Resident pasture growth and the micro-environment beneath young, wide-spaced poplars in New Zealand

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Abstract

Poplar (*Populus* spp.) trees are planted on pastoral hill country throughout New Zealand, primarily for soil conservation. The effect of wide-spaced trees (16–100/ha) aged 8–15 years on understorey pasture growth, botanical composition, and micro-environmental characteristics, was determined at Pohangina (1997–2000) and Lawrence (1998–2000) in the lower North and South Islands, respectively. Relative to environments without trees, at Lawrence pasture growth (13 100 kg dry matter (DM)/ha/yr) was reduced by 20% and 34% on north and south sides of trees, respectively. At Pohangina (7915 kg DM/ha/yr), trees had less influence (7% and 14% reduction) on understorey pasture growth. There were also strong seasonal effects at both sites, corresponding to when the trees were foliated. Swards at each site comprised 81–93% grass. At Lawrence, swards had similar botanical composition beneath and beyond trees. Swards on the north side of trees at Pohangina comprised relatively high grass and low legume content compared with those on the south side and in the open. Compared with open pasture, areas beneath young poplars received up to 24% less rainfall and 31% less solar irradiance, and soil water content (0–200 mm depth) was up to 33% lower in summer and autumn. At intermediate soil water contents (0.25–0.35 m^3/m^3), the profile of soil water content around trees during drying was frequently U-shaped, being lowest beneath the stem and increasing with distance away from the tree. Likely reasons for the pasture responses and variation in tree-pasture interactions between sites are discussed. The results will be used to model changes in tree-pasture interactions over time.

Keywords: agroforestry, poplar, *Populus*, silvopastoralism, soil conservation, soil water, tree-pasture interactions

Introduction

Poplars (*Populus* spp.) are deciduous, hardwood trees that are frequently planted on pastoral hill country throughout New Zealand, mainly for soil conservation (van Kraayenoord & Hathaway 1986; Wall *et al.* 1997). Other potential benefits exist in such environments including shade, shelter, supplementary forage during droughts, landscape beautification, fauna habitat and timber production (Wilkinson 1999; McGregor *et al.* 1999).

Comprehensive studies on the influence of poplars on resident understorey pasture growth are scarce and confined to situations where significant interaction occurred between tree crowns. For example in Manawatu, annual resident pasture growth beneath untended trees (37 stems/ha) aged 25+ years was 40% less than in pastures beyond the influence of the trees (Guevara-Escobar *et al.* 1997). This reduction has significant long-term implications for stock carrying capacity and hence farm incomes. It may discourage continued strategic planting of poplars on farms for effective soil protection if the benefits of slope stabilisation and the other benefits of trees do not exceed the loss in pasture growth.

A primary objective in current and planned research programmes is to determine poplar spacings and canopy/root architectures that provide effective soil conservation while minimising losses in pasture growth and deleterious changes in botanical composition and nutritional value. This needs to be addressed in a range of regions with varying environmental limitations to poplar and pasture growth. Robust computer models will ultimately be developed for land managers, consultants and farmers, and these will require accurate information on the effect young and mature poplars have on pasture dynamics.

Accordingly, this study aimed to determine the effect of young, wide-spaced poplars on 1) understorey resident pasture growth and botanical composition on commercial sheep and beef farms; and 2) surrounding soil water and radiation patterns, rainfall, and soil temperature. Results from a large 3-year trial in Manawatu (Hurst *et al.* 2000), and 2 years of data from a trial in Otago, are reported.

Materials and methods

Sites

The Manawatu trial was conducted near Pohangina, 35 km north east of Palmerston North, and the Otago trial was conducted near Lawrence, about 60 km south west of Dunedin. Site topography and climate, soil type and characteristics, and tree characteristics are described in Table 1. The Olsen P level at Pohangina was half that at Lawrence, while levels of other nutrients were similar. Superphosphate was applied at 300 kg/ha to the Lawrence trial site in spring 1999, after soil testing. Trees in the trials were established from poles and were untended. Those at Pohangina were *Populus maximowiczii* x *P. nigra* clones and trees were spaced 10–20 m (100–25 trees/ha) apart, whereas those at Lawrence were *Populus* x *euramericana* (syn. *Populus deltoides* x *nigra*) and spaced 15–25 m (44–16 trees/ha) apart. Resident pasture several months before the trials commenced comprised at least 70% grass, with the major species being *Agrostis capillaris, Anthoxanthum odoratum*, *Holcus lanatus* and *Lolium perenne* at Pohangina and *Cynosurus cristatus*, *Lolium perenne* and *Poa* spp. at Lawrence.

Table 1 Trial site and poplar tree characteristics at Lawrence and Pohangina.

Attribute	Site Lawrence	Pohangina
Latitude/longitude	45°S, 169°E	40°S, 175°E
Altitude (m a.s.l.)	110	260
Slope and aspect	5–12°, S	5–10°, E & SE
Rainfall (mm/yr)[1]	700	1,250
Mean air temperature (°C)[1]		
June	4.5	7.9
January	14.0	17.4
Soil		
Type	Waitahuna silt loam	Raumai sandy loam
pH[2]	5.8	5.6
Olsen P (mg/kg)	20	10
S (SO$_4$) (mg/kg)	12	9
K[3]	15	9
Ca[3]	7	5
Mg[3]	35	23
Trees		
Age (years)	10–15	8–11
Height (m)	11.3	17.4
s.d.[4]	1.8	1.3
DBH (cm)[5]	28.1	31.9
s.d.[4]	6.4	5.4

[1] long-term averages; [2] 1:2.1 v/v water slurry; [3] "Quick test" units; [4] standard deviation; [5] diameter at breast height (DBH; 1.4m); height and DBH measured in 1998 and 2000 at Lawrence and Pohangina, respectively; soil sampling conducted in 1998/99.

Treatments and experimental design

In each trial, there were three environments, with three (Pohangina) and six (Lawrence) replicates:

1. South side of trees, which was shaded when trees had full canopy;
2. North side of trees; and
3. Adjacent area of open pasture without trees (open).

Plots (areas of pasture) in all environments were located on areas of similar topography (Table 1). Plots beneath trees extended approximately 9 m from a tree along a north-south transect and were 4 m wide (2 m either side of transect), and those in the open were 3 x 3 m.

In both trials, plots were grazed as part of the surrounding pasture. Those at Pohangina 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. At Lawrence, plots were grazed rotationally with sheep and occasionally cattle, except from September to November (lambing) when paddocks were set-stocked at 10–15 SU/ha.

Measurements

Environmental

A range of environmental variables was measured at each site to quantify the effect of the trees on the pasture micro-environment. At Pohangina, variables around a nearby tree of similar size to those used in the experiment were logged hourly (datalogger model CR10, Campbell Scientific Instruments) including rainfall and soil temperature at 100 mm depth. In the open and tree plots, global and diffuse short-wave radiation were estimated during 2000 using scanned hemispherical photographs which were analysed using the Gap Light Analyzer software (*http://www.rem.sfu.ca/forestry/gla/index.htm*). Soil water content was measured around all three trees along a north-south transect to determine the effect of water extraction by tree roots on the soil water profile. Measurements were made at 3–6 weekly intervals using Time Domain Reflectometry (TDR) (Topp *et al.* 1980) at 0–200 mm depth and four distances from the trunk (1, 2, 4 and 8 m) on the north and south sides of the three trees, and at the same depth in open plots. Environmental parameters were measured between February 1998 and March 2000.

At Lawrence, environmental variables were measured 4–8-weekly from December 1998 to January 2001. These included rainfall, measured using rain gauges, and gravimetric soil water content (w/w; 0–200 mm depth) and soil temperature (100 mm depth) at 2 m from the trunk on north and south sides of two (randomly selected) of the six trees, and in the open.

Pasture growth and composition

Growth and botanical composition in all plots were determined every 4–8 weeks from May 1997 to April 2000 at Pohangina, and from December 1998 to November 2000 at Lawrence, using a standard pre-trimming technique involving one 0.2 (Pohangina) or 0.5 (Lawrence) m^2 grazing exclusion cage (Radcliffe 1974) per plot.

In plots beneath trees, areas selected for pasture sampling were those that were likely to differ the most in terms of radiation received. This was achieved by determining for each tree, the length of the shadow cast along a north-south transect at solar noon in autumn/spring and summer. Across the three southern plots at Pohangina and six southern plots at Lawrence, the mean tree shadow extended from 1.4 m to 4.4 m from the trunk, and 1.8 m to 5.0 m from the trunk, respectively. Pasture measurements were made within these ranges and extended 1 m either side of the centred transect to create rectangular pasture sampling areas. Each area was divided into quarters and the exclusion cage rotated clockwise to the next quarter after each harvest. The pasture sampling area on the north side of each tree had the same dimensions and distance from the trunk as that on the south side.

Herbage in the caged areas of all plots was cut to a residual sward height of 1–2 cm. A subsample of the harvested herbage from each plot was dissected into grass, legume, weed, dead matter and poplar leaf litter, and component dry weights (12 hrs at 80°C) were determined.

Data analysis

To facilitate comparisons between sites and between the three environments within sites, one year (December 1998 to December 1999) of data for soil water content (v/v) at both sites, and soil temperature at Lawrence, were subjected to analysis of variance. The bulk density of soil at Lawrence was approximately 1.0 g/cm^3 (J Paton, unpubl. data) and therefore volumetric soil water content in the plots equalled gravimetric content. Total rainfall over the year was calculated from a summation of readings from rain gauges. At Lawrence, data for total rainfall beneath the two trees were averaged.

Pasture growth, with and without poplar leaf litter, was calculated for each month from May 1997 to April 2000 at Pohangina and from December 1998 to November 2000 at Lawrence. For botanical composition data, harvests were classified into seasons defined as spring (September to November), summer (December to February), autumn (March to May) and winter (June to August). Contents of grass, legume, weed and dead matter were expressed as percent of pasture DM. PROC GLM in SAS (SAS Institute 1989–1996) was used for all analyses.

Results

Tree-pasture environment

Tree presence significantly influenced the micro-environment of the surrounding pasture at Pohangina but effects were smaller at Lawrence. At Pohangina, rainfall was about 24% lower beneath the tree canopy (641 mm) compared to in the open (842 mm). Soil temperature on the south side of trees was 1–2°C lower than on the north side. At Lawrence, annual rainfall on the north side of the two trees (489 mm) averaged 10% less than on the south side (545 mm), and the latter reading was similar to rainfall recorded in open pasture (560 mm). Mean seasonal soil temperature beneath trees was similar ($P>0.05$) to that recorded in the open (13.2°C) and ranged from 1.0°C in June to 20.3°C in February.

For the year as a whole, solar irradiance beneath the trees at Pohangina was 31% lower than that in the open plots, and the southern plots received around 14% less solar radiation than the northern (Figure 1a,b,c). When the trees were foliated, solar irradiance beneath the trees was around 38% lower than that in the open plots, and was 18% lower on the southern compared to the northern side. During the non-foliated period, solar irradiance beneath the trees was only 9% lower than that in the open plots, and the variation with side of tree was small. When trees were in leaf, most of the variation in global radiation between north and south sides was accounted for by relatively large differences in direct compared with diffuse radiation. On clear days, there was less solar radiation on the south side compared to the north side, but on cloudy days, when a high proportion of global radiation is diffuse, the difference was small.

Soil water content averaged 0.28 m^3/m^3 at Pohangina and 0.25 m^3/m^3 at Lawrence ($P>0.05$), and over both sites, there were no overall significant differences in content between tree and open plots. However, beneath trees, soil water content on the south

Figure 1 Mean global, direct and diffuse irradiance flux densities incident at Pohangina on the north and south of the trees, and in the open during 2000. Trees were foliated from September until April. Error bars indicate standard error of the mean.

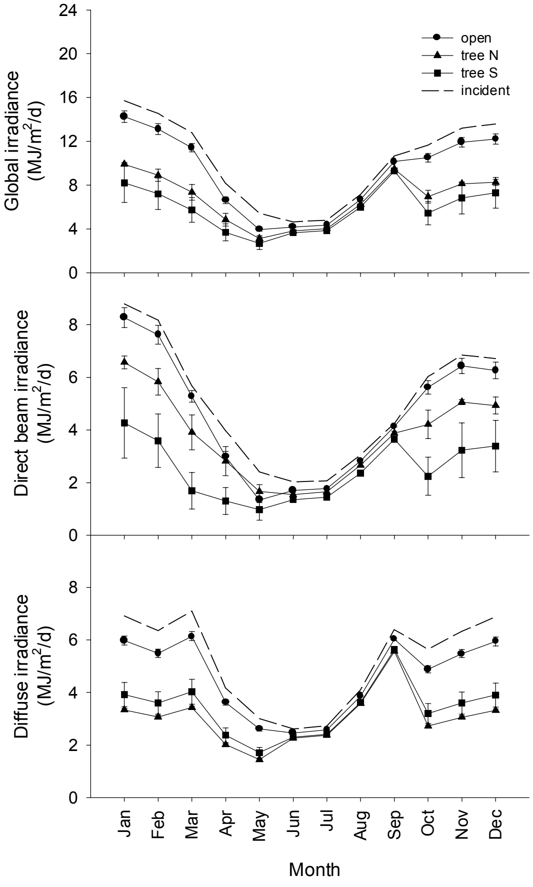


Figure 2 Soil water content (v/v; 0–200 mm depth) around poplar trees aged 5–11 years at (a) Pohangina and (b) Lawrence from December 1998 to December 1999. Error bars indicate standard error of the mean.

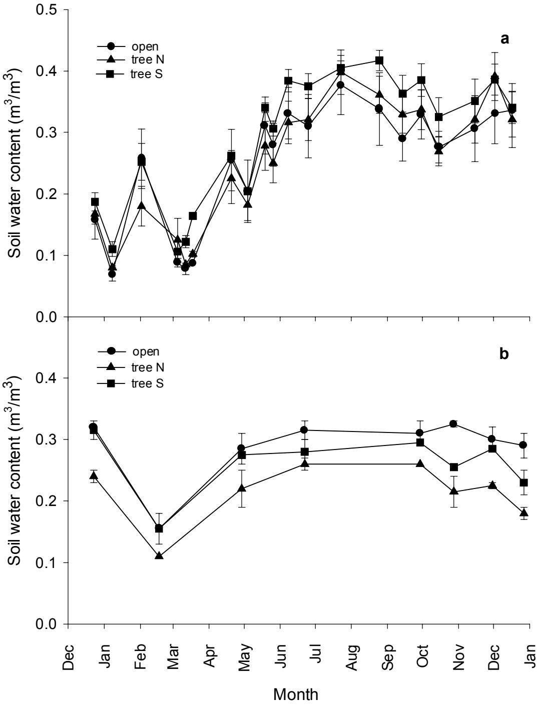
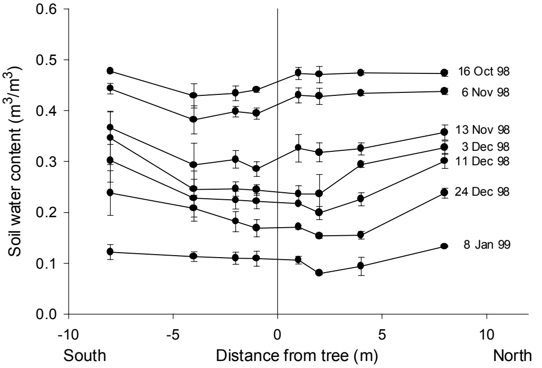


Figure 3 Mean soil water content (v/v; 0–200 mm depth) around three trees aged 10 years at Pohangina from October 1998 to January 1999. Error bars indicate standard error of the mean.



side (0.29 m^3/m^3) was higher ($P<0.05$) than on the north (0.25 m^3/m^3). At Pohangina, soil water content was frequently 0.05–0.20 m^3/m^3 from January to March and 0.30–0.40 m^3/m^3 from June to December (Figure 2a), whereas at Lawrence, it was mostly 0.15–0.30 m^3/m^3 throughout the year (Figure 2b). At both sites, soil water content in February/March was relatively low compared with at most (Pohangina) or all (Lawrence) other times of the year.

During a drying phase at Pohangina (16/10/98 to 8/1/99), soil water content was lowest adjacent to the tree, and increased with distance away from the tree (Figure 3), resulting in a U-shaped profile of soil water content around the trees along the north-south axis. The concave profile was most pronounced at intermediate soil water contents (0.25–0.35 m^3/m^3) and it was asymmetrical along the axis, depending on the stage of soil drying. Hence in the initial stages of drying, soil water content was lowest 2–4 m from the south side of trees and as drying advanced, greater soil water depletion occurred on the north side within several metres of the trees. At the height of the dry period, the soil was equally dry beneath and beyond the trees. Similarly, when the soil was close to field capacity, the soil water content did not vary greatly with distance from the stem.

Pasture growth and botanical composition

Open pasture at Lawrence produced 66% more herbage (P<0.01) annually than pasture at Pohangina (Table 2), the greatest differences between sites occurring in summer and autumn (Figure 4). For example, growth at Lawrence in February was almost three-fold higher than at Pohangina. Pasture growth was similarly low at both sites in winter.

The presence of trees dramatically reduced annual pasture growth at Lawrence with pastures on the north and south sides of trees producing 20% and 34% less, respectively, than open pasture. In contrast, trees at Pohangina resulted in less depression in annual pasture growth (7% and 14% on north and south sides, respectively), with treed and open plots (7065 and 7915 kg DM/ha/yr, respectively) producing similarly (P>0.05). At Lawrence and Pohangina, the contribution of poplar leaf litter to total understorey biomass (pasture + leaf litter) peaked in May, being 40% and 50%, respectively, and contributions were similar on both sides of trees.

Differences in pasture growth beneath trees and in the open were strongly dependent on season, and largely reflected the presence or absence of leaves on trees. For example, in March and April at Pohangina, pastures beneath trees produced 29–37% less than in the open, whereas in May and June, growth was similar (Figure 4). At Lawrence, understorey pasture in October and February produced 15% and 39% less herbage, respectively, than open pasture. In terms of absolute monthly pasture growth, differences between tree and open plots were greater from December to March at Lawrence than at Pohangina.

When the trees were foliated, differences in pasture growth between sides of trees varied considerably between sites (Figure 4). At Lawrence, pasture growth on the north side consistently equalled or exceeded that on the south side at all times. At Pohangina, pasture on the north side of trees produced more than on the south in September and October, growth on each side was similar (P>0.05) in November and December, and pasture on the north side grew less than on the south in January and February.

Grass content exceeded 90% and 80% of pasture DM at Lawrence and Pohangina, respectively (Table 2). At Pohangina, pastures on the north side of trees comprised up to 10% more grass and 50% less legume than those on the south side and in the open, and weed content on the north side was 70% less than in the open. In contrast, no overall differences in botanical composition were detected between tree and open pastures at Lawrence. There was minor seasonal variation in grass content of pastures in environments at each site (not presented).

Figure 4 Mean pasture accumulation (kg DM/ha/month) at Pohangina and Lawrence over 3 and 2 years, respectively (sample size = 9 or 12). Trees were foliated from September until April. Error bars indicate standard error of the mean.

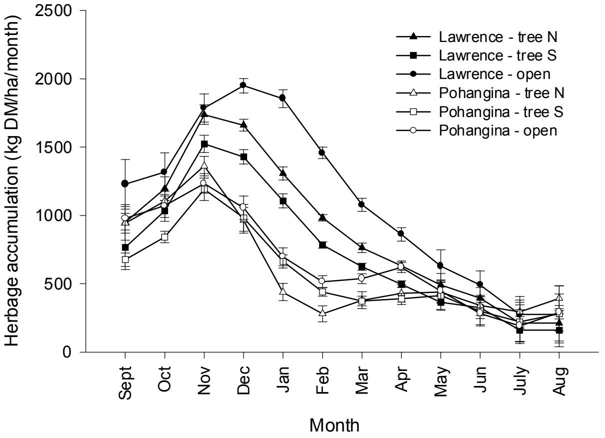


Table 2 Mean total yield (kg dry matter (DM)/ha/yr) and botanical composition (%DM) of resident pasture beneath north (Tree N) and south (Tree S) sides of wide-spaced poplars and in the open at Lawrence and Pohangina (n = sample size).

			--------------------------	Component	(%DM)	--------------------------
Site	Environment	Yield (kg DM/ha/yr)[1]	Grass	Legume	Weed	Dead Matter
Lawrence	Open	13100 a	92.8 a	2.2 b	2.7 b	2.3 a
(n=12)	Tree N	10440 b	91.8 a	2.7 b	2.4 b	3.1 a
	Tree S	8670 c	91.0 a	2.0 b	2.4 b	4.6 a
Pohangina	Open	7920 c	81.5 b	6.8 a	6.7 a	5.0 a
(n=9)	Tree N	7360 c	89.4 a	3.4 b	2.0 b	5.2 a
	Tree S	6770 c	83.5 b	6.3 a	4.3 ab	5.9 a

[1] Within columns, figures with different letters differ at 5% significance level.

Discussion

The sites at Pohangina and Lawrence represent the likely climatic extremes under which poplars are grown in hill pastoral farming systems in New Zealand. The Pohangina site is relatively moist and warm compared to the Lawrence site, which experiences frequent, severe frosts and sometimes snow. At both sites, the poplars have been planted predominantly to reduce the risk of soil slips and other erosion forms through reduction in surplus soil water content and mechanical reinforcement by roots.

Micro-environment characteristics

The results of this study show that young, wide-spaced poplars have a significant effect on the surrounding micro-environment and growth of the pasture understorey, and that responses can vary considerably between sites. Although comparisons between sites are confounded because of differences in tree age and clones, and associated canopy development (for example, mean tree height at Pohangina was 6 m greater than at Lawrence), the results still highlight the important effects young trees can have on their immediate surroundings.

The micro-environmental effects of young poplars found here include a) up to 24% reduction in rainfall beneath trees compared to open plots; b) up to 33% lower soil water content (0–200 mm soil depth) beneath trees relative to that in open pasture in summer and autumn; c) a 31% reduction in solar irradiance beneath trees compared with the open plots, with plots on the south of trees receiving 14% less solar radiation than those on the north; and d) often equal or higher soil water content on the south versus north side of trees, probably owing to the differences between sides of trees in irradiance, rainfall and soil temperature. Soil temperature effects were less consistent across sites, being 1–2°C lower on the south side of trees at Pohangina and similar between tree and open plots at Lawrence.

The findings from a study beneath a canopy of mature, untended poplars (37 stems/ha, aged 25+ years) near the current Pohangina site (Guevara-Escobar *et al.* 1997), indicate the possible effects of the trees in this study as they mature, on the surrounding aerial and soil environment. Relative to areas without trees, Guevara-Escobar *et al.* (1997) found that beneath the canopy, photosynthetically active radiation in spring and summer was reduced 40–90%, soil temperature (100 mm depth) was 0.6 to 3.3°C lower, and soil water content (0–150 mm depth) was reduced by 0 to 14 percentage units. The current results and these earlier findings will be useful for developing models to describe environmental changes around poplars over time.

The asymmetry of the U-shaped profile of soil water content beneath the trees at Pohangina could be the net result of several factors. These include differences between sides of trees in rainfall interception, greater evapotranspiration by understorey pasture on the north versus south side of trees as drying progressed, and possible variation in tree root development and hence soil water extraction patterns in different directions around the trees. Determining the soil water profile along an east-west axis would be a useful complement to the data obtained here.

Pasture growth

Pastures beneath and beyond trees at Lawrence grew more than those at Pohangina, probably because of the high soil nutrient status. Soil fertility differences between sites would have also been accentuated by the application of superphosphate in spring 1999 at Lawrence. Pastures at both sites often comprised more than 80% grass, usually over half of which was *L. perenne*. However, pastures at Pohangina also comprised a wider range of species that grow on low to moderately fertile soils such as *A. capillaris*, *A. odoratum* and *H. lanatus*. Soil water content may have also been influential because it was slightly higher at Lawrence than Pohangina during summer when most of the relatively high pasture growth at Lawrence occurred. There was no observable effect of pasture pests and diseases at either site.

The presence of trees at Lawrence reduced annual pasture growth by an average (over both sides of trees) of 27% compared with open pasture, whereas at Pohangina, growth reduction was 10.5%. These differences may be owing to the interaction of soil water content and solar irradiance (Guevara-Escobar *et al.* 1997; Wall *et al.* 1997) at the two sites. At the Pohangina site, low soil water content during the late spring and summer may have limited pasture growth more than solar irradiance in both the tree and open plots. Under these conditions, variation in pasture growth owing to the presence of trees is reduced. In contrast, at the Lawrence site there was less seasonal variation in soil water content, which means that differences in absorbed radiation beneath the trees and in the open are more likely to result in greater differences in pasture growth, as was observed. Measurements of seasonal irradiance beneath trees and in the open are required at the Lawrence site to support this hypothesis.

Other factors may also have contributed to the different effect of trees on pasture growth between sites. Relative to the trees at Pohangina, those at

Lawrence were shorter (11 vs 17 m) and had thinner trunks (DBH; 28 vs 32 cm). The trees at each site were of different species and it is possible that there were differences between them in canopy attributes such as leaf size, leaf density, and canopy width, and physiological function. Pasture species exhibit a range of tolerance to shade (Ludlow 1978), and *L. perenne*, which comprised up to 85% of pasture biomass at Lawrence, is relatively sensitive to low light conditions compared with other pasture species (Devkota *et al.* 1998). Dead matter content of pastures at Lawrence in autumn was 17%, 11% and 8% DM for south and north sides of trees and in the open, respectively, and it is suggested that part of the relatively high dead matter content on the south side was because of leaf tissue senescence in response to shade, cooler temperatures and perhaps slower decomposition.

The seasonal differences in pasture growth between sides of trees at Pohangina, particularly from spring to summer, were driven strongly by the interaction between irradiance transmitted to the ground surface and soil water content. In September and October, pasture growth on the north side of trees was relatively high, indicating that low irradiance was limiting growth on the south side. In contrast, by January and February, growth on the north side was less than on the south, indicating that growth of the northern pastures was limited predominantly by low soil water content. The spatial and temporal changes in soil water content beneath the experimental trees at Pohangina during a drying phase support these views. At Lawrence, the relative importance of soil water content in accounting for the almost constant absolute difference in pasture growth between north and south sides of trees from September to April was less apparent.

The effect of the young trees on annual pasture growth responses was at variance with (Lawrence), or similar to (Pohangina), the results of Gilchrist *et al.* (1993). On pastures near Gisborne (relatively warm and dry) which produced 6710 kg DM/ha/yr, these authors found over 3 years that pasture growth was similar on north and south sides of single trees of *Populus* x *canadensis* (= x *euramericana*) aged 16–19 years. Insufficient data were presented to indicate the extent of seasonal differences in pasture growth between sides of trees, but they were significant in the current study. Pasture growth was measured at 1, 4, 7 and 10 m from the trunk of each tree by Gilchrist *et al.* (1993) whereas in this study, measurements were conducted at single, equidistant positions on the north and south sides of trees such that differences in radiation received were maximised. Consequently, the reductions in pasture growth determined here, for example 34% on the south side of trees at Lawrence relative to open pasture, represent the greatest possible values under the prevailing plant and site conditions. Miller *et al.* (1996) reported that willows (*Salix* spp.) aged only 6–10 years reduced annual pasture growth by 40% compared with that on stable, open ground, but planting density was 400 stems/ha, so that there was probably considerable canopy interference between adjacent trees. A reduction in pasture growth of 40% per year was also found beneath a canopy of mature, untended *P. deltoides* trees at 37 stems/ha (Guevara-Escobar *et al.* 1997).

Pasture botanical composition

The grass content of pastures at Lawrence and Pohangina exceeded 75% DM at all times and was frequently more than 85% DM. This contrasted with the results of Guevara-Escobar *et al.* (1997) where grass comprised 45–73% DM and 51–83% DM beneath and beyond trees, respectively. Botanical composition of understorey pasture at Lawrence was similar to pasture beyond trees, and this trend was in general agreement with findings by Guevara-Escobar *et al.* (1997). However at Pohangina, the extent of botanical differences beneath and beyond trees was highlighted with the grass content of pastures on the north side of trees being up to eight percentage units higher than that on the south side and in the open, in all seasons. In addition to the interactions between irradiance transmitted and soil water content, other factors such as soil nutrient status around trees and in the open, and animal grazing habit, could partly explain the results. Further study in this complex ecosystem is required.

Applicability of findings

Caution should be exercised in extrapolating results from the Pohangina and other studies in the lower North Island (Gilchrist *et al.* 1993; Guevara-Escobar *et al.* 1997) to other regions, because, as found in this study, there are some fundamental differences between distant sites in the interaction between young poplar trees and the pasture understorey. Furthermore, the underlying reasons for the differences in pasture and other responses can vary between sites, and this has implications for site-specific recommendations on appropriate tree spacings and clones, livestock management and stock carrying capacity, possible silvicultural practices, and pasture species and cultivars best suited to each tree-pasture environment.

Conclusions

Young, wide-spaced poplar trees significantly modify the hill pasture micro-environment in New Zealand, both above and below ground. Considerable variation exists between distant sites in the interaction between trees and understorey pasture, including the extent and timing of reductions in pasture growth.

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