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Interactions between widely spaced young poplars (*Populus* spp.) and introduced pasture mixtures

G.B. Douglas[1,]*, A.S. Walcroft[2,4], S.E. Hurst[2], J.F. Potter[1], A.G. Foote[1], L.E. Fung[2], W.R.N. Edwards[3] and C. van den Dijssel[2]

*[1]AgResearch Grasslands, Private Bag 11008, Palmerston North, New Zealand; [2]HortResearch, Private Bag 11030, Palmerston North, New Zealand; [3]Edwards Industries, P.O. Box 227, Otaki, New Zealand; [4]Present address: Landcare Research, Private Bag 11052, Palmerston North, New Zealand; *Author for correspondence (e-mail: grant.douglas@agresearch.co.nz; phone: +64-6-351-8072; fax: +64-6-351-8032)*

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Abstract

Silvopastoral systems involving poplars are widespread in rural landscapes in a number of regions of New Zealand. The effect of widely spaced trees of *Populus nigra* × *P. maximowiczii*, aged 8–11 years, on the growth and botanical composition of understorey pasture mixes was determined over 3 years at a southern North Island hill country site. Pasture mixes comprised existing pasture, and two introduced test swards comprising new grass (*Agrostis capillaris, Dactylis glomerata, Lolium perenne*) and legume (*Lotus uliginosus, Trifolium repens*) cultivars. Pasture accumulation beneath trees (6.6 t DM ha^{-1} $year^{-1}$) was 23% less than open (unshaded, no trees) pasture (8.6 t DM ha^{-1} $year^{-1}$) and differences in accumulation occurred between tree aspects (North and South sides of trees) when trees were foliated. In early spring, North plots produced 11–14% more herbage than South plots whereas in late summer, South plots produced up to 44% more herbage than North plots. Yield of both test swards (6.4 and 8.0 t DM ha^{-1} $year^{-1}$) was not significantly different from that of the existing sward (7.4 t DM ha^{-1} $year^{-1}$) but productivity varied between swards in spring and summer. One test sward included *Lotus uliginosus* cv. Grasslands Maku, and the sward produced 30% more DM than the other swards in mid-summer. *Dactylis glomerata* cv. Grasslands Wana comprised 37% of the DM of swards in which it was sown and was the most successful cultivar, followed by Grasslands Maku. Both cultivars are recommended for silvopastoral systems where pasture is lightly grazed.

Introduction

Poplar (*Populus* spp.) trees are an integral part of many New Zealand pastoral hill country landscapes, where they have been planted for many decades, primarily for soil conservation (Wilkinson 1995). Poplars have proven effective for controlling a range of erosion types such as soil slip and gully erosion, and are one of the few species that can be planted in the presence of grazing livestock – as poles with protective plastic sleeves. Approximately 80,000 poles/year are planted in the southern North Island (Douglas et al. 2005) and these planting rates are expected to continue.

In appraising poplars for use in silvopastoral systems, livestock farmers, land resource managers and consultants require accurate information about their effect on annual and seasonal understorey pasture productivity and botanical composition, as they impact directly on stock carrying capacity and nutrition, and hence feed and financial budgets. Pasture responses beneath evergreen tree species, particularly *Pinus radiata*, are well established in young (Yunusa et al. 1995) and mature (Hawke 1991) stands, but interactions between poplars and pasture have received much less attention.

In poplar-pasture systems, reductions in growth and changes in composition of understorey pastures compared with those in the open are less pronounced than in systems involving *P. radiata*. In a stand of poplars aged >25 years (Guevara-Escobar et al. 1997), where the tree canopy was essentially closed, net herbage accumulation was 42% less than for open or unshaded pasture, which produced 10.6 t DM ha^{-1} $year^{-1}$. Annual pasture accumulation was similar beneath widely spaced trees aged 16–19 years, and open pasture (Gilchrist et al. 1993), and 10–27% less beneath isolated trees (aged 8–15 years) relative to open pasture, at sites in the lower North and South Islands (Douglas et al. 2001). In these studies, when trees were in leaf during spring and summer, understorey pasture was as much as 70% less productive than open pasture whereas in late autumn and winter, differences between yields of swards beneath trees and in the open were negligible. Pastures beneath mature poplars and in the open had similar overall botanical composition but the chemical composition of understorey pasture was slightly poorer than open pasture, for example crude protein was 15.6% vs. 18.2%, respectively (Guevara-Escobar et al. 1997).

Pastures measured in these studies comprise old cultivars or unselected germplasm, and have existed for at least 20 years. Plant breeding programmes have developed new cultivars of numerous pasture species which are better adapted, more persistent, and more productive in grazed hill country than older cultivars and naturalised germplasm. New cultivars of *Agrostis capillaris* auct. brit., *Dactylis glomerata* L., *Lolium perenne* L., *Lotus uliginosus* Schkuhr. (syn. *L. pedunculatus* Cav.), and *Trifolium repens* L., are commonly included in seed mixes for oversowing pasture, e.g. *D. glomerata* cv. "Grasslands Wana", *L. uliginosus* cv. "Grasslands Maku", and *T. repens* cv. "Grasslands Tahora" (Barker et al. 1985; Charlton and Stewart 1999). As pasture oversowing and planting of poplars continue on hill country, it is likely that poplars will be established increasingly on pastures comprising new cultivars. There is, therefore, a particular need to determine their growth potential in the understorey environment.

This study aimed to determine the effect of intermediate-aged (8–11 years), widely spaced poplars on herbage accumulation and botanical and chemical composition of pasture mixtures comprising modern cultivars. The effect of the trees in this study on the surrounding aerial and soil micro-environment has been documented in a companion paper (Douglas et al. 2005), and only limited results describing the environment in which the pastures grew are presented here.

Materials and methods

Site

The trial was conducted on a commercial sheep and beef cattle farm in the Pohangina Valley, 34 km north east of Palmerston North, in the southern North Island of New Zealand (latitude 40°10′ S, longitude 175°45′ E, 260 m a.s.l.). The soil is a Raumai hill soil (Douglas et al. 2005). Mean daily air temperature at the site ranges from 7.9 °C in June (winter) to 17.4 °C in January (summer), and average annual rainfall is 1200–1300 mm (Rijkse 1977).

The site was in a 10 ha paddock which had unevenly spaced (5–20 m apart, or 25–400 trees/ha), unpruned poplar (*Populus maximowiczii* Henry × *P. nigra* L.) trees aged 8 (in 1997) to 11 years, on 5–10° slopes in gullies facing east and south-east. In October 2000 the trees had a mean height of 17.4 (s.d. = 1.3) m, stem diameter at breast height (1.4 m) averaged 31.9 (s.d. = 5.4) cm, and individual tree crowns did not overlap. Existing pasture in August 1996 comprised 65% grass (mostly *L. perenne, Anthoxanthum odoratum* L., *A. capillaris*, and *Holcus lanatus* L.), 10% legume (>95% *T. repens*), 10% other species (*Ranunculus* spp, *Juncus* spp, *Achillea millefolium* L.), and 15% dead matter. Areas of existing pasture to be oversown with pasture mixtures were sprayed with glyphosate (1.8 kg a.i./ha) and dicamba (0.2 kg a.i./ha) in August 1996.

Treatments and experimental design

There were three pasture mixtures in three environments, arranged in three randomised complete blocks. Environments were:

1. South side of trees, which was shaded in the middle of the day when trees had full canopy (South);
2. North side of trees, which was unshaded for most of the day (North); and
3. Adjacent areas of open pasture without trees (Open).

Pasture mixtures (sowing rates for new cultivars in kg/ha in brackets) were:

1. Three species mixture (TSM)

   None *Agrostis capillaris* cv. Grasslands Muster (3)
   None *Dactylis glomerata* cv. Grasslands Wana (27)
   None *Trifolium repens* cv. Grasslands Tahora (19)

2. Four species mixture (FSM)

   None *Dactylis glomerata* cv. Grasslands Wana (27)
   None *Lolium perenne* cv. Grasslands Nui (60)
   None *Lotus uliginosus* cv. Grasslands Maku (24)
   None *Trifolium repens* cv. Grasslands Tahora (19)

3. Existing pasture – control

Plots (experimental units) in all environments were located on areas of similar topography on the gentle slopes of gullies. Plots beneath trees extended 9 m from a tree along a north–south transect and were 4 m wide (2 m either side of transect), and those in Open plots were 3×3 m. Seed of pasture species was sown at high rates to facilitate successful establishment and to minimise weed establishment from buried seed and ingress from surrounding vegetation. All seed was coated, and seed of the legumes was inoculated with appropriate *Rhizobium* strains. Seed was broadcast by portable spreader in October 1996, and then partially buried by trampling with mixed-age sheep. Establishing swards were trimmed periodically to 3 cm height to stimulate tillering of the grasses and reduce shading and encourage branching of the companion legumes. Beginning in autumn 1997, swards were grazed by sheep as part of the normal grazing management for the paddock, which comprises a total of approximately 35 days grazing at 80 stock units (SU)/ha from January to August and 120 days grazing at 20 SU/ha from September to December. Cattle were excluded from the pasture plots by electric fences but sheep access was unhindered.

Measurements

Environmental parameters

A range of parameters was measured including rainfall, air temperature and relative humidity, global and diffuse shortwave (400–1100 nm) radiation in the Open environment and under the shade of the canopy, soil temperature at 100 mm depth, soil water content, soil pH, and concentrations of several soil nutrients (Douglas et al. 2005).

Pasture growth and composition

Growth and botanical composition in all plots were determined every 4–8 weeks from February 1997 through May 2000 using a standard pre-trimming technique involving one 0.2 m^2 grazing exclusion cage (Radcliffe 1974) per plot. In tree plots, areas selected for pasture sampling were those likely to differ the most in radiation interception. This was achieved by determining for South plots, the length of the shadow cast by each tree along the north-south transect at solar noon in mid-autumn/spring (sun elevation angle 37°) and in mid-summer (sun elevation angle 73°). Across the nine South plots, the average tree shadow extended from 1.4 m (range 1.1–1.7 m) to 4.3 m (range 3.4–5.1 m) from the trunk. Pasture measurements were conducted in rectangular areas within the length of the mid-day tree shadow specific to each tree and extending 1 m either side of the transect. Each area was divided into quarters and the cage was moved clockwise to the next quarter after each harvest. For each tree, the pasture sampling area in the North plot had the same dimensions and distance from the trunk as that in the South plot.

At each harvest, herbage in the caged areas of all plots was cut with electric shears to a residual sward height of 1 cm above the ground. A sub-sample was dissected into grass, legume, other species, dead matter and poplar leaf litter and component dry weights (12 h at 80 °C) were determined. Species were separated in spring (24 October 1997, 19 October 1998, 15 November 1999) and autumn (6 May 1998, 12 April 1999, 10 May 2000).

Pasture and poplar leaf chemical composition

From the herbage harvested on 19 October 1998 and 12 April 1999, a second sub-sample (excluding poplar leaf litter) was taken, oven-dried for 24 h at 60 °C, and then ground with a Wiley mill to pass through a 1-mm diameter sieve. Samples were analysed by near infrared reflectance spectroscopy (NIRS; Corson et al. 1999) for dry matter concentrations (%DM) of: ash, crude protein, lipid, soluble carbohydrate, neutral detergent fibre (NDF), acid detergent fibre (ADF), and *in vitro* organic matter digestibility (OMD); and metabolisable energy (ME; MJ/kg DM). A pasture standard was used for all analyses. Up to three samples of healthy green poplar leaves in autumn 1999, leaves 2 or 3 days old from understorey litter (young), and leaves > 20 days old from understorey litter (old), were also analysed using NIRS.

Statistical analyses

Herbage mass (kg DM ha^{-1}), with and without poplar leaf litter, was calculated for each of the 36 months from May 1997 through April 2000 using linear interpolation. For botanical composition data, harvests were classified into seasons of spring (September to November), summer (December to February), autumn (March to May) and winter (June to August). Contents of grass, legume, other species, and dead matter, were expressed as percent of pasture DM, as were each sown grass and legume species in the six harvests in which they were dissected. All data, including those for chemical composition, were analysed using a split-plot in time analysis of variance. For herbage mass, separate analyses (uncorrected; and assuming autoregressive structure) of monthly data and of year means were conducted using Residual Maximum Likelihood (REML).

All data were analysed using of GENSTAT (2002) and mean separation was achieved using the Least Significant Difference test at the 5% significance level.

Results

Site environmental characteristics

Mean daily air temperature varied seasonally between 9 and 23 °C and mean daily air vapour pressure deficit rarely exceeded 2 kPa for most of the experimental period. Global shortwave irradiance varied from 5 MJ m^{-2} d^{-1} during winter to 18 MJ m^{-2} d^{-1} during summer. Across the year, mean transmitted irradiance in tree plots, averaged over North and South aspects, was 33% lower than irradiance in Open plots. North and South plots had similar total mean daily transmitted irradiance across the year.

Mean annual rainfall was 983 mm, with most (29%) falling in winter and least (18%) falling in summer. Soil water content was highest in spring and winter (0.35–0.39 m^3 m^{-3}) and lowest in summer and autumn (0.21–0.26 m^3 m^{-3}). The effect of trees on soil water content was most apparent during summer and winter. In summer, Open plots (0.26 m^3 m^{-3}) had nearly 10% higher soil water content than those beneath trees (0.24 m^3 m^{-3}) whereas in winter, tree plots at both depths (0.39 m^3 m^{-3}) were 9% wetter ($p <$ 0.01) than Open plots (0.36 m^3 m^{-3}). In summer, North plots were slightly drier ($p < 0.01$) than South plots, and in autumn, the reverse trend occurred with North plots being 7% wetter than South plots. Sward type generally had no significant effect on soil water content.

Mean monthly soil temperature varied from 8.5 to 21.8 °C and mean annual temperature in the North environment (14.9 °C) averaged 1.1 °C warmer than in the South (13.8 °C). Across the three environments, soil pH levels in 1998 were similar and averaged 5.71 whereas in 2000 they were in the order ($p < 0.05$) North (5.70) > South (5.56) > Open (5.45). Soil beneath the existing and two introduced swards had similar pH and macronutrient concentrations.

Herbage accumulation

Across 3 years, average total biomass accumulation (sward + poplar leaf litter) in North (8.40 t DM ha^{-1} $year^{-1}$), South (8.14 t DM ha^{-1} $year^{-1}$), and Open (8.80 t DM ha^{-1} $year^{-1}$) plots did not vary significantly. However pasture alone accumulated about 6.60 t DM ha^{-1} $year^{-1}$ in North and South plots, which was 23% less ($p < 0.01$) than swards in Open plots (8.58 t DM ha^{-1} $year^{-1}$). Poplar leaf litter comprised a major proportion of understorey above-ground biomass from March to June, peaking at 49% in May (Figure 1a).

Sward productivity beneath trees relative to that in Open plots varied considerably with year and month. In Year 1, yield of North and South plots averaged 8% less than Open plots (8.68 t DM ha^{-1} $year^{-1}$), compared with in Year 2 (7.73 t DM ha^{-1} $year^{-1}$) and Year 3 (9.32 t DM ha^{-1} $year^{-1}$) when yields were 25 and 36% less ($p < 0.01$), respectively, than in Open plots. Mean monthly herbage accumulation of swards in the tree plots from September to April was often at least 0.20 t DM ha^{-1} less ($p < 0.05$) than in Open plots, whereas from May to August, sward productivity beneath trees was similar to that in the Open environment (Figure 1a).

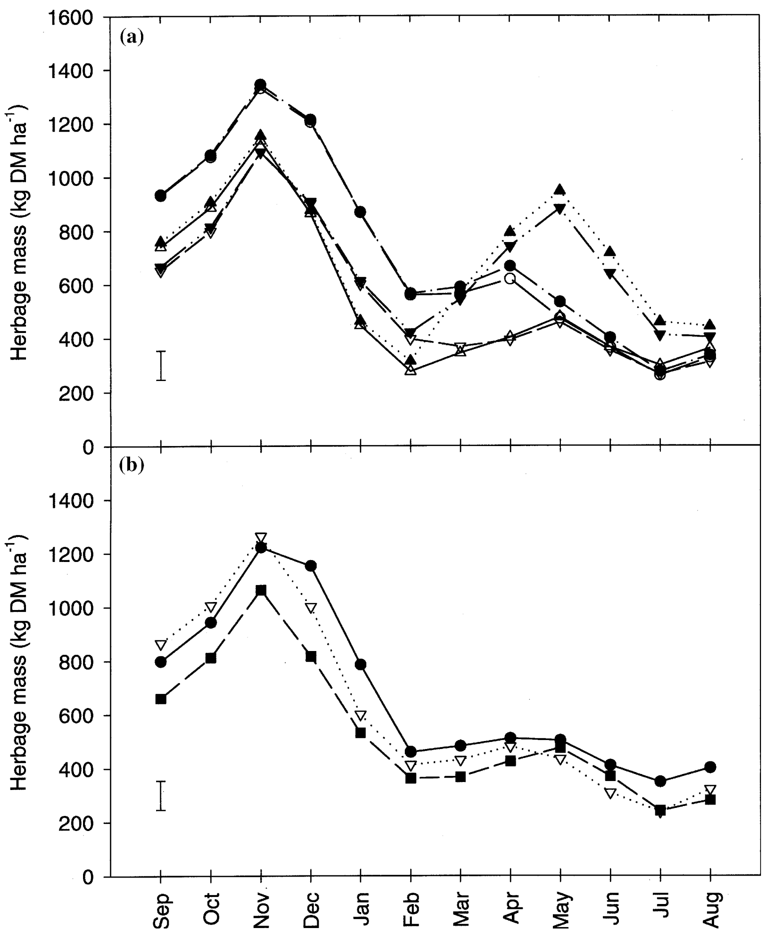

Figure 1. Herbage accumulation in the poplar tree – pasture system near Palmerston North, New Zealand, averaged over 3 years; (a) swards only, and swards plus poplar leaves, on North (hollow and filled triangle up, respectively) and South (hollow and filled triangle down) sides of trees and in the Open (hollow and filled circle); (b) Existing (hollow triangle), Three-species mixture (filled square), and Four-species mixture (filled circle) swards. Vertical bars = LSD at $p < 0.05$.

The relative growth of swards in North and South plots changed during the period when the trees were foliated (Figure 1a). In early spring, North plots produced an average of 14% (September) and 11% (October) more herbage ($p < 0.05$) than South plots, but in November and December there were no significant differences between tree aspects. In late summer, herbage accumulation in South plots exceeded that in North plots by 34% (January) and 44% (February). Absolute differences in monthly herbage accumulation between North and South plots were also slightly larger in January and February (0.12–0.15 t DM ha^{-1}) than in September and October (0.09 t DM ha^{-1}).

Mean total herbage accumulation of the FSM sward (8.00 t DM ha^{-1} $year^{-1}$) exceeded that of the TSM sward (6.39 t DM ha^{-1} $year^{-1}$), and accumulation of the Existing sward (7.35 t DM ha^{-1} $year^{-1}$) was not significantly different from either introduced sward. These trends were consistent across years and within the tree and Open environments. There were significant differences between swards in accumulation in spring and summer compared with in other seasons (Figure 1b). For example, the FSM and Existing swards produced 0.15–0.35 t DM ha^{-1} $month^{-1}$ more ($p < 0.05$) than the TSM sward from September to December, and in December, accumulation of the FSM sward exceeded that of the Existing sward by 15%. The FSM sward produced 30% more than both other swards in January (Figure 1b).

Pasture botanical composition

Sward dry matter usually comprised at least 80% grass throughout the year (Table 1) and the mean annual grass content of swards in the three environments did not vary significantly. However the seasonal content of grasses in Open plot swards in spring, summer and autumn was 6–10% less than in tree plots, whereas in winter, swards in all environments had similar grass content. Tree aspect had no significant effect on grass content in any season. The FSM sward had lower ($p < 0.05$) grass content in spring and summer (68%) than the other swards (85–91%), whereas in winter and autumn, between-sward variation was negligible (data not presented).

Overall legume content of swards beneath trees and in Open plots varied with season (Table 1). In summer and autumn, legume content of Open plot swards was 5–7% higher ($p < 0.05$) than in swards beneath trees, whereas in winter and spring it did not vary significantly between environments. Legume content of swards in winter was low in all environments. From spring to autumn, swards in Open plots maintained approximately constant legume content compared with those beneath trees, which comprised about 50% less legume in autumn

Table 1. Mean seasonal botanical composition of introduced and existing swards on North and South sides of young poplar trees, and in the Open, near Palmerston North, New Zealand, from 1997 to 2000 (no significant environment × season interaction for weed component).

Component	Environment	Composition (% dry matter)				Mean
		Winter	Spring	Summer	Autumn	
Grass[a]	Open	84.3	77.2	74.9	72.1	77.2
	North	87.1	86.2	84.2	81.9	84.9
	South	83.6	83.1	85.8	81.3	83.4
Legume[b]	Open	3.5	14.1	15.4	12.6	11.4
	North	3.8	10.5	9.8	4.8	7.2
	South	5.5	11.9	9.7	5.0	8.0
Weed	Open	5.6	5.7	7.3	6.4	6.3
	North	1.8	1.1	3.2	1.8	2.0
	South	2.3	2.9	2.6	3.1	2.7
Dead matter[c]	Open	6.5	2.9	2.4	8.9	5.2
	North	7.3	2.2	2.7	11.5	6.0
	South	8.6	2.2	1.9	10.7	5.8

[a,b,c]LSD (5%) for environment × season interaction = 4.5, 2.8, 2.1, respectively; sample size = 27.

than in spring and summer. Overall legume content of the FSM sward was 18% which was 3–6 times ($p < 0.05$) that of the Existing (5%) and TSM (3%) swards, and its legume content in spring and summer was 2–3 times that in autumn and winter (data not presented). In all seasons, Existing and TSM swards comprised less than 7% legume.

The weed content of swards in Open plots was over twice ($p < 0.05$) that of swards beneath trees in all seasons (Table 1), and across the three environments, the Existing and two test swards had similar weed content. All swards had highest ($p < 0.05$) dead matter content in autumn and content of swards in North plots during autumn exceeded that of swards in Open plots. In the other seasons, swards in all environments comprised similar proportions of dead matter and they were lowest in spring and summer. There was an interaction between season and sward, mainly because dead matter content of the Existing (13%) and TSM (11%) swards in autumn was almost twice that of the FSM sward, whereas dead matter content did not vary significantly between swards in the other seasons.

Throughout the trial, sward content of sown species varied beneath trees and in Open plots. Among the grasses, *Lolium perenne* was similar in the three environments (mean of 9% of DM), *Dactylis glomerata* was higher beneath trees (30%) than in the Open (16%), and content of *Agrostis capillaris* was in the order Open (22%) > North (15%) > South (10%). Swards in each environment comprised similar contents of the legume *Lotus uliginosus* (6%), whereas *Trifolium repens* had a higher content in Open swards (6%) than under trees (2%).

The content of sown species varied considerably between the three swards, with that of *L. perenne* being higher ($p < 0.05$) in the FSM and Existing swards (12%) than in the TSM sward (3%). *Dactylis glomerata* comprised a very significant proportion of the FSM and TSM swards in which it was sown (37%), compared with the Existing sward (1%), and the content of *A. capillaris* was similar in all swards (16%). *Lotus uliginosus* averaged 17% of sample DM in the FSM sward, but <1% in the other two swards, and this contrasted with *T. repens*, which comprised 3% DM in all swards. The trends observed for the content of all sown species in swards were consistent across environments.

Pasture and poplar leaf chemical composition

Swards in the three environments had very similar chemical characteristics and no differences in chemistry were detected between the Existing and two introduced swards (Table 2). An exception occurred for ADF where the TSM sward had higher ($p < 0.05$) concentration than the FSM sward. Swards in spring compared to those in autumn had higher concentrations of protein (+15%), lipid (+28%), ash (+13%), ADF (+19%) and NDF (+48%), and 49% lower soluble carbohydrate concentration. For the herbage samples analysed by NIRS, botanical composition of swards was similar across all environments and averaged 79% grass, 12% legume, 4% weed, and 5% dead matter. The TSM and Existing swards (82–83% grass, 5–7% legume) had higher ($p < 0.05$) grass and lower legume contents than the FSM sward (70% grass, 24% legume). Composition of the swards in both seasons was the same except for contents of legume (15 and 9% in spring and autumn, respectively) and dead matter (1 and 9%).

The chemical composition of poplar leaves on trees was similar to that of autumn pasture, except that poplar leaf protein concentration was about 5% lower (Table 2). Relative to leaves on trees, those in the understorey litter that had fallen 2 or 3 days previously had lower ($p < 0.05$) concentrations of protein (−37%) and soluble carbohydrates (−25%); higher concentrations of ADF (+20%) and NDF (+23%); and lower OMD and ME. Leaves in the understorey litter that had fallen >20 days previously comprised relatively high fibre concentration and low soluble carbohydrate concentration, OMD and ME.

Discussion

This study showed that intermediate-aged (8–11 years) poplars grown at wide spacing in a silvopastoral system significantly affected understorey pasture production and botanical composition, pasture cultivar performance, and herbage chemical composition. The results are a consequence of the marked effect of these trees on the surrounding aerial and soil micro-environment (Douglas et al. 2005), principally on radiation transmittance and interceptance, and on the profile of soil water

Table 2. Concentration of protein, lipid, ash, acid (ADF) and neutral (NDF) detergent fibre and soluble carbohydrates (CHO), and *in vitro* organic matter digestibility (OMD) and metabolisable energy (ME) of three pasture swards in three environments in two seasons, and poplar leaves in autumn 1999, near Palmerston North, New Zealand.

Variable		Protein (% DM)	Lipid (% DM)	Ash (% DM)	ADF (% DM)	NDF (% DM)	CHO (% DM)	OMD (% DM)	ME (MJ/kg DM)
Environment (sample size [n] = 18)									
Open		21.4	4.4	10.7	23.3	38.1	11.6	73.7	11.0
North		20.1	3.9	10.9	23.7	34.3	13.4	75.9	11.3
South		19.6	4.0	10.6	23.4	33.8	13.9	76.2	11.4
SEM[@]		0.4	0.2	0.2	0.6	2.9	1.3	1.9	0.3
Sward (n = 18)									
FSM[#]		20.6	4.3	10.4	22.5b	33.6	13.5	75.6	11.3
TSM		19.6	4.2	10.8	24.3a[β]	36.7	12.4	74.0	11.0
Existing		20.9	3.9	11.0	23.6ab	35.8	13.0	76.2	11.4
SEM		0.4	0.2	0.2	0.6	2.9	1.3	1.9	0.3
Season (n = 27)									
Spring 1998		21.8a	4.6a	11.4a	25.5a	42.2a	8.8b	72.9	10.9
Autumn 1999		18.9b	3.6b	10.1b	21.4b	28.5b	17.1a	77.6	11.6
SEM		0.3	0.2	0.1	0.5	2.3	1.0	1.6	0.2
Poplar leaf class	Description								
Intact (n = 3)	80–90% green, 10–20% yellow	13.7a	4.5	7.8	24.0b	26.6b	16.8a	75.7a	11.3a
Young (n = 3)[δ]	10–20% green, 80–90% yellow, brown margins	8.6b	4.6	6.2	28.7a	32.7a	12.6b	61.1b	9.1b
Old (n = 1)[§]	> 90% brown	10.6	4.3	10.1	35.8	39.9	4.4	46.2	6.9
SEM[‡]		0.2	0.2	0.6	0.5	0.7	0.5	1.4	0.2

[@]Standard error of mean; [#]FSM, four species mixture; TSM, three species mixture; [β]for each category, values within columns with different letters differ at $p < 0.05$; [δ]2–3 days on ground; [§] > 20 days on ground; [‡]for intact and young leaves.

content. The trees in this study were representative of many poplars planted recently on erosion-prone slopes in New Zealand with respect to tree spacing, parentage of species, and growth form.

Pasture growth

Plant biomass beneath trees comprised pasture, and up to 50% poplar leaf litter (during autumn), which resulted in annual total biomass beneath trees (8.3 t DM ha^{-1} $year^{-1}$) being similar to that in the Open (8.8 t DM ha^{-1} $year^{-1}$). In New Zealand, some farmers use fallen poplar leaves as supplementary stock fodder during drought (McGregor et al. 1999) and this study showed that they contributed about 225 kg DM ha^{-1} in March through to 400 kg DM ha^{-1} in May. Little is known about optimum management of poplar leaf fall to maximise stock benefit, but results suggested that good nutritive value is not maintained very long after leaves fall, and hence livestock should be managed to utilise fallen leaves as quickly as possible. Leaves are lost from a site by livestock consumption, wind, and decomposition. The strategic use of livestock can hasten a reduction in the extent and duration of shading of the underlying pasture by leaves. However this needs to be balanced with the risk of excessive leaf removal by livestock possibly upsetting long-term nutrient cycling beneath the trees. Also, leaf fall is spread over a number of weeks and the rate of leaf fall is not sufficient to support the number of animals required to ensure sufficient grazing pressure to force them into eating fallen leaves. This would result in heavy grazing pressure on pastures and can result in significant treading damage when soils are moist.

Pasture accumulation beneath trees averaged 23% less than in the Open environment, compared with a 40% reduction measured under mature, untended *Populus deltoides* trees (37 trees ha^{-1}) at a nearby site (Guevara-Escobar et al. 1997). The trees in that study had much larger crowns than those evaluated here, and the crowns frequently touched those of neighbouring trees to create an essentially closed canopy when the trees were foliated. The presence of 10–15 year-old trees of *Populus deltoides* × *P. nigra* on a farm in the southern South Island that experiences frequent, severe frosts, and sometimes snow, reduced annual pasture growth by 27% compared with open pasture (Douglas et al. 2001). The results from this study contrasted with those at a relatively warm, dry site on the east coast of the North Island (Gilchrist et al. 1993), where no significant difference was found between pasture growth at 1 m from the trunk (5.9 t DM ha^{-1} $year^{-1}$) of single trees of *Populus* × *canadensis* (= × *euramericana*) aged 16–19 years, and open pasture at 13 m from the trunk (6.7 t DM ha^{-1} $year^{-1}$). The open pasture yield at the east coast site was about 2 t DM ha^{-1} $year^{-1}$ less than in this study (8.6 t DM ha^{-1} $year^{-1}$), which suggests that it was a relatively poor site, which probably limited both tree and pasture growth, and hence reduced tree effects on understorey productivity.

As the trial progressed, pasture yield reduction beneath trees compared with in the Open environment increased from 8% in Year 1, to 25% in Year 2, and 36% in Year 3. This may have been because of increasing tree age, and associated likely increased crown size, as has been found for evergreen radiata pine, for example an 11% reduction in pasture yield beneath trees aged 8 years planted at 100 trees ha^{-1}, increasing to a 44% reduction by tree age 11 (Hawke 1991). However in this study, pasture yield in the Open environment also varied with year, mostly reflecting changed weather patterns during the trial, such as spring 1997 being warmer and more humid than spring 1999. Hence the effects of poplar tree age and other factors such as weather were confounded, but they could be isolated by conducting an experiment with single trees of several ages, for example 5, 10, 15 and 20 years.

Pasture botanical composition

The intermediate-aged poplar trees had a significant effect on pasture botanical composition, which often varied with season. Guevara-Escobar et al. (1997) found seasonal variation in botanical components in their study involving mature *Populus deltoides* but there were similarities and differences between the results of the respective studies. For example, grass content in this study was significantly higher beneath trees than in Open plots in all seasons except winter, when pasture growth was lowest, and no differences were detected between environments. In the earlier investigation, grass content under trees was less than in Open pasture in March (early autumn) and June, but was similar at other times. From spring to autumn in this study, legume content was similar in Open plots whereas beneath trees, content was progressively lower as the season advanced. Under mature trees (Guevara-Escobar et al. 1997), legume content in March was 2.4% compared with 10.7% in the open, in contrast to results in January when legume content was higher under trees (16.3 %) than in the open (5.0%), but no differences were detected between environments at other times. The results of this study and those of Guevara-Escobar et al. (1997) suggest that although there may be changes in botanical composition at intermediate tree ages, pasture composition beneath mature poplar trees varies little from that in the Open environment.

The highest pasture dead matter content recorded in this study was 11.5% in autumn on the North side of trees and it was about one-third of the maximum values estimated beneath mature trees (30.3%) and in the open (39.1%) (Guevara-Escobar et al. 1997). The considerable difference in tree age/crown size in the two studies, and their consequent effects on the micro-environment, likely accounted for the differences observed in pasture dead matter content. However reasons for the large variation in the Open pasture results were less certain, but could be related to possible differences in stock grazing pressure in the respective studies. It was not possible to compare the botanical composition results from this study with those of the only other known study involving individual, intermediate-aged poplar trees on pastoral land (age 16–19 years) (Gilchrist et al. 1993), because data for individual components were not presented.

The seasonal differences in pasture growth between tree aspects during foliation can be explained by the interaction between global irradiance received at the ground surface, and soil water content, as soil nutrient effects were negligible (Douglas et al. 2005). Over 3 years, average pasture growth in North plots in September and October was about 13% greater than in South plots, and over 2 years, average soil water content in spring was similar in both aspects. Irradiance around trees was determined using measurements and simulations in 2000, near the end of the trial. Trees were smaller earlier in the trial, but it is suggested that the North aspect likely received significantly more direct beam irradiance in spring than the South aspect, and probably had warmer soil. In January and February, the aspect effect reversed and pasture growth averaged 39% higher in South plots, despite the likely higher direct beam irradiance and 2.8 °C higher soil temperature on the North side (Douglas et al. 2005). However during this period, soil water content in North plots was 6% lower than in South plots, indicating that late summer pasture production on the North side of trees was probably limited by soil water deficit.

Pasture mixtures and cultivar performance

The higher annual yield of the Four Species Mixture (FSM) (comprising *Dactylis glomerata* cv. Grasslands Wana, *Lolium perenne* cv. Grasslands Nui, *Lotus uliginosus* cv. Grasslands Maku, and *Trifolium repens* cv. Grasslands Tahora) compared with the Three Species Mixture (TSM) (comprising *Agrostis capillaris* cv. Grasslands Muster, *Dactylis glomerata* cv. Grasslands Wana, and *Trifolium repens* cv. Grasslands Tahora), beneath trees and in the Open environment, was mainly because of significantly higher spring and summer production. Major differences between both swards during these seasons were the much higher legume content in the FSM (25%) than TSM (4%) swards, and the relatively low grass content (68 vs. 90%). *Lotus uliginosus* comprised over 90% of the FSM legume dry matter, and the results suggest that this species was largely responsible for the relatively high yields of this sward. The target environment for Grasslands Maku is acid, low fertility, moist, lax-grazing situations, and it has been used successfully in a range of sowings in pastoral hill and extensive lowland country, and plantation forestry (Chapman and Macfarlane 1985; West et al. 1991), the latter where it has also exhibited good shade tolerance. The cultivar appeared well suited to the site and management conditions in this trial.

The other legume cultivar introduced, *T. repens* Grasslands Tahora, failed to grow and persist as well as Grasslands Maku, with its highest content in a test sward being only 3% in the TSM sward. Grasslands Tahora is a low-growing, small-leaved, multi-branched type of *T. repens*, with high stolon density (Caradus and Woodfield 1996), and is recommended for continuous, close grazing situations, particularly those involving sheep. The low grazing pressure in this trial undoubtedly disadvantaged Grasslands Tahora because plants likely experienced intense competition from companion grasses, which had the opportunity for significant height growth. The Existing sward comprised *T. repens* at a similarly low content as found in the swards sown with Grasslands Tahora, and its growth was likely also curtailed by the relatively abundant grass growth. This is the first report of a higher (3-fold) average content of *T. repens* in Open swards compared with beneath poplar trees, but this trend has been observed for a number of years beneath different tree ages and densities of evergreen *Pinus radiata* in agroforestry systems (Percival and Hawke 1985).

The similarly high contribution of *D. glomerata* Grasslands Wana to pasture DM in the FSM and TSM swards indicated the ease of establishment and potential usefulness of this cultivar in poplar-pasture systems. Seed of Grasslands Wana was sown at 27 kg/ha in each test sward to ensure high establishment, and was within the range of 8–60 kg/ha used previously for this cultivar in seed mixes broadcast sown in New Zealand hill country (Barker et al. 1985). Grasslands Wana is sensitive to grazing management and yields significantly higher under lax grazing conditions, as encountered in this trial, than under continuous grazing (Barker et al. 1991). The cultivar grows well and persists in dry environments (Barker et al. 1985) and the results indicated that its growth was not adversely affected by the significantly drier soil beneath trees during summer, than in the Open environment. The twice higher content of Grasslands Wana in swards under trees compared with those in the Open contrasted with the results for *L. perenne*, which did not vary significantly between environments. This may have been because Grasslands Wana was more shade-tolerant than *L. perenne* Grasslands Nui (Devkota et al. 1998), and perhaps the existing *L. perenne*.

D. glomerata and L. uliginosus were the only species where the contribution of the respective sown cultivars to overall sward content of each species could be estimated with reasonable confidence. Grasslands Wana comprised nearly all the *D. glomerata* in the two test swards, and Grasslands Maku was nearly all the *L. uliginosus* in the FSM sward because the content of each species in the Existing sward, and of *L. uliginosus* in the TSM sward, was 1% or less. In contrast, *A. capillaris* Grasslands Muster was sown only in the TSM treatment and yet sward content of *A. capillaris* in the Existing and two test swards was similar and averaged 16% of DM. Hence it is likely that *A. capillaris* in the TSM sward comprised a significant proportion of existing germplasm and Grasslands Muster, or even mostly existing germplasm, but the relative contributions of each could not be estimated. Similar interpretational difficulties applied to the composition of the *T. repens* and *L. perenne* components in swards, so that it was not possible to determine the contributions of Grasslands Tahora and Grasslands Nui. In this study, by far the most successful cultivars with respect to establishment success and contribution to sward DM were *D. glomerata* Grasslands Wana and *L. uliginosus* Grasslands Maku.

The results for *A. capillaris* were unique in this study because in addition to swards in the Open having higher content than those beneath trees, as found for *T. repens*, there were tree aspect differences with swards in North plots (15%) comprising higher content than swards in South plots (10%). These results could be because of the soil pH differences found between Open and tree plots in one of 2 years, the lower irradiance received beneath trees compared with in Open, and the differences in soil water content in spring (similarly high in all environments) and autumn (Open and North > South) when the species dissections were conducted (Douglas et al. 2005).

The detection of *A. capillaris* (16% DM), *L. perenne* (3%), and *L. uliginosus* (1%) in test swards in which they were not sown indicated the practical difficulty of preventing ingress of species from the Existing sward. Destruction of existing vegetation in plots in which the test seed mixes were later broadcast-sown, was very effective, and sowing rates were high to encourage dominance of the introduced cultivars. Later ingress of species could have occurred by seedling establishment from buried seed, vegetative growth of stoloniferous/rhizomatous species, or seed transferred by bird/livestock defecation. The species in the Existing sward were likely represented by old cultivars, for example *L. perenne* Grasslands Ruanui, or unselected germplasm such as diploid

L. uliginosus, which occurs in moist North Island hill country (Hopkins et al. 1993). The establishment methods and management in the trial were successful in limiting the content of other species (weeds) in the test swards to < 5% throughout the trial, which was similar to weed content in the Existing pasture.

Average annual yield of the Existing sward was similar to that of the highest yielding test sward which suggests that there would not be great advantage in introducing the new cultivars to this site, except for increased yield in mid to late summer, and perhaps for potential livestock nutritional benefits. For example, apart from being a legume, *L. uliginosus* Grasslands Maku contains condensed tannins which can improve forage protein utilisation, and offer potential animal health benefits (Waghorn et al. 1998). The Existing sward was aged at least 20 years, and although it comprised assorted weed species such as *Anthoxanthum odoratum* and *Ranunculus* spp., *L. perenne* was an important component of the sward and its legume content was almost exclusively *T. repens*, which suggested that the sward had reasonable yield potential and quality.

Pasture and poplar leaf chemical composition

The similar chemical composition of swards beneath trees and in the Open environment was probably because their average botanical composition did not vary significantly between environments. Minor differences occurred between the Existing and TSM swards, and the FSM sward, in their grass and legume content, but these also had negligible effect on herbage chemical composition. The results for Open and tree environments were at variance with those found for existing pasture in the open and beneath mature, untended poplars at a nearby site, where there was significant canopy closure (Guevara-Escobar et al. 1997). For example, in the earlier study, pasture beneath trees in March had lower crude protein concentration (14.2 vs. 22.1%), dry matter digestibility (47.7 vs. 58.7%), and ME (7.0 vs. 8.7 MJ/kg DM) than open pasture, whereas in September and November, crude protein concentration followed the same trend, but ME was similar in both environments. Dry matter digestibility averaged 71.1% in both environments in November, but was lower under trees (71.1 %) than in the open (76.2%) in September. In this study, herbage sampling was conducted in April and October, which enabled partially valid comparisons of trends with those from the earlier study. The differing results of Guevara-Escobar et al. (1997) may have been because of some of the variation in legume and dead matter content of swards in tree and Open environments.

The two test swards and the Existing pasture were of good quality according to the criteria of Hodgson and Brookes (1999), for example, crude protein concentration averaged 20% DM, organic matter digestibility averaged 75%, and ME values of about 11 MJ/kg DM were near the upper end of the range of 8–12 MJ/kg DM found typically for pasture herbage. Despite seasonal differences in a number of the chemical components, nutritive value was satisfactory in each season, and was supported by the similar spring and autumn estimates of organic matter digestibility and ME. The results indicated that the Existing sward had more than adequate nutritive value for a variety of livestock types, and that there appeared negligible advantage in introducing mixtures of recent pasture cultivars at this location. Whole-sward, mixed herbage samples were analysed so that it was not possible to determine the nutritive value of individual cultivars, as has been conducted in other studies involving trees, for example *Dactylis glomerata* Grasslands Wana (Peri et al. 2001).

Poplar leaves on trees had good nutritional value, and would be most satisfactory as a supplement to pasture of poor quality or as a source of additional forage when pasture forage supply is low, such as during summer/autumn drought (McGregor et al. 1999). In contrast, leaves which had been on the ground for 2 or 3 days had lower nutritional value including lower organic matter digestibility and ME content, but livestock, particularly sheep, have eaten leaves of similar condition at this and other locations (McGregor et al. 1999). The unreplicated results for brown, old leaves, which were probably aged at least 20 days, suggested that they would be of negligible nutritional value to grazing livestock.

Conclusions

The intermediate-aged (8–11 years), widely spaced poplars significantly modified the hill pasture micro-environment. This markedly affected understorey herbage accumulation and composition, with mean annual pasture growth beneath trees being 23% less than in the Open environment. Growth variation between North and South sides of trees depended on season. Swards beneath trees and in the Open differed in contents of grass, legume, weed, and dead matter, and the grass and legume contents were influenced strongly by the presence or absence of leaves on the trees. The introduction of two different swards of new pasture cultivars failed to increase annual productivity relative to Existing pasture, but one of two test swards produced slightly more growth in summer. *Dactylis glomerata* Grasslands Wana and *Lotus uliginosus* Grasslands Maku established and grew well and seem ideally suited to a poplar pasture system, where pasture is grazed lightly. All swards and intact poplar leaves had good nutritional value. The establishment cost of poplars, and potential reductions in pasture growth following planting, need to be considered against numerous benefits (e.g. land stabilisation, fodder and timber potential, vista enhancement, and habitat improvement) in the context of a long term farm management strategy.

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