

Influence of planting four tree species on the yield and soil water status of green panic pasture in subhumid south-east Queensland

J.R. WILSON

CSIRO Tropical Agriculture, St Lucia, Brisbane, Queensland, Australia

Abstract

Four tree species were planted into an old "rundown" green panic (*Panicum maximum* var. *trichoglume*) pasture on brigalow clay soil in a subhumid region, south-east Queensland. Studies under shadecloth have shown that the "rundown" condition due to immobilisation of soil nitrogen can be partly reversed by shading the pasture. This study examined pasture productivity and soil moisture status over 8 years, to determine whether re-planting trees into old pasture may benefit grass growth through shade from their canopies increasing soil nitrogen or be a detriment through increased competition by the trees for soil water.

Eucalyptus argophloia (eucalypt), and 3 legume trees, *Acacia stenophylla* (acacia), *Albizia lebeck* (albizia) and *Leucaena diversifolia* (leucaena), were planted in January 1989 in plantations of 25 trees on a 5 m grid, with 2 replicate plots per tree species, randomised with open pasture control plots. Pasture yield was measured by cutting strips across the plots with a forage harvester towards the end of each growing season. At each harvest, pasture yield in relation to position from a tree was also measured by cutting small quadrats at 1/8, 1/4 and 1/2 the distance along a set diagonal between two adjacent trees. Soil moisture was measured at varying time intervals over the whole experiment using gypsum blocks at 0.1, 0.25, 0.5 and 1.0 m depths at positions 1/4 and 1/2 way between two trees. Tree height was measured in August 1993 and April 1997.

The experiment experienced mostly dry to very dry years, with only the growing season of

1995–96 receiving near average rainfall. Despite this, the eucalypts grew moderately well reaching an average 6.2 m height after 8 years with a final 50% shading of the plot area. The other trees grew very slowly reaching heights of 2.9 m (acacia), 1.8 m (albizia) and 2.6 m (leucaena) and providing shade levels over the plot of only c. 15–20%.

Compared with open pasture, growth of grass under acacia and albizia was not reduced, but in the final year, it was significantly reduced under leucaena by c. 25% and under eucalypts by c. 33%. Judging from both forage harvester and quadrat cuts, the decline in pasture productivity under eucalypts probably started by Year 4 or 5 after tree planting. Herbage N % was higher under trees than in the open pasture with the difference greater at the later harvests. Pasture yield under trees was higher nearer the stem than at a position midway between trees; this occurred despite lower light intensity and lower soil water concentration near the stem. The latter two results strongly suggest that tree canopy shade had a positive influence on availability of soil N. However, soil drying, particularly in the 0.1–0.5 m horizon, occurred faster under trees, especially the eucalypts. It is concluded that, in this sequence of dry years, competition between trees and grass for soil water outweighed any positive influence of tree shade on increasing availability of soil N.

Introduction

Agroforestry systems or more specifically, silvi-pastoral systems, are receiving more critical evaluation in recent times as potential alternatives to fully clearing land for pasture or for rehabilitation of degraded land. Clearing of trees has long been used as standard practice throughout Australia to increase native grass production (Burrows *et al.* 1988) or to allow development of sown grass pastures, as in the c. 8M ha of brigalow lands of southern Queensland. Ecological problems

following overclearing in many regions, particularly of soil erosion and salinisation, but also of sustainability, wildlife habitats and biodiversity, have given impetus through direct Government or local Land Care programs to re-establishment of trees in the pastoral landscape. There is now a more pressing need to understand how reafforestation or tree retention might influence the potential for pasture growth under a variety of conditions. Understanding tree-pasture interactions (Jackson 1995) is also important for increasing management effectiveness in the extensive savanna woodlands of northern Australia, southern Africa and South America.

Grass production generally increases markedly after clearing of trees (Scanlan and Burrows 1990), but it has sometimes been found that the initial stimulus to grass growth reduces greatly over time (Harrington and Johns 1990). On the brigalow clay soils in southern Queensland, the productivity of newly sown pastures on land cleared of brigalow (*Acacia harpophylla*) trees is initially very high but may decline by up to 80% after 5 years, largely as a result of the immobilisation of N under tropical grass pastures such as buffel grass and green panic (Robbins *et al.* 1989; Myers and Robbins 1991). This has, in turn, led to a marked decline in animal production per head which can be avoided only by reducing stocking rates as application of N fertiliser is not economic (Jones *et al.* 1995).

Research on various soil types (Wilson *et al.* 1986; Wild 1995; Wilson 1996) has shown that artificially shading "rundown" N-deficient pastures can increase growth of grass significantly through greater availability of immobilised soil N. Similar instances of increased growth of tropical grasses under tree canopies at moderate density/ha have been recorded in a variety of circumstances in Australia (Lowry *et al.* 1988; Wilson *et al.* 1990; Wild 1995) and southern Africa (Stuart-Hill *et al.* 1987; Belsky *et al.* 1989; Weltzin and Coughenour 1990). These responses are attributed largely to increased fertility or N availability under the tree canopy (Belsky 1994; Wilson and Wild 1995). The studies in Australia have been mainly in coastal, higher rainfall environments, although in southern Africa some studies have shown advantages from trees in rainfall zones as low as 450–700mm (Belsky *et al.* 1993). High tree density though may give excessive shade and provide detrimental competition to pasture (Cameron *et al.* 1991; Robinson 1991).

The research reported here examines whether the introduction of trees into an old "rundown" green panic (*Panicum maximum* var. *trichoglume*) pasture on cleared brigalow country could result in a shade-induced increase in grass growth. Plantations of 4 tree species were established, a eucalypt and 3 legume species. Grass growth and soil water balance were determined within the tree plantations and compared with the situation under adjacent open grass pasture.

Materials and methods

Site

The experiment was located on cleared brigalow country on the CSIRO Narayen Research Station near Munduberra, south-east Queensland (25° 41'S, 150° 53'E) in a subhumid, subtropical environment, with mean annual rainfall of 712 mm. The soil was a highly fertile dark brown clay (Gn 3.13, Northcote 1979), with very high total soil N (c. 0.6%) and organic carbon status (c. 6–7%) in the surface 0–100 mm (Catchpoole 1992).

The tree site of c. 1 ha was located in a uniform stand of old (>15 years) sown grass pasture comprising >80% green panic with small patches of rhodes grass (*Chloris gayana*) and Queensland blue grass (*Dichanthium sericeum*). *Panicum maximum* is a pasture species tolerant of shade (Wong *et al.* 1985) and is known to grow well under tree canopies (Kennard and Walker 1973; Weltzin and Coughenour 1990). The pasture was one of the treatments in the long-term grazing trial described in detail by Jones *et al.* (1995). It was originally fertilised with 100 kg/ha/yr superphosphate, but not in the several years preceding this experiment nor during the experiment. It has never been fertilised with nitrogen. The green panic pasture was grazed by cattle for about 15 years but grazing had been excluded for the past 5 years and during this experiment.

Rainfall (Table 1) was recorded at about 1 km from the site.

Treatments and design

Four tree species (a eucalypt and 3 N-fixing legumes) were chosen by CSIRO Division of Forestry, and seedlings were raised at the CSIRO Samford Research Station. *Eucalyptus argophloia* (Queensland western white gum) and

Table 1. Rainfall characteristics, average harvest yield and pasture composition for the different years of the experiment.

	1990	1991	1992	1993	1994	1995	1996	1997
<i>Rainfall</i> ¹ (mm)								
Annual total (1989–1996)	804 (+12%)	626 (–13%)	394 (–45%)	514 (–28%)	442 (–38%)	407 (–43%)	712 (0%)	547 (–24%)
Growing season	323 (–36%)	345 (–32%)	360 (–29%)	257 (–49%)	428 (–16%)	289 (–43%)	542 (+7%)	432 (–15%)
<i>Pasture characteristics</i> ²								
Harvest date	30.5.90	6.2.91	25.3.92	29.3.93	16.3.94	10.4.95	8.1.96	28.4.97
Harvest yield (t/ha)	2.94	1.62	3.84	4.04	3.32	4.38	4.92	4.70
Green panic (%)	76	22	85	76	97	98	94	91
Herbage N (%)	1.09	1.09	1.12	1.11	1.21	1.02	0.77	0.63

¹Annual total (calendar year Jan–Dec). Growing season totals (Oct–Mar inclusive) from Oct 89–Mar 90 to Oct 96–Mar 97: comparison with long-term average rainfall in brackets.

²Averaged over all treatments. Harvest means significantly different ($P < 0.001$).

Acacia stenophylla (river cooba or myall) are both native to the experimental region and useful for various timber purposes (Turnbull 1986). *Albizia lebbek* (Indian siris) is a potential fodder tree for tropical regions (Prinsen 1987) and has grown well elsewhere on the research station. *Leucaena diversifolia* (leucaena) was selected instead of the more widely used fodder tree, *L. leucocephala*, because of concerns that psyllid damage might have greatly reduced canopy development in the latter. Albizia and leucaena seedlings were inoculated with appropriate rhizobia.

The species were sown as mini-plantations of 25 trees at a 5 × 5 m spacing with rows oriented E-W/N-S with 2 replicate plantations per species. Within replicate blocks, an open pasture control plot was designated; treatment positions within replicates were allocated at random. Plot size was 20 × 20 m with 10 m laneways between plots and between replicates. Tree density, based on an overall area of 25 × 25 m, was therefore 400 trees/ha. Seedling heights at planting were: eucalypt (0.97 ± 0.05 m), acacia (0.98 ± 0.06 m), albizia (0.54 ± 0.04 m) and leucaena (0.99 ± 0.04 m). Between January 9–13, 1989, sun-hardened seedlings were planted into holes (with roughened sides) made by a post hole auger directly into the green panic pasture. The green panic was cut to ground level for a 0.3 m radius around each seedling and the ground covered with newspaper. Seedlings were supported by stakes and surrounded with a white-plastic, UV-resistant "Growtube" [which lasted about 3 years], and at planting received 150 g of di-ammonium phosphate fertiliser spiked into a

0.12 m deep hole c. 0.1 m from the stem. Trees were then well-watered by hand. The pasture was slashed in April 1989. Four acacia, 1 albizia and 2 leucaena seedlings were replaced in May 1989, and 5 albizia seedlings in January 1990. The summer of 1989–90 was very dry (Table 1). Leucaena and albizia trees were watered (16 L/plant) twice prior to January 1990 and all trees were hand watered on March 23, 1990. No further waterings were made. The green panic pasture was not fertilised or watered.

Measurements

Pasture yield. Pasture yield was measured once a year from 1990 to 1997 (Table 3). Two fixed 1.2 m wide strips were cut with a forage harvester across each plot (N–S) between Rows 2 and 3 (3 is the central row) with the first strip as near to the tree bases in Row 2 as possible, and the second strip cut adjacent to it (with c. 200 mm gap to prevent overlap); the strips were bulked for yield. The total forage bin sample was weighed fresh in the field, a large subsample (4–6 kg) was taken immediately, placed in a cloth bag and sealed into a plastic bag. This subsample was subsequently weighed fresh in the laboratory and then oven-dried at 80°C. Another fresh subsample (1 kg) was taken for drying, grinding and nitrogen analysis by Kjeldahl digestion.

Quadrat cuts (0.5 × 0.5 m) were made along 2 diagonal transects; one transect ran from each side of the central tree (in Row 3) of each plot to the nearest tree in Row 4. Positions sampled were 1/8 (0.884 m), 1/4 (1.768 m) and 1/2 (3.536 m) distance from the stem of each of these

designated trees (with 2 adjacent quadrats cut at the 1/2 position); this gave 4 quadrats per position per replicate plot. The open pasture was similarly sampled with the transects positioned in the same manner from the centre point of the plot. The quadrat cuts were dried and weighed separately, then bulked and 2 subsamples taken, one to determine species composition (green panic, rhodes grass, Queensland blue grass and weed), and the other to determine the proportions of green leaf, stem and dead material.

After harvesting, the pasture in all plots and laneways was slashed to the forage harvester cutting height of *c.* 0.12 m, with grass immediately around the tree bases slashed by hand.

After the final harvest on April 28, 1997, 5 head of cattle were put into the paddock containing the treatment plots and grazing behaviour observed over 3–4 h.

Tree growth. Tree height was measured in August 1993, and tree height, girth at 1.3 m, and number of vertically oriented branches at 1.3 m stem height, were measured at the end of the experiment in April 1997.

Light transmission. Two matched integrating light meters measuring photosynthetically active radiation were used to measure light transmission within each tree plot at 0900h and 1200h after the final pasture harvest. Incoming light was integrated over the whole plot area over about a 4-minute period. One meter was held vertically in full sun outside the canopy and the other was held vertically at knee height in a specially designed metal cradle and walked up and down each row in a pre-determined zigzag pattern from tree base to tree base. Radiation within the plot was expressed as a percentage of full sun radiation over the same time period. The light transmission was measured twice within each plot by 2 different operators and averaged.

Soil water status. Gypsum blocks were placed at soil depths of 0.1, 0.25, 0.5 and 1.0 m in 2 locations in each plot, *viz.* at 1/4 and 1/2 the distance along the diagonal from the central tree in each plot to a tree in the next row. Measurements were made using a resistance meter and converted to MPa of potential using the standard conversion relationship. Readings were taken at approximately 2-weekly intervals over the period, mainly during the growing season, following a significant rainfall event. Readings were suspended when soil water potential at 1 m depth was < -1.5 MPa for longer than 1 month. Mean water

potentials at different depths were calculated for 5 measurement periods (December 1990–April 1991; December 1991–October 1992; November 1992–April 1994; December 1994–December 1995; November 1996–March 1997). At the end of the experiment, measurements were taken on March 10, 14, 18, 20 and 26, 1997 following 109 mm rain between February 26 and March 6.

Calculations based on the moisture characteristic curve for this clay soil and a bulk density of 1.3 g/cm³ indicate 100 mm rainfall would bring dry soil (-1.5 MPa) to field capacity to a depth of only 0.5 m.

Statistical analysis

The yield and pasture composition data were analysed using a split-plot randomised block ANOVA model for 2 replicates; for forage harvester data, the tree treatments were main plots and harvests subplots; for quadrat cut data, the tree treatments were main plots, quadrat positions subplots, and harvests sub-subplots. Tree heights in each plot are expressed as mean and standard error of mean.

Results

Rainfall

Annual rainfall in the calendar year of planting (1989) was above average, but in all other years except 1995, the seasons ranged from dry to extremely dry (Table 1). Growing season rainfall (October–March) was 29–49% below average in most years (Table 1). At 1.0 m soil depth, water potential (MPa) averaged -0.92 (December 1990–April 1991), -1.27 (December 1991–October 1992), -1.16 (November 1992–April 1994), -0.48 (November 1994–December 1995) and -1.19 (November 1996–March 1997), indicating soil water levels near or below wilting point (-1.5 MPa) for much of the experiment.

On only 5 occasions (April 1989, February 1994, October and November 1995, and May 1996) did rainfall exceed 100 mm over a 5-day period to fully recharge the upper 0.5 m of soil profile. Rainfall of > 60 mm over 5 days occurred on an average of only 2.2 times/yr over the experiment.

Tree growth

Low rainfall, particularly during the early years of the experiment undoubtedly restricted tree growth to well below potential. Despite this, the eucalypts grew continuously throughout the experiment averaging 6.2 m height and 380 mm girth in April 1997 (Table 2), with individual trees to 9–10 m height. In form, they had a single, straight main stem, and carried a cylindrical, heavy leaf canopy of about 2.5–4 m spread, which extended, even after 9 years, to within about 1 m of ground level (Plate 1c). The acacias (Plate 1a) also grew steadily but rather slowly with a multi-branching form; average height was only 2.9 m, although some trees were up to 4 m. In form, they also carried a full leaf canopy, varying from cylindrical to spherical, to within a metre of ground level. Albizia (Plate 1b) and leucaena (Plate 1d) grew poorly, and only during the warmer months, thereby being greatly affected by the sequence of well below normal growing season rainfall. Frost damaged the small leucaena trees in the earlier years, with minor damage also on albizia. Leucaena grew to an average 2.6 m in height (some trees up to 4 m), and the main canopy had largely escaped frost damage in the final two years. Albizia grew to an average of only 1.8 m, but the best trees approached 3 m height. Between 1993 and 1997, the eucalypts grew 2.2 m in height compared with only 0.6–0.7 m for the other species (Table 2). The albizia and leucaena had a spreading form with a raised, generally horizontal, canopy of about

2–3 m with a few trees approaching 4 m width. The eucalypts reduced the light transmission at pasture height (averaged over the whole plot area) to about 50% (Table 2) by the end of the experiment, whereas the light transmitted for the other tree species whether due to form (acacia) or a poorly developed canopy for many individual specimens (albizia and leucaena) was still in the order of 80%, with higher transmissions at noon than in early morning (Table 2). Under the immediate tree canopy near the stem base, light transmission for all tree species would have been much lower than the averages shown in Table 2.

Pasture growth

General. Average yield (Table 1) varied from 1.6 to nearly 5 t/ha over the years reflecting both variation in harvest date and seasonal rainfall. Green panic proportion decreased dramatically to 22% in 1991 (Table 1) with a marked increase in weeds, rhodes grass and some Queensland blue grass (data not shown). It was recognised after the 1991 harvest, and with experience from a co-located experiment, that harvesting as late as May to get full season yield greatly weakens green panic pasture, allowing other species to invade the following spring–summer. Subsequent management recognised this important observation with earlier harvests, and green panic proportion recovered to above 90% in the last 4 years. Herbage-N concentrations (Table 1) were low (1.12%) to very low (0.63%).

Table 2. Tree growth¹ and degree of pasture shading at end of experiment.

Tree species	August 1993 Tree height	April 1997 — End of experiment				
		Tree height	Stem girth	No. branches ²	Light transmission (%) ³	
					0900h	1200h
	(m)	(m)	(mm)			
<i>Acacia stenophylla</i>	2.2 ± 0.06 ⁴	2.9 ± 0.09	102 ± 7.2	8	73 ± 7.1	81 ± 3.2
<i>Albizia lebbeck</i>	1.2 ± 0.08	1.8 ± 0.08	44 ± 6.0	2	84 ± 8.6	92 ± 1.6
<i>Eucalyptus argophloia</i>	4.0 ± 0.18	6.2 ± 0.50	380 ± 14.8	1	46 ± 10.0	56 ± 2.2
<i>Leucaena diversifolia</i>	2.0 ± 0.09	2.6 ± 0.11	88 ± 8.0	3	82 ± 0.7	87 ± 1.8

¹Trees planted January 9–13, 1989.

²Vertically oriented main branches at 1.3 m height.

³Photosynthetically active radiation; open pasture = 100%.

⁴Standard error of mean.

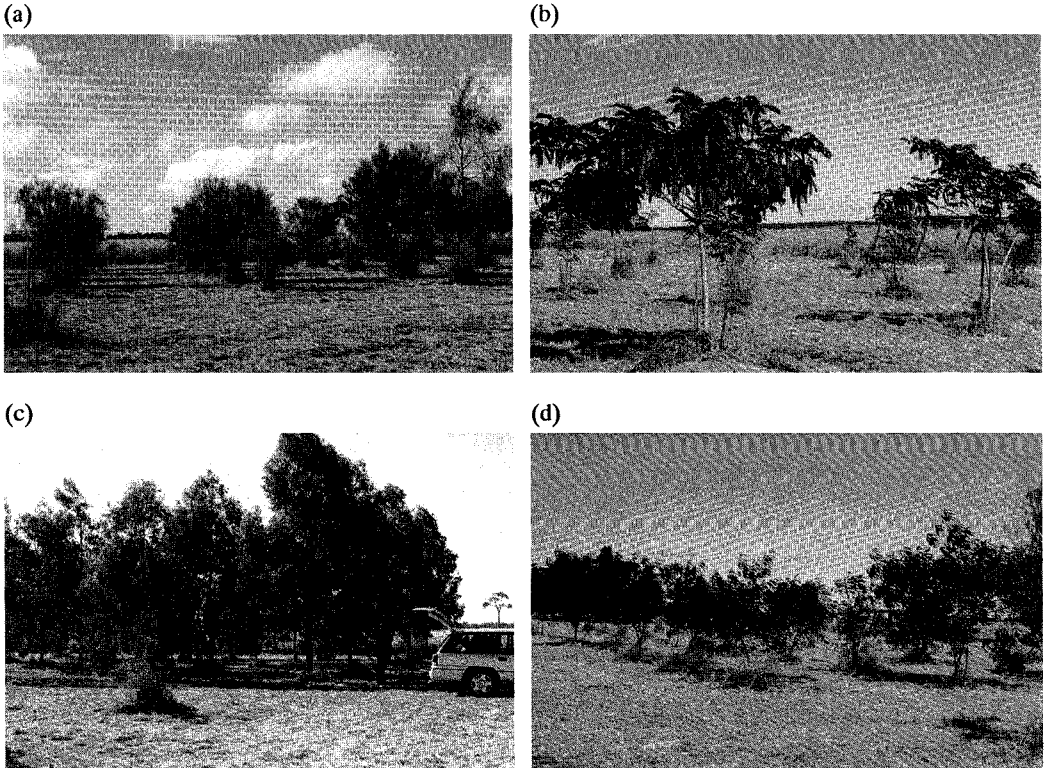


Plate 1. View of tree plots after harvest and slashing of pasture at the end of the experiment in April 1997: (a) acacia, (b) albizia, (c) eucalypt and (d) leucaena.

Tree influence on pasture yield and composition. The mean pasture yield did not differ significantly ($P < 0.05$) between any of the treatments (Table 3). However, in the final year, pasture yield under eucalypts was 33% lower ($P < 0.05$) than that of the open pasture and pasture under acacia and albizia. Data in Table 3 suggest that this decline in overall pasture yield under eucalypts may have started by Year 6 (1995) or perhaps earlier, judging by the lower yields than in open pasture evident in positions 1/4 and 1/2 way between adjacent trees by 1993 (Table 4). Green panic in the eucalypt plots was observed to be more severely wilted than in the other treatments during dry periods in the later years. Pasture yield under leucaena was 25% lower ($P < 0.05$) than under open pasture in Year 8, an effect evident in this last year only, but perhaps real, judging by the lower yield at the midway position between trees (Table 4). The proportion of green panic in

the pasture (Table 3) was consistently higher for the tree treatments than the open pasture, especially in the more heavily shaded eucalypt plots.

Pasture quality measured as % green leaf and % N in herbage (Table 3) tended to be higher in the tree plots, especially under eucalypts, than in the open pasture. The % N difference between pasture under eucalypts and in full sun was more pronounced in the 4 later harvests, e.g. 1.38 vs 1.03% ($P < 0.05$), 1.21 vs 0.88% ($P < 0.05$), 0.94 vs 0.69% and 0.74 vs 0.56%; a similar trend was evident under acacia and leucaena.

Variation in pasture yield with distance from the tree stem. The pasture yield from quadrat cuts showed significant ($P < 0.001$) interactions between position and species and harvests. Table 4 presents data for 2 of the harvests, one in the middle of the experimental period (March 29, 1993) and the other at the end of the experiment (April 28, 1997). No effect of sampling position

Table 3. Effect of tree species on pasture yield (t/ha)^{1,2} in different years and the treatment mean over harvests for other pasture characteristics.

Harvest date	Open pasture	Acacia	Albizia	Eucalyptus	Leucaena
<i>Pasture yield in different years</i>					
May 30, 1990	2.84	2.80	2.83	3.18	3.03
February 6, 1991	1.54	1.90	1.45	1.54	1.69
March 25, 1992	3.64	4.21	3.60	3.64	4.11
March 29, 1993	4.85	3.59	4.54	3.86	3.38
March 16, 1994	2.93	2.93	4.29	3.12	3.35
April 10, 1995	4.92	4.28	4.28	4.06	4.36
January 8, 1996	5.12	5.56	3.97	4.58	5.38
April 28, 1997	5.38	5.21	5.32	3.59 ³	4.02
<i>Treatment means over years²</i>					
Pasture yield (t/ha)	3.90	3.81	3.78	3.44	3.66
Prop. green panic (%)	65	77	83	92	83
Prop. green leaf (%)	21	23	21	27	23
Herbage-N content (%)	0.92	1.04	0.96	1.12	0.99

¹ Measured by two 20 m × 1.2 m forage harvester strips cut across each plot.

² LSD (P<0.05): Yield (species mean 0.53 t/ha; species × harvest 1.29 t/ha); % green panic 24.8; % green leaf 6.8; %N 0.27.

³ Estimated yield after adjustment for accidental partial grazing of Replicate 2 on day before harvest = 4.02 t/ha.

Table 4. Variation in yield (g/m²) between quadrats cut at one-eighth, one-quarter and one-half the distance along a fixed diagonal transect between 2 trees presented for a harvest at the middle and end of the 9-year experimental period.

Treatment	Harvested March 29, 1993			Harvested April 28, 1997		
	1/8	1/4	1/2	1/8	1/4	1/2
Open pasture	238	237	264	461	555	548
Acacia	148	174	159	511	516	358
Albizia	229	268	241	499	494	422
Eucalyptus	155	109	84	186	175	93
Leucaena	234	190	190	481	502	298

LSD (P<0.05) Species × harvest × position = 43.5.

in relation to the tree stem was evident for acacia and albizia in 1993 but there was a significant progressive decline in yield with distance from the tree for eucalypt, and a higher yield at the stem base in leucaena. At the final harvest in 1997, the same trend was strongly evident for eucalypt, and acacia and leucaena showed a lower yield at the midway point between trees than nearer the stem base. The hand-cut quadrat data (Table 4) showed a more marked reduction in pasture yield under eucalypts than did data from the forage cuts (Table 3); this perhaps reflects the marked decline and greater variation in grass plant density in the eucalypt plots, making the small 0.25 m² quadrats less effective for predicting overall plot yield than when grass coverage was more dense and uniform. In all tree plots at the end of the experiment, the pasture yield at the midway point between trees was significantly lower (P<0.05) than the average yield for the open pasture plots, suggesting a probable

influence of tree roots at the outer boundary of the tree canopies on soil water status.

Soil water status

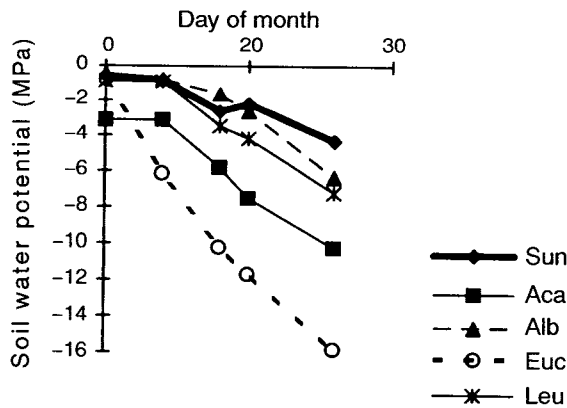
During the early years (1990–91 and 1991–92), soil water potential appeared to be consistently lower at all soil depths sampled under eucalypt and albizia than in the other treatments. This effect is evident in the data for 1991–92 presented in Table 5, and, for albizia, is unexpected because the leaf canopies of this species were much smaller than those of the other trees in these years. The low water potentials for all plots and depths evident in Table 5 indicate the high degree of water stress in this earlier period of the experiment. In the later years, soil water potentials under albizia tended to be the highest of all tree treatments, certainly in the surface layers, and only slightly lower than those under open pasture, as for the example seen in Figure 1.

Table 5. Soil water potential (MPa) at 4 depths measured by gypsum blocks placed at one-quarter and one-half the distance between 2 trees near the centre of each plot (mean of 14 occasions between December 1991 and October 1992).

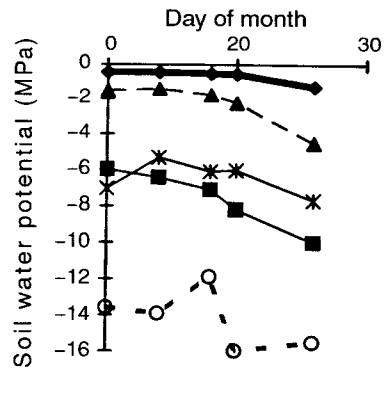
Soil depth (m)	Treatment					Mean (\pm se)
	Open pasture	Acacia	Albizia	Eucalyptus	Leucaena	
<i>One-quarter distance</i>						
0.10	-0.70	-0.78	-0.87	-1.39	-1.43	-1.03 \pm 0.17
0.25	-0.72	-0.63	-0.70	-1.37	-0.60	-0.80 \pm 0.09
0.50	-0.74	-0.93	-1.03	-1.23	-0.93	-0.97 \pm 0.08
1.0	-1.35	-0.87	-1.86	-1.54	-0.96	-1.31 \pm 0.06
<i>One-half distance</i>						
0.10	-0.70	-0.94	-1.02	-1.48	-0.81	-0.99 \pm 0.15
0.25	-0.52	-0.66	-0.88	-1.30	-0.84	-0.84 \pm 0.09
0.50	-0.65	-0.65	-1.10	-1.23	-0.88	-1.06 \pm 0.07
1.0	-1.15	-0.65	-1.42	-1.62	-1.28	-1.22 \pm 0.06
Mean (\pm se)	-0.80 \pm 0.07	-0.76 \pm 0.07	-1.11 \pm 0.09	-1.39 \pm 0.09	-0.96 \pm 0.08	

One-quarter distance from tree stem

(a) Surface soil

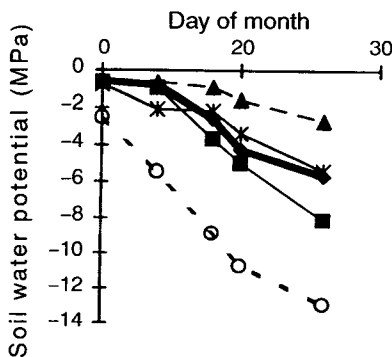


(b) 0.5 m depth



One-half distance from tree stem

(c) Surface soil



(d) 0.5 m depth

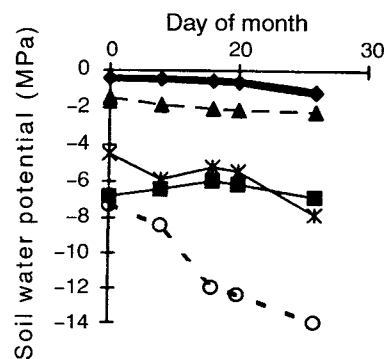


Figure 1. Soil water potentials (MPa) over a 16-day drying cycle in the last month of the experiment (March 1997) following 109 mm rainfall in the previous 10 days; measured at 1/4 distance between trees at soil depths of: (a) surface (0.1 + 0.25 m) and (b) 0.5 m; and 1/2 distance at (c) surface (0.1 + 0.25 m) and (d) 0.5 m. [sun = open pasture; aca = acacia; alb = albizia; euc = eucalypt; leu = leucaena].

Figure 1 illustrates the soil drying trend for each treatment in the last month of the experiment (March 10–26, 1997) following 109 mm rain over the 10 days up to March 6. Data for the average of the 0.1 + 0.25 m depths (trends similar) and the 0.5 m depth are presented. The 1.0 m depth was omitted because the rainfall event was insufficient to rewet the soil to this depth. At the soil surface (Figures 1a, 1c), the rate of soil drying was in the order eucalypt >> acacia > other treatments; the rate of drying tended to be slightly slower halfway between trees than at one-quarter distance, except for eucalypt plots which had already commenced drying at the half-distance by the start of the measurement period (March 10). At the 0.5 m depth (Figures 1b, 1d), it is obvious that the 109 mm total of rainfall only fully wet up the soil in the open pasture plots. Rate of drying at this depth was highest for the eucalypts, and, on average, slightly higher under the other trees than in open pasture. Soil water potential over the 10 days was clearly highest under open pasture, followed by albizia, acacia and leucaena, and very much lower under eucalypts. At both soil depths, the degree of soil drying was generally greater at 1/4 than 1/2 the distance between trees.

At 1.0 m depth, while there was no drying trend over these 16 days in March, it is important to note that the soil under open pasture had water potentials in the extremely dry range of -1.2 to -1.8 MPa. These were, on average, drier than those of any of the tree plots which ranged from -0.5 to -1.6 MPa with leucaena having the driest soil of the trees. This situation was somewhat the reverse of the upper soil layers in open pasture and illustrates clearly that green panic and tree roots were at high density in this deeper soil layer.

Discussion

The prime purpose of this study was to determine whether re-forestation of old "rundown" green panic pastures would be a benefit or detriment to grass productivity.

The current results indicate that plantations of acacia, albizia and leucaena had no effect on the production of old green panic pasture measured by forage harvester yield, even after 8 years, and no effect under eucalypts until Years 7 and 8. These "no effect" results were similar to those of

Dunn *et al.* (1994) for younger 3-year-old tree plantations of albizia, casuarina or eucalypts at Warrill View, south-east Queensland, at tree densities from 78 to 1189 stems/ha, and at Samford, south-east Queensland, for a pasture under a 4.6-year-old eucalypt plantation at densities of < 300 stems/ha (Cameron *et al.* 1989). In both these latter experiments, the trees grew better than at Narayen; viz. at Warrill View, the albizia was 2.6 m and eucalypt 4.3 m after 3 years (compare Table 2), and at Samford, the eucalypts for a comparable tree density were 13.5 m high at 4.6 years. At Narayen after 8 years, although individual trees were much taller, the albizia averaged only 1.8 m and eucalypts 6.2 m, reflecting the unusual sequence of severe drought years.

As a consequence of the years of low rainfall, the tree canopies, except for eucalypt, gave only minor shading of the pasture and therefore any potential increase in soil mineralisation through the shade mechanism (Wilson 1996) would have been slight. Furthermore, the measured surface soil water potentials were low for much of the time in all but one of the 8 growing seasons, and past research under artificial shade (Wong and Wilson 1980; Wilson 1996) suggested that increases in soil-N availability were smaller in low rainfall periods. The effect of shade is attributed to increased microbial and earthworm activity in the soil surface layers which are cooler and remain moister for longer after a significant rainfall event under shade canopies than in full sun (Belsky *et al.* 1989; Wilson and Wild 1995; Wilson 1996). Significant rainfall events, which I have categorised here arbitrarily as >60 mm over 5 days, occurred only about twice per year during this experiment. As such rainfall events were so infrequent, and because microbial activity declines linearly with increased soil water deficit (Wilson and Wild 1995), microbial activity in all treatments in this experiment would have been at minimal levels for much of the time. This would act as an extra limitation to the overall capacity of the shade canopies to increase soil mineralisation and N availability.

Despite the above qualifications, herbage-N % was highest under the eucalypts, and pasture yield was higher nearer the tree stem (0.9–1.8 m) than at the halfway point (3.55 m) between trees. Since the degree of shading was much higher under the tree canopy near the stem, and soil water deficit (at 0.1–0.25 m and 0.5 m, cf. Figure 1) was also slightly higher in this position,

the yield advantage strongly suggests a gain in N availability as a reason for the difference in grass growth. The trends in pasture yield and N for acacia and leucaena were in the same direction but not as strong. *Albizia*, with its minimal canopy, did not show a positional effect on yield. These data support evidence from Wild (1995) that, under eucalypts at 237 trees/ha, increased soil N gave better grass growth than in open pasture, even though the soil under the trees was just as dry as under open pasture. Stuart-Hill *et al.* (1987) found similar higher grass yields under an acacia canopy despite lower soil water content in this zone than in the open pasture. Campbell *et al.* (1994) observed there is an increasing literature that trees can have a positive influence on soil fertility through increased microbial activity under their canopies.

The potential for increased grass growth through tree shade increasing N availability may be counteracted by the extra water use by the tree canopy. The eucalypts dried the soil at 1.8 and 3.6 m from the stem base more quickly and to greater extent than the other trees, even early in the experiment, *e.g.* December 1991 to October 1992. Soil water potentials were in the permanent wilting point range and therefore, would have greatly restricted grass growth. The eucalypt had a dense leaf canopy extending to near ground level and thus a high transpiration potential. Its form was quite different from the sparse canopy observed for similarly aged but taller trees of *E. grandis* in plantation in the tree-grass experiment of Wild (1995). Perhaps with greater height growth, the eucalypt canopies in the current experiment may have thinned dramatically resulting in less depletion of soil water. Soil water potentials under the other trees did not consistently differ from those under open pasture until the last year, when, in the drying cycle of March 1997, the soil under acacia and leucaena dried faster than under open pasture. Only by this time had the leaf canopies of the non-eucalypts developed sufficiently to use more water than grass alone. The tree roots dried surface soil just as much as soil at 1 m depth, while in March 1997, the soil under open pasture at 1 m depth had the lowest water potential of all treatments. These data clearly indicate that grass and tree roots are competing for water from the surface soil down to at least 1 m depth, as found also by Eastham and Rose (1990) for eucalypts and Belsky (1994) for acacia. Stuart-Hill and Tainton (1989) main-

tained that grass was more efficient at depleting soil water than trees such as acacia at a low density of 42 stems/ha. In practice, this efficiency of the grass may not matter because, under grazing, the tree canopies are permanent and grass leaf is removed, so that inevitably the grass will suffer significant competition when soil water is limited.

The level of tree transpiration or shade from leaf canopies intercepting up to about 20% of PAR did not seem to influence pasture yield adversely, although the data for leucaena suggest that a negative influence may have appeared in Year 8. This was in a moderately dry year. A more normal rainfall year could perhaps raise the critical leaf canopy to maybe 25–30% interception of PAR. In an intermittently grazed leucaena-grass paddock, a tree density of much greater than 400/ha would be needed to achieve this density of tree leaf canopy.

An observation of interest in relation to grazing is that animals which accidentally entered the plots for a short period the day before the final harvest, and when given deliberate access to the experiment for 3–4 hours after the final harvest, grazed only the grass under the eucalypts and no other plots. Grazier observations vary on preference of cattle for grass under tree canopies versus open areas. Possibly, the preference in this experiment was related to the more-water-stressed foliage which other research (Wilson 1983) has shown would be of higher nutritive quality.

This experiment was not designed to evaluate the practical and economic feasibility of a grazed silvipastoral system for the brigalow clay soils. Nevertheless, a few points are worthy of comment. UV-resistant growtubes gave tree establishment of >90% success in a difficult environment, and protected against damage from native animals. Only the eucalypts grew well, and in a practical system, they would probably need to be thinned to *c.* 200 stems/ha after 4 years. Acacia, *albizia* and leucaena grew too slowly to provide adequate tree canopies after 8 years and would have provided little additional fodder; however, it should be noted that grass competition around the tree stem bases was not eliminated except at planting. A negative for planting trees on the heavy clay soils is that rainfall of 100 mm over a few days is necessary to rewet soil to 0.5 m, and *c.* 200 mm to rewet to 1 m. Once trees have dried out deeper soil horizons, the occasions of rainfall

recharge would be very rare in this environment. The feasibility of a successful silvipastoral system on the lighter granitic soils of the "spear-grass" country is perhaps much higher. Green panic on these soils shows the same shade-induced increases in soil N and productivity as on the brigalow clay soils (Wilson 1996) but, more positively, growth of pasture (and probably of trees) responds well to rainfall of 30 mm or less, and episodic events of this size are relatively frequent. Tree growth in test plots over the same years as this experiment have been better on the "granitic" soils at Narayen (personal communication, Queensland Forestry Service). Whether tree species can be found with a root distribution less competitive with the grass for soil water than are eucalypt and leucaena (Schroth 1995) will require considerable practical evaluation.

In conclusion, where a substantial tree canopy developed as under the eucalypts, giving up to 50% shade, there was evidence that this shade had a positive influence, sustaining grass growth near the stem bases at a higher level than at midway between the trees. However, over the whole plantation, this shade effect was more than balanced by increased soil water stress from the tree canopy, which greatly reduced the potential grass production in Years 7 and 8 after planting. The experiment embraced a run of extremely dry seasons which greatly restricted the growth of the 3 leguminous trees, and even after 8 years, they had not affected grass yield compared with open pasture. In a sequence of normal rainfall years, tree growth would be quicker and the size of tree leaf canopy leading to strong competitive water use with the grass would probably be achieved more quickly.

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