Tropical Grasslands (1994) Volume 28, 170–181

Early tree and pasture growth in an agroforestry system evaluating *Albizia lebbeck*, *Casuarina cunninghamiana* and *Eucalyptus maculata* in south-east Queensland

G.M. DUNN[1], K.F. LOWE[2],
D.W. TAYLOR[1] AND T.M. BOWDLER[2]
[1]*Queensland Department of Primary Industries, Queensland Forest Research Institute, Gympie, and*
[2]*Ipswich, Queensland, Australia*

Abstract

An experiment evaluating *Albizia lebbeck*, *Casuarina cunninghamiana* and *Eucalyptus maculata* at 5 densities amongst a pasture containing *Chloris gayana* cv. Callide (rhodes grass), *Chamaecrista rotundifolia* cv. Wynn (Wynn cassia), *Stylosanthes scabra* cv. Seca (stylo), *Lotononis bainesii* cv. Miles (lotononis) and *Trifolium repens* cv. Haifa (white clover) was established in south-east Queensland in 1990. The 5 planting densities (78, 182, 343, 771 and 1189 stems/ha) were replicated on lower, mid- and upper slope positions.

Over the first 3 years, *C. cunninghamiana* (mean height 5.5 m) grew significantly ($P<0.05$) faster than *E. maculata* (4.3 m), which, in turn, grew significantly faster than *A. lebbeck* (2.6 m). Due to its poor growth and a mortality rate of 12.3%, *A. lebbeck* was considered poorly suited to the site. The heights of the 3 species were not significantly affected by planting density or position on the slope. Stem diameter at 1.3 m (DBH), measured for 3-year-old *C. cunninghamiana* only, peaked at 343 stems/ha. The DBHs of mid- and lower slope trees were similar and significantly ($P<0.05$) greater, by 17.4%, than those of upper slope trees.

During the third year after establishment, median pasture yield (measured midway between trees at all spacings) was significantly ($P<0.05$) increased under the highest 2 density treatments of *A. lebbeck* (by 17.7% and 39.6%) and *E. maculata* (by 25.5% and 17.2%) when compared with the other density treatments. The proportion of pasture in each plot killed by the application of herbicide around the base of establishing trees increased with increasing density, from 1.4% (78 stems/ha) to 21% (1189 stems/ha). Thus, although median pasture yield was significantly higher under the highest densities, yields adjusted for these sprayed areas were similar and unaffected by tree density, averaging 7.4 t/ha. At this early stage, pasture yields were also unaffected by tree species or slope position.

Introduction

The broad objective of agroforestry research is to benefit from ecological and economic interactions that may exist when woody perennials (trees and shrubs) and herbaceous plants (crops and pastures) are grown in close spatial arrangements (Connor 1991). A necessary step towards the adoption of 'tree and pasture' agroforestry as a viable option in south-east Queensland is the identification and management of optimal combinations of trees and pasture. To this end, a range of tree and pasture species in various spatial combinations are being evaluated at various sites in south-east Queensland.

This paper reports on the design, establishment and results from the initial 3 years of an experiment at one of these sites, where 3 tree species were grown at 5 densities amongst a *Chloris gayana* cv. Callide (rhodes grass), *Chamaecrista rotundifolia* cv. Wynn (Wynn cassia), *Stylosanthes scabra* cv. Seca (stylo), *Lotononis bainesii* cv. Miles (lotononis) and *Trifolium repens* cv. Haifa (white clover) pasture.

The 3 tree species were selected to demonstrate potentially different benefits: (i) *Albizia lebbeck*

Correspondence: Dr G.M. Dunn, Queensland Forest Research Institute, MS 483, Fraser Road, Gympie, Qld 4570, Australia

(Indian Siris) is an exotic, nitrogen-fixing species that may be utilised for fodder, timber and fuel (Prinsen 1986); (ii) *Casuarina cunninghamiana* (River She Oak) is a fast-growing, local, nitrogen-fixing species adapted to a wide range of soil conditions and is used for windbreaks, shelterbelts and riverbank-stabilisation and makes excellent fuel (Turnbull *et al.* 1986). In Argentina, it is recommended for parquet flooring and veneer (Mendoza 1983), while El-Lakany (1983) suggests it is as good as or better than other more commonly used fodder tree species such as *Acacia saligna* or *Prosopis julifera*; and (iii) *Eucalyptus maculata* (Spotted Gum) is a local species with vigorous straight growth, good self pruning (FAO 1979) and high timber values (Watson 1971). Furthermore, results from plantations indicate that *E. maculata* can attain between 20-30 m at 10-15 years (FAO 1979). Thus, it is a species from which 'high value' transmission poles may be produced at wide tree spacings.

The pasture mixture is recommended by the Queensland Department of Primary Industries (QDPI) for pasture improvement in south-east Queensland and contains species which, with the exception of white clover, have been shown to persist in the area (Hawley and Lowe, in press). White clover performs as a self-regenerating annual in the area (Jones 1980; 1982).

Materials and methods

Site description

The experiment was established at the QDPI Animal Genetics Centre, Warrill View (27°49'S, 152°35'E), about 70 km south-west of Brisbane, on a ridge, approx. 90 m above sea level, that sloped between 2-10° to the east. The site had been cleared for grazing during the 1920s. The pasture was predominantly native grasses comprising *Heteropogon contortus*, *Aristida leptopoda* and *Sporobolus elongatus* and the naturalised, introduced grass *Paspalum dilatatum*. Remnant trees were *Eucalyptus tereticornis*, *E. crebra* and *E. intermedia*. The soils are mostly soloths and solodics (see Fisher and Baker 1989).

The long-term average rainfall is 873 mm/yr and 876 mm/yr for Ipswich (1870-1975) and Kalbar (1887-1988), respectively. The climate is typical for coastal subtropical regions, with more than two-thirds of the annual rainfall falling in the period, October-March. Pan evaporation (1511 mm) is 73% greater than annual rainfall. For the period, 1941-1992, frosts were recorded on an average of 17d/yr. These usually occurred in May (1), June (4), July (8) and August (4).

Air temperature and humidity, soil temperature, grass temperature, rainfall, wind speed and solar radiation were measured using an automated weather station, within 100 m of the experimental site. Temperature and humidity measurements were recorded at 0900 and 1500 h daily. Winter rainfall during 1991 (86 mm) was 69% lower than the long-term average for the region and, although the total rainfall in 1991 of 883 mm was similar to the long-term average of 873 mm, half (439 mm) of this fell in the month of December (Figure 1). During the first 6 months of 1992, rainfall was 22% above average. This was followed by a dry period to December 1992. Rainfall in the first 6 months of 1993 was 51% below the long-term average (Figure 1).

Site preparation and the establishment of trees and pasture

The site was slashed in February 1990. During March 1990, de-stumping was undertaken and site cultivation, using a multiple-tyne ripper, to a depth of 20-30 cm was begun. Prolonged wet weather and equipment breakdown delayed the completion of this cultivation until late April 1990. In early May 1990, the site was disc-harrowed twice and fenced to exclude cattle and hares. In keeping with more ecologically sustainable land management practices, the site was contour-ploughed and left at a rough tilth to enhance water infiltration and lessen soil erosion. However, this meant that, during the establishment period for the trees, when stock were necessarily excluded, it was considered too great a risk to harvesting machinery to obtain silage or hay from the site.

The 3 tree species (*A. lebbeck*, *C. cunninghamiana* and *E. maculata*) were planted at 5 densities, ranging from 78-1189 stems/ha, in a randomised block design. Each block was replicated on 3 slope positions referred to as lower, mid- and upper slopes. Stocking levels per plot, and plot areas are detailed in Table 1.

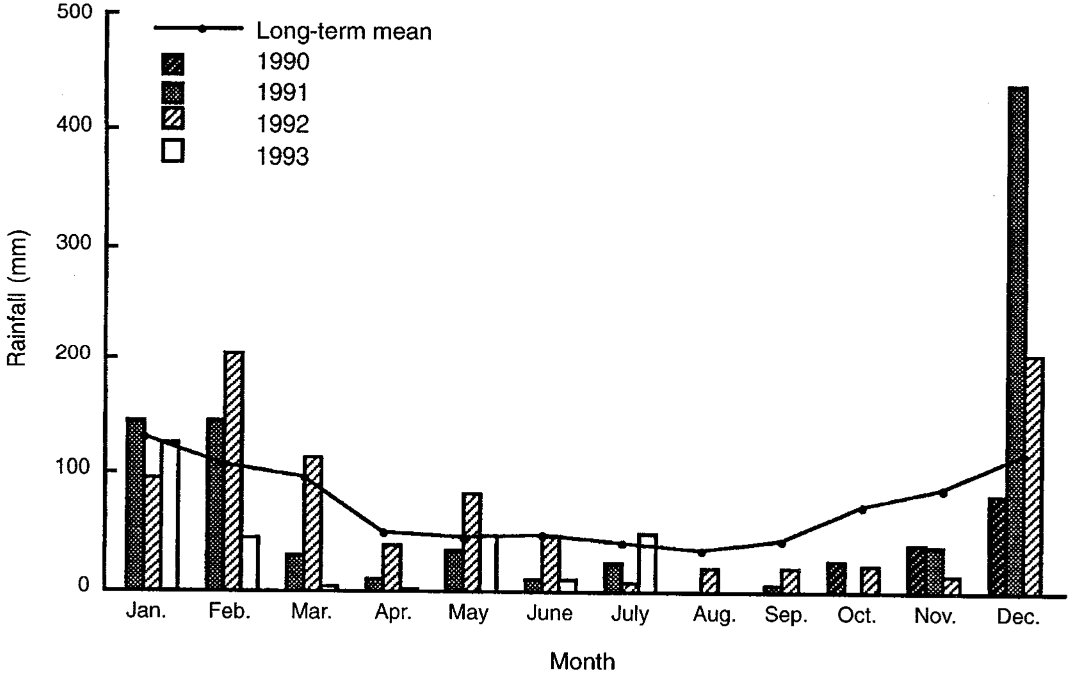

Figure 1. Long-term (1887-1988) mean monthly rainfall and monthly rainfall from October 1990 - July 1993 at Warrill View.

Table 1. Plot descriptions.

Stocking rate	Spacing	Trees/plot	Plot area
(stems/ha)	(m)		(m²)
78	11.3 × 11.3	16	2043
182	7.4 × 7.4	25	1369
343	5.4 × 5.4	25	729
771	3.6 × 3.6	49	635
1189	2.9 × 2.9	49	412

All seedlings were raised in Queensland Forestry Department tubes (Ryan *et al.* 1987). A 1:1 ratio of washed coarse sand to peat was used as a potting medium into which osmocote was incorporated at a rate of 12.5 g /L. Each *C. cunninghamiana* pot was inoculated, as described by Reddell *et al.* (1989), with the symbiotic, nitrogen-fixing soil actinomycete *Frankia* (strain JCT 287 (Shipton and Burggraaf 1983)). *A. lebbeck* was not inoculated. *C. cunninghamiana* was repotted into 1 L black polythene bags on April 7, 1990 to maintain plant vigour. The seedlings were planted out over the period June 4-5, 1990, immediately after which follow-up rain fell (20.6 mm to the end of June). Plants which died were replaced until January 1991. At planting, each tree was fertilised with 100 g Crop King 55 (N:P:K = 14.0:14.7:12.3) as a split-plot basal dressing at about 15 cm from the tree. Additional fertiliser was applied between the trees to all but the 1189 and 771 stems/ha plots to ensure that all plots received the same amount of fertiliser (4.9 kg).

To maintain weed-free conditions around the base of the seedlings during early growth, glyphosate (15 mL/L ROUNDUP) was applied within a 0.75 m radius of the base. This process was repeated at 3, 7, 9 and 19 months after planting. Simazine (8 L/ha) was also applied 9 months after planting.

The original native pasture was fertilised with urea at 427 kg/ha on February 1, 1990. On May 14, 1990, the site was sown with prill-coated seed of *T. repens* cv. Haifa (2 kg/ha) and *C. gayana* cv. Callide (8 kg/ha) using an Elly fertiliser spreader. Seven months later, the pasture was fertilised with superphosphate (9% P) at approx. 250 kg/ha and the site was slashed to promote more vigorous, stoloniferous growth of the rhodes grass. After slashing, the pasture was oversown with *C. gayana* cv. Callide (2 kg/ha), *C. rotundifolia* cv. Wynn (2 kg /ha), *S. scabra* cv. Seca (2 kg/ha) and *L. bainesii* cv. Miles (0.5 kg/ha). All legume seed was inoculated. Each year, immediately after pasture productivity and pasture composition measurements were made, the pasture was slashed.

Measurement of early tree growth, pasture growth and pasture composition

Tree height was measured upon establishment, at six-monthly intervals for the next 2 years and at a further 12 months after that. The crown diameter of all 3-year-old trees was measured, as was the diameter at breast height (1.3 m, DBH) of 3-year-old *C. cunninghamiana* trees. Three-year-old *A. lebbeck* trees exhibited a multi-stemmed habit while many 3-year-old *E. maculata* displayed branching at points lower than 1.3 m. For these reasons DBH was not measured on either of these species.

Pasture yield, botanical composition and frequency of occurrence of species were visually assessed using the **BOTANAL** method (Tothill *et al.* 1978) in March and August 1991, May 1992 and May 1993. The number of quadrats evaluated per treatment was adjusted for plot area, with 20, 15, 15, 10 and 10 quadrats in the 78, 182, 343, 771 and 1189 stems/ha plots, respectively. Quadrats were positioned midway between the trees at all tree densities. Therefore pasture yield was measured at the position in all densities where tree influence would have been at its lowest. This measurement is called **Median pasture yield**. The effect of ROUNDUP was restricted to the area of application, where all the pasture was killed. This 'dead area' comprised 1.4, 3.2, 6.0, 13.6 and 21.0% of the total plot area for the 78, 182, 343, 771 and 1189 stems/ha plots, respectively. Median pasture yield for each plot was adjusted by reducing each value by the proportion of plot area affected by ROUNDUP. This measurement is defined as **Adjusted pasture yield**.

Statistical analysis

To test for edge effects on height and DBH for the tree plots, unpaired 't' tests between edge trees and inner trees were performed for each species at each density. The results showed that, at this stage of the experiment, no edge effects were significant and, therefore, mean heights and DBHs were calculated from whole plots.

Data relating to tree and pasture growth and pasture composition were assumed to be normal and homoscedastic and analysed by ANOVA. Least significant differences between means were calculated from the error mean square with $P<0.05$ using the appropriate 't' value.

Results

Early tree mortality

During the first 6 months, 39 *A. lebbeck*, 8 *E. maculata* and 1 *C. cunninghamiana* seedlings died. Over the next 18 months, only 3 *E. maculata* trees died. However, during the third year, a further 19 *A. lebbeck* and 1 *E. maculata* trees died. Of the total *A. lebbeck* deaths, 41.4% and 43% were lower and upper slope, respectively, while 15.5% were mid-slope.

Samples of wood from the dead *A. lebbeck* trees contained fungal fruiting bodies of *Shaesopsis* sp. on the bark (I. Hood, personal communication) and *Xylopsocus gibbicollis* (auger beetle) in cortical tissue (F.R. Wylie, personal communication). *Shaesopsis* is either saprophytic or weakly pathogenic on stressed trees. Similarly, *Xylopsocus gibbicollis* is a 'secondary' insect which attacks mainly log or sawn timber but will attack dead or dying tissue in trees. This species also tends to feed on sapwood with a high starch content (F.R. Wylie, personal communication).

Early tree growth

An analysis of pooled heights during the initial 3 years showed that heights were not significantly ($P>0.05$) affected by planting density or slope position (Table 2). Both *C. cunninghamiana* and *E. maculata* attained height at a faster rate than *A. lebbeck*, which was dormant throughout winter (Figure 2).

Two-way analyses of variance of the heights of 3-year-old trees revealed no significant interactions between spacing and species or between slope position and species, with the exception of the effect of slope position on height of *C. cunninghamiana* (Table 3). Three-year-old *C. cunninghamiana* trees on the upper slope were significantly ($P<0.05$) shorter by 13% than those on the lower and mid-slopes (Table 3).

Table 2. Mean heights (m) up to 3 years after planting of *A. lebbeck*, *C. cunninghamiana* and *E. maculata* trees grown at 5 densities on 3 slope positions.

	Time after planting (yr)					
Factor	0.0	0.51	1.01	1.51	2.01	3.08
Species						
A. lebbeck	0.20	0.22	1.03	1.12	2.13	2.57
C. cunninghamiana	0.78	1.25	2.29	2.64	3.94	5.52
E. maculata	0.57	0.75	1.67	2.23	3.20	4.28
LSD ($P<0.05$)	0.05	0.13	0.25	0.28	0.29	0.40
Planting density (stems/ha)						
78	0.52	0.73	1.67	1.96	3.10	4.12
182	0.51	0.71	1.67	2.00	3.11	4.24
343	0.52	0.75	1.68	2.00	3.09	4.14
771	0.51	0.76	1.71	2.10	3.16	4.22
1189	0.53	0.77	1.57	1.92	2.98	3.89
LSD ($P<0.05$)	NS[1]	0.05	NS	NS	NS	NS
Slope position						
Lower	0.52	0.72	1.70	1.94	3.12	4.17
Mid	0.51	0.75	1.67	2.06	3.12	4.17
Upper	0.52	0.76	1.61	1.99	3.02	4.02
LSD ($P<0.05$)	NS	0.04	NS	NS	NS	NS

[1] No significant differences ($P>0.05$).

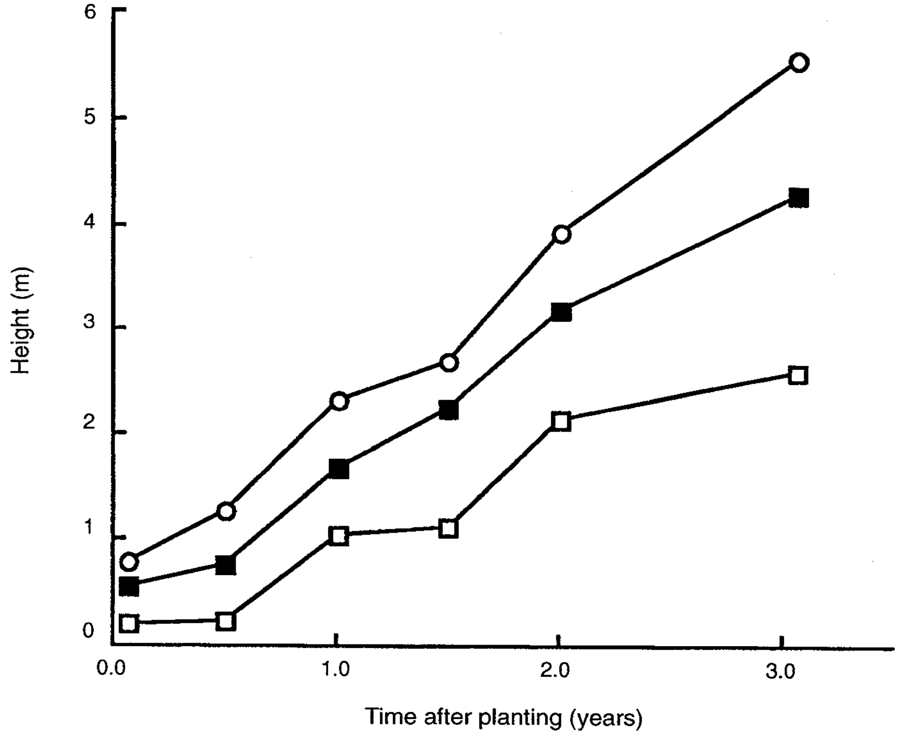

Figure 2. Mean heights of *A. lebbeck* (□), *C. cunninghamiana* (○) and *E. maculata* (■) up to 3 years after planting.

Table 3. The effect of density and slope position on the height of 3-year-old *A. lebbeck*, *C. cunninghamiana* and *E. maculata* trees.

Factor	Species		
	A. lebbeck	*C. cunninghamiana*	*E. maculata*
Planting density (stems/ha)			
78	2.49	5.43	4.43
182	2.59	5.65	4.49
343	2.36	5.93	4.14
771	2.76	4.97	4.92
1189	2.64	5.62	3.41
LSD ($P<0.05$)	NS[1]	NS	NS
Slope position			
Lower	2.3	5.7	4.5
Mid	2.6	5.8	4.1
Upper	2.7	5.0	4.3
LSD ($P<0.05$)	NS	0.7	NS

[1] No significant differences ($P>0.05$).

It is realised that height alone is a poor determinant of biomass and, when the trees are large enough, this measurement will be supplemented with, *inter alia*, DBH measurements. After 3 years, only the *C. cunninghamiana* trees were considered appropriate for DBH measurements, with DBH at 343 stems/ha significantly ($P<0.05$) greater than that at 78, 771 and 1189 stems/ha by an average of 24.2% but not significantly ($P>0.05$) different from DBH at 182 stems/ha (Table 4). Also, DBHs of the mid- and lower slope trees were similar and significantly ($P<0.05$) greater, by 17.4%, than those of the upper slope trees (Table 4).

Table 4. The effect of planting density and slope position on the stem diameter at 1.3 m (DBH) of 3-year-old *C. cunninghamiana* trees.

Factor	DBH
Planting density (stems/ha)	(cm)
78	7.4
182	8.0
343	8.9
771	6.9
1189	7.2
LSD ($P<0.05$)	1.5
Slope position	
Lower	7.9
Mid	8.3
Upper	6.9
LSD ($P<0.05$)	1.0

Crown diameters and crown cover

There was no significant ($P>0.05$) difference between the crown diameters of *A. lebbeck* (1.5 m) and *E. maculata* (1.5 m) after 3 years. However, the crowns of *C. cunninghamiana* were denser, deeper and wider (2.7 m). Neither planting density nor slope position significantly ($P>0.05$) affected the crown diameter of the 3 species. In the C. *cunninghamiana* plots, crown cover was estimated to rise from 4.3 to 64.2% as stocking rates increased from 78 to 1189 stems/ha (Figure 3). For *A. lebbeck* and *E. maculata*, crown covers increased from 1.6 to 21.4% and from 1.6 to 19 %, respectively, as stocking rates increased from 78 to 1189 stems/ha (Figure 3).

Pasture productivity and composition

Nine months after establishment (March 1991), median pasture yields on the lower, mid- and upper slopes were estimated to be 4.4, 3.3 and 2.6 t/ha, respectively. In August 1991, yields were unaffected ($P>0.05$) by position on the slope, associated tree species or tree density (Table 5) and there was no significant species by density interaction. Median pasture yield, which averaged 1.65 t/ha, was dominated by rhodes grass (90% of total yield). No tropical legumes had established at this time and white clover production averaged less than 0.001 t/ha. While there were no significant responses to tree density, there was a trend towards higher median pasture yields at the highest 2 tree densities (Table 5). Adjusted pasture yields also tended to be higher under *E. maculata* than under the other tree species.

At the end of the second growing season (March 1992), median pasture yields were still unaffected by tree species ($P>0.05$) but were higher ($P<0.05$) at 1189 stems/ha than at the lowest 3 planting densities (Table 6). However, as the proportion of pasture affected by the application of ROUNDUP for each plot increased with density, adjusted pasture yields remained unaffected by young tree density (Table 6). Adjusted pasture yields were related to position on the slope with lower > mid > upper ($P < 0.05$). Yields at this time were again dominated by rhodes grass (> 95%). Three of the legumes sown were recorded as being present in the quadrat samples: Wynn cassia in 18% of

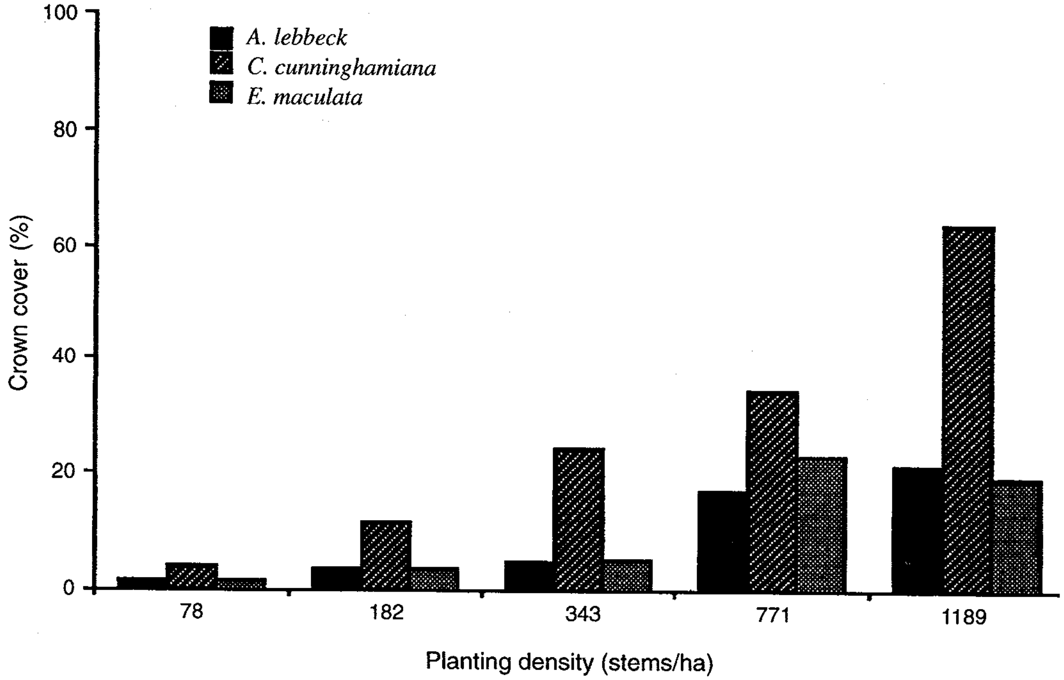

Figure 3. The effect of planting density on crown cover of 3-year-old stands of *A. lebbeck*, *C. cunninghamiana* and *E. maculata*.

Table 5. Median and adjusted pasture yields (kg/ha) 15 months after establishment under 3 tree species planted at 5 densities.

Factor	Median pasture yield[1]	Adjusted pasture yield[2]					
		Rhodes grass	Blue grasses	Native grasses	White clover	Herbaceous weeds	Total
Tree species							
A. lebbeck	1600	1306	45	21	10	105	**1452**
C. cunninghamiana	1552	1271	55	25	8	87	**1393**
E. maculata	1816	1467	48	27	5	85	**1637**
LSD (P<0.05)	403	NS[3]	NS	NS	NS	NS	**NS**
Planting density (stems/ha)							
78	1537	1342	60	27	8	77	**1516**
182	1476	1432	41	15	2	78	**1429**
343	1598	1265	71	32	9	115	**1502**
771	1711	1310	55	20	14	90	**1478**
1189	1958	1393	24	28	6	102	**1547**
LSD (P<0.05)	471	NS	NS	NS	NS	NS	**NS**
Slope position							
Lower	1603	1270	48	31	6	77	**1434**
Mid	1664	1315	54	24	5	112	**1514**
Upper	1701	1460	49	19	13	88	**1536**
LSD (P<0.05)	NS	NS	NS	NS	NS	NS	**NS**

[1] Measured at the mid-point between trees in all plots.

[2] Adjusted for areas around the base of trees treated with ROUNDUP.

[3] No significant differences (P>0.05).

Table 6. Median and adjusted pasture yields (kg/ha) 2 years after establishment under 3 tree species planted at 5 densities (herbaceous weed yields not presented).

Factor	Median pasture yield[1]	Adjusted pasture yield[2]			
		Rhodes grass	Blue grasses	Native grasses	Total
Tree species					
A. lebbeck	8600	7356	198	76	**7793**
C. cunninghamiana	8650	7460	170	97	**7767**
E. maculata	8140	7001	154	133	**7376**
LSD ($P<0.05$)	NS[3]	NS	NS	NS	**NS**
Planting density (stems/ha)					
78	7670	7209	211	75	**7559**
182	8150	7440	195	163	**7890**
343	7930	7109	129	145	**7451**
771	8920	7274	126	66	**7703**
1189	9650	7330	208	61	**7624**
LSD ($P<0.05$)	990	NS	NS	NS	**NS**
Slope position					
Lower	10820	9362	100	202	**9827**
Mid	8050	6774	274	76	**7221**
Upper	6520	5683	148	28	**5887**
LSD ($P<0.05$)	760	684	NS	91	**720**

[1] Measured at the mid-point between trees in all plots.
[2] Adjusted for areas around the base of trees treated with ROUNDUP.
[3] No significant differences ($P>0.05$).

Table 7. Frequency (%) of occurrence of pasture species 2 years after establishment under 3 tree species planted at 5 densities.

Factor	Native grasses	Rhodes grass	Blue grasses	Wynn cassia	Seca stylo	Herbs	White clover
Tree species							
A. lebbeck	8.7	100	7.0	17.0	9.0	16.7	0.33
C. cunninghamiana	8.7	100	10.0	18.0	10.7	14.3	1.0
E. maculata	8.3	100	9.0	19.7	9.3	16.0	0.0
LSD ($P<0.05$)	NS[1]	NS	NS	NS	NS	NS	NS
Planting density (stems/ha)							
78	6.9	100	8.3	19.4	10.6	17.2	1.1
182	11.1	100	11.1	13.9	12.8	21.7	0.6
343	12.2	100	10.0	19.4	13.9	20.0	0.6
771	3.9	100	5.6	18.9	6.1	9.4	0.0
1189	6.7	100	8.3	19.4	5.0	10.0	0.0
LSD ($P<0.05$)	NS	NS	NS	NS	NS	NS	NS
Slope position							
Lower	9.7	100	6.0	23.0	10.0	8.3	0.3
Mid	7.0	100	11.7	26.7	13.3	16.0	0.7
Upper	9.0	100	8.3	5.0	5.7	22.7	0.3
LSD ($P<0.05$)	NS	NS	NS	15.4	NS	8.4	NS

[1] No significant differences ($P>0.05$).

the samples; Seca stylo in 10.7%; white clover in 0.4%; and lotononis in none (Table 7).

There were still no significant ($P > 0.05$) effects on adjusted pasture yield as a result of association with different tree species at the end of 3 years (Table 8). However, in contrast to the second year yields, the lower slope yields were lower ($P < 0.05$) than those on the upper slope. Mid-slope yields were similar to those on the upper slope. Median pasture yields at the highest 2 densities were greater ($P < 0.05$) than those at the lowest 3 densities. There was a significant tree species by tree density interaction, with yield increases at the highest densities occurring only under *A. lebbeck* and *E. maculata*. However, as in year 2, these increased median pasture yields at the highest 2 densities were offset by the increased proportion of pasture affected by the application of ROUNDUP around the base of establishing trees. Thus, adjusted pasture yields remained unaffected by young tree density (Table 8).

Rhodes grass still dominated the pasture (86%) but the legume contribution increased in the third year with Wynn cassia (4%) and Seca stylo (1%) making small contributions to dry matter production. Despite this increased yield contribution, the frequency of occurrence of legumes actually declined from that of the previous year (Wynn cassia (11%) and Seca stylo (8%)).

Rhodes grass remained green under the highest density of *C. cunninghamiana* at the end of the third year despite severe water stress. The grass in the remaining treatments had all 'hayed-off'.

Discussion

Early tree growth

After 3 years of growth neither density nor slope position had any significant effect on tree height, with the exception of *C. cunninghamiana* growing on the upper slope where trees were 13%

Table 8. Median and adjusted pasture yields (kg/ha) during the third year of growth under 3 tree species planted at 5 densities (herbaceous weed yields not presented).

	Median pasture yields[1]	Adjusted pasture yields[2]					
Factor		Rhodes grass	Blue grasses	Native grasses	Wynn cassia	Seca stylo	Total
Tree species							
A. lebbeck	8306	6270	737	7	314	136	**7471**
C. cunninghamiana	7981	6085	649	7	241	82	**7240**
E. maculata	8264	6455	586	33	284	101	**7460**
LSD ($P < 0.05$)	NS[3]	NS	NS	NS	NS	NS	**NS**
Planting density (stems/ha)							
78	7399	6064	740	9	312	161	**7284**
182	7817	6101	990	4	282	176	**7567**
343	7633	5826	872	6	335	85	**7175**
771	8813	6627	497	50	319	79	**7615**
1189	9255	6732	187	8	150	29	**7311**
LSD ($P < 0.05$)	668	NS	547	NS	NS	NS	**NS**
Tree sp. × Density interaction	*[4]	NS	NS	NS	NS	NS	**NS**
Slope position							
Lower	7862	6038	599	1	321	143	**7108**
Mid	8290	6131	713	40	408	140	**7491**
Upper	8399	6642	659	5	109	35	**7572**
LSD ($P < 0.05$)	517	NS	NS	NS	148	99	**NS**

[1] Measured at the mid-point between trees in all plots.

[2] Adjusted for areas around the base of trees treated with ROUNDUP.

[3] No significant differences ($P > 0.05$).

[4] Significant interaction ($P < 0.05$).

shorter than those on the lower and mid-slopes. Also, the stem diameters of upper slope trees were 14.8% lower. Cameron *et al.* (1989) reported the heights of 2.5- and 3.5-year-old *Eucalyptus grandis* trees grown at 82, 158, 305, 595 and 1140 stems/ha in a 'Nelder wheel', at another site in south-east Queensland (20 km north-west of Brisbane). They reported that, at both ages, trees at 305, 595 and 1140 stems/ha were significantly taller than those at 82 and 158 stems/ha. Furthermore, the maximum standing biomass at 2.5 and 3.5 years occurred at 305 and 158 stems/ha, respectively. While our results do not show the effects that Cameron *et al.* (1989) observed, the site is substantially drier (by approx. 230 mm/yr) with much slower growing trees. It is probable that, at this early stage of the experiment, the trees were not large enough for any competitive or ecological interactions to affect height.

Despite there being no effect of density or slope position on early tree height, differences between species were evident. *A. lebbeck* performed poorly relative to the other species, attaining an average height of 2.57 m after 3 years. In Indian plantations, *A. lebbeck* grows relatively slowly during its first year (average height 0.7 m), after which a period of rapid growth occurs (3.99 m after 3 years, see Prinsen (1986)). However, at this site, *A. lebbeck* is exposed to higher water stress than in its natural habitat — tropical south-east Asia (Prinsen 1986). On the other hand, it has been observed (P. Voller, personal communication) to flourish on drier sites in south-west Queensland. It may be that a combination of low soil fertility of the shallow duplex soils, lack of inoculation and frost was responsible for the poor growth and high mortality of these trees.

The growth of *C. cunninghamiana* (5.5 m after 3 years) compared favourably with results from other trials. In South Africa, *C. cunninghamiana* grew 1.2–1.5 m/yr for the first 10 years (Poynton 1972). In a recent trial in Australia (Ryan and Bell 1989), on a site with higher rainfall than and similar soil fertility to that at Warrill View, trees from 2 seed lots of *C. cunninghamiana* attained mean heights of 6.1 and 5.6 m after 3 years.

Pasture growth and composition

Where trees and pastures grow together, there is normally competition for light, moisture and nutrients. Scanlan and Burrows (1990) showed that native pasture yields decreased as tree basal area increased in naturally occurring *Eucalyptus* communities in central Queensland. Likewise, the response of pasture growth to tree removal in native forests is well documented (Beale 1973; Walker *et al.* 1972, 1986; Scanlan 1992). The failure of tree species or tree density to affect pasture production in our study could be due in part to only limited shading of the pasture by the young trees. Competition for moisture could have been expected to be a critical factor, particularly with the below average rainfall conditions prevailing for most of the 3 years (Figure 1). Our results suggest that the root systems of the trees were not sufficiently developed in the upper soil layers to affect uptake of moisture and nutrients by pasture feeding roots.

Position on the slope influenced pasture yield significantly. In year 2 yield was greater on the lower slope where the soil was deeper and had a higher water-holding capacity (see Fisher and Baker 1989). Despite the lower than average rainfall in the period August 1991–November 1991, the rainfall in the period December 1991–May 1992 was above average. In particular, the heavy rain in December 1992 would have ensured that soil moisture levels remained high, allowing the heavy soils on the lower slopes to produce up towards their potential. However, during the third year, the production differences were reversed. Perhaps the lighter textured soils on the upper slope responded better to the infrequent light rainfall in what was an extremely dry year.

The failure of the tropical legumes to establish until the second year, or to produce measurable yields until the third year, was probably the result of hard seed. Unscarified seed was used and time was needed to break the dormancy. White clover established early but drought conditions resulted in complete mortality as reported by Jones (1982) and Jones and Lowe (1992). Under more favourable conditions, seed set would have provided seed reserves for re-establishment.

Legumes appeared more affected by shading than the grasses with lower yields and frequencies recorded under the highest tree densities, particularly under *C. cunninghamiana* which had the highest crown covers.

The observation that pasture did not 'hay off' under the highest density *C. cunninghamiana* treatments is intriguing. It is possible that the deep dense crowns of *C. cunninghamiana* at the higher densities, where crown cover was estimated to be 34% and 64.2%, created a microclimate which was favourable to pasture growth i.e. lessened wind speed, lowered temperatures and increased humidity. On the other hand, at these higher densities, the competition between trees and pasture for water and nutrients would be at its greatest. Wilson *et al.* (1986) recorded increased growth and nitrogen concentration of a 'rundown' green panic (*Panicum maximum*) pasture under shade during 2 years of high water stress at the CSIRO Narayen Research Station (south-east Queensland). In an earlier experiment, Wong and Wilson (1980) reported increased biomass of younger swards of green panic and siratro (*Macroptilium atropurpureum*) under shade when compared with full sunlight. In these instances, increased growth was attributed to a shade effect on N-uptake rather than a redistribution of nutrients from deeper soil layers via the tree and subsequent leaf litter.

Acknowledgements

The establishment of the experiment was funded by the Queensland Government under the Tree Care initiative. The authors would like to thank Trevor Beetson, Queensland Forest Service and Robin Sibbick, Manager, Animal Genetics Centre, for their input into the design and establishment of the experiment, respectively. The field assistance of Grant White and Tony Burridge from the Queensland Forest Research Institute was greatly appreciated.

References

Beale, I.F. (1973). Tree density effects on yields of herbage and tree components in south west Queensland mulga (*Acacia aneura* F. Muell.) scrub. *Tropical Grasslands,* 7, 135–142.

Cameron, D.M., Rance, S.J., Jones, R.M., Charles-Edwards, D.A. and Barnes, A. (1989) Project STAG: an experimental study in agroforestry. *Australian Journal of Agricultural Research,* **40**, 699–714.

Connor, D.J. (1991) Research and extension needs in agroforestry. *Agricultural Science,* 4, 20–25.

El-Lakany, M.H. (1983) Breeding and improving of *Casuarina*: a promising multipurpose tree for arid regions of Egypt. In: Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds) *Casuarina Ecology, Management and Utilisation.* pp. 58–65. (CSIRO: Melbourne).

Fao (1979) Eucalypts for planting. *Forestry Series No. 11. Food and Agriculture Organisation of the United Nations, Rome.*

Fisher, C.A. and Baker, D.E. (1989) Soils and land suitability of the Animal Genetics Centre: Warrill View. *Research Establishment Publication QR90001. Queensland Department of Primary Industries, Brisbane.*

Hawley, G.M. and Lowe, K.F. (1993) Pasture and fodder crops for south-east Queensland. *Information Series (in press). Queensland Department of Primary Industries, Brisbane.*

Jones, R.M. (1980) Survival of seedlings and primary taproots of white clover (*Trifolium repens*) in subtropical pastures in south-east Queensland. *Tropical Grasslands,* **14**, 19–22.

Jones, R.M. (1982) White clover (*Trifolium repens*) in subtropical south-east Queensland. I. Some effects of site, season and management practices on the population dynamics of white clover. *Tropical Grasslands,* **16**, 118–127.

Jones, R.M. and Lowe, K.F. (1992) Managing white clover in subtropical pastures. In: Mason. W. (ed.) *White Clover. A key to increasing milk yields.* (Dairy Research and Development Corporation: Melbourne).

Mendoza, L.A. (1983) Growth and uses of *Casuarina cunninghamiana* in Argentina. In: Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds) *Casuarina Ecology, Management and Utilisation.* pp. 53–54. (CSIRO: Melbourne).

Poynton, R.J. (1972) Characteristics and uses of trees obtainable from the Forest Department. *South African Forests Department Bulletin No. 39. 3rd Edn. Pretoria.*

Prinsen, J.H. (1986) Potential of *Albizia lebbeck* (Mimosaceae) as a tropical fodder tree. A review of literature. *Tropical Grasslands,* **20**, 78–83.

Reddell, P., Rosbrook, P.A. and Ryan, P.A. (1989) Managing nitrogen fixation in *Casuarina* species to increase productivity. In: Boland, D.J. (ed.) *Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph Series No. 10.* pp. 209–214. (ACIAR: Canberra).

Ryan, P.A. and Bell, R.E. (1989) Growth coppicing and flowering of Australian tree species in trial in southeast Queensland, Australia. In: Boland, D.J. (ed.) *Trees for the Tropics: growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph Series No. 10.* pp. 49–68. (ACIAR: Canberra).

Ryan, P.R., Podberscek, M., Raddatz, C.G. and Taylor, D.W. (1987) *Acacia* species trials in southeast Queensland, Australia. In: Turnbull, J.W. (ed.) *Australian Acacias In Developing Countries. ACIAR Proceedings No. 16.* pp. 81–85. (ACIAR: Canberra).

Scanlan, J.C. (1992). A model of woody-herbaceous biomass relationships in eucalypt and mesquite communities. *Journal of Range Management,* **45**, 75–80.

Scanlan, J.C. and Burrows, W.H. (1990). Woody overstorey impact on herbaceous understorey in *Eucalyptus* spp. communities in Central Queensland. *Australian Journal of Ecology,* **15**, 191–197.

Shipton, W.A. and Burggraaf, A.J.P. (1983) Aspects of the cultural behaviour of *Frankia* and possible ecological implications. *Canadian Journal of Botany,* **61**, 2783–2792.

Tothill, J.C., Hargreaves, J.N.G. and Jones, R.M. (1978) BOTANAL — A comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling. *Tropical Agronomy Technical Memorandum No. 8. CSIRO, Division of Tropical Crops and Pastures, St. Lucia.*

Turnbull, J.W., Martensz, P.N. and Hall, N. (1986) Notes on lesser-known Australian trees and shrubs with potential for fuelwood and agroforestry. In: Turnbull, J.W. (ed.) *Multipurpose Australian trees and shrubs: lesser-known species for fuelwood and agroforestry. ACIAR Monograph Series No. 1.* pp. 240–243. (ACIAR: Canberra).

WALKER, J., MOORE, R.M. and ROBERTSON, J.A. (1972). Herbage response to tree and shrub thinning in *Eucalyptus populnea* shrub woodlands. *Australian Journal of Agricultural Research*, **23**, 405–410.

WALKER, J., ROBERTSON, J.A., PENRIDGE, L.K. and SHARPE, P.J.H. (1986). Herbage response to tree thinning in a *Eucalyptus crebra* woodland. *Australian Journal of Ecology*, **11**, 135–140.

WATSON, C.J.J. (1971) Valuable Queensland trees. *Pamphlet No. 4. Queensland Forest Service.* pp. 38–39.

WILSON, J.R., CATCHPOOLE, V.R. and WEIER, K.L. (1986) Stimulation of growth and nitrogen uptake by shading a rundown green panic pasture on brigalow clay soil. *Tropical Grasslands*, **20**, 134–143.

WONG, C.C. and WILSON, J.R. (1980) The effect of shading on the growth and nitrogen content of green panic and Siratro in pure and mixed swards defoliated at two frequencies. *Australian Journal of Agricultural Research*, **31**, 269–285.

(Received for publication November 18, 1993; accepted March 2, 1994)