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Research Papers

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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	<u>*B. insculpta* 52193</u>	*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>*U. stolonifera*</u>	*U. mosambicensis* Nixon	*U. oligotricha*	*P. stapfianum*	*B. insculpta* 69517	*B. bladhii*	<u>*B. pertusa* Medway</u>
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	<u>*C. ciliaris* 71914</u>	<u>*D. milanjiana*</u>	*D. eriantha* Premier	*P. stapfianum*	*E. curvula* Consol	<u>*E. curvula* 30374</u>	<u>*B. pertusa* Medway</u>
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.

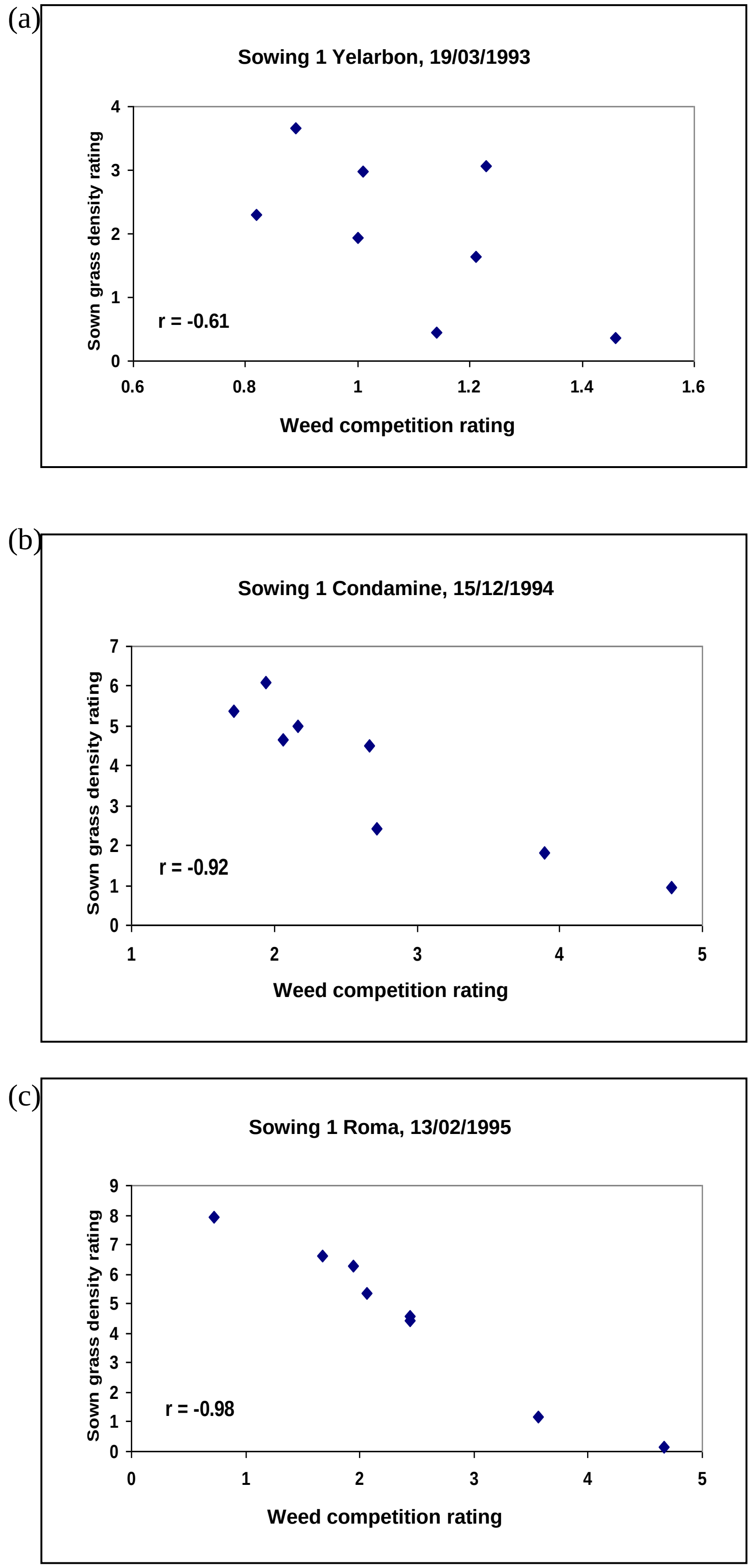

Figure 1. The depression effect of high weed competition on the mean density of individual sown grass accessions established at (a) Yelarbon, (b) Condamine and (c) Roma.

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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Perennial pastures for marginal farming country in southern Queensland. 2. Potential new grass cultivar evaluation

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Abstract

Trials in the Condamine-Balonne basin, Australia, compared 11 promising perennial pasture grass accessions (4 *Bothriochloa*, 2 *Cenchrus*, 2 *Urochloa* and 1 each of *Digitaria*, *Eragrostis* and *Panicum* species) against the best similar commercial cultivars on the basis of ease of establishment from seed, persistence once established, forage yield and ease of seed production. Accessions sown at a site were determined by prior experience with them on a range of soils. High quality seed was relatively easy to produce for both *Urochloa* species and for *Eragrostis curvula* CPI 30374 but problematic for the *Bothriochloa* spp. Once established, all accessions persisted for 3–5 years and most were well grazed, but adequate establishment was sometimes a problem with *Panicum stapfianum* and *Bothriochloa ewartiana*. The dry matter yield ratings of the non-commercial lines were similar to those of the commercial equivalents of the same species. While agronomically valuable, none of the promising new grasses was considered worthy of commercialization at this point because their strengths did not warrant the setting up of a seed-production business in competition with current commercial enterprises. Long-standing cultivars such as Gayndah buffel and Nixon sabi grass continued to exhibit their superior pasture qualities.

Resumen

En una serie de ensayos en la cuenca de Condamine-Balonne, Queensland, Australia, se compararon 11 accesiones promisorias de especies de gramíneas perennes (4 accesiones del género *Bothriochloa*, 2 de *Cenchrus*, 2 de *Urochloa* y 1 cada una de los géneros *Digitaria*, *Eragrostis* y *Panicum*) vs. los mejores cultivares comerciales de éstas o especies similares. Se evaluaron la facilidad de establecimiento por semilla, la persistencia de plantas establecidas, la producción de forraje y la facilidad para producir semillas. Las accesiones utilizadas habían sido previamente seleccionadas en trabajos de campo en un amplio rango de suelos. Fue relativamente fácil producir semilla de alta calidad de ambas especies de *Urochloa* y de *Eragrostis curvula* CPI 30374, pero fue difícil para las especies de *Bothriochloa*. Una vez establecidas, todas las accesiones persistieron durante 3−5 años y en su mayoría mostraron buen consumo por animales en pastoreo. En *Panicum stapfianum* y *B. ewartiana* se observaron algunos problemas para el establecimiento. La producción de materia seca de las accesiones fue similar a la de sus equivalentes comerciales de la misma especie. No obstante algunas ventajas agronómicas, las nuevas gramíneas no mostraron ser lo suficientemente promisorias para continuar con el proceso de comercialización puesto que sus fortalezas aún no justifican un programa de producción de semillas en competencia con las empresas comerciales actuales. Gramíneas bien conocidas como cv. Gayndah del pasto búfel (*Cenchrus ciliaris*) y cv. Nixon del pasto sabi (*Urochloa mosambicensis*) confirmaron sus cualidades superiores.

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Introduction

In southern inland Queensland (26–29º S) perennial pasture species such as lucerne or alfalfa (*Medicago sativa*) and Rhodes grass (*Chloris gayana*) are well suited to the more fertile cracking clays and krasnozems, when annual rainfall is above 700 mm, as are short-lived annual medics (*Medicago* spp.) and forage sorghums (*Sorghum* spp.) (Thompson 1988; Bellotti et al. 1991). In drier environments the number of suitable species diminishes; they become more soil-specific, and the time required in a pasture ley phase increases for adequate soil restoration. Buffel grass (*Cenchrus ciliaris*) is a common species sown on sandy soils, while Bambatsi panic (*Panicum coloratum* var. *makarikariense* cv. Bambatsi) grows well on heavy cracking clays. Lucerne (alfalfa) has a wide soil adaptation and remains important, where soil fertility is adequate and soil nematode problems are minimal. However, all 3 have deficiencies − the lifespan of lucerne pastures in this environment is short; Bambatsi panic can cause photosensitization in livestock; and buffel grass is hard to plow out from a ley pasture phase. In some places no common commercial cultivars are well adapted, e.g. on many hard-setting poplar box (*Eucalyptus populnea*) soils (Blacket 1992).

Since few perennial pasture species can be recommended for use in southern inland Queensland, there is the risk that a serious new pest or disease outbreak could decimate an existing cultivar, severely reducing available options. Hence research was needed to identify a wider range of possible cultivars than those currently available, namely buffel grass, lucerne, Premier digit grass (*Digitaria eriantha* ssp. *smutsii* cv. Premier) and creeping bluegrass (*Bothriochloa insculpta*) (Silcock et al. 2014). The emphasis was on soils other than cracking grey clays, for which a range of moderately successful cultivars exists. Soils of chief interest were those found beneath eucalypt woodlands rather than *Acacia* shrublands, but did not include cypress pine (*Callitris glaucophylla*) and spinifex (*Triodia* spp.) country, where the soils are too infertile, shallow or prone to serious erosion if cultivated.

This paper is the second of 2 that report on trials, where grass accessions, short-listed after earlier studies by Silcock et al. (2014), were compared against the best equivalent commercially available cultivars. It deals with the relative performance of these grasses and their potential for commercial release. The first paper assessed establishment success using a range of sowing techniques (Silcock and Finlay 2015).

Methods

A total of 17 perennial grass accessions (6 commercial and 11 experimental) were planted across 3 sites (Table 1). They were assessed for agronomic potential on 4 main features:

- Ease of establishment from seed,
- Persistence once established,
- Forage yield, and
- Ease of seed production (at specialist seed production facilities).

Only 8 accessions were evaluated at each site but Gayndah buffel (*C. ciliaris* cv. Gayndah) was always included as a reference standard. The soil characteristics of the sites and the sowing methods were described in Silcock and Finlay (2015). Briefly, the site near Yelarbon (28.234º S, 150.721º E) was on a grey, sandy clay loam fringing brigalow (*Acacia harpophylla*) country, the one near Condamine (26.797º S, 150.186º E) was on a brown, gritty, loamy-surfaced duplex soil, that was originally a poplar box/false sandalwood (*Eremophila mitchellii*) woodland, and the one near Roma (26.795º S, 148.766º E) was on a sandy red earth-surfaced duplex soil, that originally supported an open poplar box, belah (*Casuarina cristata*) and kurrajong (*Brachychiton populneum*) woodland.

Seedling establishment

Establishment methods consisted of 4 sowing times, 3 different seedbed preparations and 2 fertilizer levels (0 and 100 kg/ha of Starterphos – 10% N, 20% P, 2% S) (Silcock and Finlay 2015). Sowing occurred between spring and autumn from late 1992 to April 1994. Sowing dates were determined when adequate pre-sowing rain allowed the ground to be cultivated. Species were rated several times during the first year after each sowing for seedling density, weed competition and dry matter yield. Treatments were replicated 3 times and plot size varied from 25 to 200 m^2 depending on the sowing event.

Persistence and forage production

Persistence was assessed in the 1994/95 summer and in 1998 and further observations continued, if the sites remained under pasture. Observers rated each plot for the density of plants of the sown accession, sown plant vigor, plot weediness, dry matter yield of the sown plant and apparent palatability to animals at the time. When no sown plants survived, the rating was zero.

Table 1. List of the pasture accessions sown at the trial sites, their growth habit and seed characteristics and their original collection location. Homelands are listed in brackets where the lines used are from naturalized locations in Queensland.

Accession code	Botanical name	Homeland	Status	Notes	Sites sown[1]
CPI 11408	*Bothriochloa bladhii* var. *glabra*	Uncertain	Now cv. Swann	Tufted; spring tillers prostrate; hairy seed	Y, C
TN 47	*Bothriochloa ewartiana*	St George, Qld	Native	Tufted; typical hairy *Bothriochloa* seed	Y
CPI 52193	*Bothriochloa insculpta*	Zambia	Experimental	Early-flowering; like cv. Bisset	Y
CPI 69517	*Bothriochloa insculpta*	Zimbabwe	Experimental	Like cv. Bisset but larger seedhead	C
Bisset	*Bothriochloa insculpta* cv. Bisset	Kenya and Tanzania	Commercial	Creeping; hairy nodes; elongated, hairy seed	Y
Medway	*Bothriochloa pertusa* cv. Medway	(Bogantungan, Qld)	Commercial	Creeping; hairless nodes; hairy seed	C, R
CPI 71914	*Cenchrus ciliaris*	Somalia	Experimental	Like cv. Gayndah; very bristly fascicles	R
CPI 73393	*Cenchrus ciliaris*	Limpopo Province, Rep. South Africa	Experimental	Like cv. Biloela; short, soft fascicle bristles	Y, C[2]
Gayndah	*Cenchrus ciliaris* cv. Gayndah	Kenya / (Queensland)	Commercial	Tufted habit; bristly fascicles	Y, C[3], R
Premier	*Digitaria eriantha* cv. Premier	Rep. South Africa	Commercial	Tufted; non-hairy leaves; elongated seed with short hairs	R
CPI 41192	*Digitaria milanjiana*	Rep. South Africa	Experimental	Creeping + tufts; very hairy leaves; seed like cv. Premier	R
CPI 30374	*Eragrostis curvula*	Rep. South Africa	Experimental	Tufted; hairy leaves; open seedhead; tiny hairless seed	R
Consol	*Eragrostis curvula* var. *conferta* cv. Consol	Cape Province, Rep. South Africa	Commercial	Tufted; compact seedhead; tiny seed	R
CPI 73577	*Panicum stapfianum*	Rep. South Africa	Experimental	Tufted; open crown; smooth rounded seed	C, R
Nixon	*Urochloa mosambicensis* cv. Nixon	Zimbabwe	Commercial	Open crown; large, flat hairy seed	Y, C
CPI 47122	*Urochloa oligotricha*	Namibia	Experimental	Palatable; rounded, large, non-hairy seed	Y, C
CPI 60128	*Urochloa stolonifera*	Rep. South Africa	Now cv. Saraji	Like a creeping cv. Nixon; hairy seed	C

[1]Y = Yelarbon site, C = Condamine site, R = Roma site.
[2]only Sowing 4. [3]not in Sowing 4.

Post-establishment management

Grazing was controlled by a temporary fence during the establishment phase of each sowing and was used for short intervals to reduce weed competition and to enhance tillering of the young sown plants. After all sowings had established or failed due to drought (see Silcock and Finlay 2015), the fences were removed in late 1995. Thereafter the pastures were grazed when the owner's stock were in that paddock. The Yelarbon site became a cell in a time-controlled grazing system and, as such, was heavily grazed intermittently by cattle and often carried a large body of grass at other times. The Condamine site was in a small paddock and was heavily grazed by cattle at most subsequent visits, although never denuded. The Roma site was intermittently grazed in summer by sheep initially and cattle became the main grazing animals after 1998.

Seed production

Seed of non-commercial lines was increased by specialist seed production units prior to these field sowings from irrigated, fertilized plants using sequential harvesting by hand and by machine. Herbicides were used to control weeds, and accessions were tested for sensitivity to those commonly used by the seed industry, following the protocols of Loch and Harvey (1993). Flowering times, pests and diseases, competitiveness and agronomic constraints were noted. A sample from most seed batches was sent for viability testing under international protocols.

Statistical analysis

GenStat 5.0 (GENSTAT 1987) and an in-house balanced factorial analysis package (BALF) were used for statistical testing of the data. The terms adopted for the final ANOVA model were Cultivation, Fertilizer, Grasses, Grasses x Cultivation and Fertilizer x Grasses, Data were checked for variance using 'residuals' plots and non-compliant sets were transformed prior to running the ANOVA again and doing LSD tests.

Results

Seasonal conditions

During establishment, rainfall was generally low (Silcock and Finlay 2015). Seasonal rain from first sowing until the year 2000 for the nearest official gauging station is shown in Table 2. During the persistence testing phase up to 2000, the Yelarbon site had excellent summers and autumns in 1995, 1996 and 1997 and an extremely wet winter in 1998. The Condamine site had good summers in 1996 and 1998 and an excellent winter in 1998. After the establishment year, the Roma site had fair to good rainfall throughout, including the wet 1998 winter, and a good spring in 2000 but had an extremely dry winter in 1997. In dry winters, heavier ground frosts than normal are experienced (Rainman 2003).

Since pre-sowing cultivation and fertilizer had minimal influence on establishment (Silcock and Finlay 2015), the results presented are the mean of the cultivation and fertilizer treatments.

Early growth

The field emergence of *Urochloa* species, *Bothriochloa insculpta* (creeping bluegrass) accessions and Medway pertusa (*B. pertusa*) was better than expected (Silcock and Finlay 2015). Conversely, *B. bladhii* and *Panicum stapfianum* had poorer field establishment than their seed tests foreshadowed. Thus denser seedling stands than expected arose from the *Urochloa* and the exotic *Bothriochloa* species, except for *B. bladhii*. Once established, all accessions persisted well for 3–5 years. Sparse stands of the tussock grasses *B. bladhii* and *P. stapfianum* remained sparse and dense stands of other lines competed well with local weeds. Stolons of the creeping bluegrasses readily grew up through large roly-poly bushes (*Salsola kali* and *Sclerolaena muricata*) and suppressed annual weeds well.

Table 2. Seasonal rainfall conditions (mm) at the 3 trial sites between the first sowing and the year 2000. Data are taken from Rainman (2003) using the nearest long-term recording station.

Season	Long-term mean	1993	1994	1995	1996	1997	1998	1999	2000
	Yelarbon								
Summer[1]	229	173	197	448	418	389	217	193	184
Autumn	120	22	77	137	230	143	175	176	150
Winter	100	68	31	52	66	21	367	97	40
Spring	150	96	99	202	145	189	204	197	184
	Condamine								
Summer	260	138	263	283	421	289	405	215	262
Autumn	137	16	199	47	199	101	178	103	67
Winter	105	71	33	71	97	25	251	87	33
Spring	151	98	140	237	170	195	204	123	132
	Roma								
Summer	228		312	272	437	388	251	228	341
Autumn	135		162	47	168	109	163	196	128
Winter	97		30	47	81	6	187	91	63
Spring	138	116	127	219	89	140	183	146	267

[1]Summer = December of the previous year, January, February;
Autumn = March, April, May;
Winter = June, July, August; and
Spring = September, October, November.

Yield ratings and persistence

Presentation dry matter yield ratings of the non-commercial lines were generally similar to the commercial equivalents (Tables 3, 4 and 5). Of the grasses sown at Yelarbon, Bisset (*Bothriochloa insculpta*) and *B. insculpta* 52193 were often very similar (Table 3). *Urochloa oligotricha* initially grew almost as well as the other *Urochloa* species and was more palatable, hence its lower yield rating later under grazing (Tables 3 and 4). However, it did not persist in the long term (to 2008), whereas Nixon (*U. mosambicensis*) did. By comparison, standing yields of *B. insculpta* generally increased over time relative to others.

Consol lovegrass (*Eragrostis curvula*) did not grow as well as *E. curvula* 30374 (Table 5) and *Digitaria milanjiana* generally outperformed Premier (*D. eriantha*). At Roma, Gayndah buffel (*Cenchrus ciliaris*) had a poor initial yield rating (Table 5) but that improved over time, as it did at Yelarbon. Yield rating of Medway pertusa (*B. pertusa*) increased steadily over time relative to almost all the other species at Roma (Table 5), but not at the Condamine site (Table 4).

Table 3. Dry matter yield ratings of sown grasses near Yelarbon on 3 occasions after the establishment phase. Ratings were on individual plots: the plot with the greatest yield (visually) of sown grass was given 10, those lacking sown grass assigned 0, and a linear ranking applied for intermediate yields. Sowing 1 was on 10/12/92, Sowing 2 on 12/10/93, Sowing 3 on 17/12/93 and Sowing 4 on 13/4/94. LSD applies amongst accessions within an assessment date.

Assessment date	Sowing	Accession								LSD (P<0.05)
		C. ciliaris Gayndah	*C. ciliaris* 73393	*U. mosambicensis* Nixon	*U. oligotricha*	*B. bladhii*	*B. ewartiana*	*B. insculpta* Bisset	*B. insculpta* 52193	
15/4/1994	1	3.2	4.1	3.3	3.9	1.7	1.9	2.7	3.0	0.40
	2	1.0	0.7	0.7	1.7	0.1	0.2	1.3	0.7	0.42
30/1/1995	1	8.1	7.6	8.9	8.4	2.6	5.0	7.2	7.1	0.61
	2	3.1	3.4	5.7	6.6	1.3	1.9	5.6	3.1	0.97
	3	2.5	3.6	7.3	5.3	2.0	1.5	5.7	5.3	0.76
29/5/1998	1	8.4	6.7	7.4	5.3	3.1	4.7	8.4	7.2	1.12
	2	3.9	3.3	6.7	3.8	1.6	2.4	7.3	5.2	0.88
	3	4.2	4.7	8.0	4.0	4.9	4.0	8.8	8.4	1.17
	4	3.6	1.9	3.0	1.8	1.9	1.2	5.5	7.2	0.87

Table 4. Dry matter yield ratings of sown grasses near Condamine on 3 occasions after the establishment phase. Ratings were on individual plots with the plot with the greatest yield (visually) of sown grass given 10, those lacking sown grass assigned 0, and a linear ranking applied for intermediate yields. Sowing 1 was on 22/12/92, Sowing 2 on 22/9/93, Sowing 3 on 20/12/93 and Sowing 4 on 12/4/94. LSD applies amongst accessions within an assessment date.

Assessment date	Sowing	Accession								LSD (P<0.05)
		C. ciliaris Gayndah	*U. mosambicensis* Nixon	*U. oligotricha*	*U. stolonifera*	*B. bladhii*	*B. insculpta* 69517	*B. pertusa* Medway	*P. stapfianum*	
11/4/1994	1	2.5	4.0	3.0	3.8	1.2	3.8	1.8	0.6	0.60
	2	0.3	0.5	1.1	1.7	0.1	1.3	0.7	0.1	0.42
15/12/1994	1	4.7	6.1	3.9	5.0	1.8	6.2	4.6	0.7	0.96
	2	1.3	2.5	3.3	4.4	2.6	6.7	6.4	0.7	0.68
	3	0.01	1.3	0.8	2.2	0.8	0.7	0.9	0.1	0.38
24/2/1998	1	3.7	8.9	2.6	2.9	1.3	8.9	3.0	0.9	0.83
	2	4.0	8.6	1.7	2.8	2.6	8.8	2.9	1.4	1.08
	3	0.1	8.9	3.0	3.7	5.9	7.9	3.4	0.7	1.19
	4	0.2[1]	6.8	0.5	1.8	3.5	3.4	3.3	1.7	2.31

[1]Gayndah replaced by *C. ciliaris* 73393 for this sowing.

Table 5. Dry matter yield ratings of sown grasses near Roma on 3 occasions after the establishment phase. Ratings were on individual plots with the plot with the greatest yield (visually) of sown grass given 10, those lacking sown grass assigned zero, and a linear ranking applied for intermediate yields. Sowing 1 was on 23/11/93, Sowing 2 on 17/12/93 and Sowing 3 on 21/3/94. LSD applies amongst accessions within an assessment date.

Assessment date	Sowing	Accession								LSD (P<0.05)
		C. ciliaris Gayndah	*C. ciliaris* 71914	*P. stapfianum*	*B. pertusa* Medway	*D. milanjiana*	*D. eriantha* Premier	*E. curvula* Consol	*E. curvula* 30374	
6/4/1994	1	1.0	2.9	0.2	1.0	2.6	0.9	0.5	1.3	0.38
	2	2.2	3.6	0.4	1.8	3.4	1.4	1.1	1.9	0.46
13/2/1995	1	4.1	7.6	0.2	3.7	4.5	3.3	1.5	6.3	0.58
	2	3.6	6.8	0.7	3.2	3.6	2.1	1.2	5.2	0.72
5/6/1998	1	6.6	8.7	0.9	6.7	5.7	4.9	3.0	7.5	1.15
	2	7.2	8.2	0.4	8.0	6.0	4.4	4.3	6.7	1.04
	3[1]	4.5	4.8	0.0	4.0	2.2	1.5	0.4	4.2	1.23

[1]Only one replication with 3 treatment subplots (see Silcock and Finlay 2015) left after partial cultivation of the site.

The buffel grasses generally rated well as did Nixon sabi grass (*U. mosambicensis*), where it was tested (Tables 3 and 4). Conversely, *B. ewartiana* and *P. stapfianum* generally rated poorly for standing pasture yield. Ratings for these plants also remained relatively constant from 1994 to 1998 with *P. stapfianum* consistently low (Tables 4 and 5). The other accessions varied in their performance relative to Gayndah buffel (*C. ciliaris*).

At Condamine relative yield of *U. stolonifera* declined over time from excellent initial ratings for Sowings 1 and 2 (Table 4). *Digitaria milanjiana* followed a similar trend at the Roma site (Table 5), while Premier digit grass (*D. eriantha*) and Consol lovegrass (*E. curvula*) never performed better than buffel grass. In contrast *E. curvula* 30374 always had a good yield ranking at Roma (Table 5), partly because it was generally unpalatable once mature.

Although these perennial plants had the capacity to thicken up from a relatively poor seedling stand, as Bisset (*B. insculpta*) did at Yelarbon (Table 3) and *B. insculpta* 69517 at Condamine (Table 4), poor initial stands tended to remain sparse for many years. Thus no accessions in 1998 from Sowing 4 at Yelarbon (which had a low establishment success; Silcock and Finlay 2015) had ratings as good as those of the same accession from Sowing 3 (Table 3). Likewise, all sparse Sowing 3 stands at Roma rated worse in 1998 than those from Sowings 1 and 2 (Table 5), but such a pattern was not consistently evident at Condamine (Table 4). Any positive changes in yield ratings happened in the first or second year after sowing, after which declines in pasture yield over time were more common. Early improvers were Nixon sabi grass (*U. mosambicensis*) and Bisset bluegrass (*B. insculpta*) at Yelarbon (Table 3) and *B. insculpta* 69517 at Condamine (Table 4). Relative rankings of accessions tended to be consistent over time at Roma with the exception of *D. milanjiana*, which declined (Table 5).

Seed production

Seed was relatively easy to produce and harvest for both non-commercial *Urochloa* species and for *E. curvula* 30374. Seed of *U. oligotricha* is hairless so can be cleaned more readily than that of Nixon (*U. mosambicensis*) and *U. stolonifera*, while seed of *E. curvula* 30374 can be processed to almost pure caryopses if required, like cv. Consol. The non-commercial buffel grasses also produced good quantities of seed but *C. ciliaris* 73393 had to be sprayed after flowering to control the native seedhead-feeding grub, *Mampava rhodoneura*. Its dense seedhead, like that of cv. Biloela, made it more susceptible to attack compared with the more open seedhead of *C. ciliaris* 71914, which resembles cv. Gayndah.

Digitaria milanjiana flowered freely and produced seed of a quality similar to that of Premier digit grass (*D. eriantha*), without being infested with any insect pests or diseases. Likewise seed production problems in *B. insculpta* 52193 and *B. insculpta* 69517 bluegrass were similar to those normally experienced by the related commercial cultivars Hatch and Bisset. All have small, hairy seeds that ripen sequentially, do not flow readily when mechanically handled and are susceptible to ergot infection. *Bothriochloa insculpta* 52193 flowers slightly earlier than cv. Bisset, while *B. insculpta* 69517 has noticeably higher seed yield, due to a larger seedhead and caryopsis.

Medway pertusa (*B. pertusa*), though similar to the creeping bluegrasses in growth habit and seedhead structure, was very prone to ergot attack at Gympie (D. Loch unpublished data). This reduced its seed yields and purity but had little effect on the viability of any harvested caryopses.

Bothriochloa bladhii CPI 11408, released soon after as cv. Swann forest bluegrass, had good seed production characteristics because it has a concentrated flowering period in summer and its seedheads are held clear of the main foliage. It was generally resistant to ergot attack and had a relatively high seed fill percentage for a bluegrass (Silcock and Finlay 2015). By comparison, it was difficult to harvest commercially useful quantities of seed from TN 47 desert bluegrass (*B. ewartiana*). Its seedlings developed few tillers in the sowing year and there were few seedheads/m^2 compared with all others except *P. stapfianum*. In addition, its seedheads were very susceptible to ergot attack, which reduced viable seed production further. Its seed yield in subsequent years improved as the stand thickened under fertilizer application and irrigation but invading grassy weeds resulted in extra costs and management problems.

Panicum stapfianum produced moderate seed yields and its heads drooped appreciably, so that catching the heads with a mechanical header required considerable skill. Sequential ripening of florets within a seedhead, typical of *Panicum* species, meant harvesting had to be done at either an optimal time, with a lot of potential seed lost, or several times with a brush harvester. However, the harvested seed, either direct-headed, swathed or hand-picked, was easy to clean, plump and flowed readily.

Discussion

This trial was the culmination of nearly 2 decades of research to select extra commercial pasture species for either ley farming systems or as replacements in the event of future serious pest outbreaks. The benchmark was existing commercial species selected chiefly for permanent, unfertilized perennial pastures. Ley farming is not yet widely practiced in Queensland and availability of fairly cheap seed is often a major factor determining what is sown.

The 11 non-commercial lines tested provided mixed success in meeting the objectives. The decline in productivity over time of many of the species tested was not unusual (Theron and Haylett 1953; Robbins et al. 1986; Dodd et al. 1990). Called pasture rundown, it was due primarily to a decline in available soil nitrogen, as nitrogen was tied-up in the robust perennial crowns of these tropical grasses (Meyers and Robbins 1991). Combating such rundown is the subject of much pasture research around the world (Peck et al. 2011), but perennial grasses are still the basis of long-term sustainable agricultural systems in subhumid and semi-arid environments.

Accession summaries

CPI 11408 B. bladhii *var.* glabra. This accession has since been released commercially as cv. Swann (PVJ 1996). Although this plant was imported as *B. ischaemum* from Guyana in 1948, it may be a native species because it is unlike that particular species. It may be a contaminant from nearby sown plots or from adjoining native southern Queensland pastures. No DNA testing has been done to investigate its possible origins. Commercial use of this cultivar is limited but it persists on some poorer soils that are unsuited to most other sown pasture grasses (DAFF 2014a). While seed yields are high (>200 kg/ha), it produces only a single crop each year, in late summer. It has low palatability in winter but persists and provides roughage in dry seasons and winter, especially in lowly productive country. Post-emergence atrazine at 2 kg a.i. (active ingredient)/ha had no effect on this plant.

TN 47 B. ewartiana. This native grass had initial appeal in view of the strong lobby against exotic plants that may become weeds (Lonsdale 1994). While this plant can be grown commercially, seed is potentially very expensive, and it is not strongly competitive in the first growing season. Its major agronomic strengths are its persistence once established and a fairly broad soil adaptation. Established plants are resistant to atrazine, so seed-production plots can be sprayed to control summer annual grass weeds. It was tested towards the southern extremity of the natural distribution of the species at Yelarbon and may perform better further north.

CPI 52193 B. insculpta. This plant performed like cv. Bisset, but with a slightly earlier flowering time. It presented some seed production problems in a coastal environment and seed quality was a little unpredictable. There is currently no requirement for it in competition with the existing small, struggling seed market for Hatch and Bisset creeping bluegrasses. It is susceptible to both pre- and post-emergence atrazine.

CPI 69517 B. insculpta. This strain of creeping bluegrass produces plenty of seed and performed as well as *B. insculpta* 52193 (Silcock et al. 2014). Ease of seed production is a major issue for tropical grasses (Hopkinson and English 1985; Hill and Loch 1993), so ease of establishment, good persistence and palatability under grazing of this plant could allow it to replace cv. Bisset. It outperformed buffel grass at Condamine and its production there matched that of Nixon sabi grass (*U. mosambicensis*). It is not as palatable to kangaroos as sabi grass and is not as well adapted to red earths (Silcock et al. 2014). Its relatively low palatability to stock unfamiliar with it, compared with Rhodes (*Chloris gayana*) and buffel grass, means farmers would tend to avoid it for short-term leys. Its most likely future role would be on hard-setting solodic soils, where it withstands trampling in wet times. Creeping bluegrass (*B. insculpta*) provides poorer ground cover than Medway pertusa (*B. pertusa*) because the distance between rooted nodes is greater.

B. insculpta *cv. Bisset*. This plant has grown very well in the Maranoa region on a range of soil types (Lloyd et al. 2007). It is readily established from seed and persists well for many years. It is more easily plowed out than Medway pertusa (*B. pertusa*) and has not shown any tendency to spread into undisturbed native pasture. The prostrate dead litter and stubble results in lower densities of annual medics emerging in winter compared with adjacent buffel grass plots. Creeping bluegrasses (*B. insculpta*) are regarded as less nitrogen-demanding than many other grasses (DAFF 2014b), such as buffel and the panics.

B. pertusa *cv. Medway*. Medway pertusa has grown and persisted well and strains of this species are now regularly found along roadsides in the region. It is quite resistant to regular grazing and mowing and spreads easily over sparsely covered ground. While it does not have strong soil preferences, dry matter yields are quite low. Limited palatability makes its best role as a soil conservation grass. With its low tolerance of animal trampling, its use around yards and waterpoints is not recommended. Medway is not easily plowed out, but it is not as tolerant of plowing as tropical couch grasses (*Cynodon* spp.). Medway is susceptible to pre-emergence atrazine and mildly stunted by 2 kg a.i./ha once established. The Roma site was virtually devoid of it in 2006 following several lucerne crops sown with pre-emergent herbicide, combined with persistent dry years. The species is regarded as being moderately drought-tolerant but has persisted for decades in the absence of grazing at the Charleville airport and golf course (Bisset 1980). Medway is more leafy and productive than other strains of *B. pertusa* (W. Scattini pers. comm.) but fails to maintain ground cover at critical times during droughts, like most other mat-forming perennial grasses adapted to this region.

CPI 71914 C. ciliaris. This accession has performed as well as cv. Gayndah in all ways and earned a slightly higher rating for dry matter yield at Roma. Its fluffy seed poses sowing problems and its sturdy crown would break down slowly after plowing out in a ley farming system. Like most buffel grasses (Loch and Harvey 1993), it is very sensitive to pre- and post-emergence atrazine herbicide. Like cv. Gayndah, its ability to colonize and spread naturally could pose problems adjacent to conservation reserves (Fairfax and Fensham 2000). It has persisted very well at several test sites on sandy, infertile red earths and is best suited as a permanent pasture. High costs of setting up a seed production program are not justified at this time, when so much seed of similar buffel grasses is available.

CPI 73393 C. ciliaris. This accession was planted on the best soil, the Yelarbon site, in an environment where cv. Biloela is the commonly sown buffel cultivar. It generally equalled or bettered Gayndah's production at this site but was no better than Biloela for this soil type. It is another germplasm that should be held in storage in case new pests or diseases arise that have to be overcome. No data exist on whether the leaf scorch disease, that can afflict several commercial strains of buffel grass (Cook et al. 2005a), is virulent on this line.

C. ciliaris *cv. Gayndah*. Gayndah buffel is the most common sown pasture grass in inland subtropical Australia, but is criticized in some circles for modifying the environment and altering fire regimes (Friedel et al. 2011). Years ago it was the savior of the Alice Springs environment by dramatically reducing dust levels after extensive planting (Puckey et al. 2004) and is highly regarded as a forage and cover by pastoralists worldwide. It has remained virtually pest- and disease-free in Australia for over 50 years but that cannot be guaranteed (Hall 2001). Hence alternatives with similar features, such as *C. ciliaris* 71914, should be available in the event that a devastating disease or pest emerges, as happened to American buffel in the USA and Mexico in 2000 (Cook et al. 2005a) and to Townsville stylo (Partridge 2003) and annual medics (Swann 1982) in Queensland in the past.

Gayndah buffel was easy to establish and grew very well at most sites, but performed quite poorly at Condamine and continues to thin out there. The reasons for this are not clear as Nixon sabi grass (*U. mosambicensis*) and *B. insculpta* 69517 both grew well there. This is an example of how certain soil types unexpectedly do not favor a climatically adapted plant and why there need to be comparable plants available to landholders. We did not sow *C. ciliaris* 71914 at this site so cannot comment on how it would have performed. There is negligible naturalized buffel grass along roads leading to the site, so the effect may be species-wide. Conversely, another *Urochloa*, liverseed grass (*U. panicoides*), is omnipresent at the Condamine site.

The severe loss of seed viability in our cold store was disappointing. The room was not de-humidified, and the Gayndah seed was in porous hessian sacks. Thus, the high humidity seems to have more than offset the low temperature in accelerating the deterioration of the buffel grass seed (Cameron 2003), along with that of several others (Silcock and Finlay 2015).

D. eriantha *cv. Premier.* This grass established and grew well at Roma where it was being compared with *D. milanjiana*. It was always palatable and would be a good short-term pasture with good spring season growth, if soil moisture existed. It was easily plowed out and replaced with lucerne. McDonald et al. (1998) consider it poses a problem on some sandy soils in southeast Queensland, where it persists under grazing and seems to tie up much of the available soil nitrogen without providing much forage, as buffel grass can sometimes do in the Maranoa and central Queensland highlands.

CPI 41192 D. milanjiana. This strain of *D. milanjiana* produces seed more readily than many related accessions (Hall and Walker 1994), is tolerant of moderately acid soils and will persist for many years in southwest Queensland (Silcock et al. 2014). It has better frost tolerance than other accessions such as CPI 59786 and cv. Jarra, which is important in southern inland Queensland. Seed production was not difficult and its seed cleaned up well in a cone thresher. It established well at Roma with reasonable follow-up rains and is fairly tolerant of atrazine once well established. Sward density was lower than that of Medway despite producing long stolons. Those stolons did not match the rooting tenacity of Medway pertusa (*B. pertusa*) or creeping bluegrass (*B. insculpta*) (Silcock et al. 2014).

This accession is very palatable and produced a good bulk of feed in the above-average summer of 1995/96. However, it was thinning out when the trial site was plowed out in early 2000. Nonetheless, as a short-term ley pasture, it could fulfil a role on more acid mulga soils, where *D. eriantha* cv. Premier does not grow well.

CPI 30374 E. curvula. This chloromelas type (Gibbs Russell et al. 1990) establishes easily on infertile, acid soils (Filet 1988) and seed collection is very easy. It had seasonally poor palatability, especially when hayed-off, and produced masses of seedlings around parent plants. It was not grazed readily at Roma compared with cv. Consol but was far more productive and more easily established. It could not be considered for use further east than Roma because of the weed status of some naturalized strains of the species in traprock country and along roads in forestry regions. The plant was easily plowed and sprayed out from seed-production plots, and subsequent cultivation, along with cropping at the Roma site, has eliminated the plant there too.

Further west around Charleville, where it was extensively tested up to 1985, it has failed to gain a foothold and died out readily during droughts. It persists only on sandy soils around Charleville township in the absence of grazing. No further testing of it is envisaged at this time but it is a benchmark against which to compare similar plants in future. Seed is maintained in the Australian Pastures Genebank (AusPGRIS 2014), along with the other accessions reported in this paper.

E. curvula *var.* conferta *cv. Consol.* Consol lovegrass did not persist and performed quite poorly, as it has at several other test sites (Silcock et al. 2014). It cannot be recommended for commercial use in southern Queensland and poses no weed threat where used, because it is palatable and non-competitive against native pastures.

CPI 73577 P. stapfianum. This panic has reaffirmed its status as being resistant to grazing and having low demands for soil fertility (Silcock et al. 2014). However, it was difficult to establish and slow to thicken-up thereafter. Seed yields were also very low, less than 25 kg/ha. Hence there is no case at present for its future commercial release. It has no weedy features and is very palatable when growing as small patches amongst other pastures, including to wildlife (kangaroos and rabbits). Established plants are very resistant to glyphosate.

U. mosambicensis *cv. Nixon.* Nixon has been in the market place for decades but has failed to gain popularity in southern Queensland. There may be several reasons for this – high palatability to kangaroos, low frost tolerance, plus poor palatability and dead leaf retention once hayed off. Around Roma is has been called 'acid grass' by some graziers, who say it is unpalatable to stock, especially once in seed. Many have concerns about it competing with buffel grass on fertile brigalow soils.

Nixon was easy to establish and grew as much bulk as any other grass sown. Neither site has been returned to cropping yet, so Nixon's persistence, after plowing and with possible use of pre-emergent herbicides, is unknown. It was less palatable than buffel in a time-controlled grazing system at Yelarbon but was eaten and has not shown significant weedy features. It has persisted much better than anticipated. Its compatibility with annual medics is unclear, but it does not develop a thick litter mat like the creeping bluegrasses (*B. insculpta*), if lightly grazed. The mature crown is much less fibrous and persistent than those of buffel grasses.

CPI 47122 U. oligotricha. This accession displayed poor persistence but it was easy to produce commercial supplies of its large, non-hairy seed and to establish it. It had a longer leaf than Nixon (*U. mosambicensis*) and was very palatable, so is less likely to become weedy in the absence of regular grazing, e.g. along roadsides. It is not very susceptible to the pre-emergence herbicide atrazine, so special management may be needed to remove it from cultivated situations. Its appreciable level of seed dormancy may pose a weed problem, similar to that of liverseed grass.

CPI 60128 U. stolonifera. This grass showed general promise and stands thickened easily from its moderately long stolons. It is very like Nixon − susceptible to frost, unpalatable in winter, has hairy seed, while high seed yields over 200 kg/ha are easily achieved. A tendency towards red coloration on the leaves under stress is a distinguishing trait. It is susceptible to the same herbicides as Nixon (Cook et al. 2005b) and very tolerant of 2 kg a.i./ha of atrazine once established.

It has since been released as cv. Saraji for minesite rehabilitation purposes (PVJ 1997). Thus it is like many pasture grasses that are used for their environmental values, but is the only one in Australia not released primarily as a forage plant. It establishes easily and grows well on acid soils. There seems no extra role for it in forage systems, while cv. Nixon is available.

Conclusions

Several experimental accessions of perennial grass proved to be as agronomically valuable as the current limited list available for sown pastures in subhumid, southern inland Queensland. Table 6 summarizes the performance of the tested accessions for both short- (1−3 years) and long-term (15 years or more) roles under local property grazing management. Some are potential alternatives should commercial types succumb to a new pest or disease, provided that they too are not susceptible. None was sufficiently superior to justify starting commercial seed production at present, especially as seed production of bluegrasses (*B. insculpta*) is difficult due to ergot susceptibility of the inflorescence in moister environments, where the seed production industry is based.

Table 6. Summary of the relative performance and persistence as pasture biomass of the accessions tested. Note: not all accessions were sown at each site, because prior testing had identified those most likely to grow and persist well.

Trial site: Soil attributes:	Yelarbon grey sandy medium cracking clay		Condamine firm brown gritty loam over mottled clay		Roma hard-setting red sandy loam over brown clay	
Time period:	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term[1]
Best performing	*C. ciliaris* 73393, Nixon	Bisset, Nixon	Nixon	Nixon, *B. insculpta* 69517	*C. ciliaris* 71914, *D. milanjiana*	*C. ciliaris* 71914
Performed well	*U. oligotricha*, Bisset	Gayndah, *B. insculpta* 52193	Gayndah, *U. stolonifera*	Medway, *B. bladhii*	*E. curvula* 30374, Gayndah, Medway	Medway, Gayndah, *E. curv*ula 30374
Worst performing	*B. ewartiana*, *B. bladhii*	*U. oligotricha*	*P. stapfianum*	Gayndah, *U. oligotricha*, *P. stapfianum*	*P. stapfianum*, Consol	*P. stapfianum*

[1]Not well assessed here because plowed out several times and oversown with lucerne. Assessment based on surviving plants in the surrounding headlands.

The very palatable *U. oligotricha* seems suited for short-term pastures, if sufficient demand arises in future. By contrast, despite being native and environmentally well adapted, *B. ewartiana* TN 47 is not agronomically suited for a ley pasture role in this region.

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Effect of nitrogen on yield and quality of *Panicum maximum* cvv. Mombasa and Tanzania in Northeast Thailand

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Keywords: Guinea grass, crude protein, leaf production, fertilizer responses.

Abstract

A field trial in Northeast Thailand during 2011–2012 compared the effects of nitrogen fertilizer, applied as urea in the wet season, on the growth and quality of *Panicum maximum* cvv. Mombasa and Tanzania. In the establishment year, increasing rates of nitrogen (0, 20, 40 and 60 kg N/ha every 40–45 days) (0–180 kg N/ha for growing period) progressively increased stem, leaf and total DM production (P<0.05). At higher rates (80 and 100 kg N/ha or 240–300 kg N/ha for growing period), only total DM increased at the highest rate. In the second year, a rate of 20 kg N/ha every 40–45 days (80 kg N/ha for growing season) doubled the amount of DM compared with no nitrogen, and 80 kg N/ha every 40–45 days (320 kg N/ha for growing period) produced significantly higher stem, leaf and total DM yields than most other rates. The yield response (kg DM/kg N) decreased linearly (24.7 to 20.3 in 2011; 56.7 to 15.1 in 2012) from the lowest to the highest rate of nitrogen. In both years, increasing rates of nitrogen significantly increased CP and NDF concentrations in stems and leaves and ADF concentrations in stems. Mombasa produced 17 and 19% more leaf and 18 and 22% more total DM than Tanzania, in the first and the second year, respectively. Mombasa also produced 30% more stem DM than Tanzania in the second year. While Tanzania produced higher CP levels than Mombasa in the establishment year, in the second year, Tanzania had higher levels than Mombasa only when N rates of 80–100 kg N/ha were applied every 40–45 days (320–400 kg N/ha for growing period). Applying 60 kg N/ha every 40–45 days appears to be a reasonable compromise to achieve satisfactory DM yields in the wet season (8,000 kg/ha first year and 12,000 kg/ha second year), leaf percentage of 68–70% and leaf CP concentrations above 7%.

Resumen

En el noreste de Tailandia durante 2011−2012 se compararon bajo condiciones de campo los efectos de la fertilización con nitrógeno, aplicado en forma de urea en época de lluvias, en el crecimiento y la calidad de los cultivares Mombasa y Tanzania de *Panicum maximum*. En el año de establecimiento, el incremento de los niveles de nitrógeno (0, 20, 40 y 60 kg/ha, aplicados cada 40−45 días, o sea 0−180 kg N/ha para el período de crecimiento) aumentó proporcionalmente la producción de materia seca (MS) de tallos y hojas, así como la MS total (P<0.05). En los 2 niveles más altos (80 y 100 kg/ha o 240−300 kg N/ha para el período de crecimiento), sólo la producción de MS total mostró respuesta significativa y sólo al nivel más alto de N. En el segundo año, la fertilización con 20 kg N/ha cada 40−45 días (80 kg N/ha para el período de crecimiento) duplicó la producción de MS en comparación con el testigo (0 kg N/ha), y la aplicación de 80 kg N/ha cada 40−45 días (320 kg N/ha para el período de crecimiento) permitió obtener producciones de MS de tallos, hojas y MS total significativamente mayores que los de demás niveles de N aplicados. La respuesta de la producción a la fertilización (kg MS/kg N) disminuyó linealmente (de 24.7 a 20.3 en 2011, y de 56.7 a 15.1 en 2012) desde el más bajo hasta el más alto nivel de N aplicado. En ambos años, el incremento de los niveles de N aumentó

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significativamente las concentraciones de proteína cruda (PC) y fibra detergente neutro en tallos y hojas y las concentraciones de fibra detergente ácido en tallos. El cv. Mombasa produjo 17 y 19% más MS de hojas y 18 y 22% más MS total que Tanzania, en el primero y el segundo año, respectivamente. Mombasa también produjo 30% más MS de tallos que Tanzania en el segundo año. Mientras en el año de establecimiento las concentraciones de PC fueron en todos los niveles de N más altas en Tanzania que en Mombasa, en el segundo año Tanzania presentó concentraciones superiores que Mombasa solamente cuando las dosis de N de 80−100 kg N/ha fueron aplicadas cada 40−45 días (320−400 kg N/ha para el período de crecimiento). La aplicación de 60 kg N/ha cada 40−45 días aparentemente resulta razonable para obtener en la época de lluvias producciones de MS satisfactorias (8 t/ha el primer año y 12 t/ha el segundo), con 68−70% de hojas y concentraciones de PC en las hojas mayores que 7%.

Introduction

Pastures in Northeast Thailand are usually grown on the poorest soils, as more fertile soils are used for growing food and cash crops. Many improved pastures in the region are nitrogen-deficient, as village farmers usually apply a maximum of only 20–40 kg N/ha in the 6-month wet season, if they apply any fertilizer at all. The exceptions are the larger commercial dairy farms (about 1,000 larger farms, milking on average 100 cows with an average size of 20 ha) and small village farmers, who grow guinea grass for sale as fresh forage. In both of these systems, fertilizer is applied at rates of 10–20 kg N/ha 3–6 times in a wet season or when irrigated in the dry season (Udchachon et al. 1998; Nakamanee et al. 2008).

Tanzania guinea grass [*Panicum maximum* − now *Megathyrsus maximus* − cv. Tanzania (cv. Si Muang in Thailand)] is the most commonly grown grass in Thailand (Khemsawat and Phaikaew 2007; Phaikaew et al. 2007). In a 3-year field trial in Northeast Thailand, Tanzania guinea grass produced dry matter (DM) yields of 10 and 11 t/ha in successive 6-month wet seasons, when fertilized with 200 kg NPK/ha (15:15:15) every 40–45 days, a total of 120 kg N/ha (Hare et al. 2009). Under intensive cutting every 30–40 days for the sale of fresh forage in Northeast Thailand, Tanzania guinea grass produced DM yields of 33–46 t/ha/yr (Nakamanee et al. 2008). In this system, farmers applied 125–310 kg urea/ha (46% N) or 160–310 kg NPK/ha (16:7:6) after each cut, a total of approximately 500–1,000 kg N/ha/yr. In addition, poultry manure at a rate of 2.8–5.6 t/ha was applied every 60–90 days.

Mombasa guinea grass (*Panicum maximum* – now *Megathyrsus maximus* – cv. Mombasa) was introduced to Thailand 7 years ago from Brazil (Hare et al. 2013). Since there were no data on growth of Mombasa in Thailand, a series of studies has been undertaken at Ubon Ratchathani University, Thailand, to study the botanical and agronomic differences between Mombasa and Tanzania. The first of these studies found that, under cutting, Mombasa produced 17–21% more total DM and 18–24% more leaf DM than Tanzania (Hare et al. 2013). The second of these studies, examining varying seeding rates, found that Mombasa produced 23% more DM than Tanzania in successive wet seasons (Hare et al. 2014). In both studies, 200 kg NPK/ha (15:15:15) was applied every 45–50 days, a total of 120 kg N/ha/yr in the first study and 180 kg N/ha/yr in the second study.

This paper, which examines the effects of rates of nitrogen (N), deals with the third of these studies. The objective was to examine the production and quality of Mombasa and Tanzania guinea grasses under different levels of N fertilizer, in order to recommend an optimum N rate for these grasses growing on poor sandy soils in Northeast Thailand.

Materials and Methods

This study was conducted at a site at the Amnart Charoen Livestock Development Centre, Amnart Charoen province, Northeast Thailand (15.5° N, 104.4° E; elevation 130 masl) during 2011–2012. The site was on an upland sandy reddish brown earth (Haplustalf) soil (Chatturat series) (Mitsuchi et al. 1986). Soil samples taken at sowing in June 2011 showed that the soil was acid (pH 4.8; water method), very sandy (75% sand) and low in organic matter (0.6%), N (0.03%) and K (42 ppm) and average for P (24.3 ppm; Bray II extraction method). Prior to cultivation, the site had been planted with hybrid brachiaria lines for 3 years. The grasses were sprayed with glyphosate (3 L/ha) in May 2011, plowed and disked before the guinea grass seeds were sown on 16 June 2011.

Two guinea grass cultivars (Mombasa and Tanzania) were sown at 6 kg seed/ha in a randomized complete block design with 4 replications. The treatments were 2 cultivars x 6 nitrogen rates (0, 20, 40, 60, 80 and 100 kg N/ha) applied as urea (46% N) every 40–45 days. The seeds were hand-broadcast on to the seed beds and the seed lightly surface-raked into the soil. At sowing, lime (1,000 kg/ha), double superphosphate at 100 kg/ha (19.8 kg P/ha) and potassium chloride at 100 kg/ha (49.8 kg K/ha) were applied. Plots measured 4 x 3 m.

All plots were cut to 5 cm above ground level on 19 July 2011 and the N treatments commenced. Nitrogen was applied again after each sampling, except at the final cut, when the trial ceased over the dry season. In the first year (2011), N was applied 3 times (19 July, 1 September and 13 October) for totals of 0, 60, 120, 180, 240 and 300 kg N/ha for the various treatments. In the second year (2012), N was applied 4 times (25 April, 7 June, 23 July and 6 September) for totals of 0, 80, 160, 240, 320 and 400 kg N/ha.

Forage sampling, from six 0.25 m^2 quadrats per plot, was carried out in the first year, on 1 September, 13 October and 30 November 2011. After the November sampling, all plots were cut to 5 cm above ground level and not cut again until April 2012, when the fertilizer applications recommenced on the same plots. Forage sampling then occurred on 7 June, 23 July, 6 September, and 24 October 2012.

At each sampling, the fresh samples from the 6 quadrats were combined and weighed and a 300 g subsample from each plot was hand-sorted into leaves and stems and dried at 70 °C for 48 h to calculate DM of stems and leaves and total DM. Samples from the dried material were analyzed for total N (Kjeldahl method) in order to calculate crude protein (%N x 6.25), acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations. After each sampling, the remaining forage in the plots was cut to 5 cm above ground level before applying fertilizer.

Data from the trial were subjected to analysis of variance, using the IRRISTAT program from the International Rice Research Institute (IRRI). Entry means were compared by LSD at P=0.05 probability level.

Results

Rainfall

Rainfall from sowing in June 2011 until November 2011 was 25% higher than the 12-yr mean for the same period (Figure 1), with particularly heavy rainfall in August 2011. In the second year, rainfall from April to October 2012 was 27% lower than the 12-yr mean.

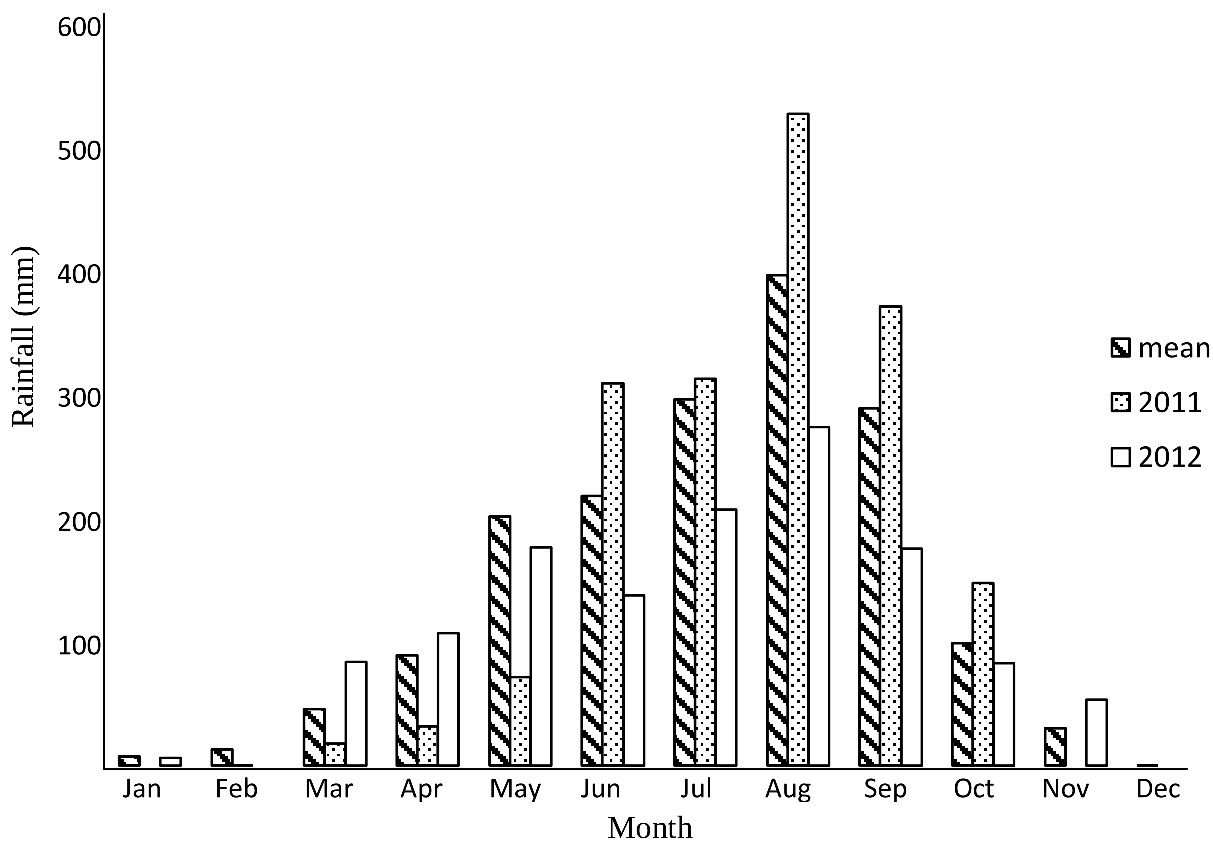

Figure 1. Rainfall during the trial at the Amnart Charoen meteorological station, 9 km from the research site, and the 12-yr mean (2000–2012).

Dry matter production and quality

In the establishment year, increasing rates of fertilizer up to a rate of 60 kg N/ha, progressively increased stem, leaf and total DM production (P<0.05). At higher N rates, increases in production were slight and significant for total DM at 100 kg/ha only (Table 1). In the second year, while a rate of 20 kg N/ha almost doubled the amount of DM compared with unfertilized plots, yield increases occurred up to 80 kg N/ha and then declined when 100 kg N/ha was applied (Table 2). A rate of 80 kg N/ha produced significantly higher stem, leaf and total DM yields than all other rates except 60 kg N/ha (Table 2). In both years, the percentage of leaf in the forage was significantly reduced when nitrogen was applied (Tables 1 and 2).

Mombasa produced 17% more leaf and 18% more total DM than Tanzania in the establishment year (Table 1), and 30% more stem DM, 19% more leaf and 22% more total DM than Tanzania in the second year (Table 2). There was a significant interaction in the second year, with both cultivars having similar yields for stem, leaf and total DM at rates of 0, 20, 40 and 60 kg N/ha, while at higher rates, Mombasa produced more stem, leaf and total DM than Tanzania. Tanzania produced a higher percentage of leaf than Mombasa at rates of 20, 60 and 80 kg N/ha in the second year (Table 2).

Increasing rates of nitrogen significantly increased crude protein (CP) and NDF concentrations in stems and leaves of both cultivars (Tables 3). However, ADF levels in stems increased in Mombasa but were not affected in Tanzania, while levels in leaves remained almost constant for both cultivars (Table 3). Mombasa overall had significantly lower CP concentrations than Tanzania and higher concentrations of fiber.

Table 1. Effects of nitrogen fertilizer on dry matter production and leaf percentage of Mombasa and Tanzania guinea grasses in the establishment year.

Treatment (kg N/ha)		Stem dry matter	Leaf dry matter	Total dry matter	Leaf percentage
Per application	Total		(kg/ha)		(%)
0	0	741	2,895	3,636	79.6
20	60	1,088	4,033	5,121	78.7
40	120	1,644	4,941	6,585	75.0
60	180	2,598	5,704	8,302	68.7
80	240	2,669	6,031	8,700	69.3
100	300	3,156	6,578	9,734	67.5
LSD (P<0.05)		635	812	1,371	3.4
Cultivar					
Mombasa		2,156	5,433	7,589	71.6
Tanzania		1,809	4,627	6,436	71.8
LSD (P<0.05)		ns	469	792	ns
N x cultivar		ns	ns	ns	ns

Table 2. Effects of nitrogen fertilizer on dry matter production (kg/ha) and leaf percentage of Mombasa and Tanzania guinea grasses in the year after establishment.

Treatment (kg N/ha)		Stem dry matter		Leaf dry matter		Total dry matter		Leaf percentage	
Per application	Total	Mombasa	Tanzania	Mombasa	Tanzania	Mombasa	Tanzania	Mombasa	Tanzania
0	0	1,196	1,084	4,729	4,348	5,925	5,432	80.1	80.2
20	80	2,196	2,694	7,400	8,138	9,596	10,832	71.1	76.0
40	160	3,040	2,460	8,964	7,832	12,004	10,292	74.7	76.1
60	240	3,614	2,944	9,859	8,968	13,473	11,912	73.2	76.0
80	320	4,959	2,871	11,948	8,214	16,907	11,085	71.5	74.2
100	400	3,713	2,381	10,281	7,088	13,994	9,469	73.5	74.8
LSD (P<0.05)		1,153		1,809		2,891		2.3	

Table 3. Effects of nitrogen fertilizer on mean crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations (%) in stem and leaf of Mombasa (M) and Tanzania (T) guinea grasses over two wet seasons.

Treatment (kg N/ha)		CP				ADF				NDF			
Per application	Total	Stem		Leaf		Stem		Leaf		Stem		Leaf	
		M	T	M	T	M	T	M	T	M	T	M	T
0	0	2.8	3.1	6.3	6.7	40.0	40.5	36.3	36.7	67.7	67.3	62.2	62.4
20	60*/80**	2.8	3.6	6.1	7.1	41.6	40.5	36.3	36.9	69.3	67.9	63.0	63.1
40	120/160	3.2	3.4	6.4	7.0	43.2	40.8	36.0	36.9	69.9	68.4	63.9	62.9
60	180/240	3.3	4.1	7.0	8.0	42.9	40.8	36.2	37.1	69.9	68.1	63.9	63.0
80	240/320	4.2	4.6	7.8	8.6	42.6	40.6	36.6	36.5	69.6	69.4	64.2	63.7
100	300/400	4.9	5.8	9.0	10.4	43.0	40.8	35.8	36.5	69.4	69.3	63.1	63.9
LSD (P<0.05)		0.5		0.5		0.9		0.5		1.1		0.5	

* establishment year; ** second year.

Discussion

This study has shown that applying 40–60 kg N/ha to guinea grass every 40–45 days during the wet season will more than double the DM yield over that of unfertilized pasture. Even rates as low as 20 kg N/ha increased guinea grass DM yields by 40 and 80% in Years 1 and 2, respectively, above yields in control plots. While higher N rates increased DM yields further, there was no significant increase above 80 kg N/ha/application.

While these responses are outstanding, they are much lower than the increases of up to 250% recorded by Hare et al. (1999), when 20 kg N/ha was applied to *Paspalum atratum* on similar soils in Northeast Thailand every 30 days. These authors found that nitrogen applied as urea is quickly leached out of the soils with low organic matter content and urea must be applied frequently (every 30 days) in the wet season to be effective.

In both years, no further significant increase in total DM production of guinea grasses occurred after a total amount of 240 kg N/ha had been applied. This curvilinear response has not been found in Brazil, where in general, DM yields of Mombasa and Tanzania increased linearly with N fertilizer up to as high as 800 kg N/ha/yr (Freitas et al. 2005; Viana et al. 2014; Cecato et al. 2014a). Under irrigation and grazing in Brazil, Mombasa DM yields with 200 kg N/ha/yr were nearly twice those from pastures receiving no N (Cecato et al. 2014a). When the rate increased to 800 kg N/ha/yr, Mombasa DM yields were more than 4 times those from pastures receiving no N. In comparison, increases in annual DM yields of Tanzania under irrigation and grazing in Brazil were >80% with 200 kg N/ha/yr and 177% with 800 kg N/ha/yr compared with yields with no N (Viana et al. 2014).

In contrast with the curvilinear response of total DM to applied N in our study, the yield response (kg DM per kg N) decreased linearly from the lowest to the highest rate of total nitrogen applied (Table 4). The yield response was therefore not typically curvilinear (Humphreys 1987), with increased dressings of N giving progressively lower increases in DM per unit of N. In the second year, the yield response from applying the lowest rate of nitrogen was twice that of the response in the first year.

Table 4. Yield responses (kg DM/kg N) from applying nitrogen fertilizer to Mombasa and Tanzania guinea grasses.

Year	Total N applied (kg N/ha)	Increase in DM above control (kg DM/ha)	Yield response (kg DM/kg N)
1	60	1,485	24.7
	120	2,949	24.6
	180	4,666	25.9
	240	5,064	21.1
	300	6,099	20.3
2	80	4,535	56.7
	160	5,469	34.2
	240	7,013	29.2
	320	8,317	25.9
	400	6,052	15.1

The addition of nitrogen had interesting effects on composition of the forage, as increasing rates of N increased the amounts of both stem and leaf, but the percentage of leaf decreased with each application of N. This contrasts with findings in Brazil, where increased dressings of N reduced the percentage of Mombasa leaf in spring, and increased it in summer, but had no effect in autumn and winter (Cecato et al. 2014a).

The critical dietary CP level in tropical forages is 7% (Milford and Minson 1966), below which voluntary intake is depressed. In our study, nitrogen rates of 60–100 kg N/ha every 40−45 days were required to produce CP concentrations in leaves of guinea grass above 7%. At lower rates of 20–40 kg N/ha, rapid growth of the guinea plants occurred, producing a dilution effect, so that CP concentrations in leaves were similar to those in plants receiving no nitrogen. Intermediate N rates have also been found to increase DM yields but not CP concentration in Tanzania in Brazil, particularly during cooler periods of the year (Viana et al. 2014).

In considering the importance of crude protein in leaves, we suggest that applying 60 kg N/ha on each occasion appears a good compromise to achieve satisfactory DM yields, leaf percentage >70% (second year swards) and leaf CP concentrations above 7%.

Two previous research studies in this series on Mombasa and Tanzania found that Mombasa produced 23% more DM than Tanzania (Hare et al. 2013; 2014), due primarily to Mombasa having larger tillers and leaves than Tanzania (Hare et al. 2014). This study confirms the superior production of Mombasa, with Mombasa producing 17 and 19% more leaf and 18 and 22% more total DM than Tanzania, in the first and the second years, respectively. Mombasa also produced 30% more stem DM than Tanzania in the second year. It also supports earlier findings under grazing in Central and South America, where Mombasa produced 28–40% more DM than Tanzania (Cook et al. 2005).

Generally the quality of Tanzania has been found to be superior to Mombasa in terms of crude protein and fiber levels (Hare et al. 2013; 2014). This study supports that finding, particularly when higher rates of N were applied. However, it is Mombasa's greater DM production and tall structure which appeal to farmers in Thailand, who mainly grow forages in "cut-and-carry" systems and not as grazed pastures as in Central and South America (Viana et al. 2014; Cecato et al. 2014a, 2014b). The choice of which forage to plant will depend on whether quantity or quality of forage is the primary objective.

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Botanical name changes – nuisance or a quest for precision?

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Abstract

To understand the need for the seemingly regular changes to plant names applied to many tropical forage species, it is necessary to be aware of the rules that govern botanical nomenclature. The binomial naming system, first proposed in 1753, is governed by rules defined in the International Code of Nomenclature for algae, fungi and plants (ICN). These rules have been strengthened as necessary over the years in the interest of providing practitioners with plant names that are unique for each species, and presented in an hierarchical format that shows the evolutionary relationships between plants. This paper includes a table of name changes accepted by the USDA Germplasm Resources Information Network (GRIN) for species used in tropical forage research and development over the last half century. The need to use legitimate plant names is emphasized and suggestions are made on how practitioners might best deal with the changes.

Resumen

Para entender la necesidad de cambios, aparentemente regulares, de nombres científicos de muchas especies forrajeras tropicales, es necesario estar al tanto de las normas que rigen la nomenclatura botánica. El sistema binomial propuesto por primera vez en 1753, se rige por las reglas definidas en el Código Internacional de Nomenclatura para algas, hongos y plantas (ICN, por sus siglas en inglés). Estas reglas han sido fortalecidas a lo largo de los años, según las necesidades y con el interés de proveer a los investigadores con nombres de plantas que son únicos para cada especie y que en un formato jerárquico presentan las relaciones evolutivas entre las plantas. Se presenta un cuadro con los cambios, producidos durante el último medio siglo y aceptados por el USDA Germplasm Resources Information Network (GRIN), de nombres de especies forrajeras tropicales utilizados en trabajos de investigación y desarrollo. Se enfatiza la necesidad de usar nombres de plantas legítimos y se sugieren maneras cómo los investigadores pueden hacer frente a los cambios.

Introduction

Since the hierarchical system of nomenclature was proposed by the Swedish biologist and medical doctor, Carl von Linné (Carolus Linnaeus), in "Species Plantarum" in 1753, and a set of rules to administer it, "Lois de la nomenclature botanique", was advanced by Alphonse de Candolle in 1867, there has been an ongoing attempt to inject identity and order into what hitherto was simply a naturally occurring assemblage of randomly named organisms. This system, as it has evolved to the current day, requires that plants be named according to a series of basic tenets laid out and expanded on in the International Code of Nomenclature for algae, fungi and plants (ICN) by McNeill et al. (2012), formerly named International Code of Botanical Nomenclature (ICBN), and overseen by the International Botanical Congress that usually meets every 6 years. The system is designed to avoid confusion, not create it, as is often claimed by people who routinely use binomial plant names in their work.

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Why not use common names?

Common or vernacular names are those non-scientific names applied locally to a particular plant in a given locality. The main problem with common names is that they are not common; that is, they are not universal. Each country, each state or province within a country and often each district within a state or province, may well have its own common name for a particular plant. For example, the now widespread shrub species known as "guaje" and almost 20 other names in its native Mexico, is also known as "ipil ipil" in the Philippines or "koa haole" in Hawaii, and by different names in virtually every locality where it is currently found. However, regardless of where this plant is growing in the world, it will be identified by botanists as "*Leucaena leucocephala*".

Another problem with common names is that one common name may be applied to more than one species, particularly if there is a superficial resemblance. For example, the name "sensitive plant" is usually used to refer to *Mimosa pudica*, but is also sometimes used to refer to another species in the legume subfamily Mimosoideae, *Neptunia gracilis*, and even to one in subfamily Caesalpinioideae, *Chamaecrista nictitans*. The characteristic that all 3 species have in common is that the leaflets exhibit thigmonasty (touch-induced movement).

Another issue, as demonstrated in the latter example, is that common names tell nothing about the relationship between plants, a factor that can be important in relation to disease susceptibility or, in the case of legumes, selection of an effective rhizobial strain. Finally, many of the species we sow as forages have no common name in any language, leading to the nonsensical situation of creating common names to satisfy the requirements of a vernacular plant description, as was the case for cultivar registration in earlier years in Queensland, Australia.

Mejia (1984) compiled an extensive list of Spanish, English and Portuguese common names to assist practitioners in making the link with botanical names for a large range of more common grasses and legumes. Cook et al. (2005) provide an alternative online source for this connection.

Basic tenets of the ICN

The ICN is an extremely detailed document that has developed since "Lois de la nomenclature botanique" into a very detailed set of rules, covered in 9 chapters and 62 articles, the latest version being known as the "Melbourne Code" (McNeill et al. 2012). The main themes that affect us are:

1. A botanical name for a particular taxon is attached to a type specimen, usually preserved in an herbarium.
2. Botanical nomenclature is based upon priority of valid publication after 1 May 1753, the publication date of "Species Plantarum". This means that a more recent species name is to be replaced if an older one, validly published, is discovered. Accordingly, each taxon of a particular circumscription, position and rank should have only one correct name.
3. Scientific names are expressed in Latin.
4. The rules and regulations of the ICN are retroactive, unless there is an explicit statement that this does not apply.

For a new or alternative name to be considered for acceptance by the scientific community, it must meet the requirements of valid publication. While there are many articles in the Code referring to this issue, some of the major provisos that must be met are:

1. The name must be effectively published in a document that is generally available to botanists. Effective publication now includes electronic material published online in Portable Document Format (PDF) with an International Standard Serial Number (ISSN) or an International Standard Book Number (ISBN).
2. The name must be published in the correct form, properly Latinized with the correct rank ending (e.g. "aceae" for plant families, "oideae" for subfamilies, and "eae" for tribes), ranks simply reflecting a level in the hierarchy.
3. The name must be accompanied by a description that will distinguish the taxon from similar or closely related taxa. Prior to 2012, it was essential that a name be published with a Latin description or diagnosis, or with a reference to such. However, the description can now be published in either Latin or English, usually along with a vernacular description, if the original is not in English.
4. A nomenclatural type, which is usually a herbarium specimen permanently associated with the name, must be indicated (for genus and below, that is: species, subspecies, botanical variety or form).

Valid publication alone does not guarantee that a name will be accepted. Over time, a proposal is subjected to scrutiny by systematic botanists, who assess the strength of the argument for change or the adequacy of the diagnosis. A validly published name may still be considered illegitimate if it does not follow one or more rules of the ICN. The situation can arise, where one expert or group of experts considers the proposed change sound, while others might reject the change, leading to confusion among practitioners simply using the names. For example, GRIN accepts *Pennisetum ciliare* (L.) Link as the name for buffel grass, whereas the Catalogue of New World Grasses and Royal Botanic Gardens, Kew, retain the name proposed by Linnaeus, *Cenchrus ciliaris* L. The only way to ensure that we are referring to a particular nomenclatural type is to follow the plant name with the abbreviation of the author's name according to Brummitt and Powell (1992) for the rank of family, genus, species and subspecific taxon (subspecies, variety or form).

Why names change

Systematic botanists around the world conduct exhaustive library and laboratory research to ensure that names of species are in accordance with the rules of the ICN. In doing so, they might determine that a name, as currently used, is inappropriate under the rules of botanical nomenclature and should be changed for the following reasons:

1. Discovery of an earlier, validly published, different name for a particular taxon, which, under the ICN rule of priority, would necessitate the renaming of that taxon. For example, *Macroptilium longepedunculatum* (Mart. ex Benth.) Urb. was initially used for the Australian cultivar, Maldonado. However, this species, whose name derives from the original name, *Phaseolus longepedunculatus* Mart. ex Benth., was found to be the same as the earlier-named *Phaseolus gracilis* Poepp. ex Benth., now accepted as the basionym (the original or first validly described name for a species or other taxon). With the reassignment of a number of species formerly in *Phaseolus* to *Macroptilium*, 'Maldonado' now belongs to *Macroptilium gracile* (Poepp. ex Benth.) Urb. (Note the change in the specific epithet, "*gracilis*" to "*gracile*", to accommodate the change in gender of the generic name.)
2. The name has been found to be contrary to one or more of the ICN rules, and is therefore illegitimate. The name can either be legitimized by valid publication, as is the case with the species that is now *Arachis pintoi* Krapov. & W.C. Greg. rather than *A. pintoi* Krap. et Greg. nom. nud., or altered to a legitimate format as with *Stylosanthes guianensis* var. *vulgaris* M.B. Ferreira & Sousa Costa, which is now *S. guianensis* (Aubl.) Sw. var. *guianensis*.
3. With the benefit of closer scrutiny, or using a molecular taxonomic approach, there may be justification for a change of circumscription, which is the definition of the limits of a taxonomic group. This can entail merging of existing taxa, as was the case with *Digitaria eriantha* Steud., which now includes *D. decumbens* Stent, *D. pentzii* Stent and *D. smutsii* Stent; or the disassembling of an existing taxon, as was the case with the legume genus, *Dolichos*, initially described by Linnaeus, where some members were retained in *Dolichos*, while others were reassigned to *Lablab*, *Macrotyloma* and *Vigna*, among others. This apparent "split" has, in part, been brought about through the elevation of the species, *lablab*, and the subgenus, *Macrotyloma*, to the rank of genus.
4. The name in current common use does not apply to the species to which it is applied. We cite 3 representative examples:
   - The type specimen of *Centrosema pubescens* Benth. more appropriately refers to the species formerly known as *C. schiedeanum* (Schltdl.) R.J. Williams & R.J. Clem., which has a limited natural distribution and is represented by the Australian cultivar, Belalto, while *C. molle* Mart. ex Benth. is now accepted as the most appropriate botanical name for the naturally widespread species known as common centro (Fantz 1996).
   - Similarly, for many years, research and development personnel referred to most *Desmanthus* species with which they were working, as *D. virgatus* or *D. depressus.* Following publication of the *Desmanthus* monograph (Luckow 1993), it has become apparent that much of the germplasm formerly identified as *D. virgatus* was, in fact, *D. pernambucanus* (L.) Thell., while *D. depressus* was *D. virgatus* (L.) Willd. Accordingly, it is necessary to be somewhat circumspect about the identity of *Desmanthus* species in papers published prior to 1993.
   - Some studied species have simply been misidentified. This is a common problem among the more robust *Cynodon* spp., that bear a superficial resemblance to one another (see *C. plectostachyus* in Table 1).

Tables 1 and 2 summarize name changes as accepted by GRIN, together with some commonly encountered through misidentification. It must be emphasized that this list of species represents those encountered by practitioners working with tropical and subtropical forages, and in no way is intended to be an exhaustive list of legume and grass name changes.

Table 1. Name changes in a selection of tropical forage legume species during the past 50 years.

Name previously	New name[1]
Acacia angustissima (Mill.) Kuntze	*Acaciella angustissima* (Mill.) Britton & Rose
Acacia boliviana Rusby	*Acaciella angustissima* (Mill.) Britton & Rose
Arachis pintoi Krap. et Greg. nom. nud.*[2]	*Arachis pintoi* Krapov. & W.C. Greg.
Arachis prostrata Benth. auct. Aust.*	*Arachis glabrata* Benth.
Cassia rotundifolia Pers.	*Chamaecrista rotundifolia* (Pers.) Greene
Centrosema pubescens auct., non Benth.	*Centrosema molle* Mart. ex Benth.
Centrosema schiedeanum (Schltdl.) R.J. Williams & R.J. Clem.	*Centrosema pubescens* Benth.
Chamaecytisus palmensis (Christ) F.A. Bisby & K.W. Nicholls	*Chamaecytisus prolifer* (L. f.) Link subsp. *prolifer* var. *palmensis* (Christ) A. Hansen & Sunding
Cratylia floribunda Benth.	*C. argentea* (Desv.) Kuntze
Desmanthus depressus Humb. & Bonpl. ex Willd.	*Desmanthus virgatus* (L.) Willd.
Desmanthus virgatus auct., non (L.) Willd.	*Desmanthus pernambucanus* (L.) Thell.
Desmodium canum (J.F. Gmel.) Schinz & Thell.	*Desmodium incanum* (G. Mey.) DC.
Desmodium gyroides (Roxb. ex Link) DC.	*Codariocalyx gyroides* (Roxb. ex Link) Hassk.
Desmodium ovalifolium (Prain) Wall. ex Merr.	*Desmodium heterocarpon* (L.) DC. subsp. *ovalifolium* (Prain) H. Ohashi
"Desmodium rensonii"[3, 4]	*Desmodium cinereum* (Kunth) DC.
Dolichos axillaris E. Mey.	*Macrotyloma axillare* (E. Mey.) Verdc.
Dolichos biflorus auct.	*Macrotyloma uniflorum* (Lam.) Verdc.
Dolichos daltonii Webb	*Macrotyloma daltonii* (Webb) Verdc.
Dolichos lablab L.	*Lablab purpureus* (L.) Sweet subsp. *purpureus*
Flemingia congesta Roxb. ex W.T. Aiton	*Flemingia macrophylla* (Willd.) Merr.
Glycine javanica auct.	*Neonotonia wightii* (Wight & Arn.) J.A. Lackey
Leucaena diversifolia subsp. *stenocarpa* (Urb.) Zárate	*Leucaena trichandra* (Zucc.) Urb.
Leucaena glauca auct.	*Leucaena leucocephala* (Lam.) de Wit
Listia heterophylla E. Mey.	*Lotononis listii* Polhill
Lotononis bainesii Baker	*Listia bainesii* (Baker) B.-E. van Wyk & Boatwr.
Lotus pedunculatus auct. mult.	*Lotus uliginosus* Schkuhr
Macroptilium heterophyllum (Willd.) Maréchal & Baudet	*Macroptilium gibbosifolium* (Ortega) A. Delgado
Macroptilium longepedunculatum (Mart. ex Benth.) Urb.	*Macroptilium gracile* (Poepp. ex Benth.) Urb.
Mucuna cochinchinensis (Lour.) A. Chev.	*Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wight) Baker ex Burck
Phaseolus adenanthus G. Mey.	*Leptospron adenanthum* (G. Mey.) A. Delgado
Phaseolus atropurpureus DC.	*Macroptilium atropurpureum* (DC.) Urb.
Phaseolus bracteatus Nees & Mart.	*Macroptilium bracteatum* (Nees & Mart.) Maréchal & Baudet
Phaseolus lathyroides L.	*Macroptilium lathyroides* (L.) Urb.
Pueraria javanica (Benth.) Benth.	*Pueraria phaseoloides* (Roxb.) Benth.
Pueraria lobata (Willd.) Ohwi	*Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep
Pueraria thunbergiana (Siebold & Zucc.) Benth.	*Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep
Stizolobium deeringianum Bort.	*Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wight) Baker ex Burck
Stylosanthes gracilis auct., non Kunth*	*Stylosanthes guianensis* (Aubl.) Sw.
S. guianensis var. *gracilis* (Kunth) Vogel	*Stylosanthes gracilis* Kunth
S. guianensis var. *vulgaris* M.B. Ferreira & Sousa Costa	*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*
Stylosanthes guyanensis (Aubl.) Sw.*	*Stylosanthes guianensis* (Aubl.) Sw.
Stylosanthes hippocampoides Mohlenbr.	*Stylosanthes guianensis* var. *intermedia* (Vogel) Hassl.
Stylosanthes sundaica Taub.	*Stylosanthes humilis* Kunth
"Stylosanthes sp. aff. *scabra"*	*Stylosanthes seabrana* B.L. Maass & 't Mannetje
Stylosanthes mucronata Willd.	*Stylosanthes fruticosa* (Retz.) Alston
Vigna adenantha (G. Mey.) Maréchal et al.	*Leptospron adenanthum* (G. Mey.) A. Delgado
Vicia dasycarpa Ten.	*Vicia villosa* Roth subsp. *varia* (Host) Corb.
Vigna marina auct.	*Vigna luteola* (Jacq.) Benth.
Vigna sinensis (L.) Savi ex Hassk.	*Vigna unguiculata* (L.) Walp. subsp. *unguiculata*
Zornia diphylla auct. mult.	*Zornia glabra* Desv., *Zornia latifolia* Sm. and others

[1]Most of the "New names" listed are as accepted by GRIN.
[2]Some of the species in the "Names previously" column are included by virtue of the fact that they have been used in publications not referenced by GRIN. These are indicated by an asterisk (*).
[3]Referring to the plant used in Southeast Asian hedgerow systems.
[4]Names in inverted commas (" ") are names applied outside of formal publications.

Note: For the meaning of Latin abbreviations, see Symbols and Abbreviations in GRIN Taxonomy (http://www.ars-grin.gov/cgi-bin/npgs/html/paper.pl?language=en&chapter=symb).

Table 2. Name changes in a selection of tropical forage grass species during the past 50 years.

Name previously	New name[1]
Axonopus affinis Chase	*Axonopus fissifolius* (Raddi) Kuhlm.
Bothriochloa glabra (Roxb.) A. Camus	*Bothriochloa bladhii* subsp. *glabra* (Roxb.) B.K. Simon
Brachiaria brizantha (Hochst. ex A. Rich.) Stapf	*Urochloa brizantha* (Hochst. ex A. Rich.) R.D. Webster
Brachiaria decumbens Stapf	*Urochloa decumbens* (Stapf) R.D. Webster
Brachiaria dictyoneura (Fig. & De Not.) Stapf[2]	*Urochloa dictyoneura* (Fig. & De Not.) Veldkamp
Brachiaria humidicola (Rendle) Schweick.	*Urochloa humidicola* (Rendle) Morrone & Zuloaga
Brachiaria mutica (Forssk.) Stapf	*Urochloa mutica* (Forssk.) T.Q. Nguyen
Brachiaria ruziziensis R. Germ. & C.M. Evrard	*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins
Cenchrus ciliaris L.	*Pennisetum ciliare* (L.) Link
Cenchrus pennisetiformis Hochst. & Steud.	*Pennisetum pennisetiforme* (Hochst. & Steud.) Wipff
Cenchrus setigerus Vahl	*Pennisetum setigerum* (Vahl) Wipff
Cynodon plectostachyus auct., non (K. Schum.) Pilg.*[3]	*Cynodon aethiopicus* Clayton & J.R. Harlan
Cynodon plectostachyus auct., non (K. Schum.) Pilg.*	*Cynodon nlemfuensis* Vanderyst
Digitaria decumbens Stent	*Digitaria eriantha* Steud.
Digitaria pentzii Stent	*Digitaria eriantha* Steud.
Digitaria scalarum (Schweinf.) Chiov.	*Digitaria abyssinica* (Hochst. ex A. Rich.) Stapf
Digitaria setivalva Stent	*Digitaria eriantha* Steud.
Digitaria smutsii Stent	*Digitaria eriantha* Steud.
Digitaria swazilandensis auct., non Stent	*Digitaria didactyla* Willd.
Digitaria swynnertonii auct., non Rendle	*Digitaria milanjiana* (Rendle) Stapf
"Digitaria umfolozi"[4], *Digitaria x umfolozi* D.W. Hall	*Digitaria eriantha* Steud. cv. Survenola
Ischaemum aristatum auct.	*Ischaemum ciliare* Retz.
Panicum infestum Andersson	*Megathyrsus infestus* (Andersson) B.K. Simon & S.W.L. Jacobs
Panicum laxum Sw.	*Steinchisma laxum* (Sw.) Zuloaga
Panicum maximum auct., non Jacq.	*Panicum trichocladum* Hack. ex K. Schum.
Panicum maximum Jacq.	*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs
Panicum maximum var. *trichoglume* Robyns	*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs
Pennisetum americanum (L.) Leeke	*Pennisetum glaucum* (L.) R. Br.
Pennisetum typhoides (Burm. f.) Stapf & C.E. Hubb.	*Pennisetum glaucum* (L.) R. Br.
Rhynchelytrum repens (Willd.) C.E. Hubb.	*Melinis repens* (Willd.) Zizka
Setaria anceps Stapf	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb. var. *anceps* (Stapf) Veldkamp
Setaria porphyrantha Stapf	*Setaria incrassata* (Hochst.) Hack.
Setaria sphacelata var. *sericea* (Stapf) Clayton	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb. var. *anceps* (Stapf) Veldkamp
Setaria splendida Stapf	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb. var. *splendida* (Stapf) Clayton
Sorghum × *drummondii* (Steud.) Nees ex Millsp. & Chase	*Sorghum bicolor* (L.) Moench nothosubsp. *drummondii* (Steud.) de Wet ex Davidse
Sorghum roxburghii Stapf	*Sorghum bicolor* (L.) Moench
Sorghum saccharatum (L.) Moench	*Sorghum bicolor* (L.) Moench
Sorghum sudanense (Piper) Stapf	*Sorghum bicolor* (L.) Moench nothosubsp. *drummondii* (Steud.) de Wet ex Davidse
Sorghum verticilliflorum (Steud.) Stapf	*Sorghum bicolor* (L.) Moench subsp. *verticilliflorum* (Steud.) de Wet ex Wiersema & J. Dahlb.
Sorghum vulgare Pers.	*Sorghum bicolor* (L.) Moench
Urochloa bolbodes (Hochst. ex Steud.) Stapf	*Urochloa oligotricha* (Fig. & De Not.) Henrard
Urochloa maxima (Jacq.) R.D. Webster	*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs
Urochloa pullulans Stapf	*Urochloa mosambicensis* (Hack.) Dandy
Urochloa stolonifera (Gooss.) Chippind.	*Urochloa mosambicensis* (Hack.) Dandy
Vetiveria zizanioides (L.) Nash	*Chrysopogon zizanioides* (L.) Roberty

[1]Most of the "New names" listed are as accepted by GRIN.
[2]*B. dictyoneura* cv. Llanero has been reclassified as *B. humidicola,* now *U. humidicola.*
[3]Some of the species in the "Names previously" column are included by virtue of the fact that they have been used in publications not referenced by GRIN. These are indicated by an asterisk (*).
[4]Names in inverted commas (" ") are names applied outside of formal publications.

Note: For the meaning of Latin abbreviations, see Symbols and Abbreviations in GRIN Taxonomy (http://www.ars-grin.gov/cgi-bin/npgs/html/paper.pl?language=en&chapter=symb).

What about higher plant ranks?

Name changes are not restricted to the ranks of genus and below. Even the first rank below Kingdom (i.e. Division/Phylum) has changed from the traditional Angiospermae to Magnoliophyta to be in keeping with the ICN requirement that a higher rank name should have, as its stem, the name of a genus within that higher rank. Similarly, grasses now reside in class Liliopsida and not the traditional Monocotyledonae, and legumes within class Magnoliopsida and not the Dicotyledonae. This same requirement has led to a change in family names, with the added proviso that the generic stem be followed by the suffix, "aceae". The grass family is now widely accepted as Poaceae, although under Article 18.5 of the Code, Gramineae may still be used on the basis of "long usage".

However, the issue of legume family groupings has not been as simple. There has been controversy for some time whether legumes reside in a single family or 3 separate families. For many years, all legumes were placed in the family, Leguminosae, which does not have a generic stem, nor does it satisfy the "aceae" ending. This was solved by placing them all in family Fabaceae, thus satisfying Article 18.1 of the Code. In relatively recent times, legumes were divided into 3 families, Fabaceae (alternatively Papilionaceae), Mimosaceae and Caesalpiniaceae, thus creating confusion between the all-encompassing family, Fabaceae, and the more restricted pea-flowered family. There now appears to be sound evidence for a single legume family that Kew botanists, Lewis and Schrire (2003), propose should be named Leguminosae, with 3 subfamilies, Papilionoideae, Mimosoideae and Caesalpinioideae, all in accordance with Article 18 of the Code, even though there is no genus, *Papilio*, within the pea-flowered subfamily.

Selecting the correct name

A number of reliable websites can be used as sources of currently accepted plant names:

GRIN Taxonomy for Plants
www.ars-grin.gov/cgi-bin/npgs/html/queries.pl

The Plant List
www.theplantlist.org

World Checklist of Selected Plant Families
http://apps.kew.org/wcsp/home.do

Catalogue of New World Grasses
www.tropicos.org/NameSearch.aspx?projectid=10

Integrated Taxonomic Information System
www.itis.gov

International Legume Database & Information Service
www.ildis.org

The International Plant Names Index
www.ipni.org

While every effort has been made to establish an infallible system for naming plants, it must be recognized that experts may interpret the literature differently, leading to some inconsistency in accepted names of some species. For example, if we interrogate two of the above databases for the species once commonly referred to as *Desmodium canum*, GRIN accepts *Desmodium incanum* (G. Mey.) DC., whereas The Plant List accepts *Desmodium incanum* DC. Each can provide justification for the determination. In the interest of consistency, it is best to source all names used in a publication from a single reputable authority. As an example, Cook et al. (2005) chose GRIN as their taxonomic authority for the SoFT database.

Conclusion

It is important in reporting research results to be sure the plant names used are as accurate and up-to-date as possible, so the reader is confident of the identity of the species. In the interest of precision, it may be best not only to use legitimate plant names, if applicable, down to the botanical variety level, but also to include the author with the binomial name, when name changes have occurred and there might be a risk of confusion. This need only be done the first time such a species is mentioned in an article.

While results of any interrogation may vary in relation to a currently accepted name, the above sites will indicate the name and author accepted by that particular source. That name will facilitate access to alternatives accepted by other authorities. However, within any one document, it will be important to be consistent with names used.

For research publications, we suggest that, in the case of a new name, the commonly used old name also be cited the first time the plant is mentioned in a given article. Examples:
Urochloa (syn. *Brachiaria*) *decumbens* [or *Urochloa* (formerly: *Brachiaria*) *decumbens*], *Centrosema molle* (syn. *C. pubescens*) [or *Centrosema molle* (formerly: *C. pubescens*)]. If authors are too uncomfortable with the new name and prefer to continue using the earlier one in a given article, an option could be, e.g. *Panicum maximum* (now: *Megathyrsus maximus*), the first time the plant is mentioned.

The aim of any paper is to inform the reader in the least ambiguous way possible on the subject at hand, and part of this is precise identification of the plants used. In response to the questions implied in the title of this paper, correctly researched and argued name changes that we occasionally encounter may be a slight nuisance, but are essential in our quest for precision.

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Soil microbial biomass in an agroforestry system of Northeast Brazil

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Keywords: Enzyme activity, tropical soil, babassu palm, silvopastoral system; soil quality.

Abstract

Agroforestry systems (AFS) are considered alternative land use options to help prevent soil degradation and improve soil microbial biomass and organic C status. However, it is unclear how different densities of babassu palm [*Attalea speciosa* (syn. *Orbignya phalerata*)], which is an important tree in Northeast Brazil, affect the soil microbial biomass. We investigated the soil microbial biomass C and activity under AFS with different densities of babassu palm associated with *Brachiaria brizantha* grass. Soil microbial biomass C (MBC), soil microbial biomass N (MBN), MBC:total organic C ratio, fluorescein diacetate hydrolysis and dehydrogenase activity showed highest values in plots with high density of babassu palm. On the other hand, the respiratory quotient (qCO_2) was significantly greater in plots without babassu palm. *Brachiaria brizantha* in monoculture may promote C losses from the soil, but AFS with high density of babassu palm may increase the potential of soils to accumulate C.

Resumen

Los sistemas agroforestales (AFS, por sus siglas en inglés) son opciones alternativas de uso de la tierra que ayudan a prevenir la degradación del suelo y mejorar la biomasa microbiana y el estado del carbono (C) orgánico. Babasú [*Attalea speciosa* (syn. *Orbignya phalerata*)] es una importante palma nativa que forma bosques en los estados Maranhão y Piauí, nordeste de Brasil; no obstante no se conoce su efecto sobre la biomasa microbiana del suelo cuando crece en diferentes densidades. En el estudio se evaluaron los efectos sobre el C y la actividad de la biomasa microbiana del suelo en AFS con 3 densidades de babasú en pasturas de *Brachiaria brizantha*. El C y el nitrógeno de la biomasa microbiana (MBC resp. MBN) del suelo, la relación de MBC:C orgánico total del suelo, la hidrólisis de diacetato de fluoresceína y la actividad de la deshidrogenasa mostraron valores más altos en las parcelas con alta densidad de babasú. Por otra parte, el cociente respiratorio (qCO2) fue significativamente mayor en las parcelas sin babasú. El pasto *B. brizantha* en monocultivo puede promover la pérdida de C del suelo, pero los AFS con alta densidad de la palma pueden aumentar el potencial de los suelos para acumular C.

Introduction

The babassu palm [*Attalea speciosa* Mart. ex Spreng. (syn. *Orbignya phalerata* Mart.)] occurs widely in Brazil, Colombia, Bolivia and Mexico and its fruits are a source of lauric oil, having both edible and industrial uses. Over 80% of babassu palms found in Brazil are from the northeast of Maranhão and Piauí states, known as Mid-North region, and produce about 200,000 tonnes of fruit annually. Babassu palm forests and primary forests are being removed and converted to improved pastures and mechanized crop production (May et al. 1985), which has contributed to land degradation in this region (Dias-Filho 2005). On the other hand, although babassu palms are seldom planted, they may be managed within a regional agroforestry system (AFS), as it is a good strategy to plant pasture in association with babassu palm (Nair 1993).

AFS is an alternative land use system to help prevent land degradation, by allowing continued use of land to

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produce crops or pastures in association with trees on a sustainable basis (Araújo et al. 2012). Such systems involve the combination of at least one woody-perennial species with a crop or pasture, which results in ecological and economic interactions between the two components (Palma et al. 2007). The AFS provides a continuous input of organic material into the soil, especially as the deep roots of the forest component (Albrecht and Kandji 2003) increase soil organic matter (SOM) stocks (Manlay et al. 2007; Fontes et al. 2010), and improve the soil microbial biomass (Udawatta et al. 2008; Yadav et al. 2010). Several authors have reported that soil microbial biomass is greater in an AFS, owing to the effects of trees and organic matter input and differences in the quality and quantity of litter and root exudates (Gómez et al. 2000; Myers et al. 2001; Mungai et al. 2005; Sørensen and Sessitsch 2007).

The main AFS involving babassu is pastures planted under native palm stands, with common palm densities of 50–100 trees/ha. Although this system covers much of the region, it is unclear how plant density of babassu palm affects soil microbial biomass. We hypothesized that soil microbial biomass is affected by the density of trees in AFS, owing to different inputs of plant litter. In order to test these hypotheses, we determined soil microbial biomass, by measuring soil microbial biomass C as the most reliable indicator, under AFS palm-pasture with different densities of babassu palm associated with a *Brachiaria brizantha* pasture in Northeast Brazil.

Materials and Methods

The study was conducted at the farm "Água Viva", Maranhão state, Northeast Brazil (05°06'25" W, 02°59'35" S). The climate is seasonally dry tropical with a mean precipitation of 1,500 mm/yr (main rainfall from November to May) and an annual mean temperature of 30 °C, with minimum and maximum monthly temperatures of 22 °C and 40 °C, respectively. According to the Brazilian Soil Survey (Embrapa-SNLCS 1986), the dominant soils are classified as Plintossols.

We evaluated 1 ha plots of babassu palm-*Brachiaria brizantha* associations with different palm densities. We labeled palm densities as: low density (LD – 80 babassu palms/ha); medium density (MD – 130 babassu palms/ha); high density (HD – 160 babassu palms/ha); and MC (*B. brizantha* in monoculture). The plots were similar in soil type and climate (see above). All plots received 300 kg urea/ha annually. The inputs of dry litter were: MC – 1.9 t/ha; LD – 4.5 t/ha; MD – 9.5 t/ha; and HD – 15 t/ha. The plant litter (dry mass) was calculated after the collection of all litter found in 1 m^2 quadrats installed at each plot (one quadrat for each plot installed at the plot center). The litter was dried at 65 ^{o}C until a constant weight was reached. Litter contribution per hectare was then calculated.

Soil samples were collected at 0–20 cm depth in March (rainy season) and September (dry season) of 2013. In each plot, the plant cover was carefully removed from the soil surface and soil cores (2.5 cm diameter) were taken at random. In each plot, 5 soil cores were collected from each of 4 sub-plots and pooled to form a composite sample. All samples were immediately stored in sealed plastic bags in a cooler and transported to the laboratory. The field-moist samples were sieved (2-mm mesh) and stored in sealed plastic bags at 4 °C for microbial analyses.

Subsamples of the soils were ground and passed through a 0.2-mm sieve to evaluate chemical properties. Soil pH was determined in a 1:2.5 soil:water extract. Exchangeable Ca was determined using extraction with 1 M KCl. Available P and exchangeable K were extracted using the Mehlich-I extraction method and determined by colorimetry and photometry, respectively (Tedesco et al. 1995). Total organic C (TOC) was determined by the wet combustion method using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans and Bremner 1998).

Soil microbial biomass C (MBC) and N (MBN) were determined according to Vance et al. (1987) with extraction, by K_2SO_4, of C and N from $CHCl_3$-fumigated and unfumigated soils. Extraction efficiency coefficients of 0.38 and 0.45 were used to convert the differences in C and N between fumigated and unfumigated soils in MBC and MBN, respectively. Hydrolysis of fluorescein diacetate (FDA) was determined according to the method of Schnürer and Rosswall (1982) and dehydrogenase activity (DHA) was determined using the method described in Casida et al. (1964), based on the spectrophotometric determination of triphenyl tetrazolium formazan (TTF) released by 5 g of soil during 24 h at 35 °C. The respiratory quotient (qCO_2) was calculated as the ratio of basal respiration to microbial biomass C, expressed as g CO_2-C/d/g MBC. Moreover, we calculated the ratio between MBC and TOC (qMIC), which is a common measure for carbon availability (e.g. Santos et al. 2012).

The results are expressed on the basis of oven-dry soil. Least significant difference (LSD) analysis was performed and all differences reported in the text were considered significant at $P<0.05$. Data were analyzed using multivariate ordination non-metric multidimensional scaling (NMS) with Sorensen distances. Ordination was performed using the PC-ORD v. 6.0 program.

Results

Soil chemical properties were not significantly affected by palm density (Table 1), as soil pH and Ca and K concentrations were similar in all AFS systems. However, soil P concentration showed highest values in the HD system.

Total organic carbon (TOC) concentrations were higher ($P<0.05$) in HD and MD than in LD and MC in both seasons, while soil microbial biomass C (MBC) and N (MBN) showed highest values in HD and lowest under the straight grass pasture (MC) ($P<0.05$) (Table 2).

Soil respiration did not differ ($P>0.05$) among treatments in both seasons (Table 3), while the respiratory quotient (qCO_2) was significantly ($P<0.05$) greater in MC than in treatments with babassu palms. Similar to soil microbial biomass, the qMIC was highest in HD and lowest in MC plots ($P<0.05$), as were values for FDA hydrolysis and DHA activity.

Table 1. Soil pH and Ca, P and K concentrations in agroforestry systems with different densities of babassu palm in *Brachiaria brizantha* pasture.

Treatment	Soil pH		Ca ($cmol_c$/kg)		P (mg/kg)		K (mg/kg)	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
HD[1]	6.3a[2]	6.2a	3.8a	3.6a	12.3a	12.1a	80a	75a
MD	6.0a	6.5a	3.2a	3.8a	10.3b	10.4b	91a	86a
LD	6.3a	6.1a	3.7a	3.2a	9.5b	10.4b	79a	78a
MC	5.8a	6.1a	3.9a	3.5a	9.8b	10.3b	78a	89a

[1]Babassu palm density: HD – 160 trees/ha; MD – 130 trees/ha; LD – 80 trees/ha; MC – grass monoculture (no trees).
[2]Means within columns followed by the same letter are not significantly different at $P\leq0.05$ (Tukey´s HSD test).

Table 2. Total organic C (TOC), microbial biomass C (MBC) and microbial biomass N (MBN) (± SD) in agroforestry systems with different densities of babassu palm in *Brachiaria brizantha* pasture.

Treatment	TOC (g C/kg)		MBC (mg C/kg)		MBN (mg N/kg)	
	Rainy	Dry	Rainy	Dry	Rainy	Dry
HD[1]	8.9 ± 1.0a[2]	9.0 ± 1.1a	107 ± 13a	83 ± 15a	16.5 ± 4.3a	11.0 ± 1.3a
MD	9.6 ± 1.7a	9.3 ± 0.9a	81 ± 10b	52 ± 12b	10.9 ± 2.5b	8.7 ± 2.5b
LD	7.1 ± 0.9b	6.9 ± 0.8b	61 ± 9c	47 ± 10b	7.2 ± 1.3c	4.2 ± 0.8c
MC	5.4 ± 1.8b	5.1 ± 0.7c	32 ± 17d	18 ± 3c	3.2 ± 0.9d	1.9 ± 0.4d

[1]Babassu palm density: HD – 160 trees/ha; MD – 130 trees/ha; LD – 80 trees/ha; MC – grass monoculture (no trees).
[2]Means within columns followed by the same letter are not significantly different at $P\leq0.05$ (Tukey´s HSD test).

Table 3. Mean values (± SD) for soil respiration (RB), respiratory quotient (qCO_2), ratio between soil microbial biomass C (MBC) and total organic carbon content (TOC) (qMIC), hydrolysis of fluorescein diacetate (FDA) and dehydrogenase activity (DHA) in agroforestry systems with different densities of babassu palm in *Brachiaria brizantha* pasture.

Treatment	RB (mg C-CO_2/kg/d)		qCO_2 (g CO_2-C/d/g MBC)		qMIC (MBC:TOC)		FDA (µg FDA/g)		DHA (µg TTF/g)	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
HD[1]	58 ± 22a	49 ± 17a	0.5 ± 0.1a	0.5 ± 0.1a	1.2 ± 0.2a	1.1 ± 0.3a	24 ± 5a	15.4 ± 1.9a	3.0 ± 0.1a	1.6 ± 0.4a
MD	55 ± 13a	42 ± 15a	0.6 ± 0.2a	0.7 ± 0.2a	0.8 ± 0.2b	0.8 ± 0.2a	22 ± 6a	11.2 ± 2.1b	2.1 ± 0.4b	1.0 ± 0.3b
LD	36 ± 21a	38 ± 14a	0.7 ± 0.2a	0.8 ± 0.4a	0.9 ± 0.3b	0.8 ± 0.1a	14 ± 3b	7.6 ± 0.9c	1.7 ± 0.3b	0.7 ± 0.3b
MC	54 ± 16a	45 ± 19a	1.7 ± 0.3b	2.6 ± 0.8b	0.6 ± 0.2b	0.5 ± 0.1b	10 ± 2c	3.7 ± 0.5d	0.7 ± 0.5c	0.4 ± 0.2c

[1]Babassu palm density: HD – 160 trees/ha; MD – 130 trees/ha; LD – 80 trees/ha; MC – grass monoculture (no trees).
[2]Means within columns followed by the same letter are not significantly different at $P\leq0.05$ by Tukey´s test.

The non-metric multidimensional scaling (NMS) analysis identified the association of soil biological and chemical properties with evaluated plots (Figures 1 and 2). The MC plot was clearly separated from the other plots, whereas LD and MD were more similar. In both seasons, the first axis explained about 70% of the variation and was strongly correlated with qCO_2 values, which characterized the MC plot, and with soil microbial biomass and enzymes, which characterized the HD plot. In the MC plot, qCO_2 was higher, while the HD site was characterized by higher soil microbial biomass and enzyme activity.

Discussion

Treatments in this study were unreplicated but the large plot sizes and large numbers of soil samples taken in each plot should compensate for the lack of spatial replication. The results suggest that the density of babassu palm in AFS affects soil microbial biomass C and organic C. This may be associated with the increase of plant litter, which improves soil organic C status (Assis et al. 2010; Fracetto et al. 2010; Sousa et al. 2012; Albaladejo et al. 2013). The plots with babassu palm present high and constant litter deposition, compared with the grass in monoculture, contributing to the maintenance of soil moisture and lower soil surface temperatures and increasing the soil organic C (Stockmann et al. 2013). The increase in soil organic C is important for Northeast Brazil, owing to the low levels of organic matter in soils in this area. High organic C is important for sustainability, because organic matter has a positive influence on soil physical, chemical and biological properties.

As N fertilizer was the only chemical fertilizer applied, the values of soil pH, Ca and K content did not vary. On the other hand, available soil P content increased in the HD system, possibly due to the highest input of plant litter, which may supply P during decomposition of the organic residue.

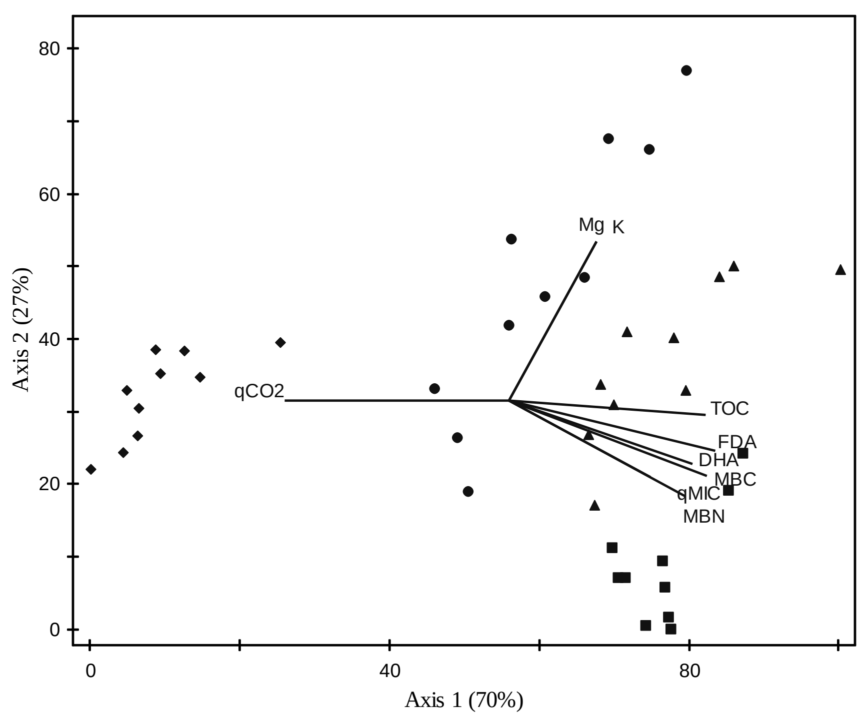

Figure 1. NMS analysis based on biological and chemical properties of soil during the dry season. Soil microbial biomass C (MBC, mg/kg); soil microbial biomass N (MBN, mg/kg); microbial respiratory quotient (qCO2, g CO_2-C/d/g soil microbial biomass C); hydrolysis of fluorescein diacetate (FDA, µg/g); dehydrogenase (DHA, µg TTF/g); and MBC:TOC (qMIC, mg/kg).
HD (■); MD (▲); LD (●); MC (◆).

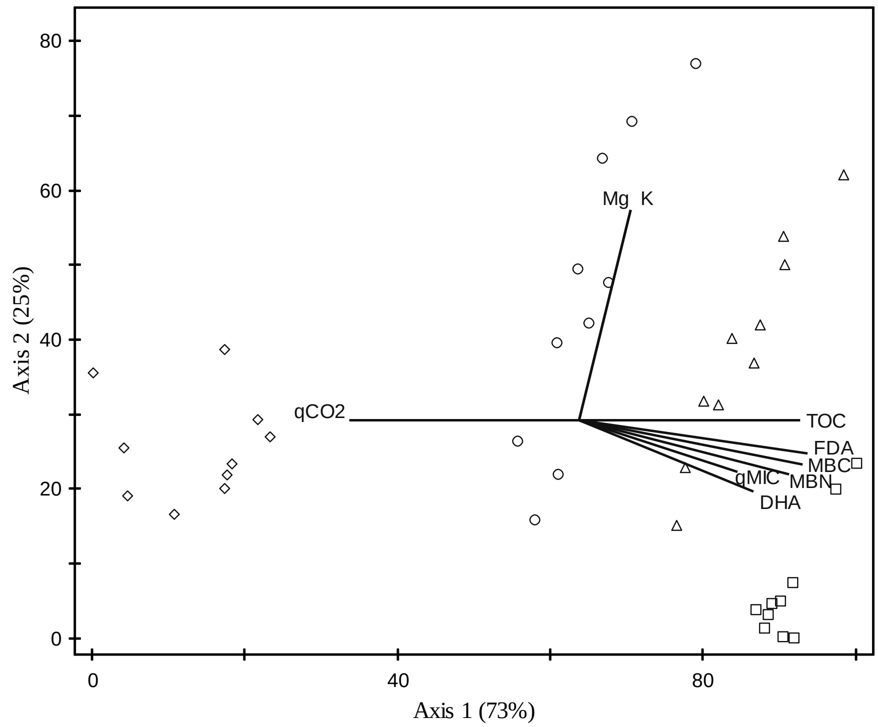

Figure 2. NMS based on biological and chemical properties of soil during the wet season. Soil microbial biomass C (MBC, mg/kg); soil microbial biomass N (MBN, mg/kg); microbial respiratory quotient (qCO2, g CO_2-C/d/g soil microbial biomass C); hydrolysis of fluorescein diacetate (FDA, µg/g); dehydrogenase (DHA, µg TTF/g); and MBC:TOC (qMIC, mg/kg).
HD (□); MD (△); LD (○); MC (◇).

Soil microbial biomass C was strongly affected by the increase in density of babassu palm, presumably by higher inputs of plant litter, that supply microbial biomass with C sources (Lopes et al. 2010). The average annual litter added in HD was much higher (15 t/ha) than in the others plots (range 1.9–9.5 t/ha) and favored the accumulation of soil microbial biomass. In addition, the quantity and quality of the rhizosphere of the plants influence soil microbial biomass (Grayston et al. 1996). Therefore, higher numbers of babassu palm may favor accumulation of soil microbial biomass through root exudation and promoting better conditions for soil microbial biomass. Other studies using different crops, that varied in amount and quality of residue inputs, showed effects on soil microbial biomass in tropical soils (Lopes et al. 2010; Araújo et al. 2013; Azar et al. 2013).

Soil respiration indicates biological activity and decomposition of organic residues (Santos et al. 2012). Our results showed similar soil respiration in all evaluated plots. Soil respiration might indicate either a disturbance of the soil or a high level of productivity in the ecosystem (Islan and Weil 2000). The respiration rate per unit of microbial biomass or respiratory quotient (qCO_2) is a variable of more straightforward interpretation (Fernandes et al. 2005). The qCO_2 reflects the efficiency of heterotrophic microorganisms to convert organic C into microbial biomass (Anderson and Domsch 1990). MC showed the lowest microbial biomass proportion (qMIC) with more efficient soil microbial communities in terms of C use than other plots.

The qMIC has been used as an indicator of changes in organic matter status and usually the values should range between 1 and 4% (Sparling 1992). The values of qMIC in the HD plot are within this range. These higher values may be due to the higher annual litter supply and the related higher soil microbial biomass C content observed in the HD plot, suggesting a large proportion of SOM being occupied by microbial biomass.

Dick et al. (1996) found that the use of different management practices, which modify SOM content, may significantly affect enzymatic activity. In our study, the increases in soil DHA and FDA, which are directly involved in the transformation of SOM, were greatest in the HD plot and lowest on the MC plot, being directly related to amounts of plant litter deposited on the soil. Previous studies reported that inputs of organic materials, like plant litter, stimulate soil DHA and FDA (Elfstrand et al. 2007; Lopes et al. 2010).

Soil microbial properties differed between seasons, and this pattern is in agreement with Silva et al. (2012) for tropical soils. Such effects of season may be mainly due to variations in soil humidity and temperature (Araújo et al. 2013). Also, it may suggest that soil microbial community structure is likely to differ between seasons and to respond differently to dry and wet conditions as reported by Araújo et al. (2013; 2014) for tropical soils from Northeast Brazil.

NMS analyses of the biological and chemical properties showed distinct patterns according to the different plots and suggest a strong relationship between the biological properties and conditions occurring in the plots. The MC plot was clustered in the NMS and characterized by a high respiratory quotient, i.e. an indicator of stress, and by low soil microbial biomass. This indicates that soil microorganisms are severely limited by low resource availability (Nunes et al. 2012; Araújo et al. 2013). On the other hand, the HD plot showed high soil microbial biomass and activity, suggesting higher availability of organic residues driven by high inputs of plant litter.

Conclusion

The results highlight that AFS has strong effects on soil organic and microbial properties. While pastures under grass monoculture may promote C losses from the soil compared with standing forest, adding babassu palms to create an AFS, especially with high density of babassu palms, may increase the potential of soils to accumulate C. Our results support the hypothesis that high palm density in pastures provides better conditions for balanced microbial diversity, reflected by higher levels of soil microbial biomass C and enzyme activity compared with grass in monoculture. Therefore, the increase in the density of babassu palm in AFS may be an important strategy to improve the function of soils considerably. As soil microbial biomass plays an important role in nutrient cycling, pasture growth should increase through higher nutrient uptake and, consequently, livestock production per hectare could be favored. However, shading effects on pasture growth need to be considered. Further research is needed to clarify these issues.

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Genetic options for improving fodder yield and quality in forage sorghum

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Keywords: Digestibility, crude protein, ADL, diallel analysis, gene effects.

Abstract

Improving yield and quality of fodder from forage sorghum is important, especially in the semi-arid tropics, where sorghum is a major source of fodder. The aim of this work was to understand the genetic basis of fodder yield and quality traits, and character associations, and to estimate combining ability of the parents. The experiment was carried out during 2 successive rainy seasons using 10 parents crossed in a half-diallel design. Significant differences among the genotypes for fodder yield, quality and cell wall constituents were observed. Important quality traits, crude protein and digestibility (IVOMD), were not correlated with fodder yield, indicating the potential to improve yield and quality simultaneously in forage sorghum. General combining ability and specific combining ability variances showed that, for almost all characters, both additive and non-additive gene effects were important, with a predominance of non-additive effects. Parental lines SEVS4, HC308 and UPMC503 were good general combiners for yield and quality. The brown midrib lines, EC582508 and EC582510, were good general combiners for low lignin and high IVOMD. Strategies for improving forage sorghum to suit animal and biofuel industries are discussed.

Resumen

El mejoramiento del rendimiento y la calidad del sorgo forrajero (*Sorghum* spp.) es especialmente importante en zonas tropicales semiáridas, donde esta gramínea es un importante forraje. El objetivo de este trabajo fue entender la base genética de importantes características de rendimiento y calidad y sus relaciones, así como estimar la aptitud combinatoria de los genotipos parentales. El experimento se realizó en Hyderabad, India, durante 2 períodos sucesivos de lluvia utilizando 10 líneas parentales que se cruzaron en un diseño dialélico medio. Se observaron diferencias significativas entre los genotipos en rendimiento de forraje y calidad, especialmente en los constituyentes de la pared celular. No se encontró correlación entre el rendimiento de forraje y factores importantes de calidad (proteína cruda y digestibilidad in vitro de la materia orgánica), resultados que indican que en sorgo forrajero existe potencial para mejorar estas características del forraje en forma simultánea. Las varianzas de las aptitudes combinatorias general y específica mostraron que para la mayoría de las características en estudio, tanto los efectos aditivos de genes como los no-aditivos fueron importantes, con un predominio de estos últimos. Las líneas parentales SEVS4, HC308 y UPMC503 fueron buenos combinantes generales para rendimiento y calidad, mientras que las líneas Brown Midrib EC582508 y EC582510 fueron buenos combinantes generales para baja concentración de lignina y alta digestibilidad. En el trabajo se discuten estrategias de mejoramiento de sorgo forrajero para su adaptación a los requerimientos de producción animal y la industria de biocombustibles.

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Introduction

Sorghum is a versatile species with potential for high biomass production. It can be used as a source of human food, grain and forage for livestock and fuel in the arid and semi-arid tropics. The demand for fodder has increased because of recent efforts to increase milk and meat production, which necessitates increased quantity and quality of green and dry fodder. In semi-arid situations, sorghum can be the major supplier of fodder, and its role becomes important during winter and summer months. Management practices to improve fodder yield and quality, such as higher application of nitrogen, may not be suitable in semi-arid regions, where the environment is highly unpredictable and drought-prone (Hall et al. 2004). The best option for increasing yield and quality of forage sorghum appears to be genetic improvement of both these characteristics in currently available cultivars through multi-dimensional programs. There is limited information available on feed quality of improved forage sorghums, which is important for commercialization of forage cultivars (Akabari and Parmar 2014).

Besides its utility as a fodder crop, sorghum has the potential to provide lignocellulosic biomass for the production of ethanol as biofuel (Carpita and McCann 2008). The shorter life cycle of bioenergy grasses compared with perennial biomass crops, and their different cell wall composition, specifically lower lignin content, make processing of biomass from grasses much less energy-intensive (Vermerris 2011). To enhance use of sorghum as a fodder and biofuel crop, it is important to improve biomass quality in terms of digestibility and saccharification of the stalk. Lignin content of cell walls determines, among other factors, sugar release and thus the efficiency of the fermentation process (Vermerris et al. 2007; Lorenz et al. 2009). The main goal of forage sorghum breeders is to develop cultivars with high fodder yield as well as high digestibility.

Diallel analysis can be used to provide information on general and specific combining abilities (GCA and SCA), determine genetic variances and estimate heritability. Combining ability describes the breeding value of parental lines to produce hybrids. Combining ability analysis helps in the identification of parents with high GCA and parental combinations with high SCA.

The objectives of this study were to: (1) assess the genotypic variation for fodder yield and quality in a set of forage sorghum genotypes; (2) study possible associations between yield and forage quality traits; (3) determine combining ability of these forage sorghum genotypes; and (4) understand the genetic basis of the important fodder yield and quality traits. Parents with appropriate attributes could then be used in forage sorghum breeding programs to improve fodder yield and quality.

Materials and Methods

The study was conducted on the research farm of the Directorate of Sorghum Research (DSR), Hyderabad, India during the rainy seasons of 2009 and 2010. In both years, all genotypes were sown during the second week of June, while harvesting occurred during the third or fourth week of August, depending on when the particular genotype flowered. Rainfall, temperature and humidity details during the growing periods of the years under study are given in Table 1.

Table 1. Meteorological data during the growing periods.

Year and month	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	Max	Min	
2009					
June	36.3	24.8	72	41	82.0
July	32.0	23.4	80	57	154.0
August	31.2	23.3	81	64	203.7
2010					
June	35.2	24.7	82	60	113.7
July	29.4	22.5	89	77	278.9
August	30.3	22.6	91	75	203.1

Field material for the study

Ten sorghum cultivars (Table 2) were used, including: 7 forage sorghums; 1 sweet sorghum; and 2 brown midrib genotypes; plus 45 hybrids derived by crossing the 10 parents in a half-diallel fashion. The parents and F_1s were evaluated in a randomized complete block design with 3 replications. The experimental unit was a single 4 m row with spacings of 45 cm between rows and 10 cm within rows. Parents and F_1s were randomly assigned to experimental units within blocks.

Observations recorded

Observations on fodder yield and quality parameters were made each year. Days to flowering was recorded on a plot basis, while other parameters were recorded on 10 random plants/plot, avoiding plants at the ends of rows.

Field observations. Days to flower (DTF) was recorded when 50% of the plants in a plot had reached mid-anthesis. Plant height (PH) was the height from

Table 2. Description of the parents used in the study.

Parental line	Origin	Characteristics
SSG59-3	HAU, Hisar, India	Popular multi-cut forage sorghum variety released under All India Co-ordinated Sorghum Improvement Program (AICSIP)
UPMC503	GBPUAT, Pantnagar, India	Male parent of the popular forage sorghum hybrid, CSH 20MF
UPMC512	GBPUAT, Pantnagar, India	Improved forage sorghum line from Pantnagar
PC23	IARI, New Delhi, India	Forage sorghum variety from Indian Agricultural Research Institute (IARI), New Delhi, India
HC308	HAU, Hisar, India	Popular forage sorghum variety released under AICSIP
Keller	USA	Sweet sorghum variety
EC582510	N598 from University of Nebraska, USA	Brown midrib line
EC582508	Atlas bmr-12 from University of Nebraska, USA	Brown midrib line
Nizamabad forage	Nizamabad, India	Forage sorghum variety from Nizamabad area of Andhra Pradesh, India
SEVS4	AICSIP, India	Dual-purpose sorghum variety under AICSIP

ground level to the tip of the main stem at flowering. The number of leaves per plant (NLP) was counted at flowering. Plants were harvested at 50% flowering by cutting the stems at the base and weighing the harvested material immediately to estimate fresh fodder yield (FY). Representative whole plant samples were collected and chopped, before drying in a hot air drier at 60–70 ^{o}C for 72 h. Dried samples were ground in a mill with a 1 mm sieve.

Observations on fodder quality. All forage samples were analyzed by Near Infrared Spectroscopy (NIRS), calibrated for this experiment. The NIRS instrument used was a FOSS Forage Analyzer 5000 with software package Win SI. Crude protein (CP) concentration was estimated by determining total nitrogen (N) in the sample by Auto Analyzer, and acid digestible lignin (ADL) according to Goering and Van Soest (1970). In vitro organic matter digestibility (IVOMD) was determined according to Menke and Steingass (1988) using an in vitro gas production test with manual syringes as modified by Blümmel and Ørskov (1993).

Data analysis

Data collected over the 2 years were subjected to analysis of variance, and simple correlations using the software Genstat 12 (GENSTAT 2011). The analysis of variance for GCA and SCA effects was carried out according to Griffing's (1956) method 1, model 2, involving parents with one set of F_1s but reciprocals were not included. Windostat (Indostat Services 2004) software was used for analysis. GCA and SCA effects for different traits were calculated across years. The model was: $Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$, where Y_{ijk} was the observed measurement for the *ij*th cross grown in the *k*th year; μ was the population mean; g_i and g_j were the GCA effects; s_{ij} the SCA effect; and e_{ijk} the error term associated with the *ij*th cross evaluated in the *k*th year. The restrictions imposed on the combining ability effects were: $\sum g_i = 0$, and $\sum s_{ij} = 0$ for each *j* (Griffing 1956). Estimates of σ^2GCA (general combining ability), σ^2SCA (specific combining ability) and their variances were computed for the random-effects model to estimate σ^2A, σ^2D and h^2 (Zhang and Kang 2005).

Heterosis (MP: mid-parent) and heterobeltiosis (BP: better parent) values, respectively, were calculated by using the formulae: MP = [(value of F_1 – mean of parents)/mean of parents] x 100; and BP = [(value of F_1 – value of better parent)/value of better parent] x 100. The critical differences for testing the significance of heterosis were calculated as follows: critical difference (MP) = √3Me/2r x t; and critical difference (BP) = √2Me/r x 4t; where Me is the error mean square, r is the number of replications, and t is the table value of t at 5 or 1% level of significance.

Results

Mean values and heritabilities

The means and ranges for all fodder yield and quality traits, plus the level of significance for the 55 sorghum genotypes studied, are reported in Table 3. Highly significant (P<0.001) differences among entries were observed for all yield and nutritional traits assessed. Heritabilities for all fodder quality and yield traits were moderate to high.

Table 3. Overall means, ranges in individual cultivar means, and heritabilities for sorghum fodder yield and quality traits. Data are from a 55-entry sorghum trial grown in two years (**P<0.001).

Variable[1]	Mean	Range	LSD	Heritability
DTF (no.)	66	59–76.3**	3.1	0.83
PH (cm)	294	165–355**	21.3	0.82
NLP (no.)	11	9–13**	1.2	0.50
FY (g/plant)	1,860	610–2,743**	513.6	0.54
CP (%)	9.62	7.43–11.7**	1.6	0.36
IVOMD (%)	50.8	45.7–55.4**	2.5	0.39
ADL (%)	4.87	3.59–5.68**	0.47	0.47

[1]DTF - Days to flower; PH - Plant height; NLP - Number of leaves per plant; FY - Fresh fodder yield; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin.

Table 4. Correlation co-efficients of fodder yield and IVOMD with other traits.

Trait	Year	DTF[1]	PH	NLP	CP	ADL	IVOMD
FY	2009	0.71**	0.73**	0.77**	-0.14	0.09	0.10
	2010	0.59**	0.69**	0.67**	0.13	-0.19	0.21
IVOMD	2009	0.06	-0.21	0.10	-0.09	-0.84**	-
	2010	0.24	-0.29*	0.02	-0.05	-0.83**	-

[1]DTF - Days to flower; PH - Plant height; NLP - Number of leaves per plant; FY - Fresh fodder yield; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin.

Table 5. Analysis of variance for combining ability for fodder yield and quality traits in forage sorghum involving 10 x 10 half-diallel analysis.

Source of variation	DF	Mean sum of squares						
		DTF[1]	FY	PH	NLP	CP	IVOMD	ADL
Environments	1	683.7**	30087.3**	64279.3**	29.52**	792.0**	3183.6**	5338.6**
Genotypes	54	146.4**	14707.2**	9189.1**	6.62**	4.12**	17.32**	75.7**
Gen * Env	54	52.9 **	3789.6**	724.0**	2.01**	2.84**	8.02**	32.8**
Error	216	7.17	2037.3	350.5	1.17	1.57	4.22	16.66
GCA	9	175.4**	16702.6**	8322.0**	6.39**	2.53**	20.04**	66.9**
SCA	45	23.5**	2542.4**	2011.2**	1.37**	1.14**	2.92**	16.9**
GCA*Env	9	51.2**	1905.4**	196.2	0.7	2.16**	3.35*	23.4**
SCA*Env	45	10.9**	1134.7**	250.4**	0.66**	0.70	2.54**	8.44*
Error	216	2.39	679.1	116.8	0.39	0.52	1.4	5.55
σ^2GCA		7.21	667.65	341.9	0.25	0.08	0.78	2.56
σ^2SCA		10.55	931.6	947.2	0.49	0.31	0.76	5.67
σ^2A		14.42	1335.3	683.7	0.5	0.17	1.55	5.11
σ^2D		10.55	931.6	947.2	0.49	0.31	0.76	5.67
GCA:SCA Ratio		0.684	0.717	0.361	0.51	0.27	1.026	0.451

[1]DTF - Days to flower; FY - Fresh fodder yield; PH - Plant height; NLP - Number of leaves per plant; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin

Relationships among fodder yield and quality traits

Highly significant correlation (r = 0.84, P≤0.001) was observed between fresh fodder yield and dry fodder yield in this study. Hence only fresh fodder yield was used further for the association studies and combining ability studies. No significant relationships were observed between fodder yield and fodder quality traits such as CP, ADL and IVOMD (Table 4). IVOMD was negatively correlated with ADL (r = -0.86, P≤0.001). The yield traits (DTF, PH and NLP) were correlated with one another and also with fodder yield.

ANOVA, GCA and SCA variances

The mean square values for inter-genotype differences and combining ability for all traits are presented in Table 5. There were significant genotype differences for all characters studied (P<0.001). Significant differences (P<0.001) due to years (environment) were also observed for all traits. The partitioning of genotype mean squares into GCA and SCA showed GCA and SCA mean squares to be significant (P<0.001) for all traits, viz. DTF, PH, FY, NLP, CP, IVOMD and ADL. Estimates of highly significant GCA and SCA variances for these characters indicated the importance of both additive and non-additive genes in the expression of the characters. Both additive and non-additive gene actions were equally important for the trait, IVOMD, while the non-additive gene actions were predominant for the traits, CP, PH, NLP, ADL, DTF and FY.

Genotype x year (environment) interactions were highly significant (P<0.001) for all traits. Partitioning of genotype x environment interactions into GCA x environment (GCA x E) and SCA x environment (SCA x E) showed that: (a) GCA x E was significant (P<0.05) for all the traits except PH and NLP; and (b) SCA x E was significant (P<0.05) for all traits except CP. Significant GCA x E interactions for the above traits are an indication of variation of general combining ability of lines under different environments. Significant SCA x E interactions for the traits mean that specific hybrids differed in the way they expressed these traits in different years.

GCA and SCA effects

Fodder yield traits. Estimates of GCA effects of the 10 genotypes for fodder yield traits showed that SEVS4, HC308 and UPMC503 had the best GCA for fodder yield (FY) (Table 6). SEVS4 and HC308 recorded high per se performance for FY (Supplementary Table 1). Apart from FY, SEVS4 and HC308 had good GCA for other plant characteristics, including plant height (PH) and number of leaves per plant (NLP). For days to flowering (DTF), EC582508, Nizamabad forage, Keller, EC582510 and SSG59-3 were good general combiners with significantly negative GCA effects for flowering. The parents, PC23, Nizamabad forage, EC582508 and Keller, flowered early with DTF less than 65 days.

Fodder quality traits. Estimates of GCA effects for fodder quality traits indicate that Nizamabad forage had good GCA for increased CP. For IVOMD, the brown midrib genotypes (EC582508 and EC582510) and the sweet sorghum genotype, Keller, had good GCA, as could be expected from parents with reduced lignin due to the bmr trait or with higher sucrose content in the sweet sorghum parent. All 3 parents had high per se performance for IVOMD. For ADL, the brown midrib genotypes (EC582508 and EC582510) had significantly negative GCA effects besides HC308. Both brown midrib lines (EC582508 and EC582510) had low lignin compared with other genotypes.

Table 6. General combining ability effects for fodder yield and quality traits in forage sorghum parents from 10 x 10 half-diallel analysis.

Parental line	DTF[1]	FY	PH	NLP	CP	IVOMD	ADL
SSG 59-3	-1.12**	-16.97**	5.47**	-0.46**	0.24	-0.44	1.42**
UPMC 503	2.04**	10.29*	16.20**	0.051	-0.58**	-0.3	0.1
UPMC 512	-0.57	-19.96**	-15.76**	-0.45**	0.06	-0.99**	1.28**
PC 23	1.25**	-36.46**	18.76**	0.11	-0.11	-1.74**	3.00**
HC 308	5.42**	30.66**	15.48**	0.99**	-0.35	0.43	-1.17*
Keller	-2.56**	-4.26	-20.26**	-0.30*	-0.04	1.07**	-0.83
EC582510	-1.82**	-8.55	-19.31**	-0.21	-0.14	0.51*	-1.29**
Nizamabad forage	-2.19**	-0.93	-0.6	-0.30*	0.59**	-0.13	0.83
EC582508	-2.90**	-8.89	-24.52**	-0.26*	0.17	1.21**	-2.76**
SEVS 4	2.46**	55.06**	24.55**	0.82**	0.15	0.37	-0.59
SE (g_i)	0.30	5.05	2.09	0.12	0.48	0.23	0.46
SE (g_i-g_j)	0.45	7.52	3.12	0.18	0.71	0.34	0.68

[1]DTF - Days to flower; FY - Fresh fodder yield; PH - Plant height; NLP - Number of leaves per plant; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin.

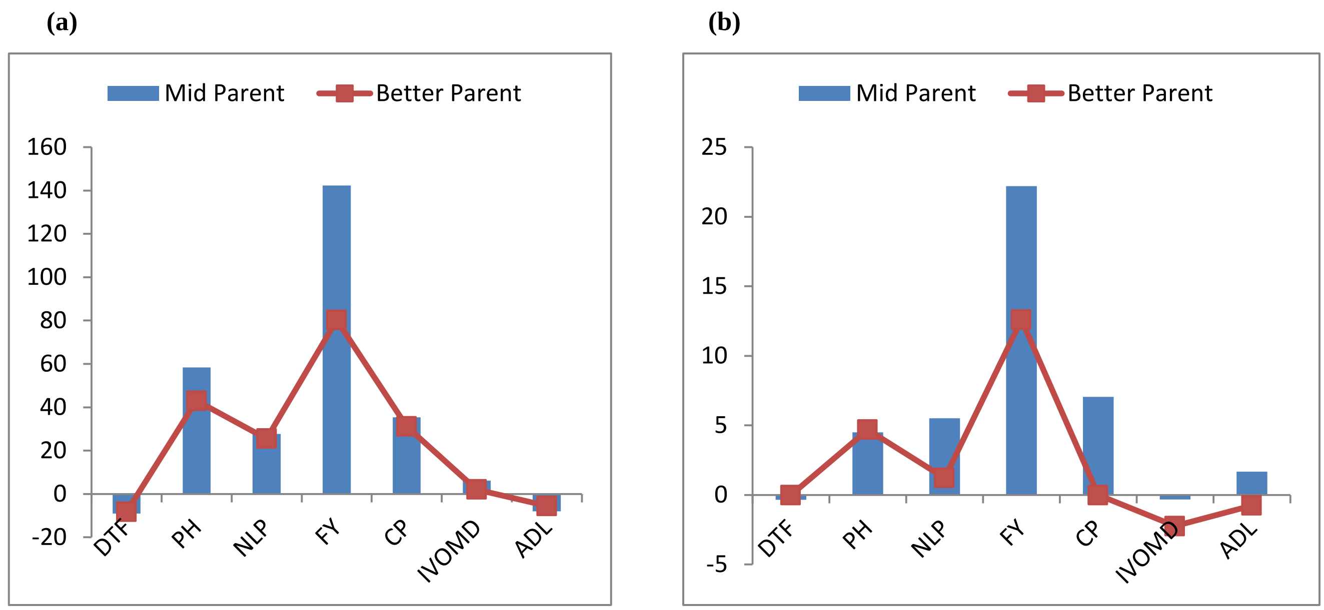

Figure 1. Heterosis for fodder yield and quality traits: (a) maximum heterosis observed among the crosses; (b) mean heterosis across all crosses. (Note different scales on the two graphs.) DTF - Days to flower; PH - Plant height; NLP - Number of leaves per plant; FY - Fresh fodder yield; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin.

Heterosis for fodder yield and quality traits

High heterosis was observed for FY, followed by CP (Figure 1). Mean heterosis for FY was observed to be 22.2 and 12.6% over the mid-parent and better parent, respectively. The best hybrid was PC23 x EC582508 with 142 and 80% heterosis over the mid-parent and better parent, respectively, followed by UPMC503 x EC582508. Both hybrids showed significant heterosis over the better parent, while 13 more hybrids expressed significant heterosis over mid-parent values (data not shown). For CP, the best hybrid was UPMC503 x EC582510, with heterosis of 34.7 and 31.1% over mid-parent and better parent, respectively, followed by SSG59-3 x EC582510 (32.7 and 24.2%) and SSG59-3 x UPMC503 (25.9 and 15.2%). For IVOMD, only one hybrid, PC23 x Nizamabad forage, recorded positive significant heterosis. Heterosis for reduced ADL was observed in PC23 x Nizamabad forage (-7.53 and -2.38% over mid-parent and better parent), HC308 x Nizamabad forage (-5.19 and -1.78%) and UPMC503 x HC308 (-6.96 and -5.5%).

Discussion

This study has provided interesting results about the potential for breeding more productive genotypes of sorghum. However, our study had some shortcomings:

- Since only a single row of plants was grown in each replicate, competition effects could have affected the results. Only single rows of plants were sown as limited availability of seed restricted how much of each genotype could be sown.
- Fresh forage yields were used in this study rather than dry matter yields. Farmers normally feed the forage fresh and there is a strong positive correlation between fresh and dry matter yields (Tariq et al. 2012; this study).

Despite these factors, we consider that the data obtained reliably indicate the true performance of these genotypes in this area of the semi-arid tropics.

A forage sorghum breeding program should aim for improvement of important fodder quality traits, such as digestibility and protein content, in addition to forage yield. Forage sorghum has good potential as a biofuel and biogas crop (Mahmood and Honermeier 2012). For efficient production of ethanol from plant biomass, reduced lignin percentage is desirable, because during saccharification, lignin acts as a physical barrier and retards the action of cellulases, impeding swelling of cellulose fibers (Vermerris et al. 2007). Reducing lignin has a highly beneficial effect on conversion of cellulose to glucose, resulting in high ethanol yield (Dien et al. 2009).

The brown midrib mutants (bmr) in forage maize and sorghum with reduced lignin and greater digestibility

(Barriere et al. 2004; Sattler et al. 2010; Rao et al. 2012) could lead to the development of forage and sweet sorghums as novel biomass crops (Sarath et al. 2008). Biorefineries present a system comparable with the rumen digestive system, where improved cellulose breakdown to sugars is achieved with enzyme mixtures rather than rumen bacteria. Programs to improve forage and biomass feedstock share the following goals: high biomass yield and low lignin content.

In the present study, these traits showed significant variation among genotypes, indicating that there is sufficient genetic variability in the parents and hybrids to obtain genetic gains in hybrid combinations. The estimates of heritability of pertinent fodder quality traits were around 0.5, suggesting opportunities for further improvement of fodder quality by genetic enhancement. The magnitudes of genotypic differences should prove meaningful for animal performance, as small changes in IVDMD of 3–4 percentage units have been observed to result in improvements of 17–24% in daily gains and production per hectare (Vogel and Sleper 1994). However, the very large genotype x year interactions observed in this study could seriously reduce the rate of genetic gain for biomass quality. Although few studies have been specifically designed to examine genotype x year interactions for stover quality, there are reports of highly significant genotype x year interactions for in vitro digestibility (Aruna et al. 2012), while other studies failed to find major genotype x environment interactions for stover digestibility (Badve et al. 1994). The presence of significant genotype x environment interactions for yield and quality traits suggests that evaluation in more than one environment may be required for accurate selection for biomass yield and quality, as was reported for maize (Lorenz et al. 2009).

Associations amongst the fodder yield and quality traits, and their interaction with the environment, will help in guiding future plant breeding strategies. In general, associations between fodder yield and important fodder quality traits, such as IVOMD, CP and ADL, were not found, indicating that these traits have independent inheritance. This paves the way for simultaneous genetic improvement of both fodder yield and quality. Significant positive association of fodder yield with PH, NLP and DTF was observed, showing that these traits contributed to the variation in fodder yield. Strong positive genotypic and phenotypic correlations between fodder yield and stem diameter, leaf length, plant height and number of leaves have already been reported (Iyanar et al. 2010; Tariq et al. 2012). Our findings indicate that, to improve fodder yield, the important traits to be addressed are PH and NLP. The leaf component is important for both yield and quality, not only because of the generally high nutritive value in leaves compared with stems, but also because leaves are more acceptable to animals, as they are easier to chew and more digestible (Reddy et al. 2003).

Since genotypic variance was significant, varietal improvement could help raise the nutritional quality of sorghum forage above current levels. Presence of highly significant GCA and SCA effects for most characters indicated the importance of both additive and non-additive genes in the expression of the traits. In the present study, the ratio of GCA:SCA variance was <1 unit for all characters, except IVOMD where it was slightly higher than 1 unit, which indicated the pre-ponderance of non-additive genetic variance, as reported earlier (Prakash et al. 2010; Aruna et al. 2012). For traits where both additive and non-additive gene effects were important, dominance variance (σ^2D) was found to be larger than the additive variance (σ^2A), showing the importance of non-additive gene effects in the control of these traits, indicating good prospects for the exploitation of non-additive genetic variation for fodder yield and quality traits in forage sorghum through hybrid breeding. As well as hybrid breeding, population breeding, which gives a chance to accumulate genes from different genotypes, can be one of the approaches for yield and quality improvement. Epistatic interactions have been found to play a major role in the genetic basis of fiber-related traits (Shiringani and Friedt 2011).

The GCA effect is considered as the intrinsic genetic value of the parent for a trait, which is due to additive gene effects and is fixable (Simmonds 1979). To get outstanding recombinants in segregating generations, the parents of the hybrids must be good general combiners for the characters to be improved (Gravois and McNew 1993; Manonmani and Fazlullah Khan 2003).

The presence of heritable variation for both fodder yield and quality traits and their independence suggest that simultaneous improvement of fodder yield and quality is possible. Genotypes HC308 and SEVS4 were the best combiners for most fodder yield parameters such as plant height, leaf number etc. and for some of the fodder quality traits, such as low lignin (HC308). The brown midrib genotypes, EC582508 and EC582510, were good combiners for early flowering, IVOMD and low lignin concentration, and can be used as a source of genes to improve fodder quality in terms of digestibility. Keller was a good combiner for early flowering and fodder quality traits such as high IVOMD and low lignin. Nizamabad forage was a good combiner for CP and early flowering. These have potential for crossing with HC308 and SEVS4 for improvement of forage sorghum for animal feed. Breeding programs can be designed to utilize these lines for improving biomass/fodder yield and quality, and multiple crosses involving these parents would result in identification of superior segregants with favorable genes for most traits associated with fodder yield and quality.

Biparental mating in early segregating generations of the crosses, involving these parents for simultaneous exploitation of both additive and non-additive gene action, can be recommended to develop sorghum genotypes with improved fodder yield and quality. It is suggested that inter-mating of the randomly selected progeny in early segregating generations (especially in F_2 and F_3) obtained by crossing these parents will release the hidden genetic variability through breakage of undesirable linkages involved in different characters. It may produce an elite population for selection of lines with high fodder yield and quality in advanced generations.

Conclusion

The main conclusion from this study is that both additive and non-additive gene effects are important, with a predominance of non-additive gene effects governing fodder yield and quality in sorghum. Multiple crosses involving the best combiners for different traits would result in the identification of superior F_1 hybrids with favorable genes for most of the traits associated with fodder yield and quality. The study also indicates the brown midrib genotypes can be used to develop cultivars with low lignin and high digestibility, which would be suitable for both animal and biofuel industries. This confirms that there is a great opportunity to improve both fodder yield and quality in breeding programs aiming at genetic enhancement of forage sorghums.

Hybrids low in lignin appear to be attainable without sacrificing high yield levels. We conclude that exploiting heterosis in forage sorghum to improve quality traits might be promising. Since many traits contribute to fodder yield and quality, population breeding or marker-assisted selection would be fruitful in forage sorghum improvement. Identifying markers for the component traits associated with yield and quality and pyramiding them into elite cultivars would help in developing forage sorghum cultivars with improved quality. The improvement in the quantity and nutritional quality of the fodder of forage sorghum cultivars could have a significant impact on livestock productivity in the sorghum-growing areas. The extent to which these results could be extrapolated to other regions is unclear, because of large genotype x environment interactions noted.

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Supplementary Table 1. Mean performance of the 10 sorghum parents for fodder yield and quality traits over two years.

Parental line	DTF[1]	PH (cm)	FY (g/pl)	NLP	CP (%)	IVOMD (%)	ADL (%)
SSG 59-3	67.2	278.0	261.7	10.1	10.8	49.7	4.96
UPMC 503	68.2	289.4	326.3	11.0	7.9	50.5	4.92
UPMC 512	65.3	165.0	240.0	10.0	11.6	50.0	4.94
PC 23	60.0	258.8	122.0	9.5	11.4	45.7	5.68
HC 308	76.3	303.0	443.3	13.2	10.1	50.7	4.77
KELLER	63.0	224.4	270.3	9.8	10.1	53.7	4.47
EC582510	65.2	204.9	207.3	9.9	9.1	54.2	3.69
Niz forage	61.7	280.6	335.3	9.7	12.4	49.5	5.11
EC 582508	62.5	211.6	250.0	10.3	11.9	55.4	3.59
SEVS 4	72.8	305.7	450.7	12.5	10.3	52.1	4.35
Mean	66.2	252.1	290.7	10.6	10.6	51.2	4.65
C.V.	3.90	4.59	23.09	7.34	9.66	4.25	5.85
C.D. (5%)	4.33	19.34	125.3	1.38	1.75	3.50	0.50
C.D. (1%)	5.93	26.50	171.6	1.89	2.40	4.80	0.69

[1]DTF - Days to flower; PH - Plant height; FY - Fresh fodder yield; NLP - Number of leaves per plant; CP - Crude protein; IVOMD - In vitro organic matter digestibility; ADL - Acid digestible lignin.

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