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Perennial pastures for marginal farming country in southern Queensland. 1. Grass establishment techniques

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Abstract

Efficient ways to re-establish pastures are needed on land that requires a rotation between pastures and crops. We conducted trials in southern inland Queensland with a range of tropical perennial grasses sown into wheat stubble that was modified in various ways. Differing seedbed preparations involved cultivation or herbicide sprays, with or without fertilizer at sowing. Seed was broadcast and sowing time ranged from spring through to autumn on 3 different soil types. Seed quality and post-sowing rainfall were major determinants of the density of sown grass plants in the first year. Light cultivation sometimes enhanced establishment compared with herbicide spraying of standing stubble, most often on harder-setting soils. A nitrogen + phosphorus mixed fertilizer rarely produced any improvement in sown grass establishment and sometimes increased weed competition. The effects were similar for all types of grass seed from hairy fascicles to large, smooth panicoid seeds and minute *Eragrostis* seeds. There was a strong inverse relationship between the initial density of sown grass established and the level of weed competition.

Resumen

Para tierras cuyo uso requiere una rotación entre cultivos y pasturas se necesitan métodos eficientes para establecer el pasto. En la cuenca de Condamine-Balonne, región interior del sur de Queensland, Australia, se condujeron varios ensayos con el objeto de evaluar diferentes maneras de establecimiento de un rango de gramíneas tropicales perennes sobre residuos (rastrojo) de cosecha de trigo. Las preparaciones del terreno incluyeron labranza del suelo o aplicación de herbicida, con o sin aplicación de fertilizante al momento de la siembra. La semilla fue sembrada a voleo en 3 diferentes tipos de suelo y la época de siembra varió desde primavera hasta otoño. En el primer año, la calidad de la semilla y la lluvia después de la siembra fueron los factores determinantes de la densidad de plantas de las gramíneas sembradas. Una mínima labranza mejoró el establecimiento en algunos casos, en comparación con aplicación de herbicida al rastrojo en pie, especialmente en suelos con tendencia a sellamiento superficial. La aplicación de un fertilizante compuesto (nitrógeno + fósforo) generalmente no mejoró el establecimiento de la pastura y por el contrario, incrementó la competencia por malezas en algunos casos. Los efectos de los tratamientos fueron similares independiente de los tipos de semilla de gramíneas, desde aquellas con fascículos hirsutos hasta semillas panicoídeas grandes y glabras, pasando por semillas diminutas como las de *Eragrostis*. Se encontró una marcada relación inversa entre la densidad inicial de las poblaciones de las gramíneas sembradas y el nivel de competencia por malezas.

Introduction

A large proportion of southern inland Queensland has been cleared and farmed. Experience shows that certain farmed soils, especially ones with a strongly duplex profile, need to be rested periodically from cropping in order to remain useful in ley farming systems (Bellotti et al. 1991; Douglas 1997; Weston et al. 2000). Pasture phases in cropping systems have been shown to be a beneficial practice in many parts of Australia (French et al. 1968; Freebairn et al. 1997) and elsewhere in the world (Del Pozo et al. 1999; Kätterer et al. 2013) to improve soil organic matter and surface physical characteristics. However, the pasture phase must have minimal weeds and achieve satisfactory livestock production quickly.

Many land types in the lower rainfall zones of subtropical Queensland have few options for perennial pasture cultivars (Bellotti et al. 1991; Blacket 1992).

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Perennial grasses are required because a longer pasture phase is needed in drier areas and regular resowing of pastures defeats a key purpose, namely minimizing tillage. Establishment failures in such a drought-prone, aseasonal rainfall environment are also expensive (Lloyd et al. 2007). Perennial grasses also provide more stable seasonal productivity and better protection of soil from erosion. Valuable annual species such as barrel medic (*Medicago truncatula*) are not precluded but merely complement a dominant perennial component.

If the pasture does not establish quickly, there can be animal health issues from toxic weeds such as pimelea (*Pimelea* spp.) and blue heliotrope (*Heliotropium amplexicaule*), that can proliferate in the absence of competition. Alternatively, wind erosion, sheet erosion during storms and undesirable plants can degrade the bare land.

Techniques are needed to rapidly establish perennial pasture on deteriorating cropping land at moderate cost with good reliability. In some cases, only pasture grasses are needed because naturalized annual medics (*Medicago* spp.) already exist in the paddocks. Establishment of small-seeded tropical pasture grasses can be difficult and a hairy seed coat on many seeds makes even distribution a challenge during sowing (Kelly and Wiedemann 1999). Press wheels, soil disturbance and pre-sowing herbicide are widely used to improve establishment reliability in southern Queensland (Lloyd et al. 2007), and coated seeds are sometimes used, but irrigation is not economical over large areas of marginal cropping land.

There is debate about whether early or late summer sowings are more hazardous in this region. Early summer rains are unreliable and mid-summer heatwaves are not uncommon, causing many failures of crops and pastures sown before December (Clem et al. 1993), particularly in more northern latitudes. Despite the greater reliability of mid-summer planting rains, establishment failures of late-sown tropical grasses from winter frosts can occur in the more southern latitudes (Campbell et al. 1995).

We conducted a series of experiments to examine aspects of the timing of sowing after cropping and minimal-cost methods of land preparation before sowing on reliability of grass establishment. We used a range of commercial and non-commercial perennial grasses, which had shown promise for ley pastures (Silcock et al. 2014) and differed markedly in seed structure, degree of inherent seed dormancy and innate seedling vigor and size. This paper is the companion to one which details the agronomic value and strengths of the sown grasses (Silcock et al. 2015).

Methods

Trials were run at 3 sites in southern inland Queensland, near Condamine (26.797° S, 150.186° E), Yelarbon (28.234° S, 150.721° E) and Roma (26.795° S, 148.766° E). Each site had been cropped for some years, principally with wheat, but soil surface characteristics required a return to perennial pasture periodically to maintain adequate structure and fertility. The site near Yelarbon had a grey sandy clay-loam (Dd1.13, Northcote et al. 1975) that experienced surface wash and rilling under cultivation despite a very low slope. Common burr medic (*Medicago polymorpha*) grew very well. The site near Condamine was on a gently sloping brown gritty loam over a tight, mottled clay (Dy2.23), where the surface soil was easily eroded by wind or water, if unprotected by vegetation. Medics were uncommon here but the exotic annual spring weed, liverseed grass (*Urochloa panicoides*), was abundant. The third site south of Roma had a hard-setting, sandy red earth surface over a red, alkaline clay (Dr2.33) and it suffered badly from wind erosion when lacking cover. Cutleaf medic (*Medicago laciniata*) was naturalized here. More details about the chemical nature of the soils are given in Table 1.

Experimental design and layout

There were 4 sowing times over 2 years at each site. At each sowing, treatments were grouped into 3 replicate blocks. A split-split design was used within each of 3 main land preparations, which were randomly assigned to one-third of each main block. Half of each land preparation was then fertilized as a block and seed of 8 different grasses was hand-broadcast in plots randomly allocated within each land preparation, so that half the area was supplied with fertilizer, comprising 100 kg/ha of Starterphos (mono-ammonium phosphate; 10% N, 21.8% P and 2.3% S) at sowing.

Sowing techniques

The intention was to sow adjacent areas after rain in consecutive summers, into new stubble in early summer and into the old stubble late in the summer, to test whether mid-summer heatwaves were potentially more hazardous to seedling establishment than winter frosts on young tropical grasses. Sites were at the edge of a much larger cropping area, so that they could be readily fenced off. The initial trials began in late 1992, shortly after a wheat crop had been harvested and enough rain had fallen to allow cultivation of the ground. An area of

Table 1. Surface layer and subsoil characteristics at the 3 trial sites.

Site	Soil layer	Soil parameter							
		pH (water)	E.C.[1] (mS/cm)	bicarb P (mg/kg)	SO_4-S (mg/kg)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)
Yelarbon									
	0–10 cm	7.3	0.05	7	4	8.4	3.4	0.3	0.8
	40–50 cm	9.1	0.17	2	5	7.6	10.0	3.0	0.2
Condamine									
	0–10 cm	6.8	0.03	21	3	3.8	2.6	0.4	0.4
	40–50 cm	8.3[2]	0.23	2	15	5.5	6.9	3.1	0.1
Roma									
	0–10 cm	6.7	0.04	8	5	6.7	1.8	0.1	0.9
	40–50 cm	8.5	0.26	2	14	9.5	6.8	4.8	0.3

[1]Electrical conductivity.
[2]$CaCO_3$ nodules were common below 50 cm depth.

Table 2. Sowing dates and post-sowing rainfall totals at each site.

Sowing event	Site		
	Yelarbon	Condamine	Roma
First (Sowing 1, S1)	10/12/1992	22/12/1992	23/11/1993
Rain (mm) in next month	24	31	142
Rain (mm) in next 3 months	75	50	261
Second (Sowing 2, S2)	12/10/1993	22/09/1993	17/12/1993
Rain (mm) in next month	12	16	0
Rain (mm) in next 3 months	51	210	201
Third (Sowing 3, S3)	17/12/1993	20/12/1993	21/03/1994
Rain (mm) in next month	25	113	0
Rain (mm) in next 3 months	161	387	37
Fourth (Sowing 4, S4)	13/04/1994	12/04/1994	19/04/1994
Rain (mm) in next month	0	7	37
Rain (mm) in next 3 months	31	37	37

about 4 ha of new wheat stubble was used at all 3 sites. At Yelarbon and Condamine, the first 2 sowings were in an area from the 1992 wheat crop and the last 2 were into the stubble of the adjacent 1993 wheat crop. All sowings at Roma were after the 1993 wheat crop, because very poor summer rains following the 1992 winter wheat crop did not allow sowings to occur. Sowing dates are shown in Table 2.

Stubble cover

The amount of stubble varied with the site's wheat-growing potential, and the amount of standing stubble plus surface litter was assessed prior to sowing. At Condamine in September 1993, the mean level was very low at only 170 kg/ha of standing stubble and 80 kg/ha of surface litter (mainly wheat straw) but did reach 370 kg/ha for both components in the densest areas. At Yelarbon there was much more stubble in both years with a mean of 2,185 kg/ha of standing and flattened surface straw in October 1993, while at Roma for Sowing 1 there was 285 kg/ha of standing stubble and 680 kg/ha of soil surface straw.

Land preparation

The 3 land preparation techniques were:

- C0, wheat stubble untouched and weeds sprayed with glyphosate at 1 kg a.i. (active ingredient)/ha,
- C1, a single, shallow (5 cm), light cultivation with a chisel plow equipped with small wings behind the points, and
- C2, a double cultivation to about 12 cm depth with the same plow.

Each cultivation treatment was surrounded by a substantial border to allow machinery to turn. Individual grass plot size was 20 x 10 m for Sowing 1 but only

5 x 5 m for the other 3 sowings owing to a restricted supply of seed of some species.

Sowing method

Since sophisticated sowing methods are regarded as uneconomic in this farming system owing to the overriding importance of subsurface soil moisture and good early rains after sowing, we broadcast the seed, mostly in its natural state. Soil was not rolled or harrowed after sowing and no supplementary irrigation was provided. Seed and prilled fertilizer were broadcast by hand but tiny *Eragrostis curvula* seed was mixed with fine sand and shaken out of small tins with holes in the base. Sowing rate was based on prior germination tests and aimed to provide 200 live seeds/m^2. The same seed sources, a mixture of harvest dates in most cases, were used for each sowing (with 2 exceptions described later) and were stored in a coldroom until needed. However, viability declined badly for the commercial Gayndah buffel seed (*Cenchrus ciliaris*) after the third sowing and it was replaced with seed of *C. ciliaris* CPI 73393, a promising non-commercial genotype (Silcock et al. 2014), for the final sowing at Condamine.

Grasses sown

Eight different grass accessions were planted at each site at each sowing time, and 17 different accessions were tested overall. Gayndah buffel grass (*C. ciliaris* cv. Gayndah) was sown as the standard, well-regarded, commercially available line at all sites. The plant list for each site is shown in Table 3. Commercial cultivars used were Gayndah buffel, Bisset creeping bluegrass (*Bothriochloa insculpta* cv. Bisset), Premier digit grass (*Digitaria eriantha* ssp. *smutsii* cv. Premier), Consol lovegrass (*Eragrostis curvula* var. *conferta* cv. Consol) and Nixon sabi grass (*Urochloa mosambicensis* cv. Nixon). The experimental lines had similar agronomic features but had not yet achieved endorsement for commercial release. Native desert bluegrass (*Bothriochloa ewartiana* TN 47) was used as an example of the most agronomically useful native plant found for these soils from previous local research (Silcock et al. 2014).

Table 3. Perennial grass cultivars and accessions sown at each site (X). Where an accession was used for only some sowings, those are listed, e.g. S4.

Accession	Site			Seed features
	Yelarbon	Condamine	Roma	
Bothriochloa bladhii var. *glabra* CPI 11408	X	X		Seeds less hairy than cv. Bisset; similar size
Bothriochloa ewartiana TN 47	X			Typical hairy *Bothriochloa* seed
Bothriochloa insculpta CPI 52193	X			Seed identical with cv. Bisset; 1 caryopsis
Bothriochloa insculpta CPI 69517		X		Like cv. Bisset but slightly larger seed
Bothriochloa insculpta cv. Bisset	X			Medium-sized, elongated, hairy seed
Bothriochloa pertusa cv. Medway		X	X	Hairy seeds like cv. Bisset; 1 caryopsis
Cenchrus ciliaris CPI 73393	X	S4[1]		Short, soft fascicle bristles; 1 caryopsis
Cenchrus ciliaris CPI 71914			X	Like cv. Gayndah; very bristly fascicles
Cenchrus ciliaris cv. Gayndah	X	S1,2,3	X	Large bristly fascicles; 1–3 grains in each
Digitaria eriantha cv. Premier			X	Small elongated seed with short hairs
Digitaria milanjiana CPI 41192			X	Seeds like cv. Premier
Eragrostis curvula CPI 30374			X	Tiny hairless seeds like cv. Consol
Eragrostis curvula var. *conferta* cv. Consol			X	Tiny hairless naked caryopses
Panicum stapfianum CPI 73577		X[2]	X	Smooth, shiny rounded medium-sized seeds
Urochloa mosambicensis cv. Nixon	X	X		Large, flat hairy seed; single caryopsis
Urochloa oligotricha CPI 47122	X	X		Rounded, large, non-hairy seed; 1 caryopsis
Urochloa stolonifera CPI 60128		X		Hairy seed like cv. Nixon

[1]Untreated fascicles were mixed with semi-naked seed, which had been put through a cone thresher.
[2]20% of seeds were coated with a proprietary seed-coating mix.

The species tested had very different dormancy characteristics and levels of seed-fill within the glumes (Table 4). All seed lots were tested before each sowing season to calculate how much seed was needed per plot to achieve the desired potential seedling population of 10–20/m^2. Those tests were performed in triplicate for 21 days on Whatman No. 1 filter paper wetted with town water in petri dishes maintained in a germinator alternating at 35/20 °C temperature with fluorescent light during the 12-hour warm cycle.

Almost all sown seed was cleaned to a normal commercial state (a single-seeded, hairy diaspore) except that of *E. curvula*, which was as naked caryopses. Shortfalls in available seeds of 2 lines forced the use of a mixture of natural seed and seed that had received additional commercial treatment. Thus, 20% of the seed of *P. stapfianum* CPI 73577 was coated with a proprietary commercial seed coating, that purported to enhance establishment, and 30% of *C. ciliaris* CPI 73393 seed sown at Condamine at the fourth sowing had been cone-threshed to remove the outer hairy fascicle.

Pasture recordings

Each plot was assessed regularly after sowing for the following information:

- Density of sown plants (0–9 or 0–5 scale, where 0 = no sown plants);
- Vigor of sown plants (0–3 scale);
- Number of plants of the sown accession per 0.25 m^2 quadrat; and
- Weed competition level (0–5 scale).

The wider scale of 0–9 used for some density ratings was to enable the greater variability amongst plots to be expressed.

In the large plots of Sowing 1, sampling was done by a stratified positioning of five 50 x 50 cm quadrats, one in the centre and the others near the corners of each 20 x 10 m plot. For the later sowings into 5 x 5 m plots, the entire plot was assessed for each parameter within each replicated cultivation x fertilizer treatment (3 x 3 x 2 matrix).

The data were analyzed using GenStat 8 (GENSTAT 2005) as a split-split plot design with cultivation method randomly assigned to 3 blocks within each replicate and then split for fertilizer and again for grass accession. Sites were analyzed independently.

Post-sowing management

After the first sowing, this area and the area set aside for Sowing 2 in late summer were fenced off with Hingejoint® or electric fencing to exclude stock. This fencing was extended the following year at Yelarbon and Condamine into the adjacent wheat-growing area after the wheat crop was harvested so as to include the next

Table 4. Characteristics of the seeds used, commercial and experimental lines.

Accession	Mean diaspore weight (mg)	Mean seed-fill (%)	Mean caryopsis weight (mg)	Standard germination test (%)	Pre-sowing laboratory germination (%)		
					Initial	Peak	16 mo later
B. bladhii	0.55	66	0.27	19	84	84	11[1]
B. ewartiana	0.44	16		1	24	24	2[1]
B. insculpta 52193	0.67	22	0.20	38	1	30	1
B. insculpta 69517	0.52	14	0.75		9	12	12
B. insculpta Bisset	0.92	56	0.54		20	52	49
B. pertusa Medway	0.68	20	0.46	22	1	18	18
C. ciliaris 71914	3.06[2]	92	0.77	69	38	38	34
C. ciliaris 73393	1.22	68	0.53	44	32	49	49
C. ciliaris Gayndah	2.39[2]	72	0.58		16	16	11
D. eriantha Premier	0.36	44	0.33		19	23	21
D. milanjiana	0.55	40	0.37	39	46	83	39
E. curvula 30374	0.09	99	0.09	9	16	31	5[1]
E. curvula Consol	0.09	99	0.09		61	95	61
P. stapfianum	0.44	82		55	16	23	2[1]
U. mosambicensis Nixon	2.05	95	1.10		5	7	7
U. oligotricha	1.10	75		1	13	17	8
U. stolonifera	0.80	64		6	18	24	23

[1]Rapid late fall in seed germinability.
[2]Fascicles contain 1–3 caryopses with an 8–10-fold weight range.

summer's 2 sowings into a single, fenced experimental site. The intent was to impose a short, moderate-intensity grazing after the newest pastures had established and seeded each year to encourage tillering of the grasses and to remove palatable, post-cropping weeds, most of which were annuals.

Grazing was permitted for varying lengths of time after the initial establishment phase, depending on seasonal conditions and the availability of animals. No post-establishment herbicide, fertilizer or hand-weeding was used to assist the sown pastures to compete. Selective grazing of the plots did occur at times but was not considered a major problem owing to the abundance of palatable weedy species and medics at most times. Cattle grazed the Yelarbon and Condamine sites, while sheep and cattle grazed at Roma, though sheep were the main grazers initially after establishment at Roma. Rainfall records were obtained from rain gauges installed at each site.

Results

Rainfall

The trials were conducted under generally poor rainfall conditions, especially for the final set of sowings in April 1994. However, conditions after Sowing 1 at Roma and Sowing 3 at Condamine were very favorable for pasture establishment (Table 2). Sowing 4 was initially viewed as a failure at all 3 sites, as was Sowing 3 at Roma, with almost no post-sowing rain. Despite this, plant populations of many accessions were reasonable at all sites after Sowings 1, 2 and 3, except at Roma (Tables 5–8). Sowing 4 was not a complete failure at Yelarbon.

Weeds at sowing

Weed populations were generally very low immediately after the wheat was harvested, so the glyphosate applied was very effective in killing most growing plants in C0. The light cultivation (C1) killed most existing weeds, except some growing between the lines of tyne furrows, whereas the double cultivation treatment (C2) killed all weeds and volunteer wheat existing at sowing. By late summer when most second sowings were scheduled, weed populations varied greatly depending on recent rains. In March 1994 at Roma, weed growth during a wet early summer boosted cover levels to an average 5,500 kg/ha from a mix of annual button grass (*Dactyloctenium radulans*), annual small burrgrass (*Tragus australianus*) and weakly perennial spring grass (*Eriochloa pseudoacrotricha*). By comparison, at Yelarbon weed growth in the Sowing 4 plots had reached 3,165 kg/ha from a mixture of grasses and non-grasses. At Condamine, above-ground litter and weeds amounted to 1,760 kg/ha at the same time. This amount of weed growth severely hampered an even cultivation and also seedling establishment in the spray treatment plots (C0) at all sites for the late sowings.

Cultivation effects

In general there was no significant benefit from a double cultivation (C2) compared with a light chisel plowing (C1), with the possible exception of Sowing 3 at Condamine, when assessed 2 months after sowing (Table 5). Establishment was noticeably poorer where spraying weeds with glyphosate (C0) was the only pre-sowing management following the wheat crop (Table 5), but few statistically significant effects were recorded. Weed competition and lack of ground disturbance seemed to be the primary factors contributing to this C0 outcome. There were few cultivation x accession interactions across all sown grasses, despite the widely differing size, structure and dormancy levels of seed (Table 4). Statistically different ($P<0.05$) responses by individual accessions to differing land preparation were recorded at only 4 individual recording dates and they involved all sites (Table 5). There were times at Yelarbon when vigorous cultivation (C2) stimulated the germination and growth of annual weeds such as barnyard grass (*Echinochloa crus-galli*) and liverseed grass, to the extent that cultivation was slightly disadvantageous compared with a light chisel plowing and no herbicide (Sowings 2 and 4 at Yelarbon; Table 5).

Fertilizer effects

Broadcast application of 100 kg/ha of mono-ammonium phosphate failed to significantly improve early seedling density, and was correlated with a significant reduction a year after Sowing 4 at Yelarbon (Table 5). An initial significant ($P<0.05$) enhancement of pasture yield at Roma after Sowing 2 by Starterphos (mean rating 2.1 vs. 1.8) was maintained for another year (3.5 vs. 3.1). There was an isolated case, 4 months after Sowing 3 at Yelarbon, where there was a significant interaction ($P<0.05$) between species and the establishment fertilizer used in terms of sown pasture yield rating. *Urochloa* species responded significantly to fertilizer (mean ratings increased from 1.5 to 2.0), while the tufted *Bothriochloa* species (TN47 and CPI 11408) grew more poorly (ratings dropped from 0.3 to 0.2) in fertilized plots, possibly due to weed competition.

Table 5. Effect of sowing technique at 3 sites on grass seedling density rating at various dates after establishment (5 = best at the site at the time) from different sowings, plus the level of statistical significance of cultivation type, establishment fertilizer and any Accession x Cultivation type interaction. Data are means for all 8 accessions sown at each site.

	Sowing 1			Sowing 2		Sowing 3		Sowing 4
Yelarbon								
Rec. date	19/03/93	15/04/94	30/01/95	15/04/94	30/01/95	15/04/94	30/01/95	13/04/94
C0	1.4	2.5	3.9	1.0	2.7	1.4	3.0	2.6
C1	2.6	3.0	4.2	1.0	2.5	1.2	2.8	2.1
C2	2.1	2.8	4.1	0.8	2.3	1.8	3.2	1.9
Fertilizer	ns	ns	ns	ns	ns	ns	ns	***
Cult. x Accn.	ns	ns	*	ns	ns	ns	ns	**
Condamine								
Rec. date	21/01/94	4/11/94	15/12/94	4/11/94	15/12/94	4/11/94	1/12/94	failed
C0	1.3	1.8a[1]	2.8	1.8	2.4	0.5	6.6a[2]	
C1	2.6	3.1b	4.5	1.3	2.7	0.3	8.7b	
C2	2.7	3.2b	4.2	1.5	2.3	0.6	11.5c	
Fertilizer	ns	ns	ns	ns	ns	ns	ns	
Cult. x Accn.	ns	ns	ns	**	ns	ns	ns	
Roma								
Rec. date		4/06/94	13/02/95	4/06/94	13/02/95		failed	failed
C0		0.9a	3.4a[3]	2.0	1.9a			
C1		1.7b	4.6b	2.8	2.9b			
C2		2.2b	5.6b	2.9	2.7b			
Fertilizer		ns	ns	ns	ns			
Cult. x Accn.		**	ns	ns	ns			

[1]Means within sites and columns followed by the same letter are not significantly different (P>0.05).
[2]Actual counts per square meter at this assessment.
[3]Rating out of 9 instead of 5.
C0 = no cultivation, C1 = 1 light cultivation, C2 = double deep cultivation.

Table 6. Sown grass plant density ratings at Yelarbon at different times after each sowing event, meaned over cultivation and fertilizer treatments. Statistical significance of any fertilizer effects and the Accession x Cultivation type interaction are shown in Table 5.

Accession	Sowing 1			Sowing 2		Sowing 3		Sowing 4
	19/03/93	15/04/94	30/01/95	15/04/94	30/01/95	15/04/94	30/01/95	4/07/95
C. ciliaris Gayndah	3.7c[1]	3.9d	4.9d	0.6b	2.1b	0.9ab	2.2b	2.7c
C. ciliaris 73393	1.6b	2.7b	4.1c	0.5ab	2.4b	0.6ab	2.2b	1.5b
U. mosambicensis Nixon	2.3bc	4.0d	4.9d	0.8b	3.2c	1.8c	4.4d	1.7b
U. oligotricha	3.0c	3.1bc	4.7d	1.4c	3.5c	1.1b	3.4c	1.6b
B. insculpta Bisset	3.1c	3.3c	5.0d	2.4d	4.2d	2.3d	4.3d	3.1c
B. insculpta 52193	1.9b	3.0bc	4.7d	1.2bc	2.3b	3.6e	4.2d	6.1d
B. ewartiana	0.4a	1.2a	3.1b	0.2a	1.3a	0.6a	1.5a	0.2a
B. bladhii	0.4a	0.8a	1.2a	0.1a	0.9a	0.6ab	2.1b	0.7a

[1]Means followed by the same letter within an assessment date and sowing are not significantly different (P>0.05).

Differences in species response

At every sowing there were significant differences amongst the 8 sown accessions in their initial establishment success. Some species, such as creeping bluegrass (*B. insculpta* Bisset, CPI 52193 and CPI 69517), established quite reliably, while others were consistently poor, such as *P. stapfianum* and *B. ewartiana* (Tables 6, 7 and 9). There was no consistent effect of seed structure on establishment rankings. Fluffy-seeded grasses of the *Bothriochloa* group had good and poor performing accessions at all sites; e.g. Sowing 4 at Yelarbon had this group ranked 1 and 2 plus 7 and 8 (Tables 6 and 9). The buffel grasses and *Urochloa* species generally had agronomically acceptable establishment ratings (3–5% crown cover after 2 growing seasons, Silcock 1993) but individual cases showed outstanding establishment, e.g. *C. ciliaris* 71914 at Roma (Table 8) and *U. stolonifera* at Condamine for particular sowings (Table 7). Nonetheless close taxonomic affinity did not guarantee similar establishment ratings at a particular site and sowing; e.g. Gayndah buffel did significantly worse than *C. ciliaris* 71914 at Roma (Table 9) despite the adjustment made to sowing rate to compensate for germination differences (Table 4).

At Yelarbon, Bisset bluegrass and its close relative *B. insculpta* 52193 were consistently rated highly for establishment success, while *B. bladhii* and the native *B. ewartiana* were consistently the poorest establishers. This outcome was correlated with lower seed viability, despite our attempt to compensate by sowing more seeds of lines with low seed-fill or germinability. At Condamine, 2 *Urochloa* lines, *U. stolonifera* and Nixon sabi grass, were consistently the best establishers, while *B. bladhii*, again, with *P. stapfianum* was consistently poor over 3 sowings. At Roma, *C. ciliaris* 71914 consistently established well along with *D. milanjiana,* while *P. stapfianum* and Consol lovegrass (*E. curvula*) were always the poorest establishers.

Urochloa species had fairly high levels of dormancy (40–50%) in fresh seed, and *Digitaria* spp. had moderate levels (30%), while buffel grasses had low levels (1–8%) prior to the late 1992 sowings (Table 4). The proportion of viable seeds that established was generally low, with many sowings failing to achieve 1% of filled seeds reaching sufficient seedling size to be counted a few months later. The best results were from Gayndah buffel for Sowing 1 at Yelarbon, where an average of 7% of pure live seeds sown were successfully established after the 1992/93 summer. By comparison, *B. bladhii* had the worst establishment with only 0.7% establishment at the same time and location.

Table 7. Sown grass plant density ratings at Condamine at different times after each sowing event, meaned over cultivation and fertilizer treatments. Statistical significance of any fertilizer effects and the Accession x Cultivation type interaction are shown in Table 5.

Accession	Sowing 1			Sowing 2		Sowing 3	
	21/01/94	11/04/1994	15/12/94	11/04/1994	15/12/94	11/04/1994	1/12/1994[2]
C. ciliaris Gayndah	3.9c[1]	2.4c	4.6c	0.9b	1.4b	0.1ab	0.2a
U. mosambicensis Nixon	3.6c	3.8d	6.1d	1.2bc	2.3c	0.5b	14.7d
U. oligotricha	2.3b	2.7c	4.5c	1.7c	3.4d	0.3ab	6.6b
U. stolonifera	2.6b	3.6d	5.0c	2.7d	3.6d	1.4c	11.4c
B. insculpta 69517	2.6bc	4.2d	5.4c	2.6d	5.0e	0.1ab	4.4b
B. pertusa Medway	2.0b	2.9c	2.4b	2.1cd	1.9bc	1.1c	24.2e
B. bladhii	0.6a	1.3b	1.8b	0.7ab	1.4b	0.3ab	9.3c
P. stapfianum	0.2a	0.6a	0.9a	0.2a	0.7a	0.02a	0.5a

[1]Means followed by the same letter within an assessment date are not significantly different (P>0.05).
[2]Actual numbers/0.25 m^2 counted at this time.

Table 8. Sown grass plant density ratings at Roma at 2 dates after Sowings 1 and 2, meaned over cultivation and fertilizer treatments. Statistical significance of any fertilizer effects and the Accession x Cultivation type interaction are shown in Table 5.

Accession	Sowing 1		Sowing 2	
	6/04/1994	13/02/1995	6/04/1994	13/02/1995
C. ciliaris Gayndah	1.1b[1]	4.6c	2.5c	2.7c
C. ciliaris 71914	3.3e	7.9f	3.7d	3.8d
B. pertusa Medway	1.8c	6.6e	2.9cd	3.3d
D. eriantha Premier	0.9ab	4.4c	1.7b	2.2bc
D. milanjiana	2.6d	6.3e	3.6d	3.4d
P. stapfianum	0.4a	0.2a	0.7a	0.4a
E. curvula Consol	0.9ab	1.2b	2.0bc	1.8b
E. curvula 30374	2.0c	5.3d	3.2d	2.4c

[1]Means followed by the same letter within an assessment date are not significantly different (P>0.05).

Table 9. Sowings with an initial significant interaction (P<0.01) between cultivation method and density of sown grass accessions. Means within a site followed by the same letter are not significantly different (P>0.05). Accessions that showed a significant response to cultivation method are underlined.

Yelarbon Sowing 4, July 1995 assessment

	C. ciliaris Gayndah	*C. ciliaris* 73393	*U. mosambicensis* Nixon	*U. oligotricha*	*B. insculpta* Bisset	*B. insculpta* 52193	*B. bladhii*	*B. ewartiana*
C0	3.3c	2.4bc	1.6bc	1.7bc	2.7c	7.7e	1.2ab	0.2ab
C1	2.8c	1.2ab	2.0bc	1.4b	3.0c	5.4d	0.5ab	0.2ab
C2	1.8bc	0.8ab	1.5bc	1.5bc	3.5c	5.3d	0.4ab	0.2a
Mean rank	3	6	4	5	2	1	7	8

Condamine Sowing 2, April 1994 assessment

	C. ciliaris Gayndah	*U. stolonifera*	*U. mosambicensis* Nixon	*U. oligotricha*	*P. stapfianum*	*B. insculpta* 69517	*B. bladhii*	*B. pertusa* Medway
C0	1.3b	4.1d	1.9bc	1.6b	0.0a	2.2bc	0.9ab	2.2bc
C1	0.7ab	1.9bc	0.6ab	2.1bc	0.1a	3.0c	0.6ab	1.3b
C2	0.7ab	2.2bc	0.9ab	1.5b	0.3a	2.7c	0.4ab	2.8c
Mean rank	6	1	5	4	8	2	7	3

Roma Sowing 1, April 1994 assessment

	C. ciliaris Gayndah	*C. ciliaris* 71914	*D. milanjiana*	*D. eriantha* Premier	*P. stapfianum*	*E. curvula* Consol	*E. curvula* 30374	*B. pertusa* Medway
C0	1.0ab	2.6c	1.5b	0.6ab	0.1a	0.5ab	0.3ab	0.9ab
C1	0.6ab	3.9d	3.1cd	0.9ab	0.7ab	0.6ab	2.4bc	1.7bc
C2	1.6b	3.6d	3.3cd	1.2b	0.5ab	1.6b	3.3cd	2.7c
Mean rank	5	1	2	7	8	6	3	4

C0 = no cultivation, C1 = 1 light cultivation, C2 = double deep cultivation.

Grass accession x Cultivation interactions

A significant interaction between accession sown and cultivation method was not uncommon (Table 5), but the reasons for this were not often clear. Table 9 shows some of the most striking examples. At most sowings only a few species showed any significant response to cultivation method and even fewer were in the opposite direction to the general trend; e.g. for Sowing 4 at Yelarbon, only *B. insculpta* 52193 had a significant response to cultivation treatment, towards better plant density where unplowed. The same trend was non-significant for most others and *B. insculpta* Bisset showed an opposite tendency (Table 9). Over all species, the cultivation effect was non-significant (Table 5). After Sowing 2 at Condamine, only *U. stolonifera* had a significant response to cultivation type, again showing greatest establishment where not cultivated (Table 9). However, the pattern of response to cultivation type by the 8 accessions was very mixed at this sowing. In contrast, at Sowing 1 at Roma, lack of cultivation significantly depressed seedling establishment of *C. ciliaris* 71914, *D. milanjiana, E. curvula* 30374 and *B. pertusa* Medway (Table 9). This was not correlated with seed characteristics, because the caryopses of these accessions vary greatly in size (Table 4) and differ markedly in seedcoat architecture, from tiny and smooth (*E. curvula* 30374) to mid-sized and hairy to large and very bristly (*C. ciliaris* 71914).

Weed effects

Cultivation type had no statistically significant (P>0.05) impact on weed density in the first year after establishment. However, application of fertilizer increased weed competition significantly (P<0.05) after Sowing 1 at Yelarbon and Roma (rating 1.2 vs. 1.0 and 2.5 vs. 2.3, respectively) and Sowing 3 at Condamine (rating 1.8 vs. 1.5). The weedy species varied with site and season, being mainly annual grasses, but black roly-poly (*Sclerolaena muricata*) was a major weed at certain times. "Weeds" also included the naturalized annual medics, which were abundant in winter at Yelarbon and common at Roma.

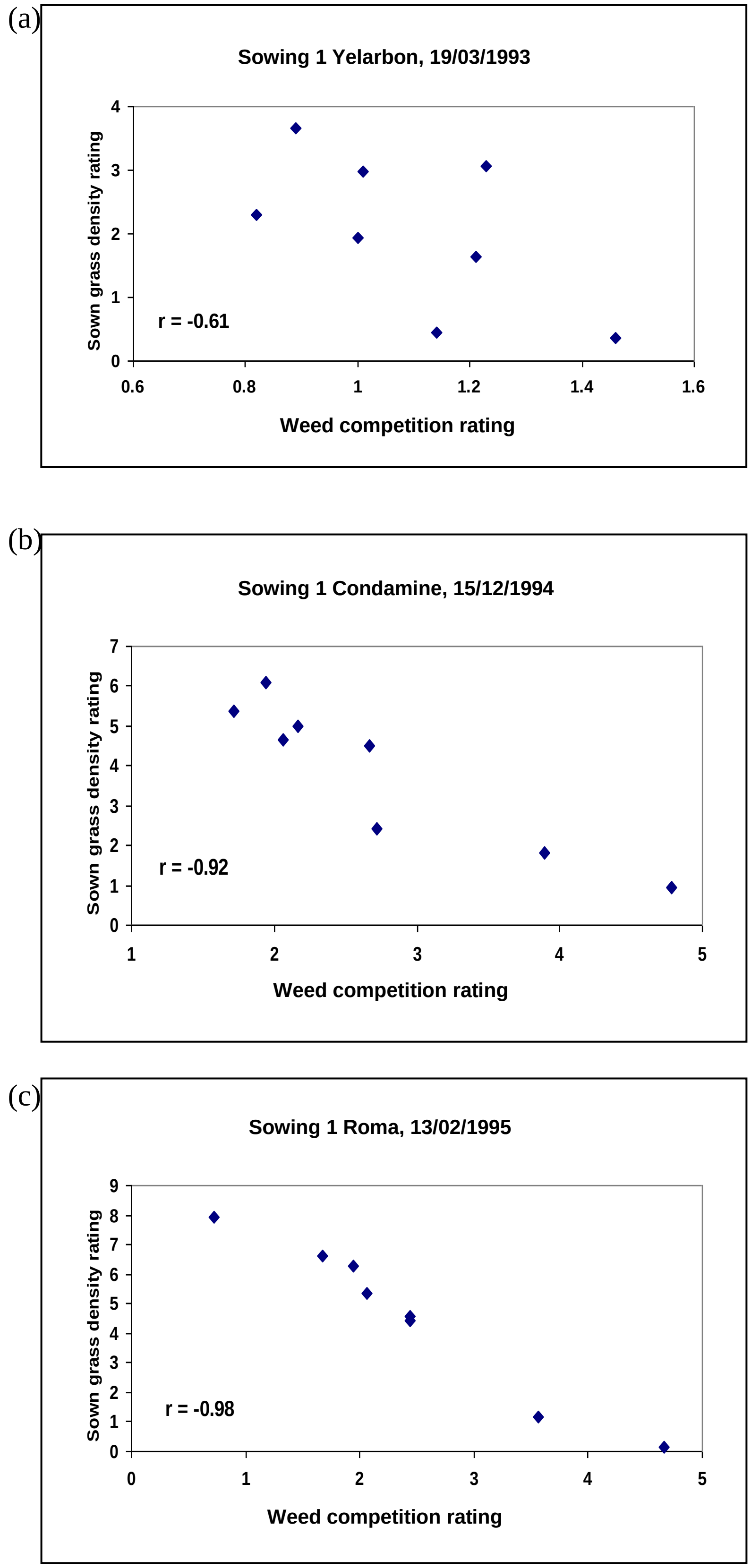

Figure 1. The depression effect of high weed competition on the mean density of individual sown grass accessions established at (a) Yelarbon, (b) Condamine and (c) Roma.

There was a consistent strong correlation between post-sowing ratings for weed competition and sown grass density (Figure 1); the greater the weed competition the poorer the sown grass seedling density rating. The weaker correlation at Yelarbon (Figure 1a) after Sowing 1 (r = -0.61) was partly due to the narrower range of weed competition levels recorded, maximum of 1.5 compared with almost 5 at the other 2 sites.

Other influences on seedling establishment

Locusts were numerous during each summer at both the Condamine and Roma sites. Hence they may have had a significant but unrecorded impact on seedling establishment, as they were species known to feed preferentially on grasses.

Grazing by sheep and cattle was encouraged for short intervals after initial establishment and appeared beneficial to the development of a healthy pasture. It removed a great deal of biomass from competing annual species, that did not regenerate rapidly, while at the same time stimulating tillering of the seedlings of the sown grasses. CPI 30374 lovegrass was the only accession to be consistently poorly grazed.

Visual rating for dry matter (DM) yield of the sown species produced similar rankings amongst species as for plant density. The exceptions were *E. curvula* 30374, whose density was relatively poorer than its standing yield rating, and *B. pertusa* Medway, that had a relatively high plant density rating relative to its yield rating.

Changes over the first 2 growing seasons

Stands of most accessions thickened up over time (Table 5), and DM yields increased. The species to show the greatest thickening from an initial sparse stand was usually *B. ewartiana* but *B. bladhii* showed a similar response. Decreases in density were recorded at Roma for *P. stapfianum*, while all others improved (Sowing 1). Both *E. curvula* lines from Sowing 2 also declined over time at Roma (Table 8), but maintained a strong presence. Repeat ratings over the first 2 growing seasons generally did not change the relative ranking of accessions for plant density (Tables 6–8). That is, the initial population of perennial grasses established was very likely to persist for some years thereafter.

Discussion

It is significant that rainfall conditions and seed quality had a bigger influence on sown grass establishment than degree of cultivation of the wheat crop stubble immediately prior to sowing. The failure of cultivation to improve establishment of any accession on most occasions made it a minor factor in the final outcome, except at Roma. In fact, establishment success achieved was very good, considering the poor seasonal conditions that prevailed most of the time. Sowings 1 and 2 at Yelarbon and Sowing 1 at Condamine received very poor rainfall in the ensuing 3 months (Table 2) but still resulted in acceptable densities of sown pasture of several commercial lines sown, such as Gayndah buffel (*C. ciliaris*) and Nixon sabi grass (*U. mosambicensis*). Though the data from the 3 sites could not be statistically combined, visual inspection showed no consistent benefit to any accession from a particular sowing factor, either surface preparation or the use of fertilizer.

Cultivation effects

Even though cultivation produced negligible effects on seedling establishment overall, it was very common for sown seedlings to be rooted in the bottom of shallow furrows left by cultivation. This was particularly noted at Yelarbon, where the established bluegrasses (*Bothriochloa* spp.) emerged almost exclusively in the furrows, and could be due to improved moisture conditions, or the accumulation of the broadcast seed in the furrow base, or a combination. Despite strong winds at many sowings, it seemed that the light, hairy seeds, such as those of *Cenchrus* and *Bothriochloa*, moved little after landing on the rough ground or amongst wheat stubble. This accords with observations by Peart (1979), that hairs or bristles on fluffy seeds quickly and decisively wedge the base of the seed into crevices and niches in the soil surface. On the sandier-surfaced soils at Roma and Condamine, wind also swept fine dry soil into furrows and hollows to further ensure that newly broadcast seed was held close to where it first fell. Only strong whirl winds could upset this process prior to the first post-sowing rains.

Cultivation did enhance early establishment success of 4 accessions with very different seed types after Sowing 1 at Roma (Table 9). The soil at this site had the strongest tendency to surface seal and was most likely to respond to cultivation in terms of pasture establishment. Stubble incorporation was not a significant issue, as reported by White et al. (1985) for more fertile black earths. The wheat stubble was not very dense on most parts of the trial sites (generally <2,000 kg/ha), which would be typical of marginal farming country in the region. Thus the broadcast seeds did not generally lodge on top of horizontal or thatched stubble that could prevent the adequate soil-seed contact needed for successful seedling establishment (Freer 2006). While such dense litter effects were seen on annual medic recruitment during these trials, it happened only in later years in our well-established creeping bluegrass plots.

Seed conformation effects

Seed of the various species sown varied greatly in size and hairiness (Table 4) but nothing in the results indicates that a particular diaspore feature conferred a great advantage to establishment success. Where sown, the tiny, smooth *E. curvula* 30374 seeds established well, while the comparatively large hairy diaspores of Gayndah buffel did not establish any better than the much smaller seeds of the creeping bluegrasses (Tables 6 and 7) or Premier digit grass (Table 8). However, seed conformation does have a large influence on the ease with which seeds can be sown from machinery or by hand. The large, smooth seeds of *P. stapfianum* and *U. oligotricha* are easy to sow by any method but the light, hairy seeds of *Bothriochloa* spp. are much more difficult to sow via machinery (Cole and Waters 1997). The tiny, naked seeds of *E. curvula* must be mixed with a carrier to enable them to be sown evenly, either mechanically or by hand.

Weed competition

Since rainfall timing interacted strongly with level of weed competition, this effect had a major impact on establishment success. Removal of soil moisture by large amounts of fallow weeds exacerbated the impact of poor post-establishment rainfall, so that establishment in the uncultivated (C0) plots for Sowings 3 and 4 at Roma, 4–5 months after the wheat harvest, was negligible. An appreciable mass of dead plant material from the sprayed weeds also shaded seedlings or entangled the seeds above the soil after using glyphosate prior to sowing (C0). Excellent rain after Sowing 2 at Roma resulted in dense stands of annual button grass and early spring grass. This did not have a big impact on seedlings from Sowing 2 that emerged at the same time, but did hamper seedlings in the uncultivated plots from the subsequent Sowing 3. When weed competition was moderate at Sowing 1 at all sites, sown grass density closely reflected that competition, irrespective of the weed species (Figure 1). Our results suggest that, if fallow weeds are dense and grass-dominant, their control using only pre-sowing herbicides is insufficient for successful grass seedling establishment from broadcast seed, even if soil moisture and post-sowing rainfall are adequate. Removal of most of the weeds by grazing, slashing or cultivation is required before sowing, even if herbicide is applied also.

Fertilizer effects

All 3 sites had very alkaline subsoils and non-saline surface soil (Table 1). The available phosphorus level of the surface soil at Condamine was much better than at the other 2 sites and would be expected to preclude a grass seedling response to the fertilizer used. All other major nutrients listed in Table 1 would be expected to be adequate for healthy dryland grass pasture growth. Soil nitrogen assays were not done because nitrate and ammonium ions are very changeable over time under dryland conditions and such data would not necessarily be relevant when the seedlings were establishing.

Available soil nitrogen might be low immediately after a wheat crop and the carbon-rich stubble on the soil surface would potentially further reduce the available nitrogen pool during the breakdown process (White 1984). Thus application of nitrogen-rich fertilizer could be expected to boost grass seedling growth and establishment success, where only glyphosate herbicide was applied as a seedbed preparation. That this did not generally happen was surprising, particularly in comparison with the cultivated treatments, which would have mineralized some soil nitrogen. Fortunately, fertilizer did not advantage weeds in most cases, with just 2 sowings at different sites recording increased weed mass after Starterphos was applied ($P<0.05$, data not presented). W. Scattini (pers. comm.) also achieved no establishment benefit from phosphate fertilizer for pasture grasses on similar soils, even though phosphorus does benefit buffel grass on very acid red earths further west (Silcock et al. 1976).

The bluegrasses have a reputation for being low nitrogen-demanding species (Bisset and Graham 1978) and *E. curvula* does not respond to phosphate in the seedling stage (Silcock 1980), but *Panicum* spp. are often responsive to good fertility (Ghannoum and Conroy 1998). Thus a differential response to establishment fertilizer was expected amongst the species but did not occur.

Fertilizing sown grass pastures

Our trials produced no convincing evidence that establishment fertilizer is required when sowing summer pastures directly after a wheat crop on these soils, even though a depletion of soil moisture (Bellotti et al. 1991) and available nitrogen on these relatively infertile soils was anticipated. Cultivation would mobilize some extra nitrogen but was seemingly not critical for the establishment of an adequate pasture. Mono-ammonium phosphate fertilizer was just as likely to stimulate weed growth, that would compete more vigorously with the emerging grass seedlings. This appeared to occur at Yelarbon after Sowing 3, where fast-growing *Urochloa* responded positively and slow-growing *Bothriochloa* spp. negatively. The cost of fertilizer for establishing pasture grasses does not seem justified, particularly in these semi-arid environments, where the crop may not receive sufficient rain to fully exploit the available soil nitrogen pool and loss from volatilization is common.

Early vs. late summer sowing

Our trial circumstances did not allow any elucidation of whether establishment would be more reliable with early or late summer sowings, because late summer rains were generally inadequate for germination. Sowings 1 and 2 at Yelarbon and Condamine were not followed by good falls of rain but reasonable populations of sown grasses resulted. Our data show that successful establishment can occur over summer with modest falls of rain over the next 3 months (say, 30 mm in the next month and 75 mm over 3 months), in the absence of heatwaves and provided weed control and grazing are well managed. Similar results have been recorded on cracking clays near Walgett (Bellotti et al. 1991), although frost damage was regarded as an important constraint in that more southern area; such was not thought to apply in our trials.

Conclusions

Lack of a consistent cultivation and fertilizer effect highlights the multitude of factors that can affect seedling establishment in the unpredictable environment of this region and emphasizes the over-riding importance of effective germination and post-emergence rainfall. The relatively low fertility of the soils was no great impediment to the seedling growth of these adapted grasses and fertilizer could often disadvantage their establishment by producing excessive weed competition. Thus any appropriate land preparation that minimizes germination risk and weed competition thereafter should benefit perennial tropical grass species sown commercially in this region.

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References

Bellotti WD; Bowman A; Silcock RG. 1991. Sustaining multiple production systems. 5. Sown pastures for marginal cropping lands in the subtropics. Tropical Grasslands 25:197–204.

Bisset WJ; Graham TG. 1978. Creeping bluegrass finds favour. Queensland Agricultural Journal 104:245–253.

Blacket D. 1992. Selecting suitable pastures. In: Lawrence D; French V, eds. Sown pasture management notes: Western Downs & Maranoa. Queensland Department of Primary Industries SQA 92002, Brisbane, Australia. p. 19–36.

Campbell MH; Bowman AM; Bellotti WD; Friend JJ; Nichol HI. 1995. Establishment and survival of pasture grasses surface-sown into wheat stubble in north-western New South Wales. Rangeland Journal 17:37–45.

Clem RL; Wildin JH; Larsen PH. 1993. Tropical pasture establishment. 12. Pasture establishment practices and experiences in central Queensland. Tropical Grasslands 27:373–380.

Cole I; Waters C. 1997. Harvesting and sowing native grasses. Proceedings of the Twelfth Annual Conference, Grassland Society of NSW, Armidale, NSW, Australia. p. 95–103. http://goo.gl/BLltxc

Del Pozo A; Avendaño J; Ovalle C. 1999. Long term productivity of a ley farming system in the "secano interior" of central Chile. In: Etienne M, ed. Dynamics and sustainability of Mediterranean pastoral systems. International Centre for Advanced Mediterranean Agronomic Studies, IAM Zaragoza, Spain. Cahiers Options Méditerranéennes 39:235–238. http://goo.gl/48yF0b

Douglas NJ, ed. 1997. Managing Ley Pastures. Workshop manual. Queensland Department of Primary Industries, Brisbane, Australia. CropLink Series QI 97101.

Freebairn DM; Connolly RD; Dimes J; Wylie PB. 1997. Crop sequencing. In: Clarke AL; Wylie PB, eds. Sustainable crop production in the sub-tropics: An Australian perspective. Queensland Department of Primary Industries Information Series QI97035, Brisbane, Australia. p. 289–305.

Freer B. 2006. Trash distribution and cultivation depth in minimal tillage and direct establishment systems for winter wheat. Home-Grown Cereals Authority (HGCA) Project Report No. 382. The Arable Group, Wymondham, Norfolk, UK.

French RJ; Matheson WE; Clarke AL. 1968. Soils and agriculture of the Northern and Yorke Peninsula Regions of

South Australia. Department of Agriculture, Adelaide, South Australia, Special Bulletin No. 1.68, p. 58–59.

Ghannoum O; Conroy JP. 1998. Nitrogen deficiency precludes a growth response to CO_2 enrichment in C_3 and C_4 *Panicum* species. Australian Journal of Plant Physiology 25:627–636.

GENSTAT 2005. GenStat Release 8. VSN International, UK.

Kätterer T; Bolinder MA; Thorvaldsson G; Kirchmann H. 2013. Influence of ley-arable systems on soil carbon stocks in Northern Europe and Eastern Canada. Proceedings, 17th Symposium of the European Grassland Federation, Akureyri, Iceland, 23−26 June 2013. p. 47–56.

Kelly PJ; Wiedemann HT. 1999. An improved distribution system for chaffy seeded grasses. Australian Journal of Experimental Agriculture 39:317–324.

Lloyd D; Johnson B; O'Brien S; Roesner L; Boschma S; Williams R. 2007. Pastures in farming systems sustaining profit and the environment, northern grain belt of Australia. Queensland Department of Primary Industries & Fisheries, Brisbane, and NSW Department of Primary Industries, Orange, Australia.

Northcote KH; Hubble GD; Isbell RF; Thompson CH; Bettenay E. 1975. A description of Australian soils. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, Australia.

Peart MH. 1979. Experiments on the biological significance of the morphology of seed-dispersal units in grasses. Journal of Ecology 67:843–863.

Silcock RG. 1980. Seedling growth on mulga soils and the ameliorating effects of lime, phosphate fertilizer and surface soil from beneath poplar box trees. Australian Rangeland Journal 2:142–150.

Silcock RG. 1993. Pasture composition in the Western Downs and Maranoa region of Queensland – does it really matter? In: Clark R, ed. The management of grazing lands in the Western Downs and Maranoa. Proceedings of a workshop held in Roma, Queensland. Queensland Department of Primary Industries Conference and Workshop Series QC93003, Brisbane, Australia. p. 113–137.

Silcock RG; Noble A; Whalley RDB. 1976. Importance of phosphorus and nitrogen in the nutrition of grass seedlings growing in mulga soil. Australian Journal of Agricultural Research 27:583–592.

Silcock RG; Hilder TJ; Finlay CH. 2014. Evaluating pasture species for less fertile soils in a subtropical aseasonal low rainfall zone. Tropical Grasslands–Forrajes Tropicales 2:223–245.

Silcock RG; Finlay CH; Loch DS; Harvey GL. 2015. Perennial pastures for marginal farming country in southern Queensland. 2. Potential new grass cultivar evaluation. Tropical Grasslands–Forrajes Tropicales, this volume.

Weston EJ; Doughton JA; Dalal RC; Strong WM; Thomas GA; Lehane KJ; Cooper JC; King AJ; Holmes CJ. 2000. Managing long-term fertility of cropping lands with ley pastures in southern Queensland. Tropical Grasslands 34:169–176.

White PJ. 1984. The effect of crop residue incorporation on soil properties and growth of subsequent crops. Australian Journal of Experimental Agriculture and Animal Husbandry 24:219–235.

White PJ; Saffigna PG; Vallis I. 1985. Effect of stubble management during different fallow periods on nitrogen nutrition of wheat on an irrigated black earth. Australian Journal of Experimental Agriculture 25:869–877.

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