.

Lucerne DM production was greater in new lucerne (2 year old) than in old lucerne plots (11-year-old). New lucerne averaged 35% and 49% more DM yield than old lucerne plots under trees and in open, respectively. Old lucerne plots had reduced plant and stem populations and patches of dense weed invasion (mainly thistles) which reduced productivity. Thus, the direct drilling of lucerne into plots under established 9-year-old pine trees was possible and successful. Together, the productivity of “old” and “new” pastures suggests lucerne is a viable option for silvopastoral systems in this environment given that lucerne competition has beneficial effects on tree quality (Peri *et al.* 2001b).

Nutritive value

Cocksfoot CP% increased slightly under tree shade. This may be attributed to either a decrease in photosynthates, with a consequent rise in the N%, or to an increase in soil organic matter mineralisation under trees that provided more nitrogen for grass uptake (Wilson *et al.* 1990). Lucerne CP% changed little under

trees compared with open. Nitrogen concentration in legumes has been reported to be similar across levels of radiation in some studies (Eriksen & Whitney 1982) but Walgenbach & Marten (1981) reported that lucerne had about 15% less soluble protein nitrogen under 73% shade cloth compared with full sunlight. Another reason suggested by Walgenbach & Marten (1981) and Wilson (1989) for reduced nitrogen concentration in shaded legumes was because nodulation and symbiotic fixation were restricted by reduced carbohydrate under low illumination conditions.

There were small differences between open and shaded pastures for OMD for both cocksfoot and lucerne. Wilson (1989) reported that shading has inconsistent effects on cell wall content and composition, lignin and *in vitro* digestibility of plant dry matter.

After calculating the mean weighted CP% and OMD for whole plant (44% leaf and 56% stem), it was noted that lucerne nutritive value was closely associated with the stage of maturity at the harvesting date. Plants grown under trees showed a delay in development particularly in summer and early autumn. This was probably owing to lower temperatures. During this period lucerne weighted averages for CP% and OMD were greater under trees than in open. Lucerne leaf had much higher crude protein values than cocksfoot (27 vs. 19 CP%).

Although cocksfoot was more 'shade tolerant' in relative terms, lucerne DM production, feeding value and animal LWG were superior to cocksfoot under trees. The concept of 'shade tolerance' (Wong 1990) may therefore be inappropriate when screening pasture species for silvopastoral systems. More useful criteria would be the ecological stability and persistence of a pasture together with animal production per hectare. Thus, long term animal performance from a shaded pasture would provide the best indicator of its value in silvopastoral systems.

Conclusions

1. The superior sheep performance on open pastures compared with pastures under trees was attributed to the greater pasture production rate, pre-grazing mass and bulk density which allowed higher stocking rates and pasture intake.
2. Lucerne was more productive than cocksfoot in open and under *Pinus radiata* shade even though it was relatively more sensitive to reduced light intensity. Sheep liveweight gains (per animal and per hectare) were greater in lucerne than in cocksfoot pastures mainly owing to the superior crude protein content and apparent intakes of lucerne.

3. Cocksfoot was a persistent shade-tolerant grass which was normally nitrogen deficient because of the low white clover sward content.

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