Selection of pasture species for groundcover suited to shade in mature macadamia orchards in subtropical Australia

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Practical Abstract

Soil erosion is a significant problem in subtropical macadamia orchards in Australia, especially when groundcover vegetation is shaded out under older orchards. The aim of this study was to identify suitable low-growing, perennial groundcovers that would persist in the low light conditions under mature macadamias. Twenty-six legume and grass accessions and 1 herb were evaluated in small plots in a 16-year-old commercial orchard near Lismore, NSW. Plant density, groundcover (%), herbage mass, sward canopy height and groundcover spread were determined in high, medium and low light in the interrow for 2 years (1996–97). Groundcover was also measured for 3 years, on 19 of the accessions in a younger orchard at another site.

Dactyloctenium australe provided the best groundcover in both high and low light and met most other specifications for an ideal groundcover for macadamias. Other promising grass species included *Paspalum mandiocanum, Panicum laxum* and *Microlaena stipoides* cv. Wakefield. However, *Paspalum mandiocanum* has been cited as having potential weediness in subtropical Australia, and is not recommended as a groundcover for macadamias. The legumes generally did not perform as well in low light as grass species. However, *Arachis pintoi* cv. Amarillo and a sterile *Arachis pintoi* x *Arachis repens* hybrid provided highest percent groundcover in high and medium light. Further assessment of these species in larger plots to determine their establishment and persistence under heavy orchard traffic and suitability for mechanical harvest operations has commenced.

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Introduction

Soil erosion is a significant problem in macadamia orchards in subtropical Australia, especially on undulating krasnozem soils in northern NSW, and may be controlled by the use of mulch. An alternative is to use live groundcovers. When the soil is protected by at least 75% live groundcover, soil losses are negligible (Edwards 1987). One of the main limitations to the use of groundcover in macadamia orchards has been the lack of suitable shade-adapted, low-growing species which can persist under the canopy of older trees.

The life of a commercial macadamia orchard may exceed 20 years, and it is important that a groundcover persists as the tree canopy enlarges. Macadamia has high light interception (tree leaf area index 14–16) (McConchie *et al*. 1999) compared with most other orchard species (LAI *ca*. 5). Hence, a groundcover species must be shade-tolerant, and meet specifications which enable mechanical harvesting of nuts from the orchard floor. These include low growth, non-twining habit, ability to form a compact, smooth surface with mowing, and a minimal mowing requirement in autumn-winter. A grower forum convened in 1994 reaffirmed the main specifications used in previous groundcover selection work (Firth and Wilson 1995) as appropriate for macadamias, but also requested that grasses be considered as well as legumes in the selection program. The main criteria were that groundcover species should be: low-growing (<30 cm), persistent, perennial legume, grass or herb species which do not climb, are relatively easy to establish, compete with weeds, tolerate orchard traffic, regenerate after mowing and do not harbour pests and diseases. In addition, the species should be adapted to shade, establish quickly and require minimal mowing in the macadamia harvest season (March–September). While *Arachis pintoi* cv. Amarillo has most of the desired attributes of a macadamia groundcover, it requires some mowing in the harvest season and provides limited cover in low light near the tree trunks.

This study represented the first stage of a program to select groundcover species better suited to macadamia orchards than *A. pintoi* cv. Amarillo. Since grasses tend to have higher shade tolerance than legumes (Barrios *et al.* 1986), the selection program included available grass species which had shown promise in orchard/plantation crops in the tropics, including *Panicum laxum* cv. Siro Shadegro, a new turfgrass species (Wilson 1997). In a previous local study, Amarillo was the most promising legume from the point of view of persistence and shade tolerance (Firth and Wilson 1995), and a number of forage *Arachis* species have been highly persistent in Australia (Cook *et al.* 1994), so emphasis was placed on other species of *Arachis.*

Materials and methods

The main experimental site was located at Wollongbar (28° 50' S, 153° 25' E), approximately 10 km north of Alstonville on the north coast of NSW in a block of 16-year-old macadamia trees of the Hinde variety planted at 10 m × 5 m spacing on krasnozem soil with pH (1:5, soil:water) 4.5–5. Tree rows were orientated SW–NE on a gentle NE slope. Tree canopies had merged within the tree row and there was approximately 4 m of open space between the canopies of adjacent rows. Tree skirts were pruned to a height of 1.5 m above ground before the first groundcover plantings in November 1995. A second experimental site was located on similar soil at Rosebank (28° 40' S, 153° 23' E), approximately 25 km from the Wollongbar site in a 7-year-old orchard of the HAES 246 variety with 7 m × 4 m spacing. Tree canopies had commenced merging along the tree row and there was approximately 4 m of open space between adjacent tree rows.

Groundcover species were selected based on the specifications previously described. Emphasis was placed on pasture species that would compete with vigorous weeds in the higher light area of the interrow and potentially withstand heavy orchard traffic. Priority was given to lines for which seed/vegetative material was commercially available or could easily be increased. Although species such as *Digitaria didactyla* and *Eremochloa ophiuroides* are not recognised as being shade-tolerant, they were included for comparison with more shade-tolerant species. Three *Microlaena stipoides* cvv. were planted to determine general suitability of the species as an orchard groundcover, as seed of the local ecotype was unavailable.

Twenty-six legume or grass accessions and 1 herb (Table 1) were planted at Wollongbar, and 19 accessions at Rosebank (Table 4). *Microlaena stipoides* (3 cvv.), *Digitaria didactyla* CPI 40639 (now cv. Aussiblue), *Eremochloa ophiuroides* ATF 1087, *Centrosema pubescens* cv. Cardillo, *Desmodium heterocarpon* CPI 86277 and *Arachis glabrata* CPI 93464 were not planted at Rosebank. There were 2 sowing times for *Arachis pintoi* cv. Amarillo and an unsown control plot, making a total of 29 treatments at Wollongbar (Table 1), and 20 treatments at Rosebank (Table 4). The control treatment consisted of an unsprayed and undisturbed plot dominated by the grasses, kikuyu (*Pennisetum clandestinum*) and crowsfoot (*Eleusine indica*).

The experimental area was comprised of 3 contiguous tree rows and adjacent interrow alleys between Rows 1 and 2, and Rows 2 and 3. Plots were randomly allocated in Rows 1 and 3 with one replicate of each groundcover species per row. Each plot was 10 m × 5 m at Wollongbar and 7 m × 4 m at Rosebank, and consisted of the entire under-canopy area of a tree and adjacent clear alley area on one side of the row. Tree trunks were used to mark plot extremities within the rows. There was a small buffer between adjacent plots along the interrow alley equivalent to the width of the tree trunk (approximately 30 cm). The centre row was not planted to provide a buffer between replicate plot lines and to obtain an indication of spread of the species into an unplanted shaded area. There were only 2 replicates because of the limited availability of seed of some accessions.

Table 1. Species planted, sowing time, sowing rates and sowing method, and establishment density counts (plants or shoots/m^2) under high and medium light at Wollongbar.

Species/Accession No	Sowing time	Sowing rate	Plant density[3] High[4]	Plant density[3] Medium[4]
Legumes		(kg/ha)	(No/m^2)	
Aeschynomene villosa CPI 37235	Jan 96	5	41 cdefgh[6]	19 def
Aeschynomene villosa CPI 91209	Jan 96	5	107 bcde	25 cdef
Arachis pintoi ATF 1006	Oct 96	28	nm[5]	nm
Arachis pintoi ATF 2320	Oct 96	28	nm	nm
Arachis pintoi cv. Amarillo	Nov 95	28	26 h	0 f
Arachis pintoi cv. Amarillo	Jan 96	28	102 bcde	47 abcd
Arachis pintoi x *A. repens* CQ 3609 [1]	Nov 95		172 abc	44 bcde
Arachis pintoi x *A. repens* CQ 3610 [1]	Nov 95		115 bcdef	23 cdef
Arachis repens CPI 28273 [1]	Nov 95		72 bcdef	37 abcd
Arachis glabrata CPI 22762 [1]	Nov 95		128 bcd	42 abc
Arachis glabrata CPI 19898 [1]	Nov 95		67 cdefgh	8 f
Arachis glabrata CPI 12121 [1]	Nov 95		85 bcde	16 bcdef
Arachis glabrata CPI 93464 [1]	Nov 95		35 defgh	2 ef
Centrosema pubescens cv. Cardillo	Jan 96	5	17 fgh	21 cdef
Desmodium heterocarpon CPI 86277	Jan 96	5	35 cdefgh	43 abcd
Vigna parkeri cv. Shaw	Jan 96	5	28 gh	13 ef
Grasses				
Dactyloctenium australe [1]	Jan 96		89 bcdefg	26 cdef
Digitaria didactyla CPI 40639 [1]	Jan 96		1105 a	262 ab
Eremochloa ophiuroides ATF 1087	Jan 96	4	0	0
Microlaena stipoides cv. Wakefield [2]	Jan 96	5	76 bcdef	40 abcde
Microlaena stipoides cv. Griffin [2]	Jan 96	5	33 cdefgh	33 abcde
Microlaena stipoides cv. Shannon [2]	Jan 96	5	52 cdefgh	34 cdef
Panicum laxum cv. Siro Shadegro	Jan 96	5	504 abc	280 a
Paspalum notatum cv. Riba	Jan 96	3.8	11 gh	16 cdef
Paspalum notatum cv. Competidor	Jan 96	5	76 bcde	23 def
Paspalum mandiocanum CPI 39969	Jan 96	5	149 bcdef	36 def
Paspalum wettsteinii cv. Warrell	Jan 96	5	98 bcde	58 bcdef
Other				
Dichondra repens [2]	Jan 96	5	28 cdefgh	7 f
Undisturbed cover (control)			180 abc	15 def

[1] Vegetatively propagated.
[2] Native species/cultivar.
[3] Plant density at 8 weeks.
[4] High = 21% full sunlight; Medium = 13% full sunlight.
[5] Not measured.
[6] Within columns, values followed by the same letter are not significantly different (P>0.05).

Three light environments within each plot were defined according to location relative to the tree canopy. The light intensity (micromoles/m^2/sec) was measured just above sward height on a sunny day in summer using a LI-COR instrument (LI-COR, Lincoln, Nebraska, USA). Full sun values ranged between 1750–1950 μmol/m^2/sec. Indicative light transmission values (mean of 3 readings) were as follows:

- highest light environment between the canopy edges of adjacent rows (21% of full light);
- medium light 0–2 m from canopy edge (13% at 1 m inside canopy edge); and
- lowest light (1 m either side of tree trunk) (2.7%).

Vegetation was killed using 1% glyphosate and the entire plot area lightly ripped before planting. No fertiliser was applied to the plots at planting time, but normal applications of fertiliser covering the entire orchard floor supplied approximately 1 tonne/ha annually of 20:10:15 NPK. Rhizomatous grasses and *Arachis* species were propagated from runners placed approximately 3 cm deep. The large-seeded *Arachis pintoi* was planted by dropping seeds into 3 cm deep furrows, 0.8 m apart, at approximately 10 cm intervals. Small-seeded species were hand-broadcast and lightly raked.

Accessions were planted in November 1995, January 1996 and October 1996 at Wollongbar, and January 1996 and October 1996 at Rosebank. Rhizomatous *Arachis* species were planted in November 1995 at Wollongbar, as spring is the preferred time to establish *Arachis* from rhizomes, but were not planted until January at Rosebank. All other species were planted in January 1996, except *Arachis pintoi* ATF 1006 and *Arachis pintoi* ATF 2320 (Wollongbar) and *Dactyloctenium australe* and *Paspalum mandiocanum* (Rosebank) which were planted in October 1996, when seed became available. *Arachis pintoi* cv. Amarillo was planted as a benchmark on each planting date at each site (except October 1996 at Wollongbar).

The sowing rate for seeded species was 5 kg/ha unless otherwise indicated (Table 1). The stoloniferous species, *Digitaria didactyla* and *Dactyloctenium australe,* both of which were commercially available lines, were planted at both sites at a rate of approximately 300 g runners/10 lineal m in 4 rows 0.8 m apart, parallel to the tree rows. Rhizomatous *Arachis* species were planted at approximately 300 g rhizomes/10 lineal m in 6 rows 0.8 m apart (Table 1).

Legume seed was inoculated with the appropriate rhizobium strain as follows, then dusted with molybdenum trioxide and lime pelleted: *Arachis pintoi* cv. Amarillo with CIAT 3101; *Arachis pintoi* ATF 1006 and 2320 with CIAT 3101/NC 92 mix; *Centrosema pubescens* with CB 1923; *Desmodium heterocarpon* with CB 3232; *Vigna parkeri* cv. Shaw with CB 1015; and *Aeschynomene villosa* with CB 2312. Vegetatively propagated *Arachis* species were not inoculated.

Measurements

Plant density, percent groundcover, herbage mass and sward height were determined at Wollongbar, and percent groundcover only at Rosebank. Plant counts/m^2 of seeded species and tiller stem counts of runner-propagated species were obtained using three 30 cm × 30 cm quadrats located at random within each shade category, 8 weeks after the January 1996 planting, or 4 months after the November 1995 planting, to determine establishment density. Establishment of accessions sown in October 1996 was not measured.

The percent groundcover and herbage dry matter (kg/ha) were measured 6 months, 1 year and 2 years after the main planting in January 1996. Initially, percent groundcover of species and weeds was derived from the mean of estimates of percent cover in 3 quadrats located at random in each light category. This was later modified due to time constraints to a simple estimate for the entire subplot area using the approach of Braun-Blanquet (1932). Maximum herbage mass was determined for each light category for each season using two 30 cm × 30 cm quadrats cut to 3 cm height where the species was most abundant, obtaining the oven dry weight (65°C for 48 h) of herbage material and converting to kg/ha. The height of the sward (cm) in highest and medium light was measured in summer, autumn, winter and spring. Measurements and observations were confined to one date in each season, irrespective of the planting dates of various species. Diseases and pests of significance, spread of species from their original planting sites and the general amenability of a species sward to mechanical harvesting of nuts using normal farm practice were noted.

Plots were mown to a height of approx. 3 cm following each sampling, when normal orchard mowing was carried out using a standard orchard mower. They were then left unmown until after sampling the next season's growth (usually about 3 months). Plots were subjected to standard orchard management procedures including mechanical harvesting from July 1996.

Monthly rainfall and mean temperature were recorded at the Tropical Fruit Research Station, Alstonville, approximately 5 km from the experimental site at Wollongbar and 30 km from Rosebank.

The effects of species, light level and their interaction on ground cover and dry matter were estimated by fitting a linear model and tested via analysis of variance. The nested structure of the experiment was catered for by including 2 error terms; a main plot error for comparisons of the species and a subplot error for the locations and location x species interaction. The error estimates were used to calculate the LSD figures to enable pair-wise comparisons of the species at each observation time. Logarithmic and square-root transformations were used to stabilise the variance. No analysis was performed on groundcover percent data at 2 years, and there were insufficient data for statistical analysis of the low light treatment. Since only 2 replicates could be used in the study and there was considerable variability of data between replicates for some treatments, statistical analysis usually found no significant differences between most treatments.

Results

Weather

Seasonal conditions were generally favourable for the growth of groundcovers in 1996–98. Except for relatively dry conditions in late winter-early spring 1995 (July–October) (Table 2), rainfall was well distributed, and exceeded the annual average in 1996 (annual average at TFRS Alstonville 1963–2001, 1853 mm). Winter conditions were relatively mild, with no frosts. A severe thunderstorm on December 24, 1997 extensively damaged the trees at Wollongbar and altered the orchard light environment to such an extent that replicated data collection was no longer warranted. Despite this, general observations were continued for a further 2 years.

Establishment

Favourable rainfall during November 1995 and summer and autumn 1996 ensured good germination and/or early establishment of most species. Best establishment (highest seedling/tiller density) was observed in the high light environment in the interrow alley for most species at Wollongbar. *Digitaria didactyla*, *Panicum laxum,* undisturbed control (established plants) and *Arachis* hybrid CQ 3609 with 1105 tillers/m^2 and 504, 180 and 172 plants/m^2, respectively, had the highest plant density in high light at 8 weeks (Table 1). Large, overlapping significance groups occurred among the species and cultivars.

Germination and early establishment were satisfactory for a number of species in the medium light environment under trees near the canopy edge. The highest plant density in medium light was recorded for *Panicum laxum* (280 plants/m^2), although this was not significantly different ($P>0.05$) from 7 other species including *Digitaria didactyla, Arachis glabrata* CPI 22762*, Arachis pintoi* cv. Amarillo, *A. repens* CPI 28273, *Desmodium heterocarpon* and *Microlaena stipoides* cvv. Wakefield and Griffin (Table 1). Establishment was very poor in low light near the tree trunk and, because the plants of species which did establish were not readily identifiable at 8 weeks, no counts were done.

Groundcover (percent)

Highest light. A number of species provided sufficient ground cover to impede soil erosion (>70%) within 6 months at the Wollongbar site, especially *Dactyloctenium australe* and *Paspalum mandiocanum* (80–82%). Those species which provided the highest percent ground cover (83–100%) after 1 year at that site were *Dactyloctenium australe, Paspalum wettsteinii*, *Paspalum mandiocanum*, *Arachis pintoi* cv. Amarillo, *Arachis* hybrids CQ3609 and CQ3610, *Panicum laxum, Paspalum notatum* cv.

Table 2. Monthly and medium-term mean rainfall and mean monthly temperature for the Tropical Fruit Research Station, Alstonville (1995–98).

Month	Rainfall					Temperature			
	Mean[1]	1995	1996	1997	1998	1995	1996	1997	1998
			(mm)				(°C)		
Jan	173	79	363	194	56	23	24	22	24
Feb	240	490	146	177	149	23	23	24	25
Mar	276	219	192	89	33	23	21	23	24
Apr	196	123	33	64	314	19	20	20	21
May	195	159	613	195	114	18	18	17	18
Jun	154	66	211	119	96	15	16	15	16
Jul	97	7	79	179	129	15	14	14	15
Aug	74	60	49	38	133	16	17	15	16
Sep	54	45	35	91	140	18	19	18	19
Oct	106	34	60	91	34	20	19	19	20
Nov	131	226	186	74	159	23	22	22	20
Dec	157	174	125	128	118	22	22	25	23
Total	1853	1682	2092	1439	1475				

[1] Medium-term mean, 1963-2001.

Competidor and *Microlaena stipoides* cv. Wakefield, although they were not significantly different (P>0.05) from a number of other species with 50–80% cover (Table 3). All except *Panicum laxum* (70%) maintained this cover after 2 years (Table 3). The untreated control provided 80–85% percent cover of weeds after 1–2 years.

At Rosebank, *Dactyloctenium australe* and *Paspalum mandiocanum* (planted Oct 1996), and *Paspalum wettsteinii* (80–93%) were outstanding after 1 year, while *Panicum laxum, Paspalum notatum* cv. Competidor and legume species, except for *Vigna parkeri,* generally were much slower to cover than at Wollongbar (Table 4). *Paspalum notatum* cv. Competidor and the best legumes reached maximum cover after 3 years, while *Panicum laxum* declined.

Medium light. The most outstanding species in highest light were also prominent in medium light, although the percent groundcover was generally lower in medium light than in higher light. The exception was *Panicum laxum* which spread better in medium light at Rosebank (Tables 3 and 4). *Dactyloctenium australe, Microlaena stipoides* cv. Wakefield, *Paspalum mandiocanum, Arachis pintoi* cv. Amarillo (Jan 1996), *Panicum laxum, Paspalum wettsteinii* and *Vigna parkeri* provided the highest percent cover (72–93%) in medium light after 1 year at Wollongbar (Table 3). *Dactyloctenium australe* and *Paspalum mandiocanum* maintained this cover after 2 years while other species declined *ca.* 10–15%. It is unlikely that statistical analysis would show any significant difference between 11 species with 50–90% cover (Table 3). *Panicum*

Table 3. Mean groundcover percent in high, medium and low light at Wollongbar at 1 year and 2 years after Jan 1996 planting.

Species/Accn	Groundcover								
	High light [1]			Medium light			Low light	
	1 Year		2 Years	1 Year		2 Years	1 Year	2 Years
Legumes				(%)				
Aeschynomene villosa CPI 37235	5	h[2]	0	4	i	0	0	0
Aeschynomene villosa CPI 91209	70	abcd	0	35	cdef	0	0	0
Arachis pintoi ATF 1006	45	bcdef	73	15	defghi	20	3	0
Arachis pintoi ATF 2320	33	defg	70	16	defghi	25	5	0
Arachis pintoi cv. Amarillo (Nov 95)	40	cdefg	70	7	hi	20	3	10
Arachis pintoi cv. Amarillo (Jan 96)	95	ab	100	82	a	68	8	13
Arachis pintoi x *A. repens* CQ 3609	95	ab	100	47	bcd	68	3	8
Arachis pintoi x *A. repens* CQ 3610	93	ab	95	48	bcd	83	0	8
Arachis repens CPI 28273	75	abc	75	38	cde	55	0	3
Arachis glabrata CPI 22762	23	efgh	3	16	defghi	5	0	0
Arachis glabrata CPI 19898	10	gh	0	8	ghi	3	0	0
Arachis glabrata CPI 12121	15	fgh	3	13	efghi	3	0	0
Arachis glabrata CPI 93464	10	gh	13	5	hi	3	0	3
Centrosema pubescens cv. Cardillo	20	efgh	0	34	cdef	11	0	0
Desmodium heterocarpon CPI 86277	50	abcde	3	70	ab	15	0	0
Vigna parkeri cv. Shaw	53	abcde	10	72	ab	55	0	0
Grasses								
Dactyloctenium australe	100	a	100	93	a	90	15	30
Digitaria didactyla CPI 40639	55	abcde	30	23	defgh	3	2	0
Eremochloa ophiuroides	3	h	0	0	j	0	0	0
Microlaena stipoides cv. Wakefield	83	abc	80	84	a	73	5	18
Microlaena stipoides cv. Griffin	15	efg	30	59	abc	45	10	8
Microlaena stipoides cv.Shannon	40	cdefg	80	57	abc	50	0	0
Panicum laxum cv. Siro Shadegro	93	ab	70	75	ab	65	5	10
Paspalum notatum cv. Riba	15	fgh	40	11	fghi	13	3	0
Paspalum notatum cv. Competidor	90	ab	93	25	defg	40	0	0
Paspalum mandiocanum CPI 39969	98	a	100	83	a	80	5	10
Paspalum wettsteinii cv. Warrell	100	a	100	74	ab	63	5	13
Other								
Dichondra repens	73	abcd	58	25	defg	13	0	0
Undisturbed cover (control)	80	abc	85	7	hi	15	0	0

[1] High = 21% full sunlight; Medium = 13% full sunlight; Low = 2.7% full sunlight.
[2] Within columns, values followed by the same letter are not significantly different (P>0.05).

Table 4. Mean percent groundcover in high, medium and low light at 1 year and 3 years after sowing at Rosebank.

Species/Accn	Groundcover					
	High light[1]		Medium light		Low light	
	1 Year	3 Years	1 Year	3 Years	1 Year	3 Years
Legumes:			(%)			
Aeschynomene villosa CPI 37235	0 c[2]	0 e	0 d	0 g	0 c	0 b
Arachis pintoi ATF 1006	28 ab	35 ab	8 bc	8 de	1 bc	0 b
Arachis pintoi ATF 2320	33 a	98 a	3 cd	30 abcde	0 bc	0 b
Arachis pintoi cv. Amarillo (Oct 96)	43 a	95 a	5 bc	18 bcde	3 bc	0 b
Arachis pintoi cv. Amarillo (Jan 96)	3 c	11 bc	2 d	9 de	0 c	0 b
Arachis pintoi x A.repens CQ 3609	5 c	35 ab	0 d	15 cde	0 c	0 b
Arachis pintoi x A.repens CQ 3610	8 bc	60 a	1 cd	10 de	0 c	0 b
Arachis repens CPI 28273	3 c	0 e	0 d	0 g	0 c	0 b
Arachis glabrata CPI 22762	0 c	1 de	0 d	0 g	0 c	0 b
Arachis glabrata CPI 19898	3 c	0 e	1 d	0 g	0 c	0 b
Arachis glabrata CPI 12121	3 c	0 e	1 cd	0 g	1 bc	0 b
Vigna parkeri cv. Shaw	55 a	55 a	28 b	38 abcde	0 bc	0 b
Grasses						
Dactyloctenium australe[3]	90 a	100 a	23 ab	85 a	3 b	38 a
Panicum laxum cv. Siro Shadegro	33 ab	8 bc	90 a	80 a	40 a	30 a
Paspalum notatum cv. Riba	8 bc	18 cd	1 d	20 ef	1 bc	0 b
Paspalum notatum cv. Competidor	30 ab	95 a	8 bc	55 abc	0 bc	0 b
Paspalum mandiocanum[3] CPI 39969	80 a	100 a	20 ab	75 ab	10 bc	30 a
Paspalum wettsteinii cv. Warrell	93 a	100 a	80 a	65 abc	20 a	18 a
Other						
Dichondra repens	3 c	0 e	1 d	0 g	3 bc	0 b
Unplanted control	95 a	75 a	25 ab	14 cde	0 c	0 b

[1] High = 21% full sunlight; Medium = 13% full sunlight; Low = 2.7% full sunlight.
[2] Within columns, values followed by the same letter are not significantly different (P>0.05).
[3] Planted Oct 1996.

laxum and *Paspalum wettsteinii* had the highest percent cover at Rosebank after 1 year (80–90%) (Table 4). *Dactyloctenium australe* and *Paspalum mandiocanum*, which were planted later, had only about 20% cover after 1 year, but this increased to 80% and 50%, respectively, after 2 years, and 75% for *Paspalum mandiocanum* after 3 years. While *Desmodium heterocarpon* had high plant density (Table 1), it tended to have an open, prostrate habit and did not produce a high level of groundcover, except after 1 year (Table 3). Percent cover increased from 1 year to 2 years at Wollongbar for *Arachis* hybrids CQ 3609 (47 to 68%) and CQ 3610 (48 to 83%). Their percent cover also improved at Rosebank, but only from negligible levels after 1 year (≤1%) to 15% after 3 years. The percent cover of *Arachis repens* CPI 28273 (Wollongbar only) and *Paspalum notatum* cv. Competidor (both sites) also increased.

Low light. Only a few species provided any cover in the low light conditions near the tree trunks. *Dactyloctenium australe, Microlaena stipoides* cvv. Wakefield and Griffin, *Arachis pintoi* cv. Amarillo (Nov 1995, Jan 1996), *Paspalum mandiocanum, Paspalum wettsteinii, Panicum laxum* and *Arachis* hybrid CQ 3609 were the only species that provided cover at 1 year at Wollongbar and maintained or increased cover after 2 years (Table 3). *Arachis pintoi* cv. Amarillo and the above grasses (except *Microlaena stipoides*) were the only species represented at Rosebank after 3 years (Table 4). *Dactyloctenium australe* was the most prominent species with 30% cover at 2 years and 38% cover at 3 years at Wollongbar and Rosebank, respectively, (statistical difference undetermined).

Rate of spread. There was minimal lateral movement of most species into adjacent plots. However, *Dactyloctenium australe* had spread approximately 5 m from the original plot after 2 years, and invaded adjacent plots in both high and medium light. *Arachis* hybrids CQ 3609 and CQ 3610 had spread approximately 2 m, and *Arachis repens* CPI 28273 approximately 0.5 m, in highest light after 2 years. Four years after planting, *Dactyloctenium australe* had spread 10 m from the original planting site in highest light conditions.

Herbage mass

High light. The highest producers of dry matter (>3000 kg/ha) in highest light after 1 year were *Paspalum wettsteinii,* untreated control, *Paspalum mandiocanum*, *Paspalum notatum* cv. Competidor, *Panicum laxum, Digitaria didactyla* and *Dactyloctenium australe* (Table 5). However, there was no statistical difference (P>0.05) between these and 17 other species/accessions. The above species together with 6 other species/cvv. (Table 5) were the highest yielding accessions after 2 years.

Medium light. Herbage yield under medium light was generally less than under higher light (Table 5). After 1 year, *Microlaena stipoides* cv. Wakefield, *Dactyloctenium australe* and *Paspalum wettsteinii* (1400–1800 kg/ha) headed a group of 9 species/cvv. which were not significantly different (P>0.05) (Table 5). *Panicum laxum*, *Microlaena stipoides* (all cultivars) and *Digitaria* appeared to decline in yield from 1 year to 2 years (Table 5), while yield of several other species, including *Arachis pintoi* cv. Amarillo and *Dactyloctenium australe,* appeared to increase.

Low light. Panicum laxum and *Microlaena stipoides* cv. Griffin established quickly and were the only treatments that produced measurable herbage after 6 months. Nine treatments produced measurable yields (25–375 kg/ha) after 1 year as did 8 treatments after 2 years (Table 5). The highest yielding species in both years were *Dactyloctenium australe* and *Panicum laxum.*

Sward height

Sward height classes were established as follows: ≤15 cm, 16–30 cm and >30 cm. Confidence limits were established for each treatment based

Table 5. Herbage dry matter for high, medium and low light at 1 year and 2 years after Jan 1996 planting at Wollongbar.

Species/Accn	Herbage mass					
	High light[1]		Medium light		Low light	
	1 Year	2 Years	1 Year	2 Years	1 Year	2 Years
Legumes			(kg/ha)			
Aeschynomene villosa CPI 37235	119 def[2]	0 d	0 e	0 f	0	0
Aeschynomene villosa CPI 91209	1364 abcd	0 d	547 ab	0 f	0	0
Arachis pintoi ATF 1006	450 abcdef	1333 a	228 abcd	414 abcd	0	0
Arachis pintoi ATF 2320	533 abcdef	1350 a	283 abcd	769 ab	0	0
Arachis pintoi cv. Amarillo (Nov 95)	1308 abcd	1403 a	89 d	300 cdef	0	0
Arachis pintoi cv. Amarillo (Jan 96)	2197 abc	2308 a	906 a	1414 a	289	150
Arachis pintoi x *A. repens* CQ 3609	2214 abc	2442 a	900 a	606 abc	25	0
Arachis pintoi x *A. repens* CQ 3610	2233 abc	2550 a	517 abc	703 ab	0	0
Arachis repens CPI 28273	1281 abcd	1656 a	356 abc	394 abc	103	36
Arachis glabrata CPI 22762	619 bcdef	244 bcd	414 abcd	11 f	0	0
Arachis glabrata CPI 19898	739 abcde	44 d	239 abcd	75 def	0	0
Arachis glabrata CPI 12121	419 abcdef	61 d	214 abcd	40 ef	0	0
Arachis glabrata CPI 93464	289 abcdef	67 d	28 cd	0 f	0	0
Centrosema pubescens cv. Cardillo	617 abcde	0 d	844 a	19 f	122	89
Desmodium heterocarpon CPI 86277	736 abcde	0 d	472 abc	179 abcde	83	0
Vigna parkeri cv. Shaw	389 f	147 d	389 bcd	158 abcde	0	0
Grasses						
Dactyloctenium australe	3053 abc	2994 a	1522 a	1906 a	375	506
Digitaria didactyla	3072 abc	1917 a	606 a	0 f	0	0
Eremochloa ophiuroides	0 f	0 d	0 e	0 f	0	0
Microlaena stipoides cv. Wakefield	1850 abc	1237 a	1814 a	622 abc	0	165
Microlaena stipoides cv. Griffin	1000 ef	1906 a	975 a	417 abc	61	0
Microlaena stipoides cv. Shannon	1397 abcd	1229 a	994 a	513 abc	0	0
Panicum laxum cv. Siro Shadegro	3300 ab	1994 a	1008 a	758 abc	320	414
Paspalum notatum cv. Riba	844 cdef	921 abc	164 abcd	1211 ab	0	0
Paspalum notatum cv. Competidor	3517 ab	1772 a	325 abc	700 abc	0	0
Paspalum mandiocanum CPI 39969	3708 ab	1888 a	894 a	1113 a	0	88
Paspalum wettsteinii cv. Warrell	4453 a	1847 a	1450 a	1547 a	61	128
Other						
Dichondra repens	561 abcde	432 abc	328 abcd	44 bcdef	0	0
Undisturbed cover (control)	3931 ab	1739 a	0 e	428 abc	0	0

[1] High = 21% full sunlight; Medium = 13% full sunlight; Low = 2.7% full sunlight.
[2] Within columns, values followed by the same letter are not significantly different (P>0.05). Low light values not analysed.

on the standard error relative to the mean height. *Dichondra repens* was the lowest-growing species, although 14 other accessions, mostly legumes (except for *Paspalum notatum* cv. Riba), were allocated to Class 1 (≤15 cm) under the highest light conditions (Table 6). Twelve species/accessions, mainly grasses, were allocated to Class 2 (16–30 cm), while the untreated control (dominated by weeds including kikuyu and crowsfoot in summer, and *Drymaria cordata* in winter) and *Paspalum wettsteinii* (mean 42 cm) were allocated to Class 3 (>30 cm).

Discussion

When attributes for the ideal groundcover were considered, including percent ground cover in low and relatively high light, ability to cover soil quickly, persistence, low sward height, and sufficient herbage mass for effective erosion control, the most promising species and accessions for a mature macadamia orchard in subtropical northern New South Wales were the grasses, *Dactyloctenium australe, Paspalum mandiocanum, Panicum laxum* and *Microlaena stipoides* cv. Wakefield, and the legumes *Arachis* hybrids CQ 3609 and CQ 3610, *Arachis pinto*i cv. Amarillo and *Arachis pintoi* ATF 2320. Observations since the cessation of measurements confirmed that these grass and legume accessions merited further assessment in larger plots and this is currently under way.

There is concern for potential weediness of *Paspalum mandiocanum* in subtropical Australia because of its unproven palatability, heavy seed production, high seed viability and persistence (Qld Herbage Plant Liaison Committee). Hence, NSW Agriculture will not proceed with an

Table 6. Height of sward (mean of 5 seasons, 1996–97) at the high and medium light intensities represented by 3 height classes: 1=≤15 cm, 2=16-30 cm, 3=>30 cm.

Species/Accn	High light [1]			Medium light		
	Height	s.e.	Class	Height	s.e.	Class
Legumes	(cm)			(cm)		
Aeschynomene villosa CPI 37235	30.0	0.0	2	20.0	0.0	2
Aeschynomene villosa CPI 91209	12.0	2.4	1	8.3	1.2	1
Arachis pintoi ATF1006	12.2	2.1	1	17.6	3.4	2
Arachis pintoi ATF 2320	14.1	2.3	1/2	17.0	2.8	2
Arachis pintoi cv. Amarillo (Nov95)	13.2	1.6	1	12.7	3.0	1
Arachis pintoi cv. Amarillo (Jan96)	12.6	1.9	1	13.7	3.1	1/2
Arachis pintoi x *A. repens* CQ 3609	12.5	2.8	1	15.8	3.3	1/2
Arachis pintoi x *A. repens* CQ 3610	13.1	2.2	1	14.8	2.3	1/2
Arachis repens CPI 28273	8.3	1.8	1	11.0	3.0	1
Arachis glabrata CPI 22762	17.9	2.4	2	17.2	2.7	2
Arachis glabrata CPI 19898	18.0	3.3	2	18.8	2.2	2
Arachis glabrata CPI 12121	13.2	2.1	1	13.3	2.3	1
Arachis glabrata CPI 93464	13.5	2.0	1	25.0	2.6	2
Centrosema pubescens cv. Cardillo	11.3	2.0	1	13.7	2.1	1/2
Desmodium heterocarpon CPI 86277	10.9	2.5	1	16.0	2.1	2
Vigna parkeri cv. Shaw	6.3	1.3	1	7.3	1.8	1
Grasses						
Dactyloctenium australe	18.8	1.8	2	19.7	3.1	2
Digitaria didactyla CPI 40639	25.8	3.7	2	27.5	2.5	2
Eremochloa ophiuroides [2]	—	—	—	—	—	—
Microlaena stipoides cv. Wakefield	26.3	2.1	2	21.9	2.0	2
Microlaena stipoides cv. Griffin	20.1	3.3	2	18.3	2.3	2
Microlaena stipoides cv. Shannon	22.3	1.7	2	20.3	2.2	2
Panicum laxum cv. Siro Shadegro	24.0	3.8	2	21.1	3.3	2
Paspalum notatum cv. Riba	12.3	2.0	1	14.7	3.0	1/2
Paspalum notatum cv. Competidor	20.3	3.8	2	18.3	3.1	2
Paspalum mandiocanum CPI 39969	21.3	3.2	2	22.5	3.1	2
Paspalum wettsteinii cv. Warrell	42.1	3.9	3	38.3	2.6	3
Other						
Dichondra repens	5.4	0.9	1	5.5	1.8	1
Undisturbed cover (control)	35.7	3.5	3	35.0	0.0	3

[1] High = 21% full sunlight; Medium = 13% full sunlight.
[2] Failed to establish.

application for release of this species as a groundcover for macadamias.

Grass species generally provided higher percent groundcover than legumes in the medium and low light environments (Tables 3 and 4), as found in other studies (Mannetje *et al*. 1980; Barrios *et al.* 1986; Ng *et al*. 1997). *Dactyloctenium australe, Paspalum mandiocanum, Paspalum wettsteinii, Panicum laxum* and *Microlaena stipoides* cv. Wakefield were outstanding, with 74–100% cover in high and medium light in the mature orchard after 1 year (Table 3), although *Dactyloctenium australe* and *Paspalum mandiocanum* were slow to establish in medium and low light at Rosebank because they were planted later (Table 4). While *Paspalum wettsteinii* provided a high percent groundcover, it grows too tall and rank for macadamia orchards. *Microlaena stipoides* cv. Griffin had a high percent cover in medium to low light (Table 3) as did *Panicum laxum*, which had 65% and 10% cover, respectively, after 2 years at Wollongbar (Table 3), and 80% and 30%, respectively, after 3 years at Rosebank (Table 4). While *Panicum laxum* is recognised for providing groundcover in high and low light (Wilson 1997) and attained similar percent cover to the best species in high light at one site (Table 3), it was slower to provide ground cover in the first 6 months, and appeared to decline in percent cover in all light environments after 2 years at both sites.

The most promising species, *Dactyloctenium australe,* established quickly, provided high percent groundcover in highest, medium and low light environments, formed a dense mat of stoloniferous growth which appears to be potentially effective for minimising erosion, and has persisted for 4 years. While seeded species were planted over the entire plot area, runner-propagated species including *Dactyloctenium australe* were not planted under the tree canopy. Hence, *D. australe* spread under the trees by runners emanating from parent plants in the high light area. This species has the disadvantage of being propagated by runners, although they are commercially available, and requires some mowing to control growth in the harvest season, which was minimised if the sward was cut short in autumn. The mown sward appeared to provide an adequate surface from which to mechanically harvest nuts but further assessment is required.

There are a number of possible reasons for the apparent success of *Dactyloctenium australe* and *Paspalum mandiocanum* as groundcovers in macadamias compared with *Panicum laxum.* Wilson (1997) refers to the need to consider other adaptive features for shade tolerance which may be just as important as tolerance of low light, including morphological features, and physiological adaptations such as tolerance of periodic drought conditions, low soil temperatures and periodic litter-fall under trees in the subtropics. He suggests that one of the reasons for the success of subtropical rainforest grasses such as *Oplismenus* is that they produce long stolons with sparse leaves presumably to exploit gaps in the forest canopy. *Dactyloctenium australe* is a vigorous species which produces stolons with sparse leaves under the tree canopy some distance from the parent plant, while *Panicum laxum* is less vigorous, slower to establish and non-stoloniferous. Apart from the obvious advantage of being able to spread from stoloniferous growth, *Dactyloctenium australe* may be less susceptible to potentially destructive management practices such as the passage and the blowing action of mechanical harvesters. However, *Panicum laxum* is relatively easy to uproot in the establishment year and some plants were damaged. The species has suffered considerable damage from the passage of tractor wheels in wet soil conditions in the middle of the interrow in current trial work. In addition, its carbon reserves would be more easily depleted by continuous mowing compared with *Dactyloctenium australe* because it does not have storage in runners or the ability to replenish reserves from a parent plant growing in higher light in the middle of the interrow. For the same reason, *Dactyloctenium australe* may have better drought tolerance, which would undoubtedly be important in late winter and spring in macadamia orchards, when potential drought stress is high with low rainfall and the competition with macadamia feeder roots under the tree canopy. Wilson (1997) found soil under grass growing under eucalypt trees in the subtropics was below permanent wilting point much of the time and suggests that the ability of plants to tolerate water stress may be more important than their ability to tolerate low light in seasonally dry environments. In addition, the possibility of different species reactions to potential allelopathic secretions from macadamia feeder roots in dry soil, although less likely, cannot be dismissed. Further information on the effect of management practices on the performance of *Dactyloctenium australe, Paspalum* *mandiocanum* and *Panicum laxum* may be obtained in larger plot trials currently in progress.

Arachis pintoi cv. Amarillo (Jan 1996) and *Arachis* hybrids CQ 3609 and CQ 3610 had similar percent groundcover and herbage mass in the highest and medium light environments, but *Arachis pintoi* cv. Amarillo provided cover in the low light conditions while the hybrid accessions did not. This may be at least partly due to the larger, more horizontally oriented leaves of *Arachis pintoi* cv. Amarillo as suggested by Schwenke (1996). *Vigna parkeri* favoured the medium light environment at Wollongbar (Table 3), and higher light at Rosebank (Table 4), but its performance was variable, as this species and *Arachis repens* ATF 28273 did not provide ground cover in low light. Cover of *Vigna parkeri* appeared to decline in the higher light conditions in the second year at Wollongbar and third year at Rosebank, which is in agreement with its record of low persistence in the study environment. In an assessment of a number of grass and legume species for sheep grazing in rubber plantations in Malaysia, Ng *et al*. (1997) found *Panicum laxum* and *Paspalum wettsteinii* were outstanding grasses and that *A. pintoi* cv. Amarillo and *A. repens* CPI 28273 were the only legumes to survive declining light. *Arachis pintoi* cv. Amarillo has been reported as harbouring rats feeding on tubers in an unmown sward in bananas (Johns 1994), but we found no evidence of rat build-up in mown swards in this study.

Groundcovers must tolerate harvest machinery and require minimal mowing in the harvest season (autumn-winter), so species which require regular mowing at that time to reduce sward height and herbage mass are inappropriate under bearing macadamias. The average height of species with highest percent groundcover, *i.e. Dactyloctenium australe* (20cm), *Panicum laxum* (30 cm), *Paspalum mandiocanum* (20 cm) and *Microlaena stipoides* (30 cm) (Table 6), was within the acceptable height limit of <30 cm for macadamia orchards. While *Paspalum wettsteinii* provided high percent groundcover in high and low light, its tall growth and tendency to excessive herbage production in high light render it unacceptable. We noted that *Panicum laxum* tended to form a shorter, more compact sward after regular mowing in the first year, which confirmed the finding of other workers (J.R. Wilson, personal communication). *Dactyloctenium australe* produced a dense sward which regrew quickly after mowing in summer. However, if low-mown with an orchard mulcher after each harvest round in autumn–winter (approximately monthly), regrowth was short and a mechanical harvester could be operated effectively. It may require chemical control to reduce herbage near the tree trunk in young orchards where competition is potentially greatest. The less dense swards formed by *Microlaena stipoides* cultivars and *Panicum laxum* suggests they may be more suited in legume-grass mixes and may be potentially less competitive with young trees.

The similar morphology and growth habit of the 2 *Arachis* hybrids suggest that there is no reason to differentiate between them in future work. The low growth rate and low percent groundcover of *Arachis repens* CPI 28273 in low light will preclude its use as a groundcover in mature orchards even though it has a low sward height and growth habit. *Arachis pintoi* ATF 2320 and ATF 1006 had a similar growth habit to the *Arachis* hybrids. Like *Arachis pintoi* cv. Amarillo, these accessions have the advantage of being seed-propagated as opposed to the vegetative propagation of other *Arachis* accessions assessed. They were planted late in the assessment program, and require further evaluation.

A number of species were either too slow to establish, provided insufficient cover and herbage mass or were not persistent enough to be effective mono-specific groundcovers. *Dichondra repens*, while having ideal low growth, had all of the above negative features. *Paspalum notatum* cvv. Competidor and Riba, in particular, were slow to establish, although Competidor provided high percent groundcover (90%) after 1 year in the highest light at Wollongbar (Table 3) and 95% at Rosebank after 3 years (Table 4). Cover provided by this species in medium and low light was significantly less than that of some other accessions, but it may have a role in species mixtures. Schwenke (1996) postulated that *Paspalum notatum* performed poorly under shade because it has a very high rhizome plus root mass as a proportion of total biomass compared with more shade-tolerant species. The ability to reduce root mass is an important part of reducing respiratory load in shade-adapted species. A*rachis glabrata* accessions provided low levels of groundcover and, with the disadvantage of requiring vegetative propagation, do not merit further consideration.

This study has identified some promising accessions which are currently being assessed on a larger scale. Grass and legume mixes of these and other potentially useful species show promise of being able to help maximise groundcover in all light environments as the orchard ages. Selection of a suitable species has to balance ideal turf species attributes of slow growth, a low, compact, lax habit and long leaf duration, as indicated by Wilson (1997), with the need for rapid and vigorous establishment to withstand weed competition and tolerate orchard traffic soon after planting. The search for the most suitable combination of groundcover species and management technology to maximise the benefits of groundcover and minimise competitive effects on trees is continuing. We realise that, in overlooking species for which seed or vegetative material was not readily available, some potentially useful species were not included in this work. These species would include *Stenotaphrum secundatum*, which is now commercially available and which is included in one of our current trials as cv. Palmetto, and the Australian native species of *Oplismenus* and *Ottochloa*.

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References

BARRIOS, E.P., SUNDSTROM, F.J., BABCOCK, D. and LEGER, L. (1986) Quality and yield response of four warm-season lawngrasses to shade conditions. *Agronomy Journal*, **78**, 270–273.

BRAUN-BLANQUET, J. (1932) *Plant Sociology: The Study of Plant Communities* (Translated and edited by G.D. Fuller and H.C. Conrad). (McGraw Hill Book Co., Inc.: New York).

COOK, B.G., JONES, R.M. and WILLIAMS, R.J. (1994) Regional experience with forage *Arachis* in Australia. In: *Biology and agronomy of forage* Arachis. pp. 158–168. (International Centre for Tropical Agriculture (CIAT): Cali, Colombia).

EDWARDS, K. (1987) Runoff and Soil Loss Studies in N.S.W. *Technical Handbook No. 10. Soil Conservation Service of N.S.W., Sydney.*

FIRTH, D.J. and WILSON, G.P.M. (1995) A preliminary evaluation of permanent groundcovers for subtropical orchards on the North Coast of New South Wales. *Tropical Grasslands*, **9**, 18–27.

FIRTH, D.J., McFADYEN, L.M., JONES, R.M. and COOK, B.G. (1999) Evaluation of groundcovers for macadamia orchards. *Final Report to the Horticultural Research and Development Corporation for Project MC 95013. NSW Agriculture, Tropical Fruit Research Station, Alstonville*.

JOHNS, G.G. (1994) Effect of *Arachis pintoi* groundcover on performance of bananas in northern New South Wales. *Australian Journal of Experimental Agriculture*, **34**, 1197–1204.

MANNETJE, L. t', O'CONNOR, K.F. and BURT, R.L. (1980) The use and adaptation of pasture and fodder legumes. In: Summerfield, R.J. and Bunting, A.H. (eds) *Advances in Legume Science*. pp. 537–551. (Royal Botanic Gardens; Ministry of Agriculture, Fisheries and Food: Kew, UK).

McCONCHIE, C.A., McFADYEN, L.M., MEYERS, N.M. and HUETT, D. (1999) Canopy management for consistent yield in macadamia. *Final Report to Horticultural Research and Development Corporation, Project No. MC 95008. CSIRO Division of Plant Industry and NSW Agriculture*. pp. 86–93.

NG, K.F., STUR, W.W. and SHELTON, H.M. (1997) New forage species for integration of sheep in rubber plantations. *Journal of Agricultural Science*, **128**, 347–355.

SCHWENKE, T. (1996) *Predicting maximum potential yield and persistence of tropical pastures under shade*. Ph.D. Thesis. University of Queensland, Brisbane, Australia.

WILSON, J.R. (1997) Adaptive responses of grasses to shade: relevance to turfgrasses for low light environments. *International Turfgrass Society Research Journal*, **8**, 575–591.

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