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Relationship between tree canopy height and the production of pasture species in a silvopastoral system based on alder trees

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Abstract Silvopastoral systems in New Zealand that incorporate trees planted to control soil erosion on hills largely rely on the productivity of the pastoral system for financial returns. The effect on pasture productivity of increasing the tree canopy height by pruning Italian gray alder (*Alnus cordata*) was investigated by measuring the response of light, soil moisture, soil temperature, pasture production of major pasture species, and grazing behaviour of sheep. A split-plot design with four replicates was used. The main plot treatments were three levels of shade (81, 23, and 12% of available photosynthetic photon flux (PPF)), created by pruning 11 year old alder grown at the same density. The sub-plot treatments were four pasture mixes: perennial ryegrass (*Lolium perenne*), Yorkshire fog (*Holcus lanatus*), and cocksfoot (*Dactylis glomerata*), each sown with white clover (*Trifolium repens*), and cocksfoot sown with lotus (*Lotus pedunculatus*). Soil temperature was highest under light shade. Total herbage yield at 50 mm stubble height from October to May under heavy and medium shade was 60 and 80%, respectively, of the total herbage harvested under light shade. Cocksfoot had the greatest herbage yield, either with lotus or white clover. The tillering of perennial ryegrass was suppressed by shade more than for the other grass species making ryegrass unsuitable for use in this silvopastoral system. More sheep grazed in the light shade than in the heavy shade, but there was no difference in sheep preference for cocksfoot or Yorkshire fog. Lotus was grazed more frequently than white clover. Pruning of alder to increase canopy height has the potential to improve the productivity of the understorey pasture and its acceptability to sheep.

Keywords Cocksfoot · Perennial ryegrass · Lotus · Pruning · Shade tolerance · Silvopastoral systems

Introduction

Large areas of hill land used for pastoral agriculture in New Zealand are susceptible to soil erosion (Blaschke et al. 1992). The main technology used to sustain pastoral agriculture on hills has been the planting of trees for soil conservation, particularly poplar (*Populus* spp.), willow (*Salix* spp.), alder (*Alnus* spp.), blackwood (*Acacia melanoxylon*), *Eucalyptus* spp., and *Pinus radiata* (Miller et al. 1996; Wilkinson 1999). The success of these

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silvopastoral systems depends on the profitability of the pastoral component. Pasture production decreases under all these tree species, but there is less reduction under deciduous than evergreen species (Guevara-Escobar et al. 1997; Hawke and Knowles 1997; Power et al. 2001).

Understorey pasture production normally depends on the degree of competition between trees and pasture for light, moisture, and nutrients (Dodd et al. 2005; Eastham and Rose 1988). Studies on *Pinus radiata* in New Zealand indicated that understorey herbage production decreases as crown density increases (Hawke and Knowles 1997; Pollock et al. 1994). Guevara-Escobar et al. (1997) concluded that of all the competitive constraints, shade has the greatest negative effect on pasture production under mature poplars in New Zealand. Pasture production under deciduous trees is increased by pruning the trees to decrease the canopy area and by the use of short rotations (New 1985).

The impact of deciduous tree shade on the productivity and persistence of understorey pastures has received relatively little research attention in temperate climates (Knowles 1991; Wall et al. 1997), and there is little information available on the effect of pruning soil conservation trees on the growth of understorey pasture species. Additionally, research is needed to investigate the observations of farmers that sheep dislike grazing under trees. Peri et al. (2001) demonstrated that sheep production under *Pinus radiata* is lower than on open pasture due to both a decrease in pasture production and a decrease in the bulk density of the sward reducing herbage intake. Consequently an experiment was conducted on the effect of pruning height of alder on the understorey microenvironment, the understorey pasture production of sown pasture species with known shade tolerance, and the grazing behaviour of sheep. The main objective was to determine the effect of pruning height on the productivity of a pastoral system under alder.

Materials and methods

The experiment was located on a moist, lowland site with 11 year old Italian gray alder (*Alnus cordata*) at the Horticulture Research Institute's field station at Aokautere, 5 km east of Palmerston North, New Zealand (latitude 40.22°S, longitude 175.35°E). The soil was a Manawatu silt loam, moderately drained with medium to poor fertility. The mineral fertility of the soil and pH were measured before and after the experiment (Table 1). The pH was determined in a 1:2.5 soil:water suspension, S by CaH_2PO_4 extractable SO_4–S, exchangeable cations in 1 M ammonium acetate, pH 7, and P by Olsen P (Blackmore et al. 1987).

The 50 years mean annual rainfall is 995 mm with the drier months typically being January to April (Anon 1993). The long term mean annual air temperature is 12.9°C (Oppong 1998). The site had been established with evenly spaced Italian gray alder (*Alnus cordata*) trees with *Robinia pseudoacacia* planted alternately in each row in rectangular spacing (width between rows 3.0 m and width within rows 4.0 m). The *Robinia* were used to ensure erect growth by the alder, and were removed 3 months before the experiment. The alder trees had not previously been pruned. The site was surrounded by widely spaced deciduous tree species.

The site was divided into three main plots (25 stems in one main plot of 12 × 16 m^2, 192 m^2). Within each main plot there were four replications of four sub-plot treatments, with 2 × 4 m of cultivable area per sub-plot leaving a 0.5 m margin from the line of the tree trunks on each side of the plot.

The main plots were unreplicated shade treatments created by pruning trees to different heights from ground level, and the sub-plot treatments were mixed grass/legume swards. The main plot shade treatments were unreplicated because of insufficient area of trees to manage edge effects if smaller shade treatments had been used. The variance within the main plots was

Table 1 Nutrient levels to 75 mm depth in the soil under alder before and after the experiment

Date	pH	Olsen *P* (ug g^{-1})	*S* (ug g^{-1})	Exchangeable cations (meq 100 g^{-1})		
				K	Ca	Mg
2 Dec 1996 before experiment	5.4	11.4	5.8	0.5	5.0	1.3
5 Oct 1998 after experiment	5.5	6.8	3.2	0.4	5.3	1.2

assumed to estimate the variance for the whole experiment. The experimental site was homogeneous in terms of soil type and original tree condition, and the site was surrounded by other tree species.

Height to the lowest branches on the alder in the three shade treatments was 2.5 m (unpruned), 5.0, and 7.0 m from the ground after pruning, which gave tree canopy closures of 89, 75 and 41%, respectively (Devkota et al. 2001). The three canopy heights resulted in three different levels of transmitted PPF, hereafter called heavy, medium, and light shade, respectively, as determined by measuring PPF just above the sward at each end and in the middle of each sub-plot. Measurements were monthly on clear sky days between 1,200 and 1,300 h using a LI-COR (Model LI-185) portable quantum sensor positioned vertically. The R:FR ratio of the light was also measured monthly with a Skye Sensor just above the swards under the trees. Soil temperature was recorded monthly at 100 mm depth in each treatment. Likewise, volumetric soil moisture (v/v %) was estimated from 0 to 200 mm depth randomly in each plot using the time domain reflectometry technique (TDR, Soil moisture Co. Santa Barbara, CA., USA).

The four sub-plot treatments were perennial ryegrass (*Lolium perene*, 'Grasslands Nui'), Yorkshire fog (*Holcus lanatus*, 'Massey Basyn'), and cocksfoot (*Dactylis glomerata*, 'Grasslands Wana'), each grown with white clover (*Trifolium repens*, 'Grasslands Tahora') as the legume component, and also cocksfoot combined with lotus (*Lotus pedunculatus*, 'Grasslands Maku'). On 25 September 1996, plots were sprayed with glyphosate (a.i. 360 g l^{-1}) to kill existing vegetation, and on 8 October, were prepared with a rotary cultivator. Land was levelled and seed hand sown on 14 October 1996. Legume seeds were treated with appropriate *Rhizobium* strains. After germination, plots were hand weeded regularly from December 1996 to early January 1997. Sprinkler irrigation was used twice, once in November and once in December, to help establishment of the swards, but was not used thereafter. No chemical or organic fertilizer was used so that soil fertility was maintained at a similar level to found on hill farms that use alder. Plots were mowed monthly at 50 mm height from late December 1996 to 24 April 1997. Leaf fall began at the end of April 1997 and was completed by the first week of June. The fallen leaves were completely raked away from the site. The mowing of the plots re-commenced 28 October 1997.

Measurements

Tree measurements and leaf area index (LAI)

Tree height, diameter at 1.4 m (DBH) and LAI were measured at the end of the experiment. LAI of the trees was estimated using a LAI 2000 Plant Canopy Analyser (LI-COR inc., Lincoln, Nebraska, USA).

Herbage production

The first experimental harvest was on 28 October 1997 and monthly harvests continued until the next leaf-fall in May 1998. At each harvest, a randomly selected 1.0 m^2 area in each sub-plot was mowed at 50 mm stubble height, and herbage fresh mass was recorded. Residual forage was mowed at 50 mm height. Representative samples of 150–200 g from each sub-plot were taken, dried at 70°C for 24 h, and weighed to determine herbage dry mass harvested above the defoliation height of 50 mm (re-growth).

Tiller population and tissue dynamics

At each harvest, tillers m^{-2} of the grass component, and number of growing points or branches m^{-2} for legumes were counted in two randomly placed quadrats (10 × 10 cm) in each sub-plot and the mean calculated.

Leaf elongation and senescence were measured from 28 November 1997 to 16 December 1997 (Spring) and from 1 March 1998 to 22 March 1998 (Autumn), using the techniques of Bircham and Hodgson (1983) for grasses, and as modified by Williams et al. (1964) for white clover. Four individual rooted grass tillers and four white clover stolons were selected at random at 20 cm intervals in each of two 2 m long transects per plot, alternating grass and white clover. There were no reproductive tillers in either period, and no measurements were made in the cocksfoot/lotus plots.

For all marked grass tillers, the elongation of the laminae was recorded on three occasions over 19 days (1, 9 and 18 days post harvest) in the autumn measurements, and over 23 days (1, 13 and 22 days post harvest) in the spring measurements. The leaf lengths were measured as the distance from the point of insertion to the tip of the leaf or, in senesced leaves, to the base of the chlorotic tissue. The lengths of all laminae, and the lengths of the pseudostem of vegetative tillers were measured. At the end of the measurement period ten tillers per plot were randomly harvested and the relationships were determined for leaf length (mm) to dry mass (mg), and stem length to dry mass. Estimates of leaf mass per unit length were then used (Hernandez-Garay et al. 1997a, b) together with tillers m^{-2} to calculate net leaf expansion per tiller (mm $tiller^{-1}$ day^{-1}) and mass change per tiller (mg $tiller^{-1}$ day^{-1}), as well as mass change per unit ground area (g m^{-2} day^{-1}).

Net mass accumulation was calculated as:

Gross tissue growth (G) = increase in leaf mass of expanding leaves

Senescence (S) = decrease in mass of senescing leaves

Net accumulation (NA) = (G − S) + change in pseudostem mass

For white clover, petiole elongation and leaf expansion were estimated from measurements of four stolons per plot. Elongation measurements of white clover petioles were made from the stipule to the tip or to the lower edge of the senescent region (Hernandez-Garay et al. 1997a, b). Stolon length was measured to the tip of the growing point. Leaf lamina expansion was determined according to visual assessment of leaf area in cm^2 using standard scores (Williams et al. 1964). To estimate the relationship between leaf area expansion, stem length, petiole length and their mass, 10 stolons were randomly collected at the end of the measurements and separated into leaf, stolon and petiole. Leaf area and stolon and petiole lengths were measured. The components were separately oven dried for 24 h at 70°C, and dry mass was taken to calculate net (stolon + petiole + leaf) expansion per growing point (mm growing $point^{-1}$ day^{-1} for stolon and petiole) and mass change per growing point (mg growing $point^{-1}$ day^{-1}), and per unit area (g m^{-2} day^{-1}), using the procedure described above for grasses.

Grazing behaviour

A grazing preference experiment was carried out at the end of the herbage experiment (June 1998), following destruction of the perennial ryegrass plus white clover plots with glyphosate (a.i. 360 g l^{-1}). This was done to provide homogeneity of the swards being evaluated for selective grazing since the growth of perennial ryegrass was poor compared to the other three grass treatments. The three main plots were divided longitudinally with an electric fence to provide two blocks with an equivalent random distribution of sub-plots within them.

Grazing observations were made for 2 h in the afternoons of two successive days, covering one block each day. Twelve dry mixed age Romney ewes (4–6 years of age and 60–70 kg live weight) were used for grazing. Sheep were allowed to graze a nearby area with scattered trees each morning, and were then placed on test in the afternoon. The distribution of sheep activity (grazing, walking, resting) was recorded at 2 min intervals over 2 h by three observers concealed behind nearby bushes (Hodgson 1982).

Before grazing a 2 m transect was marked in each plot and along it five legumes (growing points/branches), and five grass tillers were identified, alternately every 20 cm, and marked with plastic wire. The number of marked tillers and marked legumes grazed (out of five each) was recorded after grazing. The ratio of grazed grass tillers to grazed legume growing points was calculated.

Statistical analysis

The experiment was analyzed as a split-plot design with the shade treatments as the main plots and the pasture treatments as the sub-plots. Analysis of variance was for each harvest date, with repeated measures analysis used to test for any main effects of treatments or interactions of shade and pasture treatments over time. Analysis of variance, using fixed effects, was with the PROC GLM procedures of SAS (SAS 1997). The within main plot variance was used as an estimate of variance for the experiment based on the variances within each main plot being found to be similar. Residuals were examined for their normality and transformations used when needed.

Results

Tree measurements

Mean tree height in each main plot at the end of the experiment was 10.4 ± 0.4 m, 10.9 ± 0.5 m, and

9.9 ± 1.3 m for heavy, medium and light shade, respectively. Mean DBH was 15.1 ± 2.3 cm, 16.3 ± 1.8 cm and 14.0 ± 1.4 cm for heavy, medium and light shade, respectively. Mean LAI of the trees was 6.4 ± 0.7, 3.6 ± 0.7, and 1.7 ± 0.1 for heavy, medium and light shade, respectively, at the end of experiment.

Environmental measurements

The mean monthly rainfall for September 1996–November 1998, measured 9 km from the experimental site (AgResearch, Palmerston North), was 71.3 ± 39.4 mm, which was lower than average. The mean global radiation was 403 ± 176.1 MJ m^{-2} $month^{-1}$. The Olsen *P* and *S* values for the soil declined during the experiment (Table 1).

The mean PPF under light shade was ~7 times greater than the mean PPF under heavy shade (Table 2). The PPF under light shade was slightly less than under open sky, while PPF under medium and heavy shade was sufficiently low to limit plant growth (Table 2). The mean R:FR was lower the greater the level of shade.

Soil moisture percentages were greater in light than heavy shade from October 1997 to January 1998 ($P < 0.05$, Table 3). However, there was no effect of shade on the soil moisture percentage from February to May 1998. There were no differences in soil moisture percentage between pasture species, nor was there an interaction between shade and species across all dates.

The effect of shade on soil temperature was significant for all months from November 1997 to March 1998, and in May 1998, with soil being warmer in light shade and cooler in heavy shade (Table 4). Soil temperature was highest in December 1997 and lowest in October 1997 and March 1998. Species and shade × species were not significant across all dates.

Herbage production

There was a significant effect ($P < 0.01$) of shade and forage species on the understorey herbage production at each date, and across all dates, except for shade in March 1998 (Table 5). For most dates, the light shade treatment yielded the most herbage

Table 2 Levels of transmitted PPF (photosynthetic photon flux) and R:FR (red:far-red) ratio measured at various occasions under three levels of alder tree shading during November 1997–May 1998

Shade levels	PPF (moles photons m^{-2} s^{-1})		Mean R:FR ± SEM
	Mean ± SEM	Mean % full PPF	
Heavy	183 ± 55.1	12	0.6 ± 0.02
Medium	360 ± 99.9	23	0.9 ± 0.05
Light	1264 ± 96.8	81	1.3 ± 0.08
Open	1566 ± 103.4	–	1.4 ± 0.02

SEM standard error of the mean

Table 3 Soil moisture percentage at 200 mm depth under three levels of alder tree shade during November 1997–May 1998

Shade/treatments	Months							
	29 Oct 1997	26 Nov 1997	22 Dec 1997	13 Jan 1998	11 Feb 1998	20 Mar 1998	8 Apr 1998	14 May 1998
Heavy shade	31	27	25	14	7	12	9	26
Medium shade	32	32	28	15	6	11	9	27
Light shade	35	34	30	19	7	10	9	25
SEM	0.77	0.54	0.90	0.85	0.48	0.32	1.02	0.93
Probability	$P < 0.05$	$P < 0.001$	$P < 0.05$	$P < 0.01$	NS	NS	NS	NS

NS not significant at $P < 0.05$

SEM standard error of the mean

Table 4 Soil temperature at 100 mm depth under three levels of alder tree shade during October 1997–May 1998

Shade treatments	Months							
	28 Oct 1997	26 Nov 1997	22 Dec 1997	13 Jan 1998	27 Feb 1998	9 Mar 1998	8 Apr 1998	4 May 1998
Heavy shade	12.1	16.7	20.3	19.6	20.8	21.2	17.1	9.6
Medium shade	11.6	17.9	21.5	19.8	21.9	22.1	17.5	11.4
Light shade	12.0	20.1	23.7	21.2	22.4	22.6	18.6	11.0
SEM	0.16	0.18	0.34	0.37	0.19	0.23	0.50	0.17
Probability	NS	$P < 0.001$	$P < 0.001$	$P < 0.05$	$P < 0.01$	$P < 0.01$	NS	$P < 0.001$

NS not significant at $P < 0.05$

SEM standard error of the mean

Table 5 Herbage dry matter harvested above 50 mm (g m^{-2}) at each month, and total herbage harvested (g m^{-2}) (October 28,1997–May 28,1998 (212 days) under three levels of alder tree shade

Treatments	Herbage harvested above 50 mm at each harvest (g m^{-2})								
	28 Oct 1997	24 Nov 1997	23 Dec 1997	23 Jan 1998	27 Feb 1998	27 Mar 1998	23 Apr 1998	28 May 1998	Total herbage
Shade (A)									
Heavy shade	89	49	46	46	40	50	33	37	390
Medium shade	139	64	74	85	54	57	39	41	552
Light shade	196	68	92	104	46	57	46	46	654
SEM	4.9	3.7	5.1	5.3	2.3	2.6	1.3	1.6	15.7
Probability	$P < 0.001$	$P < 0.05$	$P < 0.01$	$P < 0.001$	$P < 0.01$	NS	$P < 0.001$	$P < 0.05$	$P < 0.001$
Species (B)									
RW	116	52	59	58	38	53	29	33	439
YW	150	59	69	77	41	49	34	32	513
CW	134	67	73	96	52	60	47	49	578
CL	165	61	81	81	55	58	49	50	600
SEM	6.8	2.6	4.2	4.0	4.1	2.3	2.3	2.2	11.6
Probability	$P < 0.001$	$P < 0.01$	$P < 0.01$	$P < 0.001$	$P < 0.01$	$P < 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.001$
A × B	NS	NS	NS	NS	NS	$P < 0.01$	NS	NS	NS

RW perennial ryegrass + white clover, *YW* Yorkshire fog + white clover, *CW* cocksfoot + white clover, and *CL* cocksfoot + lotus

SEM standard error of the mean

NS non significant at $P = 0.05$

harvested, while heavy shade yielded the least. Herbage harvested under light shade was particularly greater than for medium and heavy shade in October, December and January. The shade × species interactive effect was not significant for any date, except March 1998 ($P < 0.01$).

Cocksfoot, with white clover or lotus, yielded more herbage at each date than most other treatments. Perennial ryegrass had the lowest yield. Herbage harvested over the three shade levels for Yorkshire fog yielded similarly to perennial ryegrass, except from October to December 1997, when Yorkshire fog had similar yields as cocksfoot. Cocksfoot, either with white clover or lotus, also had the greatest total herbage yield followed by Yorkshire fog and perennial ryegrass.

Sward characteristics and dynamics

Growing points

Shade level and forage species significantly ($P < 0.001$) affected the number of tillers m^{-2} within and across all dates (Table 6). Highest tiller number m^{-2} occurred under light shade at each date, followed by medium shade, then heavy shade. The shade × species interaction within dates was not significant, but the interaction was significant across all dates. Tiller density was greater for cocksfoot and Yorkshire fog than for ryegrass within each shade level ($P < 0.05$). For example, ryegrass tiller density in light, medium and heavy shade was 3011, 2375 and 1757 ± 115.3 tillers m^{-2}, respectively, whereas for cocksfoot with white clover it was 3732, 3204, and 2793 ± 115.3 tillers m^{-2}, respectively ($P < 0.05$). Cocksfoot and Yorkshire fog tiller densities were similar within each shade level, except in light shade where tillers m^{-2} were 4,100 and 3,732 ± 115.3 for Yorkshire fog and cocksfoot, both with white clover, respectively ($P < 0.05$).

Shade significantly decreased the number of growing points (GP) of white clover and branches of lotus across all dates, but the effect of shade was not significant within November, December and March (Table 7). White clover growing point density was consistently greater with ryegrass than cocksfoot. Interactive effects between shade and legume species were not significant.

Net herbage production

Shade and forage species significantly affected net herbage production per tiller and per growing point (Table 7). Forage species significantly affected net herbage production per area, but the effect of shade was only significant in November/December. Species × shade effects were not significant. Net herbage production rate of grass was greatest in light shade, with production in medium and heavy shade similar in March (Table 8). Net herbage production per tiller and per area of grass was greatest for cocksfoot. Net herbage production per growing point and per area of white clover was lowest for cocksfoot and greatest for ryegrass.

Grazing behaviour

The limited area available around the experimental site meant that the sheep could not be acclimatised to the sward conditions before the grazing observations

Table 6 Tiller density (number m^{-2}) of the grass component of the grass-legume mixtures under three levels of alder tree shade

Treatments	24 Nov 1997	20 Dec 1997	17 Jan 1998	21 Feb 1998	20 Mar 1998	18 Apr 1998	20 May 1998
Shade (A)							
Heavy shade	2363	2094	2044	2200	2713	2725	2669
Medium shade	2894	2494	2894	2600	3094	3444	3438
Light shade	3763	3163	3569	2994	3413	3844	4144
SEM	130.0	95.0	131.6	77.8	97.8	108.8	151.9
Probability	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.01$	$P < 0.001$	$P < 0.001$
Species (B)							
RW	2975	2125	2408	2300	2167	2392	2408
YW	2600	2983	3533	2808	3400	3858	3883
CW	3467	2733	2958	2775	3358	3625	3783
CL	2983	2492	2442	2617	3367	3475	3592
SEM	161.0	129.2	121.1	96.7	97.4	107.4	86.9
Probability	$P < 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
A × B	NS	NS	NS	NS	NS	NS	NS

RW perennial ryegrass + white clover, *YW* Yorkshire fog + white clover, *CW* cocksfoot + white clover, and *CL* cocksfoot + lotus

SEM standard error of the mean

NS non significant at $P = 0.05$

Table 7 Density of growing points or branches (number m^{-2}) for white clover and lotus in grass-legume mixtures under three levels of alder tree shade

Treatments	24 Nov 1997	20 Dec 1997	17 Jan 1998	21 Feb 1998	20 Mar 1998	18 Apr 1998	20 May 1998	Repeated measures
Shade (A)								
Heavy shade	6.39 (596)	631	5.96 (388)	356	669	781	888	679
Medium shade	6.71 (821)	856	6.29 (539)	519	700	900	1013	832
Light shade	6.59 (728)	913	6.61 (743)	669	800	1056	1213	967
SEM	0.07	72.49	0.08	54.64	59.91	29.09	35.35	35.04
Probability	NS	NS	$P < 0.01$	$P < 0.01$	NS	$P < 0.001$	$P < 0.001$	$P < 0.001$
Species (B)								
RW	6.20 (496)	483	6.14 (486)	567	792	967	1033	694
YW	6.16 (503)	358	5.90 (378)	492	725	950	925	622
CW	6.01 (351)	333	5.62 (280)	350	475	592	625	443
CL	7.82 (2502)	2025	7.48 (1915)	650	900	1142	1533	1544
SEM	0.06	70.02	0.06	37.13	47.48	55.17	35.89	40.46
Probability	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
A × B	NS	NS	NS	NS	NS	NS	NS	NS

RW perennial ryegrass + white clover, *YW* Yorkshire fog + white clover, *CW* cocksfoot + white clover, and *CL* cocksfoot + lotus. Analyses for 24 November 1997 and 17 January 1998 based on $\log_e$ transformed data. Values in *brackets* are untransformed for ease of comparison with other dates

SEM standard error of the mean

NS non significant at $P = 0.05$

started, so they had no preliminary experience of the forage-tree conditions.

There was a significant difference between shade levels ($P < 0.05$) in the total number of observations of sheep actively grazing in 2 h (Table 9). Approximately twice as many observations of grazing were made under light shade as under heavy shade. However, the choice of pasture mix, and the interaction between shade and species were not significant ($P > 0.05$). Similarly, the number of tagged tillers that were grazed by sheep was significantly different ($P < 0.01$) between the shade levels, but the pasture species and the shade × species effects were not significant.

There was no significant difference ($P > 0.05$) in the number of tagged legume branches that were grazed across the shade levels, but there were species differences ($P < 0.01$). Cocksfoot with lotus had the greatest number of tagged legume branches grazed over the three shade levels, followed by cocksfoot or Yorkshire fog with white clover. Also, cocksfoot with lotus had the lowest ratio of grazed tillers to branches/growing points over the three shade levels, compared with cocksfoot or Yorkshire fog with white clover.

Discussion

Changes in alder canopy height had major implications for the productivity of the pastoral component in a silvopastoral system. Total understorey herbage yields from October to May were 60% (heavy) and 80% (medium) of the total herbage harvested in light shade (81% open PPF). Pruning caused an increase in PPF (Table 2), maintained the R:FR and decreased soil temperature (Table 4). Light was limiting for pasture growth in the heavy shade throughout the growing season (Dodd et al. 2005; Peri et al. 2007), and the sward was observed to be less densely tillered (Table 6) due to the morphological responses of the pasture species to the low R:FR in the heavy shade. Additionally, sheep preferred grazing in light shade as opposed to heavy shade (Table 9), suggesting that utilisation and grazing management of the pasture in heavy shade would be more difficult than in light shade (Peri et al. 2001). The practical consequence of these results is that increased pruning height of alder could improve the grazing productivity of the understorey pasture.

Table 8 Rates of net herbage production (stem + leaf) per tiller (mg tiller^{-1} day^{-1} and per m^2 (g m^{-2} day^{-1}) of the grass components and rates of net herbage production (net stolon + net petiole + net leaf) per growing point (mg growing point^{-1} day^{-1}), and per unit area (g m^{-2} day^{-1}) of the white clover component

Treatments	Grass component		White clover component	
	28 Nov–16 Dec 1997	1–22 March 1998	28 Nov–16 Dec 1997	1–22 March 1998
	Per tiller (mg)		Per growing point (mg)	
Shade (A)				
Heavy shade	1.30	0.74	1.44	1.03
Medium shade	1.60	0.74	2.11	1.10
Light shade	1.73	0.84	2.18	1.45
SEM	0.09	0.31	0.18	0.10
Probability	$P < 0.05$	$P < 0.01$	$P < 0.05$	$P < 0.01$
Species (B)				
RW	1.27	0.50	2.18	1.40
YW	1.31	0.26	1.91	1.20
CW	1.87	0.97	1.63	0.97
CL	1.72	1.36	NA	NA
SEM	0.07	0.009	0.13	0.09
Probability	$P < 0.001$	$P < 0.001$	$P < 0.05$	$P < 0.01$
	Per m^2 (g)		Per m^2 (g)	
Shade (A)				
Heavy shade	2.72	2.10	0.42	0.68
Medium shade	4.10	2.42	0.89	0.74
Light shade	5.50	2.85	1.02	1.04
Probability	$P < 0.01$	NS	$P < 0.05$	NS
SEM	0.31	0.33	0.11	0.11
Species (B)				
RW	2.69	1.09	1.07	1.11
YW	4.20	0.90	0.69	0.87
CW	5.20	3.27	0.58	0.48
CL	4.35	4.58	NA	NA
SEM	0.25	0.30	0.09	0.05
Probability	$P < 0.001$	$P < 0.001$	$P < 0.01$	$P < 0.001$

RW perennial ryegrass + white clover, *YW* Yorkshire fog + white clover, *CW* cocksfoot + white clover, and *CL* cocksfoot + lotus

SEM standard error of the mean

NS non significant at $P = 0.05$

The decrease in pasture production under the 11 year old alder (Table 5) was similar in magnitude to that observed under similarly aged poplars in New Zealand (Douglas et al. 2001). Power et al. (2001), in a study of deciduous and evergreen trees, suggested that although the major effect on pasture production was shade in the range 61–90% of open PPF, other factors such as soil moisture and nutrient competition decrease pasture production. However, the small magnitude of the differences in soil moisture between the shade treatments was unlikely to contribute to differences in pasture production. There was possibly a flush of nitrogen (N) in the soil when it was cultivated as alder fix N but this would have been similar across the site. Olsen P level was limiting for pasture growth and declined during the experiment (Table 1). The low to medium soil nutrient levels over the site, low soil moisture from late summer (January) to mid-autumn (April) and high soil temperature (>20°C) possibly exacerbated the low

Table 9 Total number of observations of sheep actively grazing, number of ryegrass tillers and legume growing points/branches grazed, and the ratio of grazed tillers to legume branches for Yorkshire fog with white clover (YW), cocksfoot with white clover (CW), and cocksfoot with lotus (CL) pasture grown under three levels of alder tree shade

Treatments	Total number of sheep grazing observations	Number of tagged tillers grazed (out of 5)	Number of tagged legume branches grazed (out of 5)	Ratio of grazed tillers to grazed legume branches
Shade (A)				
Heavy shade	19	2.3	2.2	1.2
Medium shade	30	3.4	2.3	1.6
Light shade	37	3.2	2.9	1.2
SEM	3.7	0.13	0.35	0.25
Probability	$P < 0.05$	$P < 0.01$	NS	NS
Species (B)				
YW	27	2.9	2.1	1.5
CW	31	2.9	2.1	1.6
CL	27	2.9	3.1	0.9
SEM	2.4	0.17	0.19	0.13
Probability	NS	NS	$P < 0.01$	$P < 0.01$
A × B	NS	NS	NS	NS

SEM standard error of the mean

NS Non significant at $P = 0.05$

production and persistence of the perennial ryegrass relative to Yorkshire fog and cocksfoot, which are more tolerant than it of environmental stress (Kemp et al. 1999).

Cocksfoot, either with lotus or white clover, had greater herbage mass harvested than Yorkshire fog or perennial ryegrass with white clover (Table 5). Tiller number per plant, leaf area, and specific leaf area are important to sustain and produce higher shoot dry mass under heavy shade, and have been shown to be greater for cocksfoot than perennial ryegrass and Yorkshire fog (Devkota et al. 1997). In the current study, tiller population density was consistently greater for cocksfoot and Yorkshire fog than for ryegrass (Table 6), and net production per tiller was substantially greater for cocksfoot than for the other two species (Table 8). Previous results showed that cocksfoot cv. Grasslands Wana was more shade tolerant than many other cocksfoot cultivars and some other grass species (Devkota et al. 1997, 1998). Cocksfoot has been shown to produce and persist better in tree shade than many other pasture species (Peri et al. 2001; West et al. 1988).

There were consistently fewer white clover growing points with cocksfoot than with Yorkshire fog and perennial ryegrass suggesting that cocksfoot was more competitive with white clover (Table 7). Cocksfoot would have shaded white clover stolons more than the other grass species, as it was more densely tillered and productive. Moloney (1993) suggested that cocksfoot appeared to suppress white clover by competing for resources.

There was no difference in herbage mass harvested from cocksfoot grown with white clover or lotus (Table 5). Lotus was, however, more seasonal in its growth than white clover as there was more lotus in the mixture with cocksfoot during October and November compared with the later months (Devkota et al. 2000). The density of lotus branches was very low in February and March (Table 7). Gadgil et al. (1986), West et al. (1988), and (1991) all concluded that lotus is one of the more shade tolerant legume species. However, results of this experiment showed that lotus was sensitive to seasonal growth changes, was suppressed by the companion grass during a dry summer, and was selectively grazed by the sheep. Although there was evidence of a greater relative defoliation by sheep of lotus than of white clover (Table 9) the influence of the vertical distribution of grass and legume components in the sward canopy (Poli et al. 2006) was not monitored. Overall, these results suggest that lotus would be better used as a monoculture than in a mixed species pasture under trees.

The number of animals grazing and the number of defoliations of marked plants were greater under light than under heavy shade (Table 9). Vigilant behaviour while grazing (Illius and Fitzgibbon 1994; Pulliam and Caracao 1984) could explain the sheep grazing more in light shade than under heavy shade. It was observed while monitoring the grazing that sheep mostly moved as a group and were nervous when grazing in heavy shade. Therefore, the better visibility under light and medium shade could be one of the reasons why sheep concentrated their grazing there.

Differences in pasture structure between shade levels also could have played a role in diet selection (Gordon and Lascano 1993). Equally, differences in diet selection could have also been due to the sheep's response to variations in either the vertical distribution or the nutritive value of the species (Hodgson 1981; Neel et al. 2008).

In conclusion, the use of pruning to raise the height of the canopy, and decrease LAI and canopy area, of alder in a silvopastoral system increased pasture production by increasing transmitted light. Pruning also improved acceptability of the understorey pasture to sheep. The superior shade tolerance of cocksfoot and Yorkshire fog compared to ryegrass was confirmed.

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