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Research Papers

Short Communications

Evaluating pasture species for less fertile soils in a subtropical aseasonal low rainfall zone

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Keywords: Evaluation technique, Queensland, non-legume herbs, subtropical grasses.

Abstract

Grasses, legumes, saltbushes and herbs were evaluated at 6 sites in southern inland Queensland to identify potential pasture and forage plants for use on marginal cropping soils. The region experiences summer heat waves and severe winter frosts. Emphasis was on perennial plants, and native species were included. Seedlings were transplanted into the unfertilized fields in either summer or autumn to suit the growing season of plants, and watered to ensure establishment. Summer-growing grasses were the most successful group, while cool season-growing perennials mostly failed. Summer legumes were disappointing, with *Stylosanthes scabra* and *Indigofera schimperi* performing best. Some lines such as *I. schimperi* and the *Eragrostis* hybrid cv. Cochise were assessed as potential weeds owing to low animal acceptance. Native *Rhynchosia minima* grew well at some sites and deserves more study. *Cenchrus ciliaris* was always easy to establish and produced the highest yields. Persistence of some *Digitaria* and *Bothriochloa* species, *Eragrostis curvula* and *Fingerhuthia africana* at specific sites was encouraging, but potential weediness needs careful assessment. Standard species were identified to represent the main forage types, such as *Austrostipa scabra* for cool season-growing grasses, for incorporation into future trials with new genetic materials. The early field testing protocol used should be considered for use elsewhere, if unreliable rainfall poses a high risk of establishment failure from scarce seed.

Resumen

En 6 sitios localizados en el interior de la región sur de Queensland, Australia, se evaluaron gramíneas, leguminosas, arbustos de tierras salinas ("saltbushes") y hierbas con el fin de identificar potenciales plantas forrajeras para suelos agrícolas marginales. La zona se caracteriza por veranos con altas temperaturas e inviernos con heladas severas. En el trabajo se dio énfasis a especies perennes y se incluyeron algunas nativas. El establecimiento se hizo por plántulas trasplantadas a campo sin fertilización, ya sea en verano o en otoño (dependiendo de la temporada de crecimiento de las especies), y se aplicó riego para asegurar su establecimiento. Las gramíneas de crecimiento en verano constituyeron el grupo más exitoso mientras que las especies perennes de crecimiento en la época fría fracasaron en su mayoría. Las leguminosas de verano mostraron un pobre desempeño; de éllas, *Stylosanthes scabra* e *Indigofera schimperi* tuvieron el mejor desarrollo. Algunas líneas como *I. schimperi* y el híbrido de *Eragrostis*, cv. Cochise, presentaron características de malezas debido a su baja aceptabilidad por el ganado. La leguminosa nativa *Rhynchosia minima* creció bien en algunos sitios y amerita ser más estudiada. La gramínea *Cenchrus ciliaris* fue siempre fácil de establecer y produjo los mayores rendimientos. La persistencia de algunas especies de *Digitaria* y *Bothriochloa*, de *Eragrostis curvula* y *Fingerhuthia africana* fue alentadora en algunos sitios, pero su potencial de maleza requiere de una evaluación cuidadosa. Se identificaron las especies que pueden servir como representantes estándares de los principales tipos de forraje, tales como *Austrostipa scabra* como gramínea de crecimiento en época fría, para incluirlas en futuros ensayos con nuevos materiales genéticos. Se sugiere usar este protocolo de pruebas de campo iniciales para otros lugares, donde la falta de lluvias confiables y la escasez de semilla presenten un alto riesgo de fracaso en el establecimiento de las plantas.

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Introduction

In the Condamine-Maranoa region of southern inland Queensland, Australia (25–29° S), sclerophyllous woodlands and dense tall shrublands dominate the natural vegetation. Native pastures dominated by summer-active grasses are a common forage base for livestock. Their replacement by sown pastures after tree clearing or the infusion of forage legumes seems a good option in some cases (Miller et al. 1988). However, after such disturbance, woody regrowth can thrive and the poisonous pimelea (*Pimelea trichostachya*) (MLA Australia 2010) can proliferate, especially on abandoned cultivation land. Buffel grass (*Cenchrus ciliaris*) has been a major exotic pasture success story, but it tends to become a monoculture.

The better structured soils of the region are almost fully utilized for crops, so some less fertile, poorly structured soils are now cropped intermittently in response to market forces. Soil structure on these poorer soils soon breaks down (Douglas 1997), as reported in other countries (Bot and Benites 2005). Significant areas of native pastures have also been seriously degraded, with wire-grasses (*Aristida* spp.) assuming dominance. Thus, sown pasture species are needed to restore structure to some soils between cropping periods and to augment native pastures, as exists in other subtropical parts of the world, e.g. the Sahel and the Cerrado region in Brazil (Pearson et al. 1995).

Effective rainfall for establishing sown pasture seedlings is unpredictable and most cropping enterprises depend upon stored subsoil moisture to fill the seed of grain crops. Median summer rainfall (October–March) ranges from 300 to 400 mm, median winter rain is 175–200 mm (Rainman 2003), and droughts and floods are common. Frosts are common (20–60) in winter (Hammer and Rosenthal 1978) and high summer temperatures (>38 °C on many days) routine.

In the mid-1980s, we began to evaluate pasture and forage species that were best adapted agronomically for various roles in that environment and to identify benchmark species against which existing and future genetic material could be compared. The potential roles were: permanent pasture; short-term pasture; legume-augmented native pasture; and soil conservation. We focused on less fertile land that could be cropped intermittently, because that allowed agronomic intervention in a low to moderate cashflow environment. While a range of forage cultivars already existed for fertile soils, e.g. Rhodes grass (*Chloris gayana*), lucerne (*Medicago sativa*), leucaena (*Leucaena leucocephala*), forage sorghums (*Sorghum* spp.) and oats (*Avena sativa*) (Thompson 1988; Blacket 1992), only buffel grass was suitable for infertile soils. Some plants native to the region were included to ensure that our assessment was not biased by perceived virtues of exotic species (Davis et al. 2011).

Materials and Methods

Trial site details

We used 5 low-elevation (200–300 masl) field sites on commercial farms, chosen to provide a range of soil types and regional locations; 2 in the Roma district (26.5° S, 149° E; Sites L and N), and 3 near St George (28° S, 149° E; Sites M, U and W). Preliminary screening of accessions and seed increase were also done at Toowoomba (27.5° S, 151.9° E; Site T). Details of the soils and original vegetation at each site are given in Table 1. Site U had grown only one prior wheat crop, while most sites had grown several crops, and Site N had been intermittently cropped for 15 years beforehand.

Soils at the sites varied markedly (Table 1). Two sites (L and W) had a strong duplex profile with a thin, hard-setting, slightly acid loam overlying an impermeable clay subsoil that became saline-sodic at depth. Three other sites (M, T and U) had a gradational increase in clay content with depth, were non-saline and had a general red coloration. At the sixth site (N), the duplex soil was not hard-setting, was alkaline throughout and had carbonate nodules at depth. A strongly bleached A2 horizon at sites L and W was evidence of an impervious subsoil and waterlogging in abnormally wet seasons. Site T was similar to infertile, friable, red cracking clays found south of Roma (Slater and Carroll 1993).

Species evaluated

Since effective rainfall (that which wets the upper 15 cm of soil) can occur at any time, we evaluated both summer- and winter-active species, and included less-traditional forage plants such as non-legumes and browse shrubs, because their higher mineral contents may counter-balance the low levels in the local, grass-dominant pastures. Perennial species were favored, because land can be exposed to erosion for long periods in this environment with annual species. A long assessment period was required to ensure meaningful conclusions were reached.

We chose our test plants on the basis of experience by many pasture agronomists in Queensland and New South Wales, particularly Blumenthal et al. (1985), Day and Silcock (1985), Scattini (1985), Strickland and Greenfield (1988) and Bellotti et al. (1991). Well-regarded species from semi-arid regions overseas were also sourced, e.g. *Dorycnium hirsutum* and wheatgrasses (*Agropyron* spp.). The plant accessions tested at field sites are listed in Table 2 along with their homeland and principal traits.

Table 1. Details of the soil and surrounding vegetation at each trial site.

Feature	Site					
	L	M	N	T	U	W
Original vegetation[1]	Poplar box /belah	Yellow-jacket /mulga	Poplar box /yarran	Dense stringybark	Poplar box /sandalwood	Poplar box /wilga
Soil type[2]	Dy2.43	Gn2.11	Dd1.43	Gn3.11	Dr2.23	Dr2.43
Surface soil structure	Hard-setting loam	Firm loamy sand	Loose clay loam	Friable clay loam	Moderately hard-setting sandy loam	Hard-setting silty loam
Surface soil color	grey	red	grey	red	red	brown
Surface clay (%)	17	8	26	30	29	32
Surface pH[3]	6.7	5.7	8.2	6.3	6.4	6.5
Surface bicarb. extr. P (ppm)	27	2	3	14	5	16
Surface CEC[4] (meq/100 g)	8	2	23	15	6	8
Surface org. C (%)	0.5	0.5	0.5	3.5	0.9	0.8
A horizon depth (cm)	20	90	20	60	25	20
A2 horizon bleach[5]	++	-	-	-	-	++
B horizon pH	7.0	5.1	9.0	7.8	5.9	7.5
B horizon EC[6] (mS/cm)	0.11	0.01	0.26	0.03	0.02	0.42

[1]Poplar box = *Eucalyptus populnea;* Belah = *Casuarina cristata;* Mulga = *Acacia aneura;* Yellow jacket = *Eu. intertexta;* Stringybark = *Eu. eugenioides;* Yarran = *A. omalophylla;* Sandalwood = *Eremophila mitchellii;* Wilga = *Geijera parviflora.*
[2]Northcote Principal Profile Form classification (Northcote 1971).
[3]pH 1:5 water assay.
[4]Cation exchange capacity.
[5]++ = strong bleach; - = no A2 horizon bleach.
[6]Electrical conductivity.

Table 2. List of accessions evaluated, their key traits and the sites where not sown (**-**).
An **x** at a site means that the accession survived there for at least 6–7 years, while **t** means a tiny amount remained in 1 replicate after 6–7 years.

Species	Cultivar	Plant type[1]	Homeland[2]	Accession	Site					
					L	M	N	U	W	T
Summer growers										
Andropogon ischaemum		PT	Mexico	CPI90727						-
Andropogon ischaemum		PT	USA	CPI99868						-
Andropogon ischaemum		PT	USA	CPI99869			**x**			-
Anthephora pubescens		PT	South Africa	Q20321	**x**	**x**		**x**		-
Bothriochloa barbinodis		PT	USA	CPI99572						-
Bothriochloa barbinodis		PT	USA	CPI99867						-
Bothriochloa ewartiana[3]		PT	St George	TN47	**x**	**x**	**x**	**x**	**x**	**x**
Bothriochloa glabra	(Swann)[4]	PT	Uncertain/Qld.	CPI11408			**x**	**x**		-[5]
Bothriochloa insculpta		PS	Zimbabwe	CPI69517	**x**		**x**	**x**	**x**	-[5]
Bothriochloa insculpta		PS	Zambia	CPI52193	**x**	**x**	**x**	**x**		-[5]
Bothriochloa insculpta	Hatch	PS	Zimbabwe/Qld.	Hatch	**x**		**x**	**x**		-[5]
Bothriochloa pertusa	Medway	PS	Uncertain/Qld.	Medway	**x**	**x**	**x**	**x**	**x**	-[5]
Cenchrus ciliaris		PT	Namibia	CPI60733	**x**		**x**		**x**	-
Cenchrus ciliaris		PT	Somalia	CPI71914	**x**	**x**	**x**	**x**	**x**	-
Cenchrus ciliaris		PT	South Africa	CPI73390	**x**	**x**[6]	**x**	**x**		-
Cenchrus ciliaris		PT	South Africa	CPI73393	**x**	**x**	**x**	**x**	**x**	-
Cenchrus ciliaris		PT	Ethiopia	Q10077	**x**	**x**	**x**	**x**	**x**	-
Cenchrus ciliaris	Biloela	PT	Tanzania/Qld.	Biloela	**x**		**x**	**x**		-
Cenchrus ciliaris	Gayndah	PT	Kenya/Qld.	Gayndah	**x**		**x**	**x**	**x**	

Continued

Species	Cultivar	Plant type[1]	Homeland[2]	Accession	Site					
					L	M	N	U	W	T
Cenchrus hybrid		PT	Bred, USA	CPI61135	**x**	**x**	**x**	**x**	**x**	-
Cenchrus setiger		PT	Kenya	CPI17655	**x**	**x**	**x**	**x**	**x**	-
Chloris gayana	Pioneer	PS	Uncertain/Aust.	Pioneer						-
Chloris truncata[3]		PT	Miles	TN45	**x**				**x**	
Dactyloctenium sp.		PS	Peru	Q9143						-
Dactyloctenium sp.		PS	Ethiopia	Q10878						-
Dichanthium aristatum		PT	Uncertain/Bundaberg	TBA1014			**x**			-[5]
Dichanthium aristatum		PT	Uncertain/Rockhampton	TBA1024						-
Digitaria abyssinica		PS	Yemen	CPI89982						**x**
Digitaria brownii[3]		PT	Charleville	TN57					**x**	
Digitaria eriantha		PS	South Africa	CPI26832	**x**		**x**			-
Digitaria milanjiana		PS	South Africa	CPI41192	**x**	**x**	**x**	**x**		-
Digitaria milanjiana		PS	Zimbabwe	CPI59786	**x**	**x**	**x**			-
Digitaria smutsii	(hybrid)	PT	Bred, Aust.	TBA9						-
Digitaria smutsii	(Premier)[4]	PT	South Africa	CPI38869	**x**	**x**	**x**			-
Enteropogon acicularis[3]		PT	Moree	TN1					**x**	
Eragrostis bicolor		PT	South Africa	CPI98920	**x**	**x**	**x**	**x**		-
Eragrostis hybrid	Cochise	PT	USA	CPI99872	**x**	**x**	**x**	**x**		-
Eragrostis lehmanniana		PT	South Africa	CPI98954			**x**[6]			-
Eragrostis lehmanniana		PT	South Africa	CPI98960	**x**[6]	**x**		**x**		-
Eragrostis lehmanniana		PT	USA	CPI99871	**x**	**x**	**x**	**x**		-
Eragrostis obtusa		PT	South Africa	CPI98952	**x**[6]		**x**	**x**		-
Eragrostis obtusa		PT	Sthn Africa/West. Aust.	WA80/1987	**x**		**x**	**x**	**x**	-
Eragrostis superba		PT	Botswana	CPI59853	**x**		**x**			-
Eragrostis truncata		PT	South Africa	CPI98987						-
Leptochloa dubia		PT	USA	CPI99865	**t**					
Leptochloa fusca		PT	USA	CPI99880						**x**
Panicum antidotale		PT	Uncertain/Aust.	TBA1				**x**		
Panicum coloratum	Bambatsi	PT	Zimbabwe/Qld.	Bambatsi	**x**		**x**			-
Panicum decompositum[3]		PT	SW Queensland	TN8	**t**					
Panicum kalaharense		PT	South Africa	CPI73576						-
Panicum stapfianum		PT	South Africa	CPI73577	**x**	**x**	**x**	**x**		-
Pappophorum mucronulatum		PT	USA	CPI99877						
Schmidtia pappophoroides		PT	Botswana	CPI43715		**x**	**x**			-
Setaria incrassata	Inverell	PT	Zimbabwe/NSW	Inverell			**x**			-
Sorghum hybrid	Silk	PT	Bred, Queensland	Silk						-
Sporobolus actinocladus[3]		PT	Charleville	TN9						
Sporobolus fimbriatus		PT	South Africa	CPI60781	**x**					-
Themeda triandra[3]		PT	Talwood	TN35	**x**		**x**	**x**		**x**
Trichachne californica		PT	USA	CPI99561						
Trichloris crinita		PT	USA	CPI99879						
Urochloa oligotricha		PT	Zimbabwe	CPI60127	**x**		**x**			-
Urochloa stolonifera	(Saraji)[4]	PS	South Africa	CPI60128	**x**		**x**		**x**	-
Acacia angustissima		LW	Mexico	CPI84971	**x**		**x**	**x**		-
Chamaecrista rotundifolia[7]	(Wynn)[4]	LH	Brazil	CPI34721						-
Clitoria ternatea		LH	Kenya	CPI20733						-
Cullen patens[3]		LH	Charleville	CN63						
Desmanthus virgatus		LH	Mexico	CPI85178	**x**		**x**			
Desmanthus virgatus		LH	Mexico	CPI90751						
Galactia sp.		LH	Argentina	CPI78425	**t**					
Glycine tomentella[3]		LH	Allora	WRI3						**x**
Indigofera schimperi		LH	Zimbabwe	CPI69495			**x**			-
Indigofera schimperi		LH	Kenya	CPI73608						-
Leucaena leucocephala		LW	USA	CPI61815				**x**		-
Leucaena leucocephala	Cunningham	LW	Bred, Qld.	Cunningham						-
Lysiloma watsonii		LW	Mexico	CPI62129						-
Macroptilium atropurpureum		LH	Mexico	CPI90334						
Macroptilium atropurpureum		LH	Mexico	CPI90454						**x**
Macroptilium atropurpureum		LH	Mexico	CPI90455E						
Macroptilium atropurpureum		LH	Mexico	CPI90821						
Macroptilium atropurpureum	Siratro	LH	Bred, Qld.	Siratro						**x**

Continued

Species	Cultivar	Plant type[1]	Homeland[2]	Accession	Site					
					L	M	N	U	W	T
Macroptilium lathyroides		LH	USA	CPI38841						
Macrotyloma daltonii		LH	Namibia	CPI60303						-
Phaseolus filiformis		LH	Mexico	CPI85005						
Phaseolus sp.		LH	Mexico	CPI90752	x					x
Rhynchosia minima		LH	Zimbabwe	CPI52704						x
Rhynchosia minima[3]		LH	W. Qld.	TN15	x	x	x			
Rhynchosia minima[3]		LH	Tambo	TN24	x		x			
Stylosanthes fruticosa		LH	Sudan	CPI40615						
Stylosanthes fruticosa		LH	Sudan	CPI41219						-
Stylosanthes scabra		LH	Brazil	CPI55872	t					-
Boerhavia dominii[3]		OH	Augathella	TN27			x			
Evolvulus alsinoides[3]		OH	Charleville	TN6	x			x	x	
Merremia aurea[7]		OH	Mexico	CPI84982						-
Sida brachypoda[3]		OH	Charleville	TN7				x		
Aseasonal growers										
Dichanthium sericeum[3]		PT	Talwood	TN36	x		x	x		x
Eragrostis curvula		PT	South Africa	CPI30374	x	x	x	x		-
Eragrostis curvula		PT	South Africa	CPI98914	x	x	x	x		-
Eragrostis curvula		PT	South Africa	CPI98926	x	x	x	x		-
Eragrostis curvula	(Consol)[4]	PT	South Africa/NSW	SCS4663	x	x	x	x		-
Eragrostis intermedia		PT	USA	CPI99554				x[6]		-
Eriochloa pseudoacrotricha[3]		PT	Miles	TN44			x			
Fingerhuthia africana		PT	South Africa	CPI98990					x	
Thyridolepis mitchelliana[3]		FT	Charleville	TN22		x[6]		x		
Acacia aneura[3]		LW	Charleville	TN59	x			x		-
Cassia sturtii[3]		LW	Australia/Israel	CPI79501	x		x	x	x	-
Cullen patens[3]		LH	Charleville	TN29				x		
Cullen tenax[3]		LH	Charleville	CN55			x			
Cullen tenax[3]		LH	SW. Qld.	TN12	x					
Cullen tenax[3]		LH	Toowoomba	WRI19	x					
Medicago sativa	Trifecta	LH	Bred, Aust.	Trifecta						-
Atriplex canescens		CW	Mexico	CPI85166	x					
Atriplex halimus		CW	Israel	CPI79496						x
Sanguisorba minor		OH	Uncertain/New Zealand	Q22947						x
Winter growers										
Agropyron elongatum	Largo	FT	Turkey	Q20701						x
Agropyron trichophorum	Luna	FS	USSR/USA	Q20704						
Austrostipa scabra[3]		FT	Morven	TN10	x			x		
Bromus inermis		FS	Iran	Q20711						
Elymus scaber[3]		FT	Toowoomba	TN49						x
Oryzopsis miliacea		FT	Spain	CPI36101						
Stipa tenuissima		FT	France	Q20715						x
Dorycnium hirsutum		LH	Uncertain/New Zealand	Q22941						x
Medicago laciniata[7]		LH	Uncertain/Aust.	TBA7						-
Medicago laciniata[7]		LH	Uncertain/Bourke	TBA13			-	-	-	-
Medicago murex[7]	(Zodiac)[4]	LH	Italy	CD64.11.1						-
Medicago murex[7]		LH	Italy	WA5320						
Medicago polymorpha[7]	Circle Valley	LH	Bred, West. Aust.	Circle Valley					-	-
Medicago polymorpha[7]	Serena	LH	Bred, West. Aust.	Serena		-			-	-
Ornithopus compressus[7]		LH	Italy	CS146						-

[1]Plant type is described by 2 letters, the first denoting: C=Chenopod, F=C3 grass, L=Legume, P=C4 grass and O=Other; and the second indicating growth form: H=Herbaceous, S=Sward, T=Tussock and W=Woody plant; [2]Nearest Australian town if a native species; [3]Native species; [4]Brackets used if the cultivar name was given later to the accession; [5]Not sown in our trials at this site, but grew well in other trials on adjacent land; [6]Discrimination from similar-looking accessions not certain after many years; [7]Annual species.

Details of the origins of each accession can be had by contacting the senior author or by sourcing either the CSIRO Quarterly List of Introductions, starting at CPI11408 in Nbr 16 (1948) through to CPI33946 in Nbr 75 (1963) or thereafter in The Australian Plant Introduction Review (CSIRO:Australia), New Series, Volumes 1 (1964) through to CPI99880 in volume 17 (1985). For cultivars sourced from commercial seed or local ecotypes, that have probably undergone genetic shift since their introduction, their original homeland is named followed by "/ecotype collection locality", such as Zimbabwe/Qld.

Plants tested were grouped for presentation of results on their main season of growth, their perenniality and their growth form (Table 3). The seasonal classes are based on the potential season of growth in the subtropical South Queensland environment. Aseasonal means plants that can grow at any time of the year, when soil moisture is adequate and there are no severe night frosts. Wet winters normally result in mild nights and very few frosts severe enough to freeze green leaf tissue, while in dry winters, morning radiation frosts as cold as -7 °C are common (Hammer and Rosenthal 1978).

Planting details

To minimize field establishment failure, seedlings were transplanted after effective rain and watered intermittently until follow-up rain occurred. Thereafter they competed with local weeds and pests under controlled grazing without the assistance of fertilizer. Some accessions with low seed supplies were increased beforehand at Toowoomba (Site T; 640 masl), and species with many potential accessions available were screened to short-list the agronomically promising lines and to eliminate those which failed badly, such as Russian wildrye (*Psathyrostachys juncea*), which was extremely susceptible to a stem rust and failed to set seed. In a few cases, nursery plants provided vegetative material for field sowings, when germination difficulties severely limited potential sowing numbers.

Glasshouse procedures

Seedlings and a few grass transplants were established in a glasshouse in Toowoomba. Sieved soil from each site was poured into 15 cm deep expanding blocks of hexagonal paper pots (2.5–4 cm diameter). The soil was wet up with tap water and fertilized with mono-ammonium phosphate (MAP) prior to sowing the seeds. Legume and other non-grass seeds were scarified with sand-paper to remove impervious coatings if necessary, and saltbush fruits were clipped to expose the seed inside and then leached of salt, but grasses were sown untreated as clean seed with any glumes and short awns. When germination rates for grasses were low, plant numbers were augmented with plants struck from nursery ramets, using material from many different parent plants.

After sowing, legume tubes were inoculated with an appropriate rhizobial slurry. Seedlings remained in the glasshouse for 3–5 weeks, until adequate rain had fallen at the trial sites. Sometimes additional MAP was applied to keep larger plants healthy. When excessive seedling numbers occurred, stands in the tubes were thinned, so that grasses tillered and non-grasses suffered limited competitive stress. Just prior to sowing, the tops of large plants were clipped to reduce transpiration load and all were placed outside for a few days to 'harden-up' in natural sunlight and wind.

Field procedures

At field sites, seedlings were sown in rows as spaced plants into a fenced area of wheat stubble. The rows, 3 m apart, were centered along 1 m wide strips sprayed for weed control with glyphosate (1 kg a.i./ha) just before planting. Rows, containing 10–15 randomly located accessions, were blocked into each of the 2 replicates sown at a site. A line of 6 holes at 1 m spacings was dug with a mattock for each replicate of an accession and filled with water. Then the tubed seedlings were planted singly, the soil refilled around them, and each plant rewatered from either a nearby farm dam or the Toowoomba city supply. Until reasonable follow-up rains fell, plants were rewatered about once a week (Table 4). Summer and autumn sowings of appropriate species occurred at each field site (dates given in Table 4). When enough plants failed to establish, accessions were resown after

Table 3. Numbers of accessions tested in each major forage type group.

Type of plant (totals)		Summer growers		Aseasonal growers		Winter growers		All seasons	
		Exotic	Native	Exotic	Native	Exotic	Native	Exotic	Native
Grasses (78)	Perennial	52	9	5	3	5	2	62	14
	Annual	2						2	0
Legumes (43)	Perennial	19	3	1	5	1		21	8
	Annual	1				7		8	0
	Perenn. shrubs	4			2			4	2
Chenopods (2)	Perenn. shrubs			2				2	0
Others (5)	Perennial	1	3	1				2	3
Totals (128)	Perennial herbs	87		15		8		110	
	Annual herbs	3		0		7		10	
	Perennial shrubs	4		4		0		8	

rain the following year at an equivalent time. The initial sowing at each site was of summer-active species, when wheat stubble was still sturdy, but by the autumn sowing, the stubble had often thinned and weeds were established.

Domestic stock were excluded by hinge-joint fences and plants were ungrazed until the majority were well established and had flowered and seeded. This time period varied greatly as sites experienced widely differing growing conditions (Table 4).

Grazing management

The owner's stock currently in the paddock (mainly cattle but sometimes sheep and horses) were allowed to graze the plots, for only a few days initially, and stock were completely excluded for some time after the autumn sowing and again for many weeks after resowings in the second year. From about 2 years after the final resowings, plots were left open to grazing for extended periods. As some paddocks beside our plots were recropped, no domestic stock had access for extended periods, usually during winter, but local marsupials and rabbits often more than compensated for this. Grazing pressure steadily increased as the plots aged, partly due to the worsening below average rainfall seasons after 1990.

Data collection

Periodic recordings were made of the number of plants surviving in each plot, their vigor, flowering and seeding status, and general condition. Later, numbers of seedling recruits plus the distance spread from their original plots were recorded. After 5–6 years, the fences were removed and plots subjected to normal grazing. The persistence and spread of surviving plants was monitored for at least 15 years and some lines that showed weed potential were dug out. Sites U and N were replowed by the owners in 1999 and 2003, respectively, providing an opportunity to assess the ability of persistent lines to resist such practices.

Other influences

At Site M, the coarse native wiregrasses amongst the rows were rarely grazed and became quite rank. Hence we occasionally slashed or burnt the whole plot, beginning in November 1988, a management strategy commonly used to control wiregrasses. Site W was exposed to appreciable spray drift (glyphosate + 2,4-D) in autumn 1990, sufficient to defoliate trees beside the plots and brown the foliage of most plants being evaluated.

Results and Discussion

Seasonal rainfall

Table 4 summarizes the rainfall received around sowing times for each site, while Table 5 and Figure 1 present the seasonal rainfall received at each site during the first 6 years. During the first few years, growing conditions in the cool season were better and in summer were drier than 'normal' (Rainman 2003). After the initial years of reasonable rainfall, a prolonged period of below average rainfall occurred (1991–1994). From 1995 seasons were more favorable, enabling long-term persistence, spread and possible weed potential to be assessed.

Table 4. Sowing times, early rainfall received and key site management events during the first 2 years at each site, except the Toowoomba nursery.

Event	Site				
	L	M	N	U	W
First summer sowing date	30.10.86	21.10.86	5.2.86	3.12.85	5.12.85
Pre-sowing rain (mm in 2 wk)	56	55	10	33	51
Watering period after summer sowing (d)	12	21	12	18	27
Rain in 3 months after sowing (mm)	213	115	67	101	100
Winter sowing date	26.6.87	19.5.87	23.7.86	30.7.86	30.7.86
Pre-sowing rain (mm in 2 wk)	13	45	12	45	35
Watering period after winter sowing (d)	25	12	0	19	14
Rain in 3 months after sowing (mm)	61	132	161	167	138
First grazing	15.9.88	27.3.88	2.11.87	26.2.87	9.3.88
Notes	Grasses selectively eaten by locusts after summer sowing	Burnt on 16.11.88	Locusts, mostly non-grass eaters, e.g. *Monistria* sp.	Sheep camped in trial site in June 1988	Crop spray drift damage in May 1990

Early growth and establishment

The perennial summer-active grasses were the easiest group to establish and their early productivity was generally good. *Digitaria abyssinica, D. brownii, Themeda triandra, Dactyloctenium* spp. and *Cullen patens* were the most difficult species to germinate reliably, and often fewer than 12 plants were sown per site. Lines with the poorest establishment after transplantation (see Supplementary Table A) included a shrub (*Atriplex halimus*) and the grasses *Dactyloctenium* spp., *Eragrostis truncata* and *Andropogon ischaemum*. Perennial cool season-growing lines established well only at Site T (Toowoomba nursery), where the *Agropyron* species, *Elymus scaber* and *Bromus inermis* grew vigorously and spread in a relatively competition-free environment. Wynn cassia (*Chamaecrista rotundifolia*) grew but failed to set seed at any site, in contrast with its mediocre performance in other studies in the region (Strickland et al. 2000). Overall establishment was: quite good at Sites N and U, where only 16 accessions failed within a year; fair at Sites L and W (both hard-setting, strongly duplex soils); and poor at Site M (acidic, infertile), where 48 accessions were lost within the sowing year.

During planting out, healthy root nodules were seen on many legumes, including leucaena, *Desmanthus virgatus* and lucerne. Locusts were a major problem during the establishment period of the summer-active species and rabbits and marsupials selectively targeted new sowings in dry seasons. Usually a few plants of each accession survived at each site for at least the first growing season and also flowered, while all sown plants of the better-adapted lines survived for years.

Agronomic performance

On overall agronomic performance, 22 out of 128 accessions achieved a rating of ≥3 (out of 5) over the 5 field sites, while 74 had a rating of <2 (poor). Of the highly rated ones, only 2 were native (out of 27 natives), while 18 of the poorly rated lines were native species. Agronomic performance for individual accessions is reported in detail in Supplementary Tables A and B, while Table 2 shows those which persisted well at one or more sites.

In broad terms, the summer-active perennial grasses performed best and the winter-active perennial grasses the worst, despite an aseasonal rainfall pattern and several wet autumns and springs (Figure 1). Of the minor groups tested, e.g. shrubs and saltbushes, none gave an agronomically encouraging performance. Mulga (*Acacia aneura* TN59) persisted well at Sites L and U, but grew slowly. Although *A. angustissima* and *Indigofera schimperi* persisted well, they showed weed potential because of low palatability and root suckers, and were removed from 1995 onwards. Some *Eragrostis* spp. had low palatability and high seed set, e.g. Cochise and all 3 *E. lehmanniana* lines, and were dug out systematically over 3–5 years in the mid-1990s. Native species and tropical grasses generally set seed in their first growing season, notable exceptions being *Themeda triandra* and *Cassia sturtii*. However, many exotic species failed to set seed in the first year after planting despite fair shoot growth, e.g. *A. ischaemum*, *Dorycnium hirsutum*, *I. schimperi*, *Atriplex* saltbushes, *Merremia aurea*, *A. angustissima* and leucaena.

By plant type category. Grasses. The buffel grasses were clearly superior as a group, but on some soils (Sites L and N) *Digitaria* and *Bothriochloa* species showed greater early promise. At Site M, new season growth from buffels was often quite yellow, indicating possible low available soil nitrogen and hence low protein content. The Gayndah buffel type, such as CPI71914, CPI60733 and CPI73390, generally performed better than the Biloela type, like CPI73393 and cv. Biloela. CPI71914 had a leafy, low, tight crown structure and the ability to produce new plants close to parent plants. The hybrid *Cenchrus* CPI61135 grew well at most sites without gaining a potential 'commercially promising' rating.

Table 5. Comparison of seasonal conditions at the trial sites over the period 1986–1991 against the long-term data shown in Figure 1. Numbers are the total for all 3-monthly seasons based on 20 seasons (5 years) for Sites L and M and 24 seasons for Sites N, U and W. Seasons (summer, autumn, winter and spring) are described in the Figure 1 caption.

Season type	Site				
	L	M	N	U	W
Much wetter than usual	4	4	4	4	3
Typical seasonal total	9	8	6	9	6
Much drier than usual	7	8	14	11	15

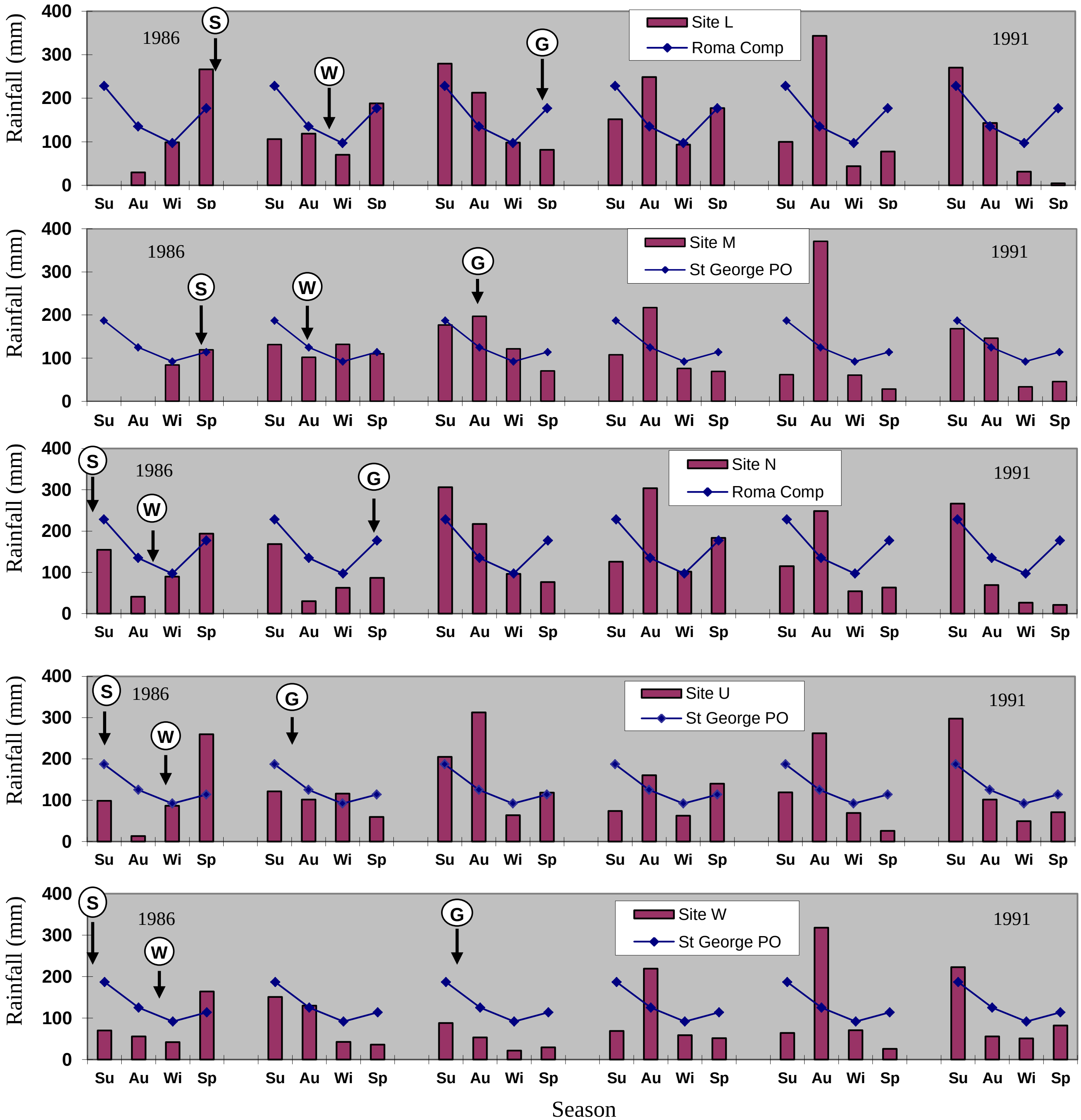

Figure 1. Seasonal rainfall experienced at each field site during the first 6 years (1986–1991) after the trial began, compared with the nearest long-term rainfall station.
Su = Summer (Dec–Feb); Au = Autumn (Mar–May); Wi = Winter (Jun–Aug); Sp = Spring (Sep–Nov)
Long-term seasonal rainfall (points joined by lines) was extracted from Rainman (2003) for Roma Composite and St George P.O.
Labelled arrows on each graph indicate when major events occurred: S = first sowing of summer-active plants; W = first sowing of winter-active plants, and G = first grazing of the site.

Eragrostis lines grew and seeded very well, as expected, but long-term persistence and palatability were variable (Table 2 and Supplementary Table B). *Eragrostis superba* had large seedhead spikelets and was quite leafy but had variable and generally low palatability. The *E. curvula* lines fell into 2 groups: the *conferta* form, which has a dense seedhead and thick, stiffly erect culms; and var. *curvula,* which has long, thin leaves and large, open seedheads that often droop. The former were usually palatable (CPI98914), but none was noticeably more so than the commercial cultivar Consol.

Fingerhuthia africana (a winter-green C4 grass) showed colonizing ability, frost tolerance and persistence on hard-setting solodics, as well as reasonable growth, but was not eaten readily by stock. The *Urochloa* species tested grew well initially at all sites and the stoloniferous CPI60128 showed good vigor and tolerance of moisture stress and appeared quite palatable. Amongst the other non-commercial species, only *Panicum stapfianum* and *Bothriochloa ewartiana* scored 3 or better overall before the drought (Supplementary Table A).

Rhodes grass and silk sorghum grew poorly in the dry summers on the relatively infertile soils chosen, but several *Digitaria*, *Dichanthium* and *Bothriochloa* species performed creditably, e.g. Premier, TBA9 (a bred variant), CPI26832, CPI41192 and CPI59786 (Supplementary Table B). *Digitaria abyssinica* is regarded as a potential weed (Invasive.org 2006) because of aggressive rhizomes and low palatability.

The exotic *Bothriochloa* species usually outperformed the exotic *Dichanthium* species, but native *Dichanthium sericeum* (Queensland bluegrass) grew well at all sites except M, and the naturalized Medway strain of *B. pertusa* from central Queensland was outstanding at Sites N, U and W. It shows great potential as a sward-forming grass for use in erosion control and is leafier than most other strains of the species. CPI11408 (*B. bladhii* ssp. *glabra*) produces prostrate tillers on winter and spring growth to resist grazing, but its seedheads are later erect and avidly browsed by cattle. This puts seeding in jeopardy and may partly explain why it has not persisted at our sites. Now released as cv. Swann, its origins are unclear, as it is not an *Andropogon ischaemum* as its passport data indicate. It may not even be from Guyana, but rather a contaminant from a nursery site in Australia. Prostrate tillers were recorded seasonally for other lines such as TN22, TN47 and TBA1024.

Herbaceous legumes. The performance of the summer-growing legumes was not encouraging. On the sandy red soil at Site M, only *Stylosanthes* and TN15 *Rhynchosia minima* established well but frosts damaged them severely each winter. Native *R. minima* and *Cullen tenax* lines have grown very well at Site L and reasonably at Site N, and their persistence is better than that of most other summer-active legumes. Both sites had reasonable soil fertility and Site N was a non-acidic soil with carbonate at depth. *Desmanthus virgatus* was not impressive but persisted well initially, and seeded quite freely once it had grown some foliage, but neither line developed into a noticeable stand at any site. The *Phaseolus* species CPI90752 from Mexico was one of the most persistent perennial legumes but produced only low yields, akin to those of native *Glycine tabacina* or *G. tomentella*, which grow at our sites. The atro bean group (*Macroptilium atropurpureum*) came from a wide range of material from the homeland of the species (Reid 1983) and some had good crown frost tolerance; however, most were susceptible to leaf rust and to persistent summer droughts. None outperformed the commercial cultivar Siratro, which is still not highly regarded in this region (Jones 1998).

Of the annual winter-active legumes, yellow serradella (*Ornithopus compressus*) was the most consistent performer. *Medicago murex* grew satisfactorily but seemed to lack adequate hardseededness for persistence in the aseasonal rainfall environment. The 2 lines of naturalized *Medicago laciniata* tested (TBA7 and TBA13) grew poorly; they persisted and set seed and were difficult to distinguish from other local genotypes of the species. Naturalized woolly burr medic (*Medicago minima*) built up noticeably at Site U during the trial and was seasonally abundant at Site N.

Others. Sheep's burnet (*Sanguisorba minor*) did not survive long at the 5 field sites, although it persisted and regenerated from seed for many years at Site T. It was extremely palatable to stock and wilted easily in hot weather, but did not suffer from any obvious pests or diseases. While the other herbaceous plants, TN6 (*Evolvulus alsinoides*), TN7 (*Sida brachypoda*) and TN27 (*Boerhavia dominii*), showed potential as standards for comparisons, they offered no agronomic benefits over the many existing local herbs. Native mulga sida (TN7) and tropical speedwell (TN6) grew reasonably at some sites but produced little edible dry matter. Seed is easy to germinate and TN6 regenerates freely from seed. TN6 has broader soil tolerance than TN7 and TN27 and its seed was easier to collect and germinate. However, TN27 came from a fertile cracking clay soil and may be different physiologically from the *B. dominii* found on our trial site earths.

Saltbushes did not thrive, even where very saline subsoils existed and grass competition was minimal, such as at Site W.

By growing season category. Summer-active species. Most summer-growing accessions at Sites U, M and L set seed. Initial persistence was good for most grasses, but legume persistence at Sites M and W was poor, except for a few *Stylosanthes* plants. This study emphasized the importance of survival after occasional hot, dry summers, either as plants or in a long-lived seedbank. Most summers were drier than 'normal' during our trials and the performance of these grasses augers well, especially as they had negligible disease issues.

Summer-growing legumes performed poorly but improved summer rainfall might enhance their long-term performance, if they set adequate amounts of hard seed to allow regular recruitment of new plants. Most have significant hardseededness (*Stylosanthes* and *Macroptilium*) but the latter atro beans were like Siratro and lacked the ability to compete with summer grasses and persist in a grazed pasture (Keating and Mott 1987). The most successful summer legumes were *R. minima* accessions but they rarely produced much growth. They suffer from legume little leaf virus and have sticky hairs on seed pods that shatter before drying out, making commercial seed production difficult.

Winter-active species. Cutleaf medic (*M. laciniata*), yellow serradella (*O. compressus*) and common wheatgrass (*E. scaber*) flowered in the first growing season and regenerated from seed at Site U. *Elymus scaber* had few pests or diseases, but seemed to require a fertile soil for adequate growth. Very erect tillering at all times makes it vulnerable to excessive grazing pressure in rangeland grazing systems. Rough corkscrew grass TN10 (*Austrostipa scabra*) performed creditably and is an obvious choice for a standard against which to compare similar grasses. It is not palatable once dry in summer and its persistence during consecutive dry years is weak, but it does have a very persistent seedbank from which to regenerate, when better cool season rainfall returns. Its sharp seed is most undesirable for wool producers, and its use in field comparisons would have to be well controlled, so as not to result in long-term problems where it was sown.

Aseasonal growers. These include the native *Cullen* species (formerly *Psoralea*), mulga, *Cassia sturtii* and mulga Mitchell grass (*Thyridolepis mitchelliana*), as well as saltbushes, lucerne, *Eragrostis curvula* and *Fingerhuthia africana*. Mulga Mitchell seems unsuited to competing with vigorous grasses in better rainfall environments and, even where it occurs naturally, the Charleville strain (TN22) performed poorly, seemingly unsuited to soils containing any significant amount of clay. As the mulga accession TN59 survived with a very clayey subsoil at Site L, once past the seedling establishment stage, it could be the forage shrub benchmark for semi-arid acid soils, since it grew well at Site U also. However, the species has failed to impress in almost all other semi-arid parts of the world outside Australia, where the soils are generally alkaline, such as the Middle East and North Africa, or are unsuitable in other ways (Gwaze 1989).

Persistence

Long-term persistence of perennial pasture plants is very important to graziers worldwide, as low returns on investments make resowing of pastures unappealing (Murphy 1992). Persistence of the tested lines is summarized in Table 2 based on data collected in 1994 and 1995 from the 5 field sites and in 1991/92 at Site T. Only the following 7 accessions persisted in the long term at all field sites sown, 5 of them being *Cenchrus* species: CPI17655 *C. setiger*; CPI71914 *C. ciliaris*; CPI73393 *C. ciliaris*; Q10077 *C. ciliaris*; CPI61135 *Cenchrus* hybrid; Medway *Bothriochloa pertusa* and TN47 *B. ewartiana.*

Fourteen others survived the drought well at all but one site (Table 2; 8 *Eragrostis* species; 5 perennial grasses; and a native shrub, *C. sturtii*). These species are adapted to a wide range of soil types, which is advantageous for a successful commercial cultivar. Queensland bluegrass is not in this list, because it is not adapted to acid soils despite its good reputation regionally. In general, the native species (TN codes) showed selective site adaptation and persisted well only at particular sites, despite initially growing well everywhere, e.g. TN10, TN24 and TN27.

A wide range of other species that survived for 6–8 years and recruited seedlings at the less stressful, higher rainfall Toowoomba site, did not survive long at any of the 5 field sites (Table 2). They included legumes, saltbushes, sheep's burnet and the C3 winter-active Eurasian grasses like *Agropyron elongatum* and *Bromus inermis.*

Future research and commercial needs

The evaluation technique

Establishing a small population of plants in the field from very limited seed supplies proved successful for initial testing. When seedlings or cuttings were grown in the glasshouse, the majority then established in the field with only limited supplementary watering. Planting out after good rain (surface soil wet to >20 cm depth) was most important, but young, pre-flowering plants must be used. If an adequate taproot does not form on non-grasses after transplantation, their drought tolerance may be reduced. This cannot be discounted amongst our results, but we have no direct evidence of it happening. Our method entails more pre-sowing effort but labor costs compared with infrastructure and equipment costs will vary depending on where the study is done and are adaptable to local resource availability. However, in an holistic sense, the major cost is the production, storage and acquisition of exotic seeds. Their death or loss without growth of replacement plants or meaningful data collection is a huge loss.

Locusts, rabbits and kangaroos

Defoliation of small seedlings could seriously compromise the evaluation of an accession. Locusts were a constant threat, particularly in late spring, and could be quite selective, preferring wilted grasses; they were particularly damaging to Rhodes grass seedlings. Winter-active herbaceous species were generally not eaten, because locusts were inactive at that time. Nocturnal rabbits and kangaroos could also heavily overgraze and kill sown plants in small plots, without being seen, and strip planting amongst coarse, unpalatable native species can accentuate this problem. In other countries, small grazers such as jack rabbits (Mexico), antelope (Africa) and capybara (South America) would have a similar effect. Kangaroos appear to prefer *Urochloa* lines to buffels, which might explain why *U. mosambicensis* has not been a commercial success in western Queensland. It has become a seasonally prominent roadside species since the 1980s, indicating it has good climatic adaptation.

Species performance compared with existing commercial cultivars

Perennial legumes. This study supports other studies that highlight a serious shortage of perennial herb legumes for pastures in semi-arid subtropical Australia (Jones 1998; Strickland et al. 2000; Clem et al. 2001). The stylos tested failed to persist in meaningful numbers, and young seedlings were often yellow and presumably died. Yellow color can indicate poor nodulation, but most *Stylosanthes* species are non-specific in their cowpea rhizobial symbiosis (Date and Norris 1979). Lack of sufficient frost tolerance may also have been an issue. Recently there has been interest in Caatinga stylo (*S. seabrana*), which has persisted in other trials (Peck et al. 2012) but was not included in ours. While Siratro and its relatives were very disappointing, their failure did not seem to be due to pests or diseases and was replicated on adjoining trials and in other studies (Clem et al. 2001).

Winter-active grasses. The next most important deficiency in current commercial pasture plants for this region is winter-active grasses. While many *Eragrostis* species grew well in winter, when soil moisture was available, most were seasonally unpalatable, making them a future weed risk. As *E. curvula* is a declared weed in nearby New South Wales and regarded as weedy in the Darling Downs and Kingaroy regions east of the Maranoa (DAFF 2013), we are unwilling to subject them to wider testing.

Annuals. Annual medics such as *Medicago minima*, *M. polymorpha* and *M. laciniata* are slowly spreading in this region as their level of hardseededness and their rhizobial symbionts slowly alter genetically and adapt, we consider, to the environment. Their burrs are contaminants in wool and mohair, and their foliage has potential to cause bloat in good spring seasons. Sown cultivars of barrel medic (*M. truncatula*) grow and persist well on some sandy red earths and we failed to identify anything better adapted to acid soils. Inadequate hardseededness seemed to be a major deficiency of the medic lines that we tested. Yellow serradella grew well for some years, especially on sandier soils, but eventually died out. Whether a bigger area, that was less susceptible to overgrazing by rabbits and kangaroos, would have improved their persistence is not known.

Native species. Few of the native species tested showed promise agronomically. Queensland bluegrass was the best for the more friable, low acidity soils (Supplementary Table B) and it is already recommended for specialized rehabilitation purposes (Huxtable 2003). Desert bluegrass TN47 also showed potential on all soils, but it was more difficult to establish this pasture from seed and to achieve good increase in the stand from a few plants. Once established, it was very persistent but had only moderate palatability (Supplementary Table B) and would be best suited for long-term pastures, while Queensland bluegrass has a valuable role in short-term, legume-rich ley pastures in farming systems. Kangaroo grass TN35 had weaker plant perenniality but better seedling recruitment than TN47, plus the added historical weakness of susceptibility to overgrazing.

The native legumes tested gave low yields and could not be considered for commercialization. Their seed can be difficult to harvest but germinates easily after scarification (if appropriate). The shrubby legumes mulga and *C. sturtii* have no apparent commercial forage role in the Maranoa, where there are so many other plants with better growth rates, palatability and digestibility. CPI79501 returned to Australia after giving good results in Israel, so it may still have potential overseas somewhere.

Summer-growing perennial grasses. This group offers the greatest scope for sown pastures in the region, establishing well, growing satisfactorily, seeding and then persisting for some years. Their ultimate value depended mainly on their persistence after the 1992/93 drought, seedling recruitment ability and palatability. Buffel grass hybrid line CPI61135 has a non-hairy seed and persisted well but was not as productive as other buffels, nor was its seedling recruitment as extensive. A similar assessment applies to white Birdwood grass CPI17655 that, though in Australia since 1952, has still not been commercially released. CPI71914 was rated more highly than the similar cv. Gayndah at most sites (Supplementary Table A), but the small advantage does not justify the expense and complications involved in setting up a seed production industry for it. As most people find Gayndah indistinguishable from cv. American, its release would make cultivar integrity very hard to maintain.

Premier digit grass did not recruit seedlings and its high palatability meant that it was often overgrazed in a mixed pasture, so did not persist as well as in higher rainfall areas (McDonald et al. 1998). While stoloniferous *Digitaria* species grew quite well, they also produced few seedlings and did not persist well, whereas the equivalent stoloniferous *Bothriochloa* species persisted better and produced more seedlings. Medway Indian couch grass was the best of these (Supplementary Tables A and B), but with its relatively low dry matter yield and vigorous sward production, it is regarded as a weed threat by some people. It is seasonally palatable and resistant to heavy grazing and could have a role stabilizing local waterways and embankments that cannot be slashed. It was not killed by intermittent light cultivation but is susceptible to prolonged drought. As it seeds freely, eradication schemes would require the use of herbicides.

Inverell purple pigeon grass performed poorly away from the heavy clay soils, where it is used commercially. Pioneer Rhodes grass, Bambatsi panic and Hatch creeping bluegrass all showed insufficient persistence to be considered for commercial recommendation on the soil types studied. The climate is too dry and drought-prone for current Rhodes grass cultivars and Bambatsi needs more friable, fertile soils to persist. We recorded no seedlings of Bambatsi anywhere, which is the norm. Hatch also failed to cope here and was rated lower than CPI52193 (Supplementary Table A), which resembles the Bisset cultivar, both of which root down at the nodes much better than Hatch.

These trials have failed to identify new commercial pasture cultivars for arable, poorly structured soils in the subtropical aseasonal rainfall region of southern inland Queensland. However, we have identified pasture species for use as standards in any future assessment program (Table 6). In view of the global diversity of the plants tested, we consider pasture users in many other subtropical regions could benefit from this information.

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Table 6. Recommended standard species or cultivars, against which new forage germplasm for infertile soils in southern inland Queensland should be assessed prior to commercial release.

Plant type	Recommended standard species or cultivar[1]
Summer growers	
perennial grass	*Cenchrus ciliaris* cv. Gayndah
annual grass[2]	- (*Urochloa panicoides* or *Dactyloctenium radulans*)
perennial legume	*Rhynchosia minima* or (*Stylosanthes seabrana*)
annual legume	- *Chamaecrista rotundifolia* cv. Wynn
perennial shrub	- (*Leucaena leucocephala* cv. Tarramba)
perennial non-legume herb	*Evolvulus alsinoides*
Aseasonal growers	
perennial grass	*Eragrostis curvula* cv. Consol
perennial legume	*Medicago sativa* cv. Trifecta
perennial shrub	*Acacia aneura* (St George *latifolia* type)
perennial saltbush	(*Atriplex nummularia*)
Winter growers	
perennial grass	*Austrostipa scabra*
annual grass	- (*Lolium rigidum*)
perennial legume	-
annual legume	(*Ornithopus compressus* cv. Paros or *Medicago truncatula* cv. Paraggio)
perennial shrub	- (*Medicago arborea*)

[1]Species in parentheses were not assessed in this experiment; **-** = none can be recommended yet, but an alternative is named; some of the alternatives are naturalized, known or potential weedy species and should be used with care.

[2]Annual species which are self-regenerating and persistent.

References

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

Blacket D. 1992. Selecting suitable pastures. In: Lawrence D; French V, eds. Sown Pasture Management Notes, Western Downs & Maranoa. Queensland Department of Primary Industries, Brisbane, Australia. p. 19–36.

Blumenthal MJ; Scattini WJ; Hilder TB. 1985. Review of tropical pasture plant introduction in the Darling Downs and Border Region. In: Plant Introduction and Evaluation Workshop. Queensland Department of Primary Industries Conference and Workshop Series QC85005. p. 75–91.

Bot A; Benites J. 2005. The importance of soil organic matter – Key to drought-resistant soil and sustained food production. FAO Soils Bulletin 80. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. http://goo.gl/s4BKYg

Clem RL; Brandon NJ; Conway MJ; Esdale CR; Jones RM. 2001. Early stage evaluation of tropical legumes on clay soils at three sites in central and southern inland Queensland. Tropical Agriculture Technical Memorandum No. 7. CSIRO Publishing, Melbourne, Australia.

DAFF. 2013. African lovegrass (*Eragrostis curvula*). Fact sheet Pest Plant PP63. Department of Agriculture, Fisheries and Forestry, Brisbane, Qld, Australia. http://goo.gl/mifjkm

Date RA; Norris DO. 1979. *Rhizobium* screening of *Stylosanthes* species for effectiveness in nitrogen fixation. Australian Journal of Agricultural Research 30:85–104.

Davis MA; Chew MK; Hobbs RJ; Lugo AE; Ewel JJ; Vermeij GJ; Brown JH; Rosenzweig ML; Gardener MR; Carroll SP; Thompson K; Pickett STA; Stromberg JC; Del Tredici P; Suding KN; Ehrenfeld JG; Grime JP; Mascaro J; Briggs JC. 2011. Don't judge species on their origins. Nature 474:153–154. DOI: 10.1038/474153a

Day JR; Silcock RG. 1985. Review of plant introduction in Central and South-west Queensland. In: Plant Introduction and Evaluation Workshop. Queensland Department of Primary Industries Conference and Workshop Series QC85005. p. 92–109.

Douglas N. 1997. Managing ley pastures – workshop manual. Queensland Department of Primary Industries Information Series QI97101. p. 2–6.

Gwaze DP. 1989. Growth and survival of Australian tree species in field trials in Zimbabwe. In: Boland DJ, ed. Trees for the Tropics. Growing Australian multipurpose trees and shrubs in developing countries. ACIAR Monograph No. 10. Australian Centre for International Agricultural

Research (ACIAR), Canberra, Australia. p. 129–138. http://goo.gl/2SjyaB

Hammer GL; Rosenthal KM. 1978. Frost and minimum temperature probabilities. Queensland Agricultural Journal 104:177–201.

Huxtable C. 2003. Rehabilitation of open cut coal mines using native grasses: Management guidelines. New South Wales Department of Sustainable Natural Resources, Parramatta, Australia. http://goo.gl/BA68zM

Invasive.org. 2006. African couchgrass − *Digitaria abyssinica* (A. Rich) Stapf. Center for Invasive Species and Ecosystem Health, The University of Georgia, Tifton, GA, USA. http://goo.gl/e5SU89

Jones RM. 1998. Evaluation of a range of tropical legumes on two clay soils in south-east inland Queensland. Tropical Agriculture Technical Memorandum No. 2. CSIRO Tropical Agriculture, St. Lucia, Qld, Australia.

Keating BA; Mott JJ. 1987. Growth and regeneration of summer-growing pasture legumes on a heavy clay soil in south-eastern Queensland. Australian Journal of Experimental Agriculture 27:633–641.

McDonald CK; Jones RM; Tothill JC. 1998. Growth and spread of *Digitaria eriantha* cv. Premier and *Urochloa mosambicensis* cv. Nixon oversown into native speargrass (*Heteropogon contortus*) pasture in south-east Queensland. Tropical Grasslands 32:41–49.

Miller CP; Wildin JH; Cooksley DG; Lowe KF. 1988. Augmenting native pastures with sown species. In: Burrows WH; Scanlan JC; Rutherford MT, eds. Native Pastures in Queensland. The resources and their management. Queensland Department of Primary Industries, Brisbane, Australia. p. 160–173.

MLA Australia. 2010. Pimelea poisoning in cattle. Meat and Livestock Australia, North Sydney, NSW, Australia. http://goo.gl/SXoI5Z

Murphy R. 1992. Economics of sown pasture development. In: Lawrence D; French V, eds. Sown Pasture Management Notes – Western Downs & Maranoa. Queensland Department of Primary Industries, Brisbane, Australia. p. 7–12.

Northcote KH. 1971. A factual key for the recognition of Australian soils. 3rd Edn. Rellim Technical Publications, Glenside, South Australia.

Pearson CJ; Norman DW; Dixon J. 1995. Sustainable dryland cropping in relation to soil productivity. FAO Soils Bulletin 72. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Peck G; Hall T; Silcock R; Clem B; Buck S; Kedzlie G. 2012. Persistence of pasture legumes in southern and central Queensland. Proceedings of the 16th Australian Agronomy Conference, October 2012, Armidale, NSW, Australia. http://goo.gl/DIB5fw

Rainman. 2003. Rainman StreamFlow (version 4.3): A comprehensive climate and streamflow analysis package on CD to assess seasonal forecasts and manage climatic risk. QI03040. Department of Primary Industries Queensland, Brisbane, Australia.

Reid R. 1983. Pasture plant collecting in Mexico with emphasis on legumes for dry regions. Australian Plant Introduction Review 15(2):1–11.

Scattini WJ. 1985. Tropical grass introduction and evaluation in sub-tropical Queensland. In: Plant Introduction and Evaluation Workshop. Queensland Department of Primary Industries Conference and Workshop Series QC85005. p. 169–172.

Slater BK; Carroll MB. 1993. Soils. Resource assessment Roma area, Queensland. 1:100,000 map. Queensland Department of Primary Industries, Brisbane, Qld, Australia. http://goo.gl/gP6c7X

Strickland RW; Greenfield RG. 1988. Forage species adaptation to red earth soils in southern Queensland. Tropical Grasslands 22:39–48.

Strickland RW; Greenfield RG; Hacker JB. 2000. Preliminary evaluation of exotic grasses and legumes for forage potential in South-West Queensland. Genetic Resources Communication No. 35. CSIRO Tropical Agriculture, Indooroopilly, Qld, Australia.

Thompson P. 1988. Improving livestock profitability with pasture and forage crops. Pasture and forage guidelines for the Darling Downs, Western Downs and Maranoa. Bowdler, English & Wehl and Annand, Robinson & Co, Toowoomba, Qld, Australia.

Supplementary Table A. Summary of overall field performance by each accession on a 1 (very poor) to 5 (very good) scale, as well as for ease of establishment, persistence, spread and yield in the first 6–7 years after sowing.

Accession	Early growth	Spread	Persistence	Yield	Overall rating	Best/worst sites[1]	Notes
Summer growers							
CPI 90727	1.5	1	2.5	1.5	1.2	L/M	
CPI 99868	3.2	1.5	3	1.5	2.2	N/W	
CPI 99869	3.2	1.5	2.2	1.5	2	N/L	
Q 20321	4.2	1	3.2	2.2	1.8	M/W	
CPI 99572	2.2	1	1.8	1.5	1.2	U/L	
CPI 99867	2.2	1	2.5	1.5	1.5	L/M	
TN 47	2.5	1	3.5	2.5	3	W/M	
CPI 11408	3	1.5	3	2.2	2.8	U/M	Did best at site U
CPI 69517	3.5	2.2	3.2	2.2	2.8	L/N	
CPI 52193	3.5	2.5	3.5	2.5	3.2	U/W	
Hatch	3.2	2	2.8	2.8	2.8	L/M	Very good at site L
Medway	4.5	2.8	4	2.2	3.5	U/M	Dense thatch of litter
CPI 60733	4.5	1	4.2	2.8	3	N/W	
CPI 71914	4.8	1.2	5	3.2	3.8	U/L	Like a hairy cv. Gayndah
CPI 73390	3.5	1.2	3.5	2.8	3.2	U/W	Very poor at site W
CPI 73393	4.5	1.2	4.5	3.5	3.8	U/L	Erect like cv. Biloela
Q 10077	4.5	1	4.5	2.5	3	N/L	
Biloela	4.5	1.2	4	3.5	3.8	U/M	Grew well at site W
Gayndah	4.2	1.5	4.5	3.2	3.8	U/N	Died out at site T
CPI 61135	4.2	1	4	3.2	3	U/N	
CPI 17655	4.5	1.2	3.8	3	3.2	W/N	Green seedhead
Pioneer	3.5	2.2	2.2	2	2	L/U	
TN 45	3.8	2.5	1.5	1.5	1.8	W/M	
Q 9143	1.8	1	1.2	1	1	W/L	
Q 10878	1.5	1.2	1.5	1	1	W/M	
TBA 1014	3.5	1	1.5	1.5	1	N/L	
TBA 1024	3.5	1.2	1.5	1.5	1.2	U/W	
CPI 89982	2	1.5	1.5	1	1.2	U/W	Good growth at site T
TN 57	2	1	2.5	1.2	1.2	W/L	
CPI 26832	3	2.2	3.8	3.5	3.5	U/L	
CPI 41192	4	2	3.8	3.2	3.5	U/N	
CPI 59786	4	1.8	2	2.2	2.2	W/U	
TBA 9	3.2	1	2.5	1.8	1.8	U/L	
CPI 38869	3.8	1	3.2	2.5	2.5	U/W	
TN 1	2	1	2.2	1.5	1.5	N/L	
CPI 98920	3.5	1.5	3.8	3.5	3	M/L	
CPI 99872	4	1.2	3.5	3.2	2.5	M/W	
CPI 98954	2	1.2	1.5	1.5	1.2	M/W	
CPI 98960	3	1	2.8	2.2	1.5	M/N	
CPI 99871	3.5	1.5	4.2	2.8	2.2	N/L	
CPI 98952	2.2	1	2.5	1.8	1.2	W/M	
WA 80/1987	4	1.5	3.5	2.2	1.5	W/L	Good persistence
CPI 59853	4.5	1	3.8	3	3.2	W/U	
CPI 98987	1.5	1	1.2	1	1	U/W	
CPI 99865	4.5	1	1.8	2	1.5	L/M	Good at site T
CPI 99880	3.5	1	1.5	1	1	L/M	
TBA 1	2.5	1	2.8	1.5	1.5	U/M	
Bambatsi	3.5	1	2.2	1.8	1.5	N/W	
TN 8	2.5	1	3.2	1.8	1.5	N/M	
CPI 73576	2.8	1	2.2	1.5	1.2	L/W	
CPI 73577	4.2	1	4	3.5	3.8	L/M	

Continued

Accession	Early growth	Spread	Persistence	Yield	Overall rating	Best/worst sites[1]	Notes
CPI 99877	3	1	2.2	1.5	1.5	U/L	OK at site T
CPI 43715	3.2	1.2	3.5	2.8	2.5	M/W	
Inverell	3	1	2.5	3.5	2.5	W/M	
Silk	4.8	1	1.2	2.2	2.2	L/W	
TN 9	1.8	1	2.5	1	1	N/U	
CPI 60781	3.2	1	2.5	1.8	1.5	U/N	No weedy features
TN 35	1.8	1.5	3.5	2	2.2	U/M	Native at site M
CPI 99561	3.2	1	2.2	1.5	1.2	U/W	
CPI 99879	2.5	1	1.8	1.5	1.5	W/L	
CPI 60127	4	1.2	2.2	2.2	2.2	M/U	
CPI 60128	4.2	2.5	4.5	3	3.8	U/W	
CPI 84971	3.5	1	3.2	2	2	U/M	Large site differences
CPI 34721	3.8	1	1.2	1.5	1.2	L/N	First year critical
CPI 20733	3.2	1	1.8	1	1	N/W	
CN 63	2	1	1	1	1	U/W	Trashy seed
CPI 85178	2.2	1	2.8	1.2	1.5	U/M	
CPI 90751	3	1	2.2	1.5	1.5	U/M	
CPI 78425	3.5	1.5	2	1.5	1.8	L/W	
WRI 3	3	1.2	1.2	1.2	1.2	N/W	Did well at site T
CPI 69495	2.8	1	3.8	2.5	2.5	U/M	
CPI 73608	2	1	2.2	1.5	1.5	L/M	
CPI 61815	2.1	1	1.5	1	1	U/M	Never >1 m tall
Cunningham	2.2	1	1.5	1.2	1.2	L/W	
CPI 62129	2	1	1.2	1	1	L/W	Failed to grow at all sites
CPI 90334	3.2	1	1.8	1.5	1.5	U/W	OK at site T
CPI 90454	3.5	1	1.8	1.5	1.5	U/W	Good at site T
CPI 90455E	3.8	1	1.5	1.5	1.5	U/M	
CPI 90821	2.8	1	2	1.5	1.5	U/M	
Siratro	4.2	1	1.5	1.2	1.2	U/M	
CPI 38841	4.8	1	1.5	1.8	1.2	L/M	Bushy habit
CPI 60303	2.8	1	1	1	1	L/U	Always very poor color
CPI 85005	2.8	1	1.2	1.2	1	L/M	OK at site T
CPI 90752	3.2	1	1.8	1	1	U/M	
CPI 52704	3.8	1.2	1.5	1.8	1.5	N/W	
TN 15	3	1.5	2.5	2	2.5	W/U	
TN 24	2.5	1.8	2.5	2.5	2.5	N/M	
CPI 40615	4.2	1	2	2.5	1.8	U/N	Annual at site T
CPI 41219	3.5	1	1.5	2	1.8	M/W	
CPI 55872	3.5	1	2.8	2.2	2.5	U/N	
TN 27	2.2	1.2	1.5	1.2	1	N/M	
TN 6	4.2	1.2	2.5	1.5	1.2	U/M	
CPI 84982	2.2	1	1.5	1	1.2	U/L	
TN 7	2.5	1.2	2.8	1.8	1.5	U/N	
Aseasonal growers							
TN 36	3	2.2	2.5	2.5	3	L/M	
CPI 30374	4	1	3.5	3.2	3	M/W	Lack of spread unusual
CPI 98914	4	1.2	3.2	2.5	2.5	U/W	
CPI 98926	4.5	1.2	2.8	3.5	2.5	M/W	
SCS 4663	4	1	3.2	2.8	3	M/N	
CPI 99554	3.2	1	1.5	2	1.5	M/W	
TN 44	4.5	2	1.5	1.8	2.5	L/M	
CPI 98990	4	2.5	3.2	2.2	3.2	W/U	Large site differences
TN 22	2.5	1	2.2	1.5	1.8	M/L	
TN 59	2.5	1	3.8	1.5	1.8	U/W	
CPI 79501	3.2	1	4.2	2.2	2.5	W/N	

Continued

Accession	Early growth	Spread	Persistence	Yield	Overall rating	Best/worst sites[1]	Notes
TN 29	2.5	1.2	2.2	1.8	1.8	U/W	Large site differences
CN 55	3.8	1.5	1.8	1.5	1.5	L/M	Sporadic presence
TN 12	3.8	1.2	1.5	1.5	1.5	U/M	
WRI 19	3.2	1.2	1.2	1.5	1.8	U/M	
Trifecta	4.5	1	3	2.8	2.5	L/W	
CPI 85166	1.8	1	1.8	1.2	1.2	L/M	
CPI 79496	1.5	1	1.5	1	1	N/U	
Q 22947	3.5	1	1.8	1	1	N/M	OK at site T
Winter growers							
Q 20701	4.2	1	1	1.5	1	W/M	Grew well at site T
Q 20704	3.2	1	1	1.2	1	W/M	Grew well at site T
TN 10	3.2	2.5	3	2	2.8	W/L	
Q 20711	3	1	1	1.5	1	W/U	Grew well at site T
TN 49	3.8	1.5	1.5	1.5	1.5	N/U	Very good at site T
CPI 36101	3.5	1	1	1.5	1	W/M	OK at site T
Q 20715	4	1	2	1.5	1.2	W/M	Grew well at site T
Q 22941	2.5	1	2.2	1.2	2	L/N	
TBA 7	3.2	1.5	2.2	1.5	1.8	U/M	
TBA 13	2.8	1.8	3	2	2.2	L>M	Poor color –Rhizobium?
CD 64.11.1	2.5	1	2	2.5	2.2	U/M	Disappeared in 5 yr
WA 5320	3.8	1.5	2.5	2.5	2.5	L/W	
Circle Valley	3.5	1.5	2.2	2	2.2	M/W	Semi-erect growth
Serena	3	1.5	2	1.8	1.8	L/N	
CS 146	4.2	1.5	2.8	2.5	3	U/N	

[1]Soil information:
Site L – hard-setting, grey, shallow duplex soil with impervious sodic subsoil; good available P
Site M – deep, infertile, acidic, sandy red earth
Site N – grey, slightly alkaline clay loam with carbonate nodules at depth
Site U – slightly acidic, sandy red earth without subsoil constraints
Site W – hard-setting, grey, shallow duplex soil with impervious sodic subsoil
Site T – deep, friable red loam with fair organic carbon levels

Supplementary Table B. Critical aspects of the dryland field performance of each accession in the first 5 years, that limited or enhanced its potential agronomic value.

Accession	Genus species	Seed set	Palatability	Pests and diseases	Leafiness	Other features
Summer growers						
CPI 90727	*And.isc*	low	uncertain	seedhead ergot	fair	low leaf DMY
CPI 99868	*And.isc*	low	fair – low	ergot in heads	low	tight, low crown; very low DMY
CPI 99869	*And.isc*	low	fair – low	ergot in seedheads	low	tight, low crown; very low DMY
Q 20321	*Ant.pub*	fair – low	high	nil	very high	sturdy rhizomes
CPI 99572	*Bot.bar*	very low	uncertain	none seen	low	feeble growth
CPI 99867	*Bot.bar*	nil	uncertain	none seen	low	very erect; >1 m tall
TN 47	*Bot.ewa*	fair	fair	ergot in seeds	fair	prostrate winter tillers
CPI 11408	*Bot.gla*	good	good; heads eaten	leaf stripe	fair	prostrate spring tillers; good seeder
CPI 69517	*Bot.ins*	good	good	nil	good	good initially at site L
CPI 52193	*Bot.ins*	good	fair	nil	good; hairs at leaf base cf. cv. Medway	good nodal rooting; can look like Medway; did well at site N
Hatch	*Bot.ins*	fairly low	fair	nil	fair; thick stolons	poor nodal rooting; grew well at site N
Medway	*Bot.per*	good	fair/good	ergot in heads in wet years	good	tight sward; withstands gentle cultivation
CPI 60733	*Cen.cil*	fair	good	nil	fair	type D; erect; grew best at site L
CPI 71914	*Cen.cil*	good	good; hairy	nil	good	tight low crown; cv. Gayndah type
CPI 73390	*Cen.cil*	good	good	nil	fair	cv. Gayndah type
CPI 73393	*Cen.cil*	fair	fair	nil	fair	cv. Biloela type; erect, rhizomes
Q 10077	*Cen.cil*	good	fair	nil	fair – low	distinctive color and growth; tolerates gentle cultivation
Biloela	*Cen.cil*	fair	fair	nil	fair	short rhizomes; stemmy once mature
Gayndah	*Cen.cil*	good	good	nil	good	high drought tolerance; reliable
CPI 61135	*Cen.hyb*	good	good	nil	good	bristle-free seed
CPI 17655	*Cen.set*	good	good	nil	good	no seed bristles; frost-tender
Pioneer	*Chl.gay*	good	high, esp. to locusts	locusts	fair	long stolons
TN 45	*Chl.tru*	prolific	good	nil	good	aseasonal growth; good frost tolerance; prolific regeneration
Q 9143	*Dac.sp*	nil	uncertain	none seen	good	feeble growth
Q 10878	*Dac.sp*	nil	uncertain	none seen	good	flowered at 1 site

Continued

Accession	Genus species	Seed set	Palatability	Pests and diseases	Leafiness	Other features
TBA 1014	*Dic.ari*	very low	low	nil	fair	low crown; short runners
TBA 1024	*Dic.ari*	very low	uncertain	nil	fair	prostrate winter growth
CPI 89982	*Dig.aby*	very low	low	leaf rust; aphids	high	feeble growth in field, weedy at site T; long rhizomes
TN 57	*Dig.bro*	low	fair	nil	high	difficult to germinate; western form
CPI 26832	*Dig.eri*	fair	good	nil	fair	some long stolons and tufts
CPI 41192	*Dig.mil*	good	good	nil	good	grew well at sites L and M
CPI 59786	*Dig.mil*	fair	good	nil	fair; stolons	low frost tolerance; eaten by rabbits at site M
TBA 9	*Dig.smu*	low	high	nil	high	looks like cv. Premier
CPI 38869	*Dig.smu*	low	high	nil	good	long seed culms; pale color at sites M and U
TN 1	*Ent.aci*	fair	fair	nil	fair	deep crown
CPI 98920	*Era.bic*	good	low	nil	fair; red stem in winter	like cv. Consol
CPI 99872	*Era.hyb*	prolific	very low	nil	very low	dug out to remove weed risk; re-roots easily
CPI 98954	*Era.leh*	good	very low	nil	low	looks like CPI 98960; weed potential; dug out after 7 years
CPI 98960	*Era.leh*	good	very low	seedhead aphids	low	weed potential; dug out
CPI 99871	*Era.leh*	high	low; stalky	nil	low	dug out to remove weed risk
CPI 98952	*Era.obt*	prolific	low	none seen	low	looks like WA 80/1987
WA 80/1987	*Era.obt*	prolific	low	nil	low	weedy nature; spreads
CPI 59853	*Era.sup*	high	variable	nil	fair	pale leaf color
CPI 98987	*Era.tru*	nil	uncertain; very erect	none seen	fair	very low DMY; sturdy rhizomes
CPI 99865	*Lep.dub*	fair	good	nil	fair	easy to collect clean seed
CPI 99880	*Lep.fus*	high	fair – low	nil	fair; stalky	looks like annual Qld native one
TBA 1	*Pan.ant*	fair – low	good	leaf blotch	good	robust, short rhizomes
Bambatsi	*Pan.col*	low	good	nil	fair	not adapted to these soils
TN 8	*Pan.dec*	fair	good	nil	fair	
CPI 73576	*Pan.kal*	nil	uncertain	none seen	low	feeble growth; basal leaves
CPI 73577	*Pan.sta*	low	high	nil	good	robust crown; persistent
CPI 99877	*Pap.muc*	high	good	nil	fair	sturdy crown
CPI 43715	*Sch.pap*	good	good; stemmy	seedling damping-off	low	best at site M

Continued

Accession	Genus species	Seed set	Palatability	Pests and diseases	Leafiness	Other features
Inverell	*Set.inc*	fair	good when green	nil	fair	best at site W
Silk	*Sor.hyb*	low	high	leaf rust	good	poor performance
TN 9	*Spo.act*	good	fair	root aphids at site T	fair	erect habit
CPI 60781	*Spo.fim*	good	good	nil	good	tussocks
TN 35	*The.tri*	fair	good; seasonal; heads browsed	nil	fair	erect culms; typical tetraploid of the species
CPI 99561	*Tri.cal*	good	uncertain	nil	good	looks like native *Digitaria brownii*
CPI 99879	*Tri.cri*	high	low – fair	nil	good	looks like *Chloris virgata;* no stolons
CPI 60127	*Uro.oli*	fair	high	nil	good	N demanding; best at site L
CPI 60128	*Uro.sto*	good	fair	nil	fair; red when dry	may be glyphosate-tolerant
CPI 84971	*Aca.ang*	low	low	weevils seen	poor	root suckers; fair seedling frost tolerance
CPI 34721	*Cha.rot*	nil	uncertain	uncertain	good	baked by summer heat on bare soil
CPI 20733	*Cli.ter*	nil	uncertain	none seen	fair	feeble growth
CN 63	*Cul.pat*	fair; poor seed viability	fair; low for cattle	seed bruchids; some leaf yellows	good	frost- and rootknot nematode-tolerant
CPI 85178	*Des.vir*	fair	fair	nil	fair	lower yield than local native *Neptunia gracilis*
CPI 90751	*Des.vir*	low	fair	none seen	fair	very prostrate; relatively large flowers
CPI 78425	*Gal.sp.*	very low	low	weevils, leafspots	good	pale color; slight frost tolerance
WRI 3	*Gly.tom*	low	good	*Amnemus* weevil	good	can root at nodes
CPI 69495	*Ind.sch*	fair	low; uneaten by marsupials	nil	fair	weed potential; bushy
CPI 73608	*Ind.sch*	fair	low	nil	low	bushy
CPI 61815	*Leu.leu*	nil	high	nil	fair	poor growth; fair seedling frost tolerance
Cunningham	*Leu.leu*	nil	very high	nil seen	fair	very slow growth; frosted
CPI 62129	*Lys.wat*	nil	low	none seen	fair	feeble growth
CPI 90334	*Mac.atr*	very low	good	none seen	fair	non-climber; rel. thin leaves
CPI 90454	*Mac.atr*	very low	good; pilose leaf	cowpea aphids	good	very late flowering; root suckers
CPI 90455E	*Mac.atr*	very low	good	none seen	good	looks like cv. Siratro
CPI 90821	*Mac.atr*	low	good	red spider mite	fair	purple stems; thick tap-root
Siratro	*Mac.atr*	low	high	leaf rust and virus	fair	low frost tolerance
CPI 38841	*Mac.lat*	fair	good	none seen	good	bushy habit; thin leaflets
CPI 60303	*Mac.dal*	nil	uncertain	leaf rust once	good	feeble growth

Continued

Accession	Genus species	Seed set	Palatability	Pests and diseases	Leafiness	Other features
CPI 85005	*Pha.fil*	nil in field; high at site T	high	*Botrytis* on pods	high	feeble growth except at site T; no hard seed
CPI 90752	*Pha.sp*	very low	low	nil	low	thin vine; tiny leaves; hypogeal emergence
CPI 52704	*Rhy.min*	nil in field	low at site T	none seen	low	thick stems, non-twining; non-hairy pods
TN 15	*Rhy.min*	low	fair/seasonal	leaf spots; mites	good; v. hairy	drops leaf in dry times
TN 24	*Rhy.min*	fair; very sticky pods	fair	leaf spots; legume little leaf	fair	good at sites L and N; hypogeal emergence
CPI 40615	*Sty.fru*	low	fair	collar rot at site T; looper caterpillars	fair	glandular leaves; erect; not suited to clays
CPI 41219	*Sty.fru*	low	uncertain	nil	poor	frost-tender
CPI 55872	*Sty.sca*	low	fair	none seen	fair	weak growth
TN 27	*Boe.dom*	low	good	hawkmoth grubs	fair	prostrate; frosted
TN 6	*Evo.als*	fair	fair – good	nil	fair	low DMY; frost-susceptible
CPI 84982	*Mer.aur*	nil	uncertain	none seen	low	feeble growth; tuber and vine
TN 7	*Sid.bra*	fair	low; seasonal	leaf beetles	good	prostrate stems
Aseasonal growers						
TN 36	*Dic.ser*	good	fair – good	*Dreschlera* leaf freckling	good	very hairy type; bluish leaf color
CPI 30374	*Era.cur*	high	fair; variable	nil	fair	winter green
CPI 98914	*Era.cur*	high	fair – good; better than CPI 30374	nil	fair	looks like cv. Consol
CPI 98926	*Era.cur*	good	fair	nil	fair	
SCS 4663	*Era.cur*	high	leaf fair; stem low	nil	good	looks like CPI 98926
CPI 99554	*Era.int*	good	uncertain	nil	fair	like *E. curvula* with wide leaves
TN 44	*Eri.pse*	fair	good	seedhead ergot	fair; lax habit	aseasonal growth
CPI 98990	*Fin.afr*	good	fair	nil	good	good frost tolerance
TN 22	*Thy.mit*	fair	good; seasonal	nil	fair; prostrate in winter tillers	aseasonal growth; some nodal rooting
TN 59	*Aca.ane*	nil	good	nil	fair	failed at site M where native
CPI 79501	*Cas.stu*	fair	low	nil	fair	slow to first flowering; bushy
TN 29	*Cul.pat*	low	fair; seasonal	caterpillars; leaf virus	good	prostrate; like CN 63
CN 55	*Cul.ten*	fair; high seedling regeneration	fair; low for cattle	*Botrytis* on stems at site T	low	frost-tolerant; best *C. tenax* line
TN 12	*Cul.ten*	fair	fair	caterpillars	fair	
WRI 19	*Cul.ten*	fair	fair – good	leaf grubs and weevils	good	ascendant habit; better than CN 55
Trifecta	*Med.sat*	very low	very high	none seen	good; drop in dry times	best at site L; nodules seen

Continued

Accession	Genus species	Seed set	Palatability	Pests and diseases	Leafiness	Other features
CPI 85166	*Atr.can*	nil	low	nil	fair	dioecious; best at site L
CPI 79496	*Atr.hal*	nil	good	nil seen	good	dioecious; never got a start
Q 22947	*San.min*	low	high	nil	high	earliest flowering line; best at site N
Winter growers						
Q 20701	*Agr.elo*	nil; good at site T	uncertain; high at site T	nil	good	feeble growth; erect at site T
Q 20704	*Agr.tri*	nil; fair at site T	uncertain; high at site T	stripe rust	high	feeble growth; short rhizomes
TN 10	*Aus.sca*	good	good	nil	good	sharp seeds; cool season growth
Q 20711	*Bro.ine*	nil; fair at site T	uncertain; high at site T	nil	high	feeble growth; good at site T
TN 49	*Ely.sca*	good	good; variable	mild leaf rust; coccids, root aphids	good	erect culms; short rhizomes
CPI 36101	*Ory.mil*	nil in field	uncertain; thick culms	none seen	low	feeble growth except at site T
Q 20715	*Sti.ten*	high	fair – low	nil	high; erect; rough	fine, wiry leaves; no sharp point on seeds
Q 22941	*Dor.hir*	low; OK at site T	low; unpalatable to locusts	nil	high; hairy	coarse, prostrate stems
TBA 7	*Med.lac*	good; burrs	high	powdery mildew	fair	good response to late spring rains
TBA 13	*Med.lac*	fair; burrs	fair	none seen; wrong *Rhizobium*?	fair	long pod spines; poor color
CD 64.11.1	*Med.mur*	fair	good	caterpillars at site U	fair	later flowering than WA 5320; spines on pod
WA 5320	*Med.mur*	good	high	nil	good	late flowering; spineless pods
Circle Valley	*Med.pol*	good	uncertain	downy mildew	good	no regrowth from late spring rains
Serena	*Med.pol*	good; v. early flowering	uncertain	none seen	good	no regrowth from late spring rains
CS 146	*Orn.com*	good	high; unpalatable to locusts	nil	excellent	like cv. Madeira

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Botanical and agronomic growth of two *Panicum maximum* cultivars, Mombasa and Tanzania, at varying sowing rates

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Abstract

A field trial in northeast Thailand during 2011–2013 compared the establishment and growth of 2 *Panicum maximum* cultivars, Mombasa and Tanzania, sown at seeding rates of 2, 4, 6, 8, 10 and 12 kg/ha. In the first 3 months of establishment, higher sowing rates produced significantly more DM than sowing at 2 kg/ha, but thereafter there were no significant differences in total DM production between sowing rates of 2–12 kg/ha. Lower sowing rates produced fewer tillers/m^2 than higher sowing rates but these fewer tillers were significantly heavier than the more numerous smaller tillers produced by higher sowing rates. Mombasa produced 23% more DM than Tanzania in successive wet seasons (7,060 vs. 5,712 kg DM/ha from 16 June to 1 November 2011; and 16,433 vs. 13,350 kg DM/ha from 25 April to 24 October 2012). Both cultivars produced similar DM yields in the dry seasons (November–April), averaging 2,000 kg DM/ha in the first dry season and 1,750 kg DM/ha in the second dry season. Mombasa produced taller tillers (104 vs. 82 cm), longer leaves (60 vs. 47 cm), wider leaves (2 vs. 1.8 cm) and heavier tillers (1 vs. 0.7 g) than Tanzania but fewer tillers/m^2 (260 vs. 304). If farmers improve soil preparation and place more emphasis on sowing techniques, there is potential to dramatically reduce seed costs.

Resumen

Entre 2011 y 2013 se evaluaron en el noreste de Tailandia el establecimiento y el desarrollo de los cultivares (cvs.) Mombasa y Tanzania de *Panicum maximum* en densidades de siembra variables desde 2 hasta 12 kg/ha de semilla comercial, con incrementos de 2 kg/ha. En los primeros 3 meses del establecimiento, mayores densidades de siembra produjeron significativamente más materia seca (MS) que la siembra a 2 kg/ha, pero a partir de entonces no hubo diferencias significativas en la producción total de MS entre las tasas de siembra de 2−12 kg/ha. Densidades de siembra más bajas produjeron menos brotes/m^2 que tasas de siembra más altas, pero estos pocos brotes fueron significativamente más pesados que los brotes más numerosos pero más pequeños que se produjeron al incrementarse las tasas de siembra. El cv. Mombasa produjo 23% más MS que el cv. Tanzania en dos épocas lluviosas sucesivas: 7 vs. 5.7 t/ha entre junio 16 y noviembre 1 de 2011, y 16.4 vs. 13.4 t/ha entre abril 25 y octubre 24 de 2012. Ambos cultivares presentaron producciones similares de MS en las épocas secas (noviembre−abril), con promedios de 2 t/ha en 2011 y 1.75 t/ha en 2012. El cv. Mombasa produjo plantas más altas (104 vs. 82 cm), hojas más largas (60 vs. 47 cm) y más anchas (2 vs. 1.8 cm) y brotes más pesados (1 vs. 0.7 g) que Tanzania; sin embargo el número de brotes/m^2 (260) fue más bajo en Mombasa que en Tanzania (304). Se concluye que al mejorar los productores la preparación del suelo y poner más énfasis en técnicas de siembra, existiría el potencial de reducir drásticamente los costos de la semilla.

Introduction

Tanzania guinea grass [*Panicum maximum* cv. Tanzania (cv. Si Muang in Thailand)] has been grown in Thailand for over 20 years (Phaikaew et al. 2007). In Thailand, it is considered to be a high quality cut-and-carry grass for dairy and beef cattle (Nakamanee et al. 2008) and not a grazed pasture grass, unlike in Brazil, where it is widely used for grazing (Santos et al. 2006). Mombasa guinea grass (*P. maximum* cv. Mombasa) was introduced to Thailand in 2007 (Hare et al. 2013a) from Brazil, where it produces high amounts of good quality herbage under grazing (Carnevalli et al. 2006). The main purpose of this introduction was to produce seed for export to Central America (Hare et al. 2013a; 2013b). However, there

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is now a rapidly growing market for Mombasa seed within Thailand and other countries in Asia, because of its reputedly greater dry matter (DM) production than that of Tanzania (Cook et al. 2005; Hare et al. 2013a).

Data from Brazil in separate trials showed that Mombasa (Silveira et al. 2010) was larger and taller than Tanzania (Santos et al. 2006) but there were no detailed data with both cultivars grown together in the same trial. There were also no comparative data of these cultivars growing in Thailand in trials at the same site.

Two studies have been undertaken at Ubon Ratchathani University, Thailand, to study these 2 cultivars, both botanically and agronomically. In the first study under cutting, Mombasa produced 17–21% more total DM and 18–24% more leaf DM than Tanzania (Hare et al. 2013a). This paper, which examines the effects of varying sowing rates, relates to the second study.

Guinea grasses are normally sown in Thailand at what might be considered a high rate of 12 kg seed/ha. The one thousand seed weights for Mombasa and Tanzania are, respectively, 1.51 and 1.16 g (Hare et al. 2013b). Sowing these seeds at 12 kg/ha with 70% germination results in approximately 555 potential seedlings/m^2 for Mombasa and 724 potential seedlings/m^2 for Tanzania. We have observed that sowing of guinea grass at 12 kg/ha produced a vast number of small plants, which competed strongly with one another. Survival of individual plants appeared lower than that of plants sown at a spacing of 50 cm x 50 cm (Nakamanee et al. 2008).

Our hypothesis was that pastures sown at a low sowing rate, while initially producing less DM than those sown at high sowing rates, would quickly compensate and tiller out strongly and, over time, these pastures would produce more DM than pastures from the high sowing rate.

Materials and Methods

This study was conducted at a single site at the Amnart Charoen Livestock Development Centre, Amnart Charoen province, northeast Thailand (15.5° N, 104.4° E; elevation 130 masl) during 2011–2013. 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), but 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, which is not a normal practice for farmers sowing forages in Thailand, plowed and disked before the guinea grass seeds were sown 3 weeks later on 16 June 2011.

Two guinea grass cultivars (Mombasa and Tanzania) were sown at 6 sowing rates (2, 4, 6, 8, 10 and 12 kg/ha) in 4 m x 3 m plots in a randomized complete block design with 4 replications. Prior to sowing, a germination test on the seeds showed 70% germination. The seeds were hand-broadcast on to the seed beds and lightly surface raked into the soil. The plots were fertilized at sowing with N:P:K (15:15:15) at 200 kg/ha and lime at 1,000 kg/ha.

Plant counts were made in four 0.25 m^2 quadrats per plot, 4 weeks after sowing. Forage cuts at 5 cm from ground level from four 0.25 m^2 quadrats per plot, were taken in the first wet season on 2 August, 16 September and 1 November 2011, in the first dry season on 25 April 2012, in the second wet season on 7 June, 23 July, 6 September and 24 October 2012 and in the second dry season on 23 April 2013, when the study ended.

At the first cut (7 weeks after sowing, on 2 August 2011), plant and tiller numbers/m^2 were counted in the 4 quadrats per plot and tiller length measured in situ on 20 tillers per plot. These tillers were cut, leaf number per tiller counted, and the length and width of a leaf from the top, middle and base of each tiller measured. At all cuts, the quadrat samples were sorted into guinea grass and weeds and weighed fresh, and a 300 g subsample was taken from the guinea grasses, sorted into leaves and stems and dried at 70 °C for 48 h to calculate dry weights of tillers, stems and leaves and total DM.

After sampling, all plots were cut to about 5 cm above ground level, the forage was removed and the plots were fertilized with N:P:K (15:15:15) at 200 kg/ha.

Data from the trial were analyzed by 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 in the first year from sowing (June 2011) until October 2011 was 28% higher than the 12-yr mean for the same period (Figure 1), with particularly heavy rainfall in August 2011. For the same period in the second year, rainfall was 30% lower than the 12-yr mean. Rainfall in the second dry season (Nov 2012–Apr 2013) was nearly 40% lower than the 12-yr mean.

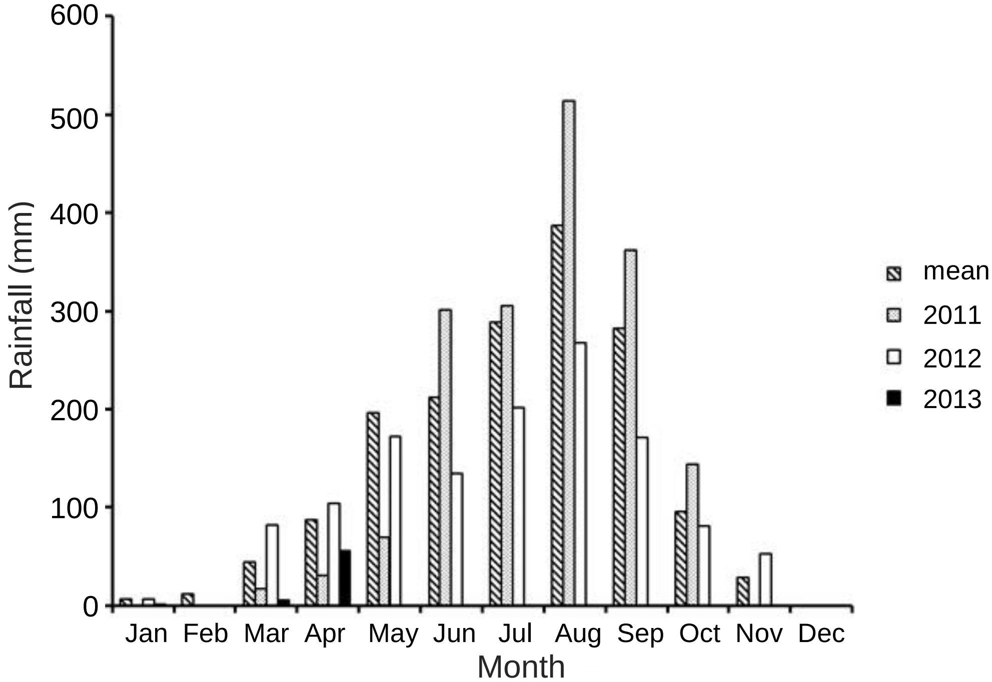

Figure 1. Rainfall at the Amnart Charoen meteorological station, 9 km from the research site, during the trial and the 12-yr mean (2000−2012).

Plant and tiller numbers

Plant populations at 4 and 7 weeks after sowing increased with increasing sowing rate up to 8 kg/ha (P<0.05), with plots sown at 8 kg/ha having twice as many plants as those sown at 2 kg/ha (Table 1). Across sowing rates, plant populations were similar (P>0.05) for both cultivars, but at a sowing rate of 12 kg/ha, Tanzania produced significantly more plants/m^2 (141) than Mombasa (99) (P<0.05).

Tiller numbers increased significantly with sowing rates up to 8 kg/ha (Table 1), and with age, particularly at low sowing rates. Between 7 and 20 weeks after sowing, tiller numbers increased 62% in plots sown at 2 and 4 kg/ha compared with 17% in the 12 kg/ha plots. At the end of the first dry season (25 April 2012), tiller numbers were significantly greater in plots sown at 8–12 kg/ha than in plots sown at 2 kg/ha (Table 2). By the end of the second wet season (24 October 2012), tiller numbers were greater in plots sown at 8−12 kg/ha than in

Table 1. Effects of sowing rate and guinea grass cultivar on plant establishment at 4 and 7 weeks after sowing and tiller numbers at 7, 13 and 20 weeks after sowing (first wet season).

Sowing rate (kg/ha)	Plants/m^2		Tillers/m^2		
	4 wk	7 wk	7 wk	13 wk	20 wk
2	39	51	151	159	243
4	54	61	171	225	280
6	79	77	190	207	281
8	92	104	233	240	303
10	106	110	233	255	322
12	106	120	279	258	326
LSD (P<0.05)	19.3	17.5	39.4	33.4	28.0
Cultivar					
Mombasa	84	87	190	204	263
Tanzania	75	88	228	242	322
LSD (P<0.05)	ns	ns	22.7	19.3	16.1
Sowing x cultivar	ns	*	*	*	*

Table 2. Effects of sowing rate and guinea grass cultivar on tiller numbers/m^2 at the ends of the first dry season, second wet season and second dry season.

Sowing rate (kg/ha)	First dry season 25 Apr 2012	Second wet season 24 Oct 2012	Second dry season 23 Apr 2013
2	282	304	323
4	295	308	342
6	305	306	346
8	315	339	365
10	320	336	359
12	325	337	339
LSD (P<0.05)	33	24	ns
Cultivar			
Mombasa	283	300	327
Tanzania	325	343	365
LSD (P<0.05)	19	14	24
Sowing x cultivar	ns	ns	ns

those sown at 2−6 kg/ha (Table 2). At the end of the second dry season (23 April 2013), all plots had similar tiller numbers (range 323–365 tillers/m^2) (Table 2).

Tanzania produced approximately 20% more tillers than Mombasa in the first wet season (Table 1), and retained an advantage until the termination of the trial, when Tanzania averaged 365 tillers/m^2 and Mombasa 327 tillers/m^2 (Table 2). In the first wet season, both cultivars had similar tiller numbers at low sowing rates (2−4 kg/ha) (P>0.05) but at higher sowing rates (8−12 kg/ha), Tanzania produced significantly more tillers/m^2 than Mombasa.

Tiller and leaf measurements

Tiller heights and leaf lengths generally increased as sowing rate increased but differences between sowing rates, 4−12 kg/ha, were mostly not significant (Table 3). Mombasa grew significantly taller tillers, longer leaves and wider leaves but fewer leaves per tiller than Tanzania (P<0.05) (Table 3).

Plants produced from low sowing rates had significantly heavier tillers than plants from high sowing rates throughout the trial (Table 4). Mombasa produced significantly heavier tillers than Tanzania until the end of the second wet season (Table 4). At the final cut (end of second dry season), tiller weights in all plots were less than half the weight of tillers harvested 6 months earlier and were lower than tiller weights at the first cut of the trial.

Table 3. Effects of sowing rate and guinea grass cultivar on tiller height, number of leaves/tiller, leaf length and leaf width at 7 weeks after sowing.

Sowing rate (kg/ha)	Tiller height (cm)	Leaves/ tiller	Leaf length (cm)			Leaf width (cm)		
			Top	Middle	Bottom	Top	Middle	Bottom
2	80.1	3.8	55.4	46.5	36.4	1.91	1.79	1.67
4	92.1	3.6	63.4	53.2	39.7	2.09	1.96	1.77
6	93.7	3.7	63.4	53.3	41.0	2.05	1.93	1.76
8	95.5	3.5	65.7	56.7	41.9	1.99	1.89	1.74
10	99.9	3.4	68.0	58.7	43.5	2.07	1.92	1.74
12	96.2	3.5	64.6	59.1	43.7	1.97	1.92	1.69
LSD (P<0.05)	9.51	ns	7.0	7.6	4.8	ns	ns	ns
Cultivar								
Mombasa	104.2	3.2	70.6	61.2	46.3	2.09	1.98	1.84
Tanzania	81.6	4.0	56.2	47.9	35.8	1.94	1.83	1.62
LSD (P<0.05)	5.5	0.14	4.0	4.4	2.8	0.12	0.12	0.08
Sowing x cultivar	ns	ns	ns	ns	ns	ns	ns	ns

Table 4. Effects of sowing rate and guinea grass cultivar on tiller dry weight (g) during the first wet season and at the ends of the first dry season, second wet season and second dry season.

Sowing rate (kg/ha)	First wet season			First dry season	Second wet season	Second dry season
	2 Aug 2011	16 Sep 2011	1 Nov 2011	25 Apr 2012	24 Oct 2012	23 Apr 2013
2	0.97	1.01	0.98	0.97	1.19	0.63
4	0.99	0.93	0.99	0.77	1.18	0.54
6	0.98	0.89	0.92	0.75	1.16	0.49
8	0.91	0.89	0.97	0.57	1.01	0.46
10	0.83	0.78	0.85	0.61	1.03	0.47
12	0.82	0.80	0.85	0.42	0.98	0.46
LSD (P<0.05)	0.26	0.15	0.11	0.23	0.12	0.11
Cultivar						
Mombasa	1.17	1.01	1.07	0.75	1.31	0.52
Tanzania	0.67	0.76	0.78	0.61	0.88	0.50
LSD (P<0.05)	0.15	0.08	0.07	0.13	0.06	ns
Sowing x cultivar	*	ns	ns	ns	ns	ns

Dry matter production

Guinea grass sown at 2 kg/ha produced lower DM yields (P<0.05) than when sown at 8 and 12 kg/ha for the first and second forage cuts in the first wet season (Table 5), with yields at other sowing rates being intermediate. However, by the third cut (1 November 2011), yields were similar for all sowing rates, and by the end of the first dry season, yields were inversely related to sowing rate (P<0.05). Plots sown at 2 kg/ha produced 12–92% more DM than the other sowing rates (Table 5).

In the second wet season and second dry season, all plots produced similar DM yields, averaging 14,890 kg/ha from 4 cuts in the second wet season and 1,750 kg/ha from a single cut in the second dry season.

Mombasa produced 23% more DM than Tanzania from 3 cuts in the first wet season, but DM yields were similar in the first dry season (Table 5). In the second wet season, Mombasa again produced 23% more DM than Tanzania (16,433 vs. 13,350 kg DM/ha) with similar DM yields (1,750 kg DM/ha) in the second dry season (November 2012–April 2013).

Leaf %

The percentage of leaf DM was similar for all sowing rates throughout the trial, with a higher proportion of leaf in the dry season compared with the wet season. The proportions of leaf DM in the first and second wet seasons averaged 75 and 73%, respectively, and 81 and 87% in the first and second dry seasons.

Mombasa and Tanzania produced similar leaf DM proportions in the first wet season (75%) but in the second wet season, Tanzania produced a higher proportion of leaf (75%) than Mombasa (71%). In the first dry season, Tanzania produced a greater proportion of leaf (82%) than Mombasa (79%) but in the second dry season, both cultivars produced similar leaf proportions of 86−87%.

Weed %

The main weed species was the annual species, *Richardia brasiliensis,* which was prevalent in the first wet season but died off during the first dry season and was not recorded for the remainder of the trial. In the first wet season, plots sown at the lowest sowing rate had a significantly higher proportion of weeds than plots sown at the higher sowing rates (Table 6). Overall, Tanzania plots were more weedy than Mombasa plots in the first wet season. At the first cutting, Mombasa plots sown at 2 kg/ha were more weedy than Tanzania plots sown at a similar rate, and at the second cutting, Mombasa and Tanzania plots sown at 2 and 12 kg/ha had similar proportions of weeds.

Discussion

This study has shown that guinea grass pastures can be established successfully with sowing rates as low as 2 kg/ha, provided that land preparation is good, and sowing rates above 4 kg/ha produce no extra DM. While higher sowing rates did produce more DM during the first 3 months after sowing than sowing at 2 kg/ha, thereafter there was no advantage in total DM production from using sowing rates as high as 12 kg/ha.

Table 5. Effects of sowing rate and guinea grass cultivar on dry matter production (kg/ha) during the first wet season and at the end of the first dry season.

Sowing rate (kg/ha)	First wet season			First dry season
	2 Aug 2011	16 Sep 2011	1 Nov 2011	25 Apr 2012
2	1,411	1,597	2,345	2,702
4	1,676	2,123	2,697	2,311
6	1,826	1,785	2,501	2,248
8	2,051	2,071	2,836	1,781
10	1,857	1,970	2,717	1,807
12	2,108	2,006	2,743	1,410
LSD (P<0.05)	503	394	ns	264
Cultivar				
Mombasa	2,202	2,059	2,799	2,106
Tanzania	1,441	1,791	2,480	1,979
LSD (P<0.05)	290	228	212	ns
Sowing x cultivar	*	ns	ns	ns

Table 6. Effects of sowing rate and guinea grass cultivar on the proportion of weeds (%) in the fresh herbage.

Sowing rate (kg/ha)	First wet season		
	2 Aug 2011	16 Sep 2011	1 Nov 2011
2	53.5	35.0	18.0
4	49.3	23.6	11.0
6	48.1	22.6	13.5
8	41.9	21.5	8.9
10	43.3	18.6	10.1
12	37.9	21.3	6.9
LSD (P<0.05)	13.6	8.4	5.9
Cultivar			
Mombasa	38.6	18.8	9.1
Tanzania	52.8	28.7	13.7
LSD (P<0.05)	7.9	4.8	3.4
Sowing x cultivar	*	*	ns

Guinea grass sowing rates from other countries vary from 2−3 kg/ha up to 10 kg/ha. In Australia, 2−7 kg/ha has been recommended, depending on the age and quality of seed (McCosker and Teitzel 1975). In South America, Acosta et al. (1995) and Spain et al. (1984) recommended sowing guinea grass at 8−10 kg/ha because of low seed germination and purity. FAO recommendations are for sowing rates of 1−2 kg/ha for cv. Hamil and 3.5−4.5 kg/ha for common guinea (FAO 2005). Cook et al. (2005) also recommended a general sowing rate of 2−3 kg/ha for all tropical regions.

Plants that established from low sowing rates compensated for fewer tillers/m^2 by producing bigger and heavier tillers than plants that established from higher sowing rates. This compensation enabled low sowing rates to produce similar DM yields to higher sowing rates after the initial period of establishment. During the first dry season, DM yields from low sowing rates exceeded those from the higher sowing rates, which could be a function of more efficient moisture utilization by the smaller number of plants on a given area. Fewer and stronger plants/m^2 are preferable to lots of weaker plants, particularly in tropical environments with distinct wet and dry seasons, where stronger plants are able to withstand animal foraging and treading and climatic stresses better than weaker plants (Cook et al. 1993a).

Some of the most important considerations in establishing a pasture are the amount of seed which germinates and emerges, and the number of seedlings which then survive and develop into mature plants (Cook et al. 1993b). Based on the numbers of seeds we sowed at the various sowing rates and plant numbers that were present 4 weeks after sowing, we calculated that only 10–15% of seed sown at 12 kg/ha and 25–35% of seed at 2 kg/ha actually produced a live plant. The low sowing rate was much more efficient in terms of live plants per kg of seed sown.

Humphreys (1987) stated that a low sowing rate is successful only if ground preparation and weed control are faultless, and that in areas receiving more than 1,000 mm annual rainfall, sowing rates preferably should be 10–12 kg/ha of good quality seed. In our study, soil preparation was very good, producing a fine tilth, and there was emphasis on seed placement and depth of sowing, plus seed coverage, which are important considerations when sowing small-seeded pasture species (Cook et al. 1993b). However, weed control post-sowing was absent, with large amounts (38–53%) of *Richardia brasiliensis* growing in the plots in the first 7 weeks of establishment. As a result, low sowing rate plots (2 kg/ha) were significantly more weedy in the first wet season than plots sown at higher rates, probably because of lower competition for light, moisture and nutrients. However, after 3 defoliations in the first wet season, this annual weed died out during the first dry season and did not regenerate in the second wet season, when guinea grass plants dominated in all plots.

Mombasa grew 27% taller and 43% heavier tillers, and 28% longer and 10% wider leaves than Tanzania in this study. Even though Tanzania grew 16% more tillers/m^2 than Mombasa, the production of larger tillers and leaves enabled Mombasa to produce 23% more DM than Tanzania in successive wet seasons, similar to results in an earlier cutting trial in the same region (Hare et al. 2013a). This greater DM production from Mombasa has resulted in Mombasa now replacing Tanzania in many villages that produce fresh forage for sale (Nakamanee et al. 2008). Furthermore, demand for Mombasa seed has come from other livestock farmers in Thailand, who are attracted by the tall structure and large leaves of Mombasa, which are considered important attributes by these farmers for forages in cut-and-carry forage systems.

The annual DM yields (15–18 t/ha second year) for both cultivars were below guinea grass yields of 20–30 t/ha commonly reported elsewhere (Cook et al. 2005). Under high inputs of fertilizer and dry season irrigation, annual DM yields of 33–46 t/ha (Nakamanee et al. 2008) and 50 t/ha (Udchachon et al. 1998) for Tanzania have been reported in Thailand. In this study with no dry season irrigation, only 1 forage cut was possible in each dry season. Although guinea grasses are considered to have only moderate drought tolerance of 4–5 months (Cook et al. 2005; FAO 2005), Mombasa and Tanzania survived very dry conditions, which did suppress growth. In the second dry season with rainfall 40% below the mean, tiller weights for both cultivars were less than half the weights in the previous wet season.

While we have demonstrated that low sowing rates can be successful under good sowing conditions, how these results relate to commercial conditions is open for debate. With good soil preparation and pre-sowing weed control, there was definitely no medium-term advantage in sowing at rates above 4 kg/ha and higher sowing rates would be indeed wasteful. However, farmers who plant forages in Thailand do not spray weeds before cultivation, usually roughly cultivate and do not cover the sown seeds with soil, exposing the seeds to high radiation and high temperatures. In addition, it may be difficult for farmers to sow the small guinea grass seeds at a 2 kg/ha sowing rate. More work is needed to determine how effectively lower sowing rates can be applied under the conditions used by farmers at sowing. If farmers are prepared to improve their soil preparation and pay more attention to sowing techniques, there is scope for them to significantly reduce the amounts of seed sown and hence seed costs.

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References

Acosta AE; Pardo BO; Durán CCV; Gualdrón AR; Soto GG. 1995. Fascículo 3. Establecimiento de Pasturas en Suelos Ácidos de Colombia. In: Zapata V; Durán CV, eds. Capacitación en Tecnologías de Producción de Pastos. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Carnevalli RA; Silva SC da; Bueno AAO; Uebele MC; Bueno FO; Hodgson J; Silva GN; Morais JPG. 2006. Herbage production and grazing losses in *Panicum maximum* cv. Mombaça under four grazing managements. Tropical Grasslands 40:165–176. http://goo.gl/0iIT4K

Cook BG; Pengelly BC; Brown SD; Donnelly JL; Eagles DA; Franco MA; Hanson J; Mullen BF; Partridge IJ; Peters M; Schultze-Kraft R. 2005. Tropical Forages: an interactive selection tool. (CD-ROM). CSIRO and DPI & F, Brisbane, Queensland, Australia, CIAT and ILRI. http://goo.gl/jE4UK1

Cook SJ; Gilbert MA; Shelton HM. 1993a. Tropical pasture establishment. 3. Impact of plant competition on seedling growth and survival. Tropical Grasslands 27:291–301. http://goo.gl/DwdaJI

Cook SJ; Clem RL; MacLeod ND; Walsh PA. 1993b. Tropical pasture establishment. 7. Sowing methods for pasture establishment in northern Australia. Tropical Grasslands 27:335–343. http://goo.gl/HpnXdj

FAO. 2005. Grassland species profiles. Grassland index. *Panicum maximum* Jacq. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. http://goo.gl/nlBRd9

Hare MD; Phengphet S; Songsiri T; Sutin N; Stern E. 2013a. Effect of cutting interval on yield and quality of two *Panicum maximum* cultivars in Thailand. Tropical Grasslands–Forrajes Tropicales 1:87–89. http://goo.gl/I15a7Z

Hare MD; Phengphet S; Songsiri T; Sutin N; Vernon ESF; Stern E. 2013b. Impact of tropical seed development in villages in Thailand and Laos: research to village farmer production to seed export. Tropical Grasslands–Forrajes Tropicales 1:207–211. http://goo.gl/84XRfT

Humphreys LR. 1987. Tropical pastures and fodder crops. 2nd Edn. Intermediate Tropical Agriculture Series. Longman Scientific & Technical, Essex, England.

McCosker TH; Teitzel JK. 1975. A review of guinea grass (*Panicum maximum*) for the wet tropics of Australia. Tropical Grasslands 9:177–190. http://goo.gl/jDYMwQ

Mitsuchi M; Wichaidit P; Jeungnijnirund S. 1986. Outline of soils of the Northeast Plateau, Thailand: Their characteristics and constraints. Technical paper No. 1. Agricultural Development Research Center in Northeast, Khon Kaen, Thailand.

Nakamanee G; Srisomporn W; Phengsavanh P; Samson J; Stür W. 2008. Sale of fresh forage – a new cash crop for smallholder farmers in Yasothon, Thailand. Tropical Grasslands 42:65–74. http://goo.gl/0cYUI6

Phaikaew C; Nakamanee G; Pholsen P. 2007. Purple guinea: a high quality grass for forage and seed that improves smallholder income in Thailand. In: Hare MD; Wongpichet K, eds. Forages: A Pathway to Prosperity for Smallholder Farmers. Proceedings of an International Forage Symposium. Faculty of Agriculture, Ubon Ratchathani University, Thailand. p. 61–76.

Santos PM; Corsi M; Pedreira CGS; Lima CG. 2006. Tiller cohort development and digestibility in Tanzania guinea grass (*Panicum maximum* cv. Tanzania) under three levels of grazing intensity. Tropical Grasslands 40:84–93. http://goo.gl/xXbPSg

Silveira MCT da; Nascimento Jr D; Cunha BAL da; Difante GS; Pena KS; Silva SC da; Sbrissia AF. 2010. Effect of cutting interval and cutting height on morphogenesis and forage accumulation of guinea grass (*Panicum maximum*). Tropical Grasslands 44:103–108. http://goo.gl/vrzeoy

Spain JM; Navas GE; Lascano C; Franco LH; Hayashi H. 1984. The gradual replacement of native savanna on an Oxisol in Eastern Colombia. In: Tothill JC; Mott JC, eds. Ecology and management of the world's savannas. Aus-

tralian Academy of Science, Canberra, Australia; CAB International, Farnham Royal, Slough, UK. p. 283–287.
Udchachon S; Boonpakdee W; Chomphoosao B. 1998. Yield of four forage species under high levels of fertiliser application and irrigation in the dry season. Annual Research Report 1998, Division of Animal Nutrition, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand. p. 255–271.

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Root development and soil carbon stocks of tropical pastures managed under different grazing intensities

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Abstract

Grasslands may act as a carbon (C) sink or C source depending on how they are managed. Soil C stocks, root biomass, root length, root length density and soil organic C concentrations were assessed on pastures of elephant grass (*Pennisetum purpureum*) managed under different post-grazing stubble heights and signal grass (*Brachiaria decumbens*) managed under different stocking rates. Soil samples were collected in 20-cm layers down to 1-m soil depth. Neither stubble height nor stocking rate had any significant effects on root parameters. Both the root system and C stocks declined in both pastures with increasing soil depth. Root biomass in the 0–20 cm layer contained 2.84 and 2.04 t C/ha, declining to 0.39 and 0.64 t C/ha at 80–100 cm for elephant grass and signal grass, respectively. Signal grass had greater root development deeper in the soil than elephant grass pastures, possibly due to its greater tolerance of Al toxicity and acidity. Total soil C stocks were greater for signal grass than for elephant grass (358 vs. 214 t C/ha, respectively).

Resumen

Las pasturas pueden actuar como reservorio o fuente de carbono (C), dependiendo de la forma de manejo. En el trabajo se evaluaron las reservas de C y la concentración de C orgánico en el suelo, la biomasa y longitud radiculares y la densidad de la longitud de las raíces en pasturas de pasto elefante (*Pennisetum purpureum*) pastoreado a diferentes alturas y de pasto braquiaria (*Brachiaria decumbens*) manejado con diferentes cargas animal. Las muestras de suelo fueron tomadas cada 20 cm hasta 1 m de profundidad. La altura del pasto elefante ni la carga animal en braquiaria afectaron los parámetros de raíz y suelo evaluados. En ambas pasturas, tanto el sistema radicular como la reserva de C disminuyeron con el incremento de la profundidad en el suelo. En pasto elefante la biomasa radicular entre 0 y 20 cm contenía 2.84 t/ha de C y entre 80 y 100 cm contenía 0.39 t/ha. En pasto braquiaria estos contenidos eran, respectivamente, 2.04 t/ha y 0.64 t/ha. Este último pasto presentó un mayor desarrollo radicular a través del perfil del suelo que el pasto elefante, posiblemente por su mayor tolerancia a acidez del suelo y toxicidad por aluminio. La reserva total de C en el suelo fue mayor en pasto braquiaria (358 t C/ha) que en pasto elefante (214 t C/ha).

Introduction

Livestock production in South America occurs usually in low-input systems based on rangelands and sown pastures (Santos et al. 2002). Tropical grasses, such as signal grass (*Brachiaria decumbens*) and elephant grass (*Pennisetum purpureum*), are commonly found on farms throughout the region, despite the fact that poor soil fertility reduces their productivity, particularly that of elephant grass. In addition, soil acidity, Al and Mn toxicities, and N and P deficiencies limit grass yields in the tropics (Silva and Ranno 2005).

Plant growth is determined by 2 main processes: (1) synthesis of organic compounds by above-ground photosynthetic tissues; and (2) water and nutrient uptake by roots (Raven et al. 2001). Thus, the root system constantly interacts with the above-ground plant tissues,

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providing water, nutrients and other compounds to promote pasture regrowth after defoliation. A vigorous root system increases plant growth rate, tolerance of water deficit, and ability to compete for soil nutrients and, consequently, leads to an increase in pasture productivity.

Research on C stocks in tropical soils has increased in recent years owing to the increasing interest in quantifying carbon sequestration in agricultural systems (Zinn et al. 2005). The conversion of native forest into pasture may increase carbon stocks in soil, highlighting the importance of pastures in minimizing atmospheric CO_2 (Chapuis-Lardy et al. 2002). However, poor management of pastures could lead to a reduction in soil carbon (Silva et al. 2004).

There is currently limited information regarding the response by root systems of tropical grasses to grazing management strategies and how these strategies will affect soil properties and C sequestration. The present work aims to address these issues by quantifying the short-term impact of grazing intensities on the root systems and soil C stocks of elephant grass and signal grass pastures.

Materials and Methods

Two grazing experiments were carried out at the Agronomic Institute of Pernambuco (IPA) Experimental Station, located in Itambé, northern coastal region of Pernambuco State, Brazil (07º25' S, 35º06' W; 190 masl) on an Ultisol. Average annual rainfall is 1,200 mm, falling mostly from May to September, and average temperature is 25 ºC (ITEP 2010). Total rainfall during the experimental period was 1,311 mm (Figure 1).

The elephant grass stand (clone IRI 381) was established in July 2003, grazed from 2003 to 2005 (Freitas et al. 2004; Cunha et al. 2007) and used for a cutting experiment during 2006–2007. Grazing was re-established in October 2007 and lasted until December 2010. Soil samples and observations of the root system in the grazing study reported in this paper (Experiment 1) were collected from August 2007 to September 2008, comparing 3 post-grazing stubble heights (40, 80 and 120 cm) in a randomized complete block design with 3 blocks per treatment. Each paddock (experimental unit) measured 833 m^2. Response variables evaluated included soil C stocks and root system characteristics (root length, root length density and root biomass); the sampling occurred at the onset of the experimental period in August 2007 and again after the completion of 7 grazing cycles, in September 2008. Initial sampling occurred 70 days after the onset of grazing cycles. Pasture stubble heights at this initial evaluation were 48, 85 and 115 cm, corresponding with 40, 80 and 120 cm treatments, respectively. Soil texture and soil chemical characteristics for Experiment 1 are presented in Table 1.

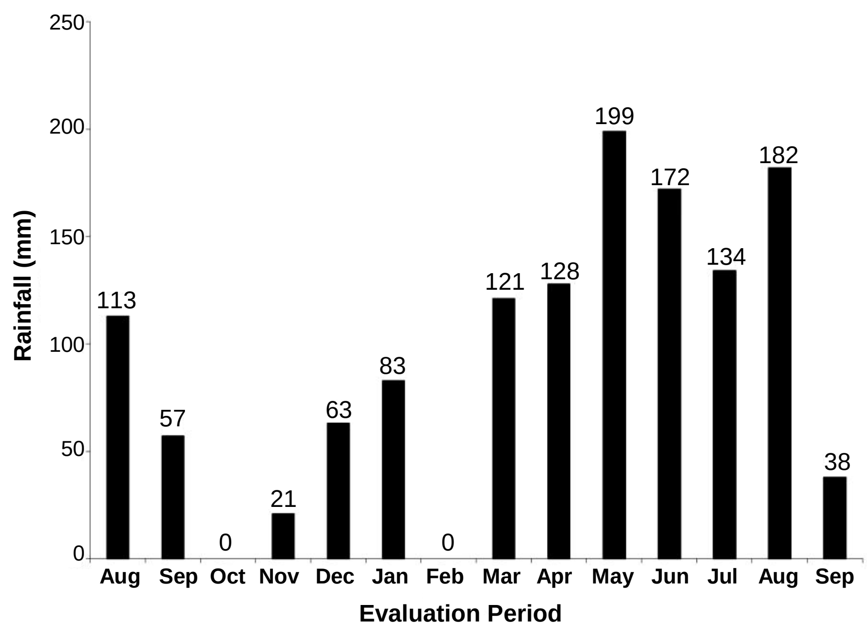

Figure 1. Rainfall at the experimental site from August 2007 to September 2008.

Table 1. Texture, density, pH and mineral concentrations of soil under elephant grass (IRI 381) pastures managed under different grazing intensities. Values are from samples taken at the completion of the study.

Soil layer	Soil texture			Soil density	pH	Soil mineral concentration		
	Clay	Sand	Silt		(water 1:2.5)	P	Ca	Al
(cm)	(%)			(kg/dm^3)		(mg/dm^3)	(cmol$_c$/dm^3)	
0–20	29	58	13	1.21	5.41	12.2	2.12	0.31
20–40	35	55	10	1.18	5.48	6.1	2.82	0.62
40–60	36	53	11	1.19	5.05	6.3	1.63	0.82
60–80	38	52	10	1.18	5.02	2.7	1.51	0.84
80–100	41	46	13	1.24	4.99	3.1	1.33	0.77
s.e.	8.6	8.1	1.5	0.07	0.19	1.98	0.44	0.16

Table 2. Texture, density, pH and mineral concentrations of soil under signal grass pastures managed at different grazing intensities. Values are from samples taken at the completion of the study.

Soil layer	Soil texture			Soil density	pH	Soil mineral concentration		
	Clay	Sand	Silt		(water 1:2.5)	P	Ca	Al
(cm)	(%)			(kg/dm^3)		(mg/dm^3)	(cmol$_c$/dm^3)	
0–20	27	60	13	1.24	5.66	18.9	2.92	0.09
20–40	35	54	11	1.29	5.33	8.7	1.92	0.64
40–60	39	52	9	1.34	5.23	3.3	1.38	0.83
60–80	40	51	9	1.35	5.11	2.5	1.22	0.73
80–100	43	44	13	1.30	4.92	2.5	1.11	0.68
s.e.	9.6	8.2	1.4	0.08	0.22	1.88	0.41	0.17

In Experiment 2, signal grass (*Brachiaria decumbens*) pastures were managed at 3 stocking rates: 2, 4 and 6 animal units (AU; 450 kg live weight) per ha. *Pennisetum* sp. hybrid HV-241 (elephant grass × pearl millet) had been planted and established at the same time as the elephant grass pastures (i.e. July 2003) but poor establishment of the hybrid led to signal grass spontaneously occupying the plots. Experimental design and experimental units were similar to those reported for Experiment 1. Evaluations for Experiment 2 occurred during the same period as for Experiment 1 (August 2007–September 2008). Soil texture and soil chemical characteristics for Experiment 2 are in Table 2.

For both experiments, a rotational stocking strategy was imposed. From January to May 2008, a grazing period of 3 days, followed by a rest period of 67 days (grazing occurred in January, March and May 2008), was employed. During the growing season (June to October 2008), the grazing period remained at 3 days, but the rest period was 32 days, resulting in a grazing cycle of 35 days (grazing occurred in June, August, September and October 2008). In Experiment 1, the number of animals varied in an endeavor to achieve target pre- and post-grazing stubble heights. Fertilizer (300 kg/ha of N:P:K 20:10:20, corresponding with 60 kg N, 13 kg P and 49.8 kg K) was applied after each grazing period during the growing season, resulting in 5 applications per year. Pasture fertilization (P and K) was based on soil testing prior to the beginning of the experiments. The high N fertilizer rate (300 kg N/ha/yr) was based on the higher stocking rate treatments in order to allow the comparison of a range of stocking rates and post-grazing stubble heights. While commercial farmers usually apply higher N fertilizer levels to elephant grass than to *Brachiaria* pastures, the same N rate was applied to both pastures.

In Experiment 1, 14 stratified soil samples were collected from each experimental unit (7 within rows and 7 between rows) across 5 layers (0–20, 20–40, 40–60, 60–80 and 80–100 cm) at the onset and completion of the study. In Experiment 2, only 7 samples per experimental unit were collected. Separate samples from grazed areas (833 m^2) and grazing exclusion areas (9 m^2) were collected to test the effects of grazing intensity on soil characteristics in the 2 pasture systems studied. Each paddock had an exclusion area, where 4 soil samples were collected (2 within rows and 2 between rows). Samples were combined to give composite samples for grazed and exclusion areas, row and inter-row and soil layer. Soil fertility analyses included pH (water), Mehlich-I P, Ca and Al levels. Soil organic carbon (SOC) was determined using the Walkley-Black modified method. Soil fertility analyses were performed according to EMBRAPA (1997).

Root biomass, root length and root length density were determined using a 200 g air-dried soil sample from each soil layer. Roots were separated from the soil using a group of sieves with 2.0, 1.0 and 0.5 mm mesh size. Root length was determined using the line intercept method (Bland and Mesarch 1990). Roots were oven-dried at 65 ºC and weighed. Root length density was determined by dividing root length by soil volume. Carbon stocks were calculated based on soil density, organic C concentration and depth of each layer (Veldkamp 1994).

Data were analyzed using the Proc MIXED procedure from the SAS statistical package (SAS 1996). Initial sampling data were used as a co-variable for the final sampling data to minimize possible initial differences at the experimental site. This was accomplished using the initial sampling as a fixed effect. Other fixed effects included post-grazing stubble height, grazed vs. non-grazed areas, soil layer and their interactions. Block and its interactions were designated as random effects. Data were analyzed in a strip-split-plot arrangement in a complete randomized block design. Means were compared using the LS-MEANS procedure from SAS and PDIFF adjusted by Tukey. Means were considered different using a 5% probability level.

Results

Post-grazing stubble height had no effects on soil C stocks, root length, root length density and root biomass for elephant grass pastures (P>0.05), and stocking rate did not affect these parameters for signal grass pastures (P>0.05). No difference between grazed areas and excluded areas was detected for soil and root characteristics in either pasture system (P>0.05) (data not presented). The absence of response to the treatments applied may be due to the short interval (13 months) between initial and final samplings.

Total root biomass from the 0–100 cm soil layer was 5.31 and 5.98 t/ha for signal grass and elephant grass, respectively (Figure 2). Root biomass was also greatest in the 0–20 cm soil layer, regardless of the forage species.

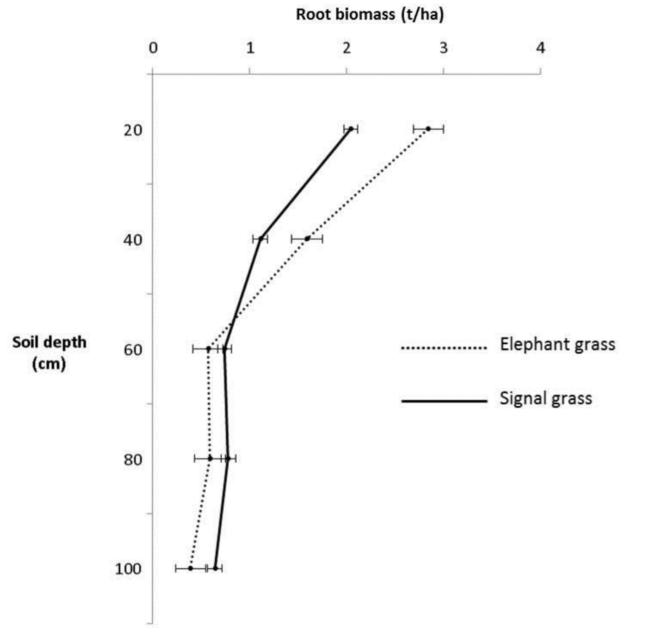

Figure 2. Root biomass of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to significantly influence this parameter. Horizontal bars represent the standard error of the mean.

Although elephant grass had more roots than signal grass, soil C stocks to 1 m under elephant grass were lower than under signal grass (214 vs. 358 t/ha) (Figure 3).

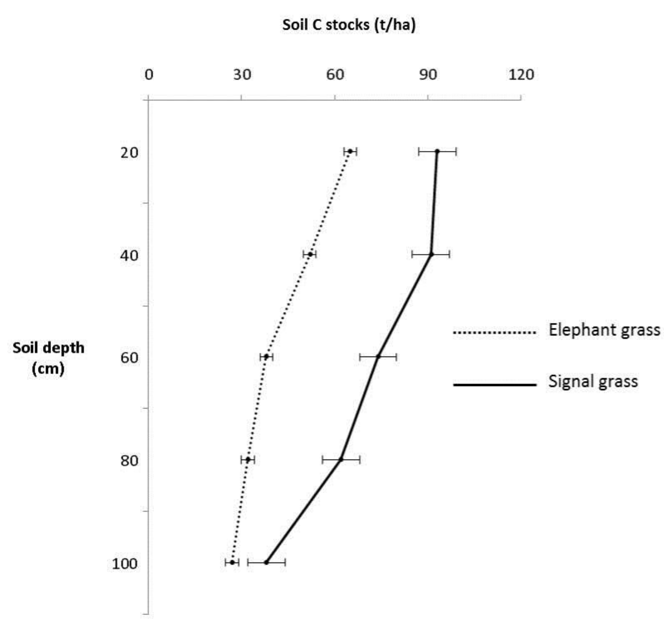

Figure 3. Soil C stocks of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

Soil C stocks in signal grass pastures declined with soil depth, from 93 t C/ha in the 0–20 cm horizon to 38 t C/ha in the 80–100 cm horizon. Carbon stocks for elephant grass also declined with increasing soil depth, from 65 to 27 t/ha for the 0−20 cm and the 80−100 cm soil layers, respectively (Figure 3).

Root system variables varied (P≤0.05) with soil depth. Root length (Figure 4) and root length density (Figure 5) of elephant grass were greater at shallower depths, with approximately 38% of root length occurring in the 0–20 cm soil layer.

Soil organic C (SOC) did not vary among soil layers for signal grass pastures, ranging from 34.98 to 17.73 g/kg (Figure 6). The SOC concentrations in elephant grass pastures, however, were greater in shallower layers, with values of 25.36 and 21.15 g/kg for the 0–20 and 20–40 cm layers, respectively. In the other soil layers, the SOC concentration ranged from 13.62 to 16.14 g/kg.

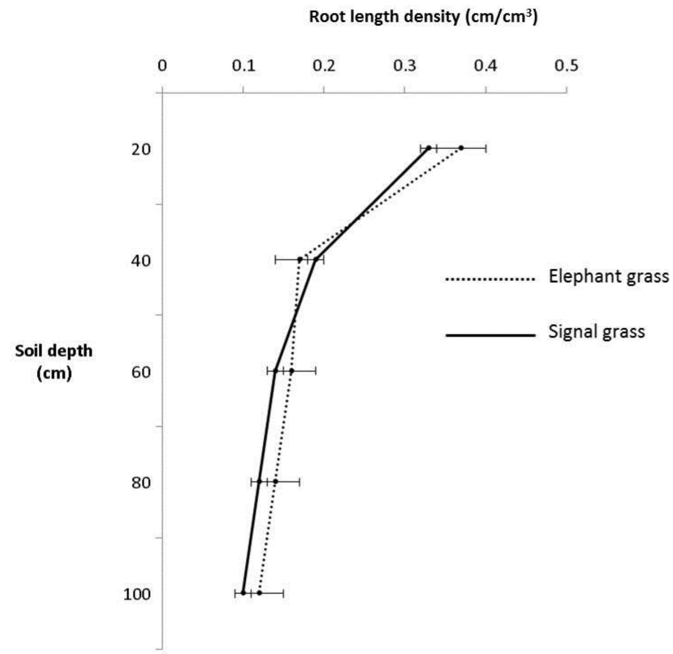

Figure 5. Root length density of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

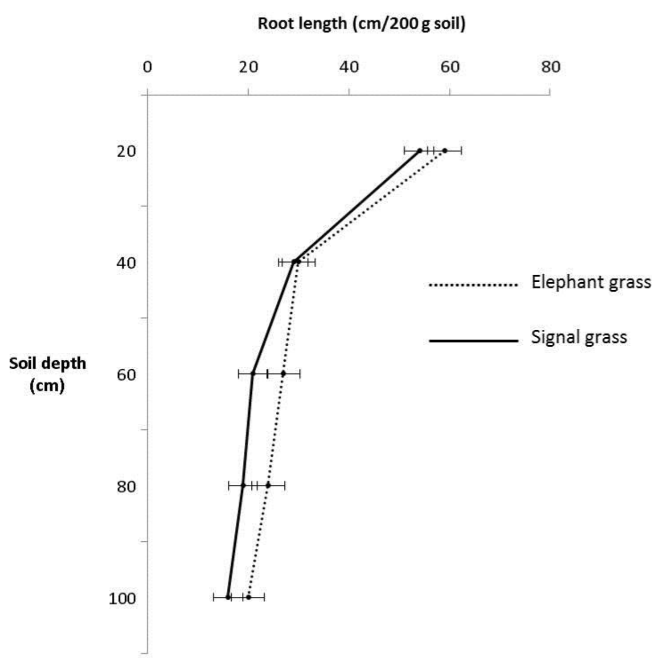

Figure 4. Root length of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

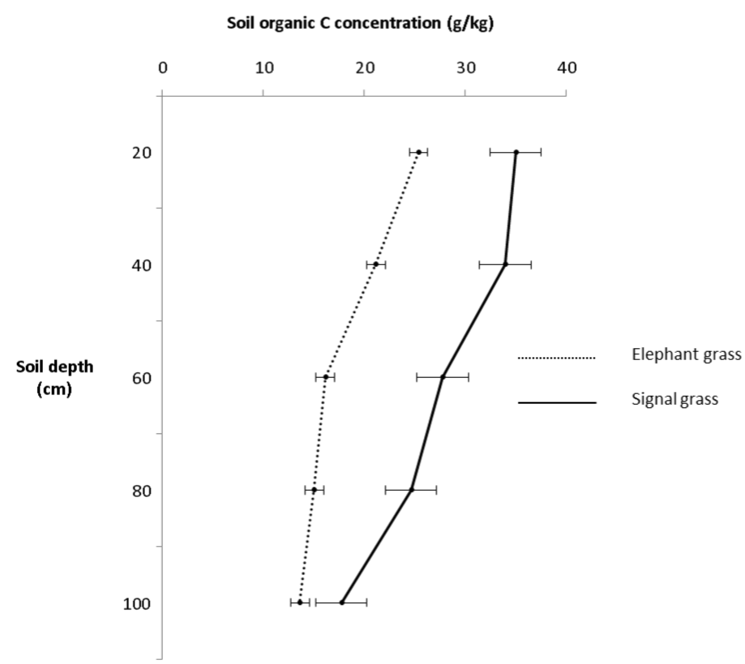

Figure 6. Soil organic carbon concentration of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

Discussion

This study has provided valuable additional information on amounts of carbon in soils under tropical grass pastures, highlighting the role that tropical grass pastures can play in removing carbon from the atmosphere.

Marchão et al. (2009) compared crop and livestock systems and observed that pasture areas in Central Brazil contained 52.2 and 53.2 t C/ha in the 0–30 cm soil layer for rotational and continuous stocking, respectively. Other studies (D'Andréa et al. 2004; Silva et al. 2004; Bayer et al. 2006) reported values of 54, 31 and 41 t C/ha for the 0–20 cm soil layer, similar to the values observed for elephant grass in the current research. Soil C stocks to 40 cm of 117 t/ha (elephant grass) and 184 t/ha (signal grass) can be compared with a range of 69.6–81.9 t/ha quoted by Fisher et al. (2007) for a range of pastures in various stages of health.

Fisher et al. (1998) speculated that differences amongst species in soil C stocks might possibly be related to differences in the composition of litter, which in turn would affect their rates and patterns of decomposition. Greater above-ground litter biomass observed in signal grass pastures may have resulted in higher soil organic C concentration in our pastures. Additionally, the lower quality of signal grass litter reduces its decomposition, leading to higher soil carbon accumulation. Higher C concentration and content at shallower soil depths is directly linked to litter deposition on the soil surface and greater root biomass in the superficial layers (Figure 2). Costa et al. (2009a) observed greater C stocks in the 0–20 cm soil layer, with the best results for well-managed signal grass pastures compared with areas of native vegetation and degraded pastures. According to these authors, greater root biomass in signal grass pastures was the main reason for greater C stocks.

Short duration of the study would have been an important factor in the failure to show differences in C stocks on different treatments. For elephant grass pastures, the lack of response to grazing intensity may also be due to the small amplitude observed for the actual post-grazing stubble heights during the experimental period, which averaged 71.5 ± 18.1 cm, 98.7 ± 12.9 cm, and 117.0 ± 9.6 cm for the target heights of 40, 80 and 120 cm, respectively. A number of factors could have contributed to the failure to achieve the desired target heights, including the addition of insufficient animals during the adjustment of stocking rate, and low forage quality, because of lignified stems left after grazing. Large variation in tiller height within each elephant grass tussock may also have affected post-grazing stubble height measurements.

The values for total root biomass in the top 100 cm of soil in this study are similar to the 5.25 t/ha reported by Fisher et al. (2007) in a 1-year-old *Brachiaria brizantha* pasture, but much lower than the 10.38 t/ha for a 7-year-old pasture of the same species. Oliveira et al. (2004) recorded root biomass levels under *B. brizantha* pastures with varying histories and ages from 4.6 to 39.7 t/ha in the top 40 cm.

Signal grass and elephant grass pastures showed similar trends in root responses, but elephant grass had greater root development at shallower depths (Figure 2). Root length and root length density varied from 16 to 54 cm/200 g of soil and 0.10 to 0.33 cm/cm^3, respectively. Increased clay content with depth in the soil could have reduced root development, through increased soil resistance to penetration. Rosolem et al. (1999) showed that development of maize (*Zea mays*) roots was reduced when clay content exceeded 40% due to soil compaction. Other factors such as lower soil fertility, especially soil P concentration, higher soil density and less aeration in deeper soil layers also restrict root development in these layers. Studying crop rotation systems, De Maria et al. (1999) related higher levels of extractable P and soil moisture in topsoil layers to higher root length density. Costa et al. (2009b) linked greater maize root length density to higher soil P concentrations at shallower depths. At the experimental site, soil P was 12.2 mg/dm^3 for the 0–20 cm layer and ranged from 2.7 to 6.1 mg/dm^3 for the other layers (Tables 1 and 2).

Highest root concentrations in the top 20 cm of soil have also been reported for *Panicum maximum* (Sarmento et al. 2008), *B. brizantha* (Oliveira et al. 2004) and *B. decumbens* (Fisher et al. 2007). Sarmento et al. (2008) observed that 85% of the roots of *Panicum maximum* were found in the 0–20 cm soil layer, when it was managed under rotational stocking and N fertilization (0, 150, 300 and 450 kg N/ha/yr), regardless of the level of N applied. The reduction in root biomass with increasing soil depth was more evident for elephant grass, which is likely due to its lower Al tolerance. Signal grass tolerance of Al toxicity depends on mechanisms of Al elimination via the root system (Wenzl et al. 2002; Hartwig et al. 2007). Hydroponic studies revealed that signal grass has a higher tolerance for Al than the most tolerant genotypes of maize, wheat (*Triticum aestivum*) and triticale (*Triticosecale rimpaui*) (Wenzl et al. 2001).

Grazing systems are increasingly perceived as an alternative to mitigate major environmental impacts encountered in intensive livestock systems, but proper pasture and grazing management are required. Well-managed pastures with good soil cover reduce soil erosion and maintain or enhance soil fertility. In poorly-managed pastures, however, pasture degradation may lead to negative environmental impacts. Dubeux et al. (2006a; 2006b) defined above-ground litter as the vegetal residue from plant senescence (shoot) deposited on the soil surface. This layer (litter) may immobilize and mineralize nutrients, acting as a buffering pool in intensive production systems.

Carbon sequestration from the atmosphere is currently considered a positive aspect that well-managed grasslands may provide. Fisher et al. (1994) reported that the global CO_2 balance from the atmosphere suggests a level of C retention of approximately 0.4 to 4.3 Gt per year through unidentified C sinks. A large part of this C, however, may be retained by deep-rooted grasses in pasture ecosystems. The same authors observed that C sequestration by such grasses in South America is of global importance owing to the extensive areas of pastures in this region.

Conclusion

While post-grazing stubble height and stocking rate did not affect soil C stocks and root systems during the evaluation period, the short duration of the study could have been a major factor. Studies over longer periods are needed to confirm these results. It is obvious that these pastures can store significant amounts of carbon below ground, which is an important attribute of tropical pastures located in more humid regions.

References

Bayer C; Martin Neto L; Mielniczuk J. 2006. Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil & Tillage Research 86:237–245.

Bland WL; Mesarch MA. 1990. Counting error in the line-intercept method of measuring root length. Plant and Soil 125:155–157.

Chapuis-Lardy L; Brossard M; Lopes Assad ML. 2002. Carbon and phosphorus stocks of clayey Ferralsols in Cerrado native and agroecosystems, Brazil. Agriculture, Ecosystems & Environment 92:147–158.

Costa OV; Cantarutti RB; Fontes LEF. 2009a. Soil carbon stock from a pasture in the Coastal Plains, southern Bahia State. Revista Brasileira de Ciência do Solo 33:1137–1145.

Costa SEVGA; Souza ED; Anghinoni I. 2009b. Phosphorus and root distribution and corn growth as related to long-term tillage systems and fertilizer placement. Revista Brasileira de Ciência do Solo 33:1237–1247.

Cunha MV da; Santos MVF dos; Lira M de A. 2007. Características estruturais e morfológicas de genótipos de *Pennisetum* sp. sob pastejo no período de seca. Revista Brasileira de Zootecnia 36:540–549.

D'Andréa AF; Silva MLN; Curi N. 2004. Carbon stocks and mineral N forms in soil submitted to different management systems. Pesquisa Agropecuária Brasileira 39:179–186.

De Maria IC; Nnabude PC; Castro OM. 1999. Long-term tillage and crop rotation effects on soil chemical properties of a Rhodic Ferrasol in southern Brazil. Soil & Tillage Research 51:71–79.

Dubeux Jr JCB; Sollenberger LE; Vendramini JMB. 2006a. Litter mass, deposition rate, and chemical composition in bahiagrass pastures managed at different intensities. Crop Science 46:1299–1304.

Dubeux Jr JCB; Sollenberger LE; Vendramini JMB. 2006b. Litter decomposition and mineralization in bahiagrass pastures managed at different intensities. Crop Science 46:1305–1310.

EMBRAPA. 1997. Manual de Métodos de Análise de Solo. 2nd Edn. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa de Solos. Rio de Janeiro, Brazil.

Fisher MJ; Rao IM; Ayarza MA. 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371:236–238.

Fisher MJ; Thomas RJ; Rao IM. 1998. Management of tropical pastures in the acid-soil savannas of South America for carbon sequestration in the soil. In: Lal R; Kimble JM; Follett RF; Stewart BA, eds. Management of carbon sequestration in soil. Advances in Soil Science, CRC Press, Boca Raton, FL, USA. p. 405–420.

Fisher MJ; Braz SP; Santos RSM; Urquiaga S; Alves BJR; Boddey RM. 2007. Another dimension to grazing systems: Soil carbon. Tropical Grasslands 41:65–83.

Freitas EV; Lira MA; Dubeux Jr JCB. 2004. Características produtivas e qualitativas de clones de capim-elefante (*Pennisetum purpureum* Schum.) avaliados sob pastejo na Zona da Mata de Pernambuco. Acta Scientiarum 26:251–257.

Hartwig I; Oliveira AC; Carvalho FIF. 2007. Mechanisms associated to Al tolerance in plants. Ciência Agraria 28:219–228.

ITEP (Instituto Pernambucano de Tecnologia). 2010. Climatological data.

Marchão LR; Becquer T; Brunet D. 2009. Carbon and nitrogen stocks in a Brazilian clayey Oxisol: 13-year effects of integrated crop-livestock management systems. Soil & Tillage Research 103:442–450.

Oliveira OC; Oliveira IP; Alves BJR; Urquiaga S; Boddey RM. 2004. Chemical and biological indicators of decline/degradation of *Brachiaria* pastures in the Brazilian Cerrado. Agriculture, Ecosystems & Environment 103: 289–300.

Raven PH; Evert RF; Eichhorn SE. 2001. Plant Biology. 6th Edn. Translated by A. Salatino. Guanabara Koogan, Rio de Janeiro, Brazil.

Rosolem CA; Fernandez EM; Andreotti M; Crusciol CAC. 1999. Root growth of corn seedlings as affected by soil resistance to penetration. Pesquisa Agropecuária Brasileira 34:821–828.

Santos HQ; Fonseca DM; Cantarutti RB. 2002. Phosphorus critical levels in the soil and in the plant for tropical forage crops at different ages. Revista Brasileira de Ciência do Solo 26:173–182.

Sarmento P; Rodrigues LRA; Cruz MCP. 2008. Root system of *Panicum maximum* Jacq. cv. 'IPR-86 Milênio' fertilized with N and submitted to rotational stocking. Revista Brasileira de Zootecnia 37:27–34.

SAS Institute Incorporated. 1996. SAS statistics user's guide. Release version 6. SAS Institute Incorporated, Cary, NC, USA.

Silva JE; Resck DVS; Corazza EJ. 2004. Carbon storage in clayey Oxisol cultivated pastures in the "Cerrado" region, Brazil. Agriculture, Ecosystems & Environment 103:357–363.

Silva LE; Ranno SK. 2005. Liming on poor-drained soils and nutrient availability in the soil solution after flooding. Ciência Rural 35:1054–1061.

Veldkamp E. 1994. Organic carbon turnover in three tropical soils under pasture after deforestation. Soil Science Society of America Journal 58:175–180.

Wenzl P; Patiño GM; Chaves AL. 2001. The high level of aluminum resistance in signalgrass is not associated with known mechanisms of external aluminum detoxification in root apices. Plant Physiology 125:1473–1484.

Wenzl P; Chaves AL; Patiño GM. 2002. Aluminum stress stimulates the accumulation of organic acids in root apices of *Brachiaria* species. Journal of Plant Nutrition and Soil Science 165:582–588.

Zinn YL; Lal R; Resck DVS. 2005. Changes in soil organic carbon stocks under agriculture in Brazil. Soil & Tillage Research 84:28–40.

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Effect of cassava chips on quality of silage from fresh forage sorghum plus Cavalcade forage legume hay mixtures

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Abstract

Two experiments investigated the effects on silage quality of adding cassava chips at a range of levels to a sorghum forage plus Cavalcade legume hay mixture at ensiling at the Experimental Farm, Khon Kaen University, Thailand. Cavalcade hay was 15% of chopped sorghum fresh weight and cassava chips were added at 0, 5, 10 and 15% of chopped sorghum fresh weight. The first experiment utilized sorghum and Cavalcade main crops and the second used the ratoon crop of sorghum and 2nd cut of Cavalcade. Dry matter percentage of ensiled mixtures and silages increased (P<0.05) with an increase in cassava chip levels in both experiments, but CP and NDF concentrations decreased (P<0.05). Dry matter degradability increased (P<0.05) with an increase in cassava chip levels up to 10% in both main and ratoon/2nd cut silages. Digestible energy and metabolizable energy of both silages increased significantly with an increase in cassava chip levels up to 10% for main crop and 15% for ratoon/2nd cut crops. While addition of cassava chips improved digestibility and energy content of silage, it lowered CP concentration. Use of fresh Cavalcade instead of hay should increase the CP levels and should be investigated along with animal feeding studies to test acceptance and animal performance.

Resumen

En el campo experimental de la Universidad Khon Kaen, Tailandia, se realizaron sendos experimentos para evaluar el efecto de la adición de trozos (chips) de yuca (*Manihot esculenta*) en la calidad del ensilaje de una mezcla de sorgo forrajero con heno de la leguminosa forrajera *Centrosema pascuorum* cv. Cavalcade, este último en una proporción de 15% del peso verde del sorgo en la mezcla. Los chips se agregaron en proporciones de 0, 5, 10 y 15% del peso fresco del sorgo picado. En un primer ensayo se utilizaron sorgo y cv. Cavalcade de la primera cosecha (material de plantas previamente no cortadas) y en el segundo, material proveniente de plantas rebrotadas después de un primer corte. El porcentaje de materia seca (MS) de las mezclas tanto al momento de ensilar como del ensilaje ya listo para consumo, aumentó (P<0.05) en la medida que en ambos ensayos los niveles de chips de yuca en la mezcla aumentaron. No obstante, los porcentajes de proteína cruda (PC) y fibra detergente neutra disminuyeron (P<0.05). La degradabilidad de la MS aumentó (P<0.05) con el incremento del nivel de chips (hasta el nivel 10%) en ambos experimentos. Las energías digestible y metabolizable de ambos ensilajes aumentaron (P<0.05) con el incremento del nivel de chips hasta el nivel 10% en el primer ensayo y 15% en el segundo. Mientras que la adición de chips de yuca mejoró la digestibilidad y el contenido de energía del ensilaje, redujo la concentración de PC. Se sugiere estudiar si el uso de material fresco de la leguminosa en lugar de heno incrementa las concentraciones de PC en el ensilaje. Además se sugiere conducir estudios con animales para evaluar la aceptabilidad de los ensilajes y su efecto sobre la producción animal.

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Introduction

Sorghum cultivation for use as livestock feed in Thailand began in 1962. Sorghum cultivars were compared from 1962 to 1966 to select for grain yield and quality (Senanarong 1977). Subsequent research concentrated on forage sorghum (Suchato et al. 1991; Phaikaew et al. 1992; Pothisoong et al. 2005). A comparison of dry matter (DM) yields of 10 sorghum varieties for forage showed that cultivar IS 23585 was the most suitable for use in Northeast Thailand, producing high DM yield and good nutritive value in both main and ratoon crops (Pholsen et al. 1998, 2001; Pholsen and Higgs 2005).

Water soluble carbohydrates (WSC) in ensiled crops are a source of energy for bacteria to produce lactic acid and lower pH to <4.2 for good silage quality (McDonald et al. 1991; Miron et al. 2007). High sucrose content (measured as brix value, one kind of WSC) in forage sorghums results in good silage quality (Phaikaew et al. 2003; Pholsen and Sornsungnoen 2004). Although excellent silages can be made from forage sorghums, crude protein (CP) concentrations decrease with increase in stage of maturity (Black et al. 1980; Pholsen and Higgs 2005). This drop in CP can be counteracted by including a forage legume at ensiling, e.g. sugarcane tops plus leucaena (*Leucaena leucocephala*) leaves (Sangchote et al. 1992) or pangola grass (*Digitaria eriantha*) plus Thapra stylo (*Stylosanthes guianensis* CIAT 184) (Khuamangkorn et al. 2006). Higher WSC in the forage legume Cavalcade centro (*Centrosema pascuorum* cv. Cavalcade) than Thapra stylo resulted in a lowered silage pH (Namsele et al. 2007).

The quality, both DM and CP, of low-DM (high-moisture) grass silage can be improved with the addition of legume hay (Church and Pond 1988; Wilkinson 1990). Adding 8% ground Cavalcade hay plus 5% cassava chips to Napier grass (*Pennisetum purpureum*) significantly increased DM content, but decreased CP concentration and lowered pH of silages to <4.27 (Pongpeajan et al. 2008). Khota et al. (2009) reported that adding Cavalcade hay at up to 20% to forage sorghum cultivar IS 23585 at ensiling significantly increased DM, CP and dry matter degradability (DMD) of the silages and all Cavalcade levels produced good silage quality with pH ranging from 3.38 to 3.70 and NH_3-N from 1.29 to 1.71% of total N. They suggested that Cavalcade hay levels from 10 to 20% of sorghum fresh weight could be the optimum levels to add to forage sorghum with DM contents ranging from 26.6 to 33.9%, CP 8.80 to 10.65% and DMD from 58.9 to 59.1%, respectively.

Cassava chips (*Manihot esculenta*) could be a useful additive to sorghum plus Cavalcade forage for making silage because it is high in energy, has high digestibility and is abundant in Thailand, where it can be produced easily by farmers, although it is low in nitrogen (Chanjula et al. 2003; WTSR 2010). Pongpeajan et al. (2008) found that adding cassava chips at 5% to Napier grass plus Cavalcade forage resulted in good quality silage, but lowered CP concentration.

There are, however, no reports of addition of cassava chips to forage sorghum and Cavalcade hay mixtures for silage making. Addition of cassava chips to these materials should result in good silage quality with high digestibility.

This laboratory experiment was designed as a preliminary study to examine the effects of addition of cassava chips to mixtures of forage sorghum and Cavalcade hay on quality, chemical composition, DMD, gross energy (GE), digestible energy (DE) and metabolizable energy (ME) of silages made from both main and ratoon crops.

Materials and Methods

Sowing ensiled crops

The sorghum and Cavalcade centro crops for these experiments were grown at the Experimental Farm, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Northeast Thailand from May to November 2008 on Korat Soil Series (Oxic Paleustults). The mean values for soil pH, soil organic matter, N, P (Bray II method) and K were 5.62, 1.15%, 0.04%, 21.8 ppm and 44.3 ppm, respectively. An area of 400 m^2 was used to grow Cavalcade centro and a similar area alongside the Cavalcade plot for sorghum (*Sorghum bicolor*).

The plots were plowed twice and harrowed once. Before the second plowing, the soil on the sorghum plot was basal dressed with fermented cattle manure at 40 t/ha, dolomite [$CaMg(CO_3)_2$] at 3,125 kg/ha and 57.5 kg P/ha. NPK fertilizer (15:15:5) at 312.5 kg/ha was applied on the Cavalcade centro plot before harrowing.

Cavalcade seed was sown on 6 June 2008, and sorghum on 11 June at seeding rates of 25 kg/ha. Sowing was by hand into furrows 5 cm deep and 50 cm apart, and seed was covered with soil. Weeds on the Cavalcade centro area were hoed at 4 weeks after emergence. Carbofuran insecticide (3% a.i.) at 37.5 kg/ha was applied to the sorghum area after sowing. After covering the sorghum seeds, the plots were sprayed with pre-emergence Atrazine herbicide at a rate of 2.19 kg/ha to control weeds. At 7 days after emergence, seedlings were thinned to allow a spacing of 1 plant per 10 cm and weeding was carried out 1 week later.

Fertilizer at 600 kg N/ha was applied to the main crop of sorghum as equal split dressings at 2, 4 and 8 weeks after emergence (WAE) and to the ratoon crop at 2 and 4 weeks after harvesting of the main crop (WAC). Potassium fertilizer at 100 kg K/ha was applied to the main and ratoon crops as equal split dressings at 2 and 4 WAE and WAC, respectively.

The sorghum plot was divided into 4 sub-plots, and an area of 4 m^2 from each sub-plot was randomly chosen for cutting to measure fresh and DM yields. On 30 August 2008 (11 WAE), 20 plants from each sub-plot were randomly chosen and were squeezed to extract juice for determining sucrose concentration in stems or brix value (as gram unit of sucrose in 100 g of sucrose solution) using a hand-held refractometer (ATAGO N-1 α, Japan). After this sampling, the remainder of the sorghum plots, excluding border rows, was cut at 15 cm above ground level and the crop allowed to ratoon (Khota et al 2009). The same cutting and measuring methods as for the main crop were used with the ratoon crop at 11 WAC on 15 November 2008. All harvested forage was chopped into lengths of 3–5 cm with a machine chopper, and the chopped plant material was thoroughly mixed for silage making.

For Cavalcade centro, the plot was divided into 4 sub-plots to measure fresh and DM yields using four 1 m^2 quadrats in each sub-plot. First cutting was made on 25 August 2008 (11 WAE) for the main crop and on 10 November 2008 (11 WAC) for the second cut. Both cutting heights were made at 15 cm above ground level (Waipanya and Poonpipat 2006). After yield sampling, all fresh Cavalcade plants, excluding border rows, were cut, dried, chopped (3–5 cm length) and kept in polythene bags for mixing with sorghum before ensiling. Samples of 500 g of each of the 4 replications of chopped sorghum and Cavalcade hay were oven-dried separately at 60 °C for 48 h, ground to pass through a 1 mm sieve and kept in air-tight polythene bags for analyses of DM, CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and DMD. Samples of cassava chips were also stored for analyses for chemical composition and DMD.

Silage preparation and experiments

The experiment had a Completely Randomised Design with 4 replications. The main crop was used in Experiment 1 and the ratoon crop (2^{nd} cut for Cavalcade) in Experiment 2. Each had 4 treatments of 4 levels of dried cassava chips, viz. 0 (control), 5, 10 and 15% of fresh weight of chopped sorghum. Chopped Cavalcade hay (15% of fresh weight of chopped sorghum) was thoroughly mixed with chopped sorghum (Khota et al. 2009). A total of 260 kg of the mixture was divided into 4 equal portions of 65 kg: 1 portion for the control treatment, with the remaining 3 portions for mixing with the cassava chips at 5, 10 and 15% of the fresh weight of sorghum in the mixture. Cassava chips were added at the appropriate levels for the various treatments to the sorghum-Cavalcade mixture and the combinations thoroughly mixed. Before ensiling, 4 replications of 500 g of each treatment mixture were randomly sampled for chemical composition and DMD determination. Black polythene bags with a dimension of 61 x 71 cm were used to make silage. Each treatment mixture was loaded into 4 polythene bags, 15 kg each, and compressed tightly, before the remaining air was removed by vacuum pump and the bags were closed immediately. The bags were stored and allowed to ferment under ambient temperature for 5 weeks, when they were opened to assess quality in terms of silage physical characteristics using methods described by Zimmer (1980).

Silage sample collection and assessments

The silage in each bag was divided into 3 equal sections, viz. top, middle and bottom, and approximately 350 g from each section was selected and thoroughly mixed to make approximately 1 kg, which was divided into 2 equal parts and stored in air-tight polythene bags at -20 °C. One part was used to determine gross energy (GE), chemical composition and DMD, and the other for pH and ammonia-nitrogen (NH_3-N) determinations. The frozen silage was thawed and extracted with water as described by Bailey (1985). One portion of extracted water was used to measure pH using a glass electrode pH meter (Consort C933, Belgium), and the second for analyzing the NH_3-N. Analyses were performed as follows: CP and NH_3-N by the Kjeldahl method; GE using a bomb calorimeter (AOAC 1990); NDF, ADF and ADL by the methods of Van Soest et al. (1991); and DMD at 48 h in rumens of Brahman cattle by the nylon bag technique described by Ørskov et al. (1980). Digestible energy (DE) and metabolizable energy (ME) were predicted by the formulae: DE (MJ/kg) = 19.66DMD (DMD coefficient) - 0.70 (Minson and Milford 1966); and ME (MJ/kg) = 0.9613DE - 1.2276 (WTSR 2010).

Statistical analyses

The data were statistically analyzed using the SAS software program (SAS 1996). The t-test at the alpha level of 0.05 was used to compare the means of DM yields and characteristics of main and ratoon/2nd cut crops before ensiling. The data from the silage experiments were analyzed by one-way analysis of variance and the treatment mean differences were determined by Duncan's New Multiple Range Test (DMRT) at P=0.05.

Results

Climatic conditions

The work took place in the rainy season (mid-May–mid-October) and partly in the cold season (mid-October–November) with climatic conditions recorded from May to November 2008. Rainfall ranged from 70 to 462 mm per month, and number of rainfall days from 4 to 19 days for November and September, respectively; maximum temperature ranged from 29.7 to 33.0 ºC, minimum temperature from 20.5 to 25.8 ºC, and average temperature from 25.1 to 29.4 ºC, for November and June, respectively; evaporation from 102 to 162 mm for September and June, respectively; relative humidity from 91 to 82%; sunshine duration from 5.1 to 8.0 h/d; and solar radiation energy from 187 to 213 cal/cm^2/d for September and November, respectively.

Crop yields and characteristics before ensiling

The growing period for main and ratoon/2nd cut crops of sorghum and Cavalcade centro was 11 weeks. Both main crops had DM yields significantly (P<0.05) higher than their ratoon/2nd cut crops (Table 1). Crude protein concentrations for Cavalcade were about double those for sorghum. Fiber concentrations (NDF, ADF) for the main sorghum crop were significantly (P<0.05) higher than for the ratoon. The main sorghum crop gave a DMD value significantly (P<0.05) lower than the ratoon, while the opposite was the case for Cavalcade, where DMD of the main crop was higher than that of the 2nd cut. Sucrose concentration in terms of brix value was significantly lower in the main sorghum crop than in the ratoon.

Chemical composition and dry matter degradability of ensiled materials

Chemical composition of cassava chips was: 91.3, 1.49, 10.4, 4.82 and 2.19% for DM, CP, NDF, ADF and ADL, respectively; 95.7% for DMD; and 18.16 MJ/kg for GE. Increase in cassava chip levels significantly (P<0.05)

Table 1. Dry matter (DM) yield, chemical composition, dry matter degradability (DMD) and brix value of main and ratoon/2nd cut crops of sorghum and Cavalcade centro before ensiling.

	DM yield (kg/ha)	DM at harvest (%)	DM of hay (%)	CP	NDF	ADF	ADL	DMD[1]	Brix (%)
				(% DM)					
Sorghum									
Main crop	20,825a[1]	23.1b		6.1b	69.5a	40.5a	7.06	64.2b	10.8b
Ratoon crop	10,025b	26.0a		7.2a	66.3b	35.5b	5.86	69.4a	13.9a
s.e.	443.9	0.11		0.06	0.20	0.75	0.70	0.51	0.64
Cavalcade									
Main crop	2,713x	18.9y	91.5	14.6x	53.8	37.2	7.05	71.8x	
2nd cut	1,781y	38.4x	92.0	13.0y	54.0	37.2	8.85	67.7y	
s.e.	53.54	0.02	1.13	0.16	0.36	0.59	0.46	0.78	

[1]Means within species in the same column followed by different letters differ (P<0.05).

Table 2. Effects of level of cassava chips on chemical composition and dry matter degradability (DMD), at ensiling, of mixtures of sorghum, Cavalcade centro and cassava chips for main and ratoon/2nd cut crops.

Parameter	Level of cassava chips (%)					Level of cassava chips (%)				
	0	5	10	15	s.e.	0	5	10	15	s.e.
	Main crop					Ratoon/2nd cut crop				
DM (%)	33.6c[1]	34.8bc	36.4b	39.0a	0.70	33.0c	37.0b	38.0ab	39.8a	0.68
CP (%)	9.26a	8.59ab	7.97bc	7.80c	0.21	9.16a	8.53b	7.61c	7.24d	0.07
NDF (%)	67.5a	63.3b	57.4c	55.1d	0.54	66.1a	62.4b	60.4c	54.7d	0.56
ADF (%)	43.2a	41.0ab	39.0bc	37.1c	0.88	39.8a	37.5a	32.0b	31.1b	0.77
ADL (%)	7.40	6.45	6.42	5.65	0.70	6.19	5.41	5.26	5.18	0.50
DMD (%)	65.1d	66.6c	69.0b	70.4a	0.38	66.5c	67.9cb	69.8b	72.9a	0.64

[1]Means within crops in the same row followed by different letters differ (P<0.05).

increased DM and lowered CP, NDF and ADF concentrations in mixtures for both main and ratoon/2nd cut crops at ensiling (Table 2). Dry matter degradability significantly ($P<0.05$) increased with an increase in cassava chip levels.

Gross energy, digestible energy and metabolizable energy of ensiled materials

Level of cassava chips had no effect on GE levels in ensiled material ($P>0.05$) (Table 3), while both DE and ME increased significantly ($P<0.05$) with increasing cassava chip levels. The highest values of DE and ME were found with the highest level of cassava chips (15%) for both crops.

Characteristics of silages

Dry matter contents of silages from both crops increased significantly with an increase in cassava chip levels (Table 4). Adding cassava chips significantly increased pH values of the ratoon/2nd cut crop silage but not of the main crop silage. Cassava chip level had no significant effect on NH_3-N concentrations in the silages.

Chemical composition and dry matter degradability of silages

Neutral detergent fiber, ADF and CP concentrations decreased significantly with increase in cassava chips in both crop silages (Table 5), while DMD increased significantly as level of cassava chips increased for both crops.

Gross energy, digestible energy and metabolizable energy of silages

Cassava chip levels had no significant effect on GE (Table 6), but both DE and ME increased with increasing levels of cassava chips.

Table 3. Effects of level of cassava chips on gross energy (GE), digestible energy (DE) and metabolizable energy (ME), at ensiling, of mixtures of sorghum, Cavalcade centro and cassava chips for main and ratoon/2nd cut crops.

Parameter	Level of cassava chips (%)					Level of cassava chips (%)				
	0	5	10	15	s.e.	0	5	10	15	s.e.
	Main crop					Ratoon/2nd cut crop				
GE (MJ/kg)	20.55	16.79	17.39	17.12	1.37	13.91	16.14	16.48	17.34	0.98
DE (MJ/kg)	12.10d[1]	12.39c	12.87b	13.15a	0.075	12.38c	12.64bc	13.03b	13.64a	0.126
ME (MJ/kg)	10.41d	10.68c	11.15b	11.41a	0.072	10.68c	10.93bc	11.28b	11.87a	0.119

[1]Means within crops in the same row followed by different letters differ ($P<0.05$).

Table 4. Effects of level of cassava chips on characteristics of silages made from mixtures of sorghum forage, Cavalcade centro and cassava chips for main and ratoon/2nd cut crops.

Parameter	Level of cassava chips (%)					Level of cassava chips (%)				
	0	5	10	15	s.e.	0	5	10	15	s.e.
	Main crop					Ratoon/2nd cut crop				
DM (%)	33.3d[1]	34.8c	38.2b	39.9a	0.40	33.0c	35.2b	37.4a	38.9a	0.48
pH	3.83	3.78	3.81	3.80	0.02	4.04b	4.08ab	4.11a	4.13a	0.02
NH_3-N (% total N)	1.64	1.87	1.89	1.89	0.23	1.65	1.88	1.88	1.88	0.24

[1]Means within crops in the same row followed by different letters differ ($P<0.05$).

Table 5. Effects of level of cassava chips on chemical composition and dry matter degradability (DMD) of silages made from mixtures of sorghum forage, Cavalcade centro and cassava chips for main and ratoon/2nd cut crops.

Parameter	Level of cassava chips (%)					Level of cassava chips (%)				
	0	5	10	15	s.e.	0	5	10	15	s.e.
	Main crop					Ratoon/2nd cut crop				
CP (%)	8.74a[1]	8.43b	7.67c	6.86d	0.06	8.65a	7.84b	7.56b	7.15c	0.11
NDF (%)	65.8a	63.6b	59.6c	57.9d	0.42	65.3a	64.4a	58.9b	55.6c	0.38
ADF (%)	41.2a	39.8a	36.6b	35.7b	0.57	35.4a	32.1b	30.8bc	29.3c	0.72
ADL (%)	6.03	5.35	5.26	5.24	0.34	4.81	4.61	4.68	4.61	0.29
DMD[2] (%)	65.0b	66.0b	69.2a	69.4a	0.39	70.4b	71.7b	73.7a	75.3a	0.60

[1]Means within crops in the same row followed by different letters differ ($P<0.05$).

Table 6. Effects of level of cassava chips on gross energy (GE), digestible energy (DE) and metabolizable energy (ME) of silages made from mixtures of sorghum forage, Cavalcade centro and cassava chips for main and ratoon/2nd cut crops.

Parameter	Level of cassava chips (%)					Level of cassava chips (%)				
	0	5	10	15	s.e.	0	5	10	15	s.e.
	Main crop					Ratoon/2nd cut crop				
GE (MJ/kg)	18.55	20.80	19.57	19.15	0.91	18.91	18.65	17.87	17.63	0.41
DE[2] (MJ/kg)	12.08b[1]	12.27b	12.91a	12.94a	0.070	13.15c	13.40c	13.80b	14.11a	0.096
ME[3] (MJ/kg)	10.38b	10.57b	11.18a	11.21a	0.076	11.41c	11.66c	12.03b	12.34a	0.092

[1]Means within crops in the same row followed by different letters differ (P<0.05).

Discussion

This study has shown that good quality silage can be made from mixtures of forage sorghum, Cavalcade centro hay and cassava chips, regardless of whether first cut or second cut forage is used. When cut at 11 weeks after sowing or at 11 weeks of regrowth, the silages had CP concentrations of 8.7 to 6.9%, DMD of 65–75% and pH of 3.8–4.1, depending on how much cassava chip was added. This indicated that there was enough WSC in terms of brix values in main (10.84%) and ratoon (13.85%) crops of sorghum with addition of Cavalcade hay (15%) and cassava chip levels (0–15%) to make good quality silage.

Available soil moisture levels could have contributed to the differences in yield of the main and ratoon crops of sorghum and Cavalcade centro, as the main crops were grown in the rainy season (mid-May–mid-October) and the ratoon crops partly in both rainy and cold seasons (September–mid-February). Hence soil moisture levels would have been adequate for the main crop and the early regrowth of the ratoon crop, while declining rainfall in October and only 69.9 mm over 4 days of rainfall in November could have limited growth. Differences in hours of sunlight and daily temperature could have played a part as well.

Sorghum and Cavalcade both produce floral parts late in the season, since they are short-day plants (Cook et al. 2005). In Thailand, Cavalcade starts to flower in mid-October and mature seed can be harvested in mid-January (Phunphiphat et al. 2004). Dry matter yield and CP concentration of Cavalcade centro in the present work were lower than the 7,456 kg/ha/yr at 16.5% CP reported by Phunphiphat et al. (2008), although our data are for 22 weeks production only. Main crop sorghum commenced flowering in late August. High vegetative growth rates of sorghum early in the season resulted in higher DM yield and fiber concentration in forage from the main crop than from the ratoon. The short period of vegetative growth of ratoon sorghum late in the season accelerated flowering and resulted in fully developed seeds with higher starch content than in the main crop. The resulting higher ADF and ADL concentrations in forage from the main crop and virtual absence of seed were reflected in higher DMD and brix values for the ratoon. With Cavalcade, the very high rainfall with high relative humidity of 91% in September caused canopy die-back in the lower layers from fungal attack. This led to a decrease in CP concentration and DM yield of Cavalcade at the second harvest. The higher ADL concentration of the 2nd cut Cavalcade also resulted in lower DMD than in the main crop. ADL has an important role in limiting cell wall (NDF) degradability, i.e. the higher the ADL content the poorer the digestibility (Van Soest 1978; Minson 1990).

In main crops, DMD of Cavalcade was higher than that of sorghum, but in ratoon/2nd cut crops, sorghum was more digestible than Cavalcade. This could be attributed to high carbohydrate levels in seed of ratoon sorghum aiding digestibility, as reflected in the higher brix values of forage from the ratoon (13.9 vs. 10.8%). Forage legumes normally have higher digestibility than tropical grasses; Devahuti et al. (1992) reported that tropical grasses (14 species, 59 samples) had mean DMD values of 66.7%, which was lower than for tropical forage legumes (7 species, 14 samples, 72.5% DMD). A range of 41–60% DMD in grasses and 69–79% DMD in forage legumes was reported by Ibrahim et al. (1995). Therefore, when legume forage is ensiled with forage sorghum, the result is a significantly higher DMD than for sorghum alone (Khota et al. 2009).

The higher sucrose concentration (brix value) of ratoon sorghum than in the main crop reflected the greater seed head development and greater plant maturity in the ratoon crop at harvest. This is in agreement with a number of other reports; brix value and WSC in tropical grasses increase with an increase in cutting ages (Kunapongkiti et al. 2004). Pholsen and Suksri (2007) reported brix values with the same cultivar of main crop sorghum ranging from 10.6 to 11.8%. Higher brix values in ratoon than main crop sorghum were also reported by Rao et al. (2011).

Cavalcade centro was considered most suitable for silage making because it accumulated more WSC than other tropical forage legumes, viz. 6.08±0.09 and 6.22±3.35% at 60 and 90 days after emergence, respectively, compared with 3.43±1.34 and 4.90±0.18% for Verano stylo (*Stylosanthes hamata* cv. Verano) (Kunapongkiti et al. 2004). Brix value reflects sucrose concentration, which, along with other WSCs in forages, is an important source of energy for bacteria to produce lactic acid in the silage fermentation process. Namsele et al. (2007) reported pH 4.53 for Cavalcade silage attained from its WSC of 5.1% and pH 4.90 for *Stylosanthes guianensis* CIAT 184 with WSC of 2.9%.

For both ensiled materials and silages of both main and ratoon crops, DM contents significantly increased as cassava chip level increased with values ranging from 33.0 to 39.8%. This is attributable to the high DM content (91.2%) of added cassava chip. Church and Pond (1988) and Wilkinson (1990) suggest that high quality silage requires 25–35% DM and preferably 30–35%. Dry matter contents in this range of silage in our study were achieved with inclusion of no cassava or 5% of cassava chips.

Cassava chip levels did not significantly affect pH and NH_3-N of silages except for pH of ratoon/2nd cut crop silage. Ranges of pH for both silages were from 3.78 to 4.13 and NH_3-N from 1.64 to 1.89% of total N. Oude Elferink et al. (2000) and Khota et al. (2009) have shown that the rapid lowering of pH to <4.0 inhibits the growth of enterobacteria and clostridia, which break down protein in the silage to form ammonia. The low NH_3-N in this study shows cassava chips are a good source of WSC that will lower pH and reduce NH_3-N production. On the basis of pH, NH_3-N values and physical characteristics, both silages were defined as of good quality (Zimmer 1980; Skerman and Riveros 1990).

While addition of cassava chips increased the degradability and ME of the sorghum-Cavalcade centro silage, it did reduce the CP concentration. However, the CP concentrations in all silages were above the 7% critical level, at which nitrogen becomes limiting for rumen microorganism activity and feed intake is depressed (Milford and Minson 1966). However, in order to attain higher protein levels in the final product, fresh Cavalcade could be substituted for Cavalcade hay, as CP concentrations in fresh material would be higher than in hay.

The decrease in NDF and ADF with increase in cassava chip levels could be attributable to levels of carbohydrates in cassava chips diluting fiber content. Neutral detergent fiber of both silages in this work at cassava chip levels of 10 and 15% addition was lower than reported by Black et al. (1980) and Miron et al. (2007). Higher fiber concentrations in forage lower digestibility (Van Soest 1978; Chaves et al. 2002). The significant decrease in NDF due to higher cassava chip levels led to significantly increased DMD in both main and ratoon crops of the mixed ensiled materials. The added cassava chip levels could have aided digestibility of both silages due to the high DMD of cassava chips (95.7%), as high DM digestibility of cassava chips in the rumen was reported by Chanjula et al. (2003).

Conclusions

Adding of cassava chips to mixtures of freshly chopped forage sorghum and chopped Cavalcade centro hay (Cavalcade at 15% of sorghum fresh weight) at ensiling will improve the quality of the resulting silage in terms of DM, DMD, DE and ME. However, CP concentration in the resulting silage is significantly lowered, when 15% cassava chip is added. The use of fresh legume should be explored to improve CP levels in the silage, along with feeding studies with animals to measure animal performance.

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References

AOAC. 1990. Official methods of analysis of the Association of Official Analytical Chemists. 15th Edn. Benjamin Franklin Station, Washington, DC, USA.

Bailey S. 1985. The Analysis of Agricultural Materials. 3rd Edn. Reference book 427, Her Majesty's Stationery Office, London, UK.

Black JR; Ely LO; McCullough ME; Sudweeks EM. 1980. Effects of stage of maturity and silage additives upon the yield of gross and digestible energy in sorghum silage. Journal of Animal Science 50:617−624. http://goo.gl/AEmTa1

Chanjula P; Wanapat M; Wachirapakorn C; Uriyapongson S; Rowlinson P. 2003. Ruminal degradability of tropical feeds and their potential use in ruminant diets. Asian-Australasian Journal of Animal Sciences 16:211−216.

Chaves AV; Waghorn GC; Brookes IM; Hedderley D. 2002. Digestion kinetics of ryegrass. Proceedings of the New Zealand Society of Animal Production 62:157−162. http://goo.gl/VjGyLP

Church DC; Pond WG. 1988. Basic Animal Nutrition and Feeding. 3rd Edn. John Wiley & Sons, New York, USA.

Cook BG; Pengelly BC; Brown SD; Donnelly JL; Eagles DA; Franco MA; Hanson J; Mullen BF; Partridge IJ; Peters M;

Schultze-Kraft R. 2005. Tropical forages: an interactive selection tool. [CD-ROM], CSIRO, DPI&F (Qld), CIAT and ILRI, Brisbane, Australia. http://goo.gl/DK8GHy

Devahuti P; Phaikaew C; Tawatun H; Boonpukdee W. 1992. Relationship between *in vivo* nylon bag and pepsin cellulase *in vitro* dry matter digestibility of some tropical forage species. An Annual Research Report 1992, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Ibrahim MNM; Tamminga S; Zemmelink G. 1995. Degradation of tropical roughages and concentrate feeds in the rumen. Animal Feed Science and Technology 54:81−92.

Khota W; Pholsen S; Rodchum P. 2009. Effect of Cavalcade (*Centrosema pascuorum* cv. Cavalcade) hay additive on silage quality of forage sorghum (*Sorghum bicolor* L. Moench). In: Proceedings of Greater Mekong Sub-region Conference on Sustainable Development, Nakhon Phanom 2009. Nakhon Phanom University, Nakhon Phanom, Thailand. p. 109−116. http://goo.gl/SF5ca7

Khuamangkorn P; Klum-em K; Martosot S. 2006. Effect of using additives on silage quality of Pangola grass. An Annual Research Report 2006, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Kunapongkiti S; Boonjaratcha J; Ketkamalas S. 2004. The study on relationship between WSC and sweetness of forage juice at various cutting intervals. An Annual Research Report 2004, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

McDonald P; Henderson AR; Heron SJE. 1991. The biochemistry of silage. 2nd Edn. Chalcombe Publications, Marlow, Buckinghamshire, UK.

Milford R; Minson DJ. 1966. Intake of tropical pasture species. In: Proceedings of the IX International Grassland Congress, São Paulo, Brazil, 1965. p. 814−822.

Minson DJ. 1990. Forage in ruminant nutrition. Academic Press, New York, USA.

Minson DJ; Milford R. 1966. The energy values and nutritive value indices of *Digitaria decumbens*, *Sorghum almum* and *Phaseolus atropurpureus*. Australian Journal of Agricultural Research 17: 411−423. DOI: 10.1071/AR9660411

Miron J; Zuckerman E; Adin G; Solomon R; Shoshani E; Nikbachat M; Yosef E; Zenou A; Weinberg ZG; Chen Y; Halachmi I; Ben-Ghedalia D. 2007. Comparison of two forage sorghum varieties with corn and effect of feeding their silages on eating behaviour and lactation performance of dairy cows. Animal Feed Science and Technology 139:23−39. http://goo.gl/vFGO94

Namsele R; Khuamangkorn P; Pholsen P; Martosot S. 2007. The study on silage quality of Ruzi (*Brachiaria ruziziensis*), Thapra Stylo (*Stylosanthes guianensis* CIAT 184), Pangola (*Digitaria eriantha*) and Cavalcade (*Centrosema pascuorum* cv. Cavalcade) at different stages of fermentation. An Annual Research Report 2007, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Ørskov ER; Hovell FDD; Mould F. 1980. The use of the nylon bag technique for the evaluation of feedstuffs. Tropical Animal Production 5:195−213.

Oude Elferink SJWH; Driehuis F; Gottschal JC; Spoelstra SF. 2000. Silage fermentation processes and their manipulation. In: Mannetje L't, ed. Silage Making in the Tropics with Particular Emphasis on Smallholders. Proceedings of the FAO Electronic Conference on Tropical Silage. http://goo.gl/ecj0CS

Phaikaew C; Boonpukdee W; Srakoopan S; Arkahat K. 1992. Yield and nutritive value of forage sorghum line UT 203 at different cutting intervals. An Annual Research Report 1992, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Phaikaew C; Pholsen P; Chompooso B. 2003. A testing sweet sorghum for silage making. An Annual Research Report 2003, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Pholsen S; Kasikranan S; Pholsen P; Suksri A. 1998. Dry matter yield, chemical compositions and dry matter degradability of ten sorghum cultivars (*Sorghum bicolor* L. Moench) grown on Oxic Paleustults soil. Pakistan Journal of Biology Sciences 1:228−231. http://goo.gl/RXwdzh

Pholsen S; Higgs DEB; Suksri A. 2001. Effect of nitrogen and potassium fertilizers on growth, chemical component and seed yield of forage sorghum (*Sorghum bicolor* L. Moench) grown on Oxic Paleustults Soil Northeast Thailand. Pakistan Journal of Biology Sciences 4:27−31. http://goo.gl/dCoCqT

Pholsen S; Sornsungnoen N. 2004. Effects of nitrogen and potassium rates and planting distances on growth, yield and fodder quality of a forage sorghum (*Sorghum bicolor* L. Moench). Pakistan Journal of Biology Sciences 7:1793−1800. http://goo.gl/YrPXvY

Pholsen S; Higgs DEB. 2005. Effect of main crop cutting age on growth, dry weight yield and fodder quality of main crop and ratoon crop of IS 23585 forage sorghum cultivar. In: Rowlinson P; Wachirapakorn C; Pakdee P; Wanapat M, eds. Proceedings of Conference on Integrating livestock-crop systems to meet the challenges of globalisation. AHAT/BSAS International Conference, Khon Kaen, Thailand. Document T137. http://goo.gl/39thC4

Pholsen S; Suksri A. 2007. Effects of phosphorus and potassium on growth, yield and fodder quality of IS 23585 forage sorghum cultivar (*Sorghum bicolor* L. Moench). Pakistan Journal of Biology Sciences 10:1604−1610. http://goo.gl/dlT8ji

Phunphiphat R; Phunphiphat W; Kulna S. 2004. Effect of cutting interval on seed yield and quality of Cavalcade Centurion (*Centrosema pascuorum* cv. Cavalcade) in Sukhothai Province. An Annual Research Report 2004, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Phunphiphat R; Klum-em K; Phunphiphat W. 2008. Effect of plant spacing and cutting interval on yield and chemical composition of *Centrosema pascuorum* cv. Cavalcade. An Annual Research Report 2008, Department of Livestock

Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
Pongpeajan S; Arananant J; Waipanya S. 2008. Effect of silage additives on silage quality of Napier grass. An Annual Research Report 2008, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
Pothisoong T; Piyapanthawanon S; Nilpayak T. 2005. KDF 404 Forage sorghum variety. In: Proceedings of the 43rd Kasetsart University Annual Conference, Bangkok, Thailand. p. 591–595. http://goo.gl/CZl7wZ
Rao PS; Jayalakshmi M; Kuma CG; Kamal A; Reddy BVS. 2011. Response of fertilizer treatments on agronomic and biochemical traits in main and ratoon crops of sweet sorghum (*Sorghum bicolor* (L.) Moench) cultivar ICSV 93046. In: The IAPSIT International Sugar Conference, New Delhi, India. p. 1–11. http://goo.gl/dASeIj
Sangchote S; Punyavirocha T; Kanjanpibul N. 1992. Nutritive value of sugarcane top and leucaena leaves silage. An Annual Research Report 1992, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
SAS. 1996. SAS/STAT User's Guide. Version 6.12. SAS Institute Inc., Cary, NC, USA.
Senanarong A. 1977. Introductory address for the ninth national corn and sorghum reporting session. In: Senanarong A, ed. Thailand National Corn and Sorghum Program. 1977 Annual Report, Kasetsart University and Department of Agriculture, Bangkok, Thailand.
Skerman PJ; Riveros F. 1990. Tropical grasses. FAO Plant Production and Protection Series. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.
Suchato W; Boontum A; Siththithai P; Suriyapan P. 1991. Study on planting time of sorghum for forage and grain yield for ratoon. Thai Agricultural Research Journal 9:17–20. http://goo.gl/p6nC6E
Van Soest PJ. 1978. Preharvest factors influencing quality of conserved forage. Journal of Animal Science 47:712–720. http://goo.gl/SiwnMC
Van Soest PJ; Robertson JB; Lewis BA. 1991. Method of dietary fiber, neutral detergent fiber and non starch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74:3583–3597. http://goo.gl/b9STjq
Waipanya S; Poonpipat R. 2006. Effects of sowing dates on yields of Cavalcade legume plants. An Annual Research Report 2006, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
Wilkinson JM. 1990. Silage UK. 6th Edn. Chalcombe Publications, Marlow, Buckinghamshire, UK.
WTSR (Working Committee of Thai Feeding Standard for Ruminant). 2010. Nutrient requirements of beef cattle in Indochinese peninsula. 1st Edn. Klung Nana Vithya Press Limited Partnership, Khon Kaen, Thailand.
Zimmer E. 1980. Efficient silage systems. In: Thomas C, ed. Proceedings of a Conference on Forage Conservation in the 80's. British Grassland Society Occasional Symposium No. 11, Brighton, 27–30 November 1979. Janssen Services, London, UK.

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Effect of season on the quality of forages selected by sheep in citrus plantations in Ghana

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Abstract

The study aimed at assessing the effects of season on chemical composition of forages selected by sheep grazing in a citrus plantation. Forage species growing in a sweet orange (*Citrus sinensis*) plantation were identified and sampled monthly for 2 years. Samples were bulked on monthly basis for chemical analysis. The average dry matter content of the forages increased from the rainy to the dry season but effects of season on the chemical components were inconsistent. Some species, such as *Asystasia gangetica*, had a higher crude protein concentration in the dry season, whereas for others, such as *Panicum repens*, the reverse occurred. However, average concentrations of crude protein, detergent fiber and components of fiber for all species for the rainy season were not significantly different from the dry season values. It was concluded that there were differences among forage species in their responses to changing seasons, such that grazing ruminants may select a diet to enable them to meet their nutritional requirements, provided forage biomass is adequate.

Resumen

En una plantación de naranjos (*Citrus sinensis*) se evaluaron los efectos de la época del año sobre la composición química de las plantas seleccionadas por ovejas pastando la vegetación espontánea en la plantación. Cada mes y durante 2 años se identificaron las especies consumidas y se tomaron muestras para análisis químico. El contenido promedio de materia seca de los forrajes se incrementó de la época lluviosa hacia la época seca, pero el efecto en los otros componentes químicos no fue consistente. Algunas especies, como *Asystasia gangetica*, presentaron una mayor concentración de proteína cruda durante la época seca, mientras que en otras especies, p.ej. *Panicum repens*, ocurrió lo contrario. En la época de lluvias las concentraciones promedio de proteína cruda, fibra detergente y componentes de la fibra en todas las especies no fueron significativamente diferentes de los valores de la estación seca. Se concluye que las diferencias encontradas entre las especies en sus respuestas a los cambios de estación les permiten a los animales en pastoreo seleccionar una dieta adecuada para satisfacer sus necesidades nutricionales, siempre y cuando la cantidad de la biomasa forrajera ofrecida sea adecuada.

Introduction

A major constraint to ruminant livestock production in Ghana and tropical Africa is the seasonal fluctuation in forage availability and quality due to the modal rainfall patterns. Drastic declines in forage quality have been reported for grasses, with crude protein (CP) concentrations as low as 20¬30 g/kg in the dry season being reported (Fianu et al. 1972; Crowder and Chheda 1982; Peters 1992). However, quality declines are not consistent for all forages. In Ghana, Sottie et al. (1998) observed higher CP in shrubs and trees, such as *Delonix regia, Millettia thonningii* and *Securinega virosa*, during the dry season than in the rainy season. Sarkwa et al. (2011) reported an increase in CP of *Ficus exasperata* in the dry season, whereas the opposite was observed for 7 other browse species studied. Larbi et al. (1998) also reported higher CP during the dry season in some species, such as *Ficus exasperata*, *Senna siamea* and *Acacia angustissima*, in southwestern Nigeria.

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It is important to evaluate the full array of species selected by sheep to have a comprehensive idea of the actual effects of season on quality of forages grazed. Many small ruminants are grazed in tree plantations and the unique environment created by the trees may influence the effects of season on the quality of forages growing in these plantations. Some studies have been conducted on forages found under oil palm in Ghana (Fianu et al. 1994), and oil palm and coconut plantations in Malaysia (Wattanachant et al. 1999; Wahab 2001) and the Philippines (Wong and Moog 2001). However, data on seasonal changes in forages under citrus are lacking. This study was therefore planned to evaluate the effects of season on forage species selected by sheep in a citrus plantation in Ghana.

Materials and Methods

Project site

The project was undertaken at the Forest and Horticultural Crop Research Centre of the University of Ghana, situated at Okumaning near Kade in the Eastern Region of Ghana. The Centre lies in the semi-deciduous forest belt (6.16º N, 0.95º W) (Google Maps). The soils at the study site occur on a catena stretching from the upper to the bottom slope. The forages covered part of the upper and middle slopes on mainly Nzima and Kokofu soil series, classified as Kandic Paleudalf and Udic Kandiudalf, respectively (Owusu-Benoah et al. 2000). An area of about 8 ha, planted with sweet orange (*Citrus sinensis*) of the Late Valencia variety, was selected for the study. No cover crops were planted under the tree crop and no fertilizer was applied to the citrus trees.

Determination of the seasons

Data on monthly mean rainfall amount and number of rainy days were collected from the on-site weather station. Data for 4 years (2007–2010) were averaged and used to define the rainy and dry seasons for the study site. The rainy season is between March and November (inclusive) and the dry season from December to February (Figure 1).

Experimental animals and determination of forage species selected

An area of about 5 ha was selected within the plantation and was stocked with 30 female West African Forest type sheep. The sheep were deliberately selected with a weight range of 12–25 kg to mimic a natural flock. They were grazed between 08.30 and 14.30 h each day. After 2 weeks of grazing to acclimatize, the sheep were observed during grazing and samples of forages they selected were collected according to a direct observation method described by Hirata et al. (2008). One adult sheep (20–25 kg live weight) was randomly selected on each observation day and observed closely by a single observer for 4 h in the morning (08.30 to 12.30 h). This was done to get the complete array of species selected during the period of active grazing. Forage species eaten were recorded and sampled for subsequent identification at the Livestock and Poultry Research Centre (LIPREC) of the University of Ghana. Observations were made on 5 consecutive days at the beginning of each season. Care was taken not to interfere with the normal grazing of the animals.

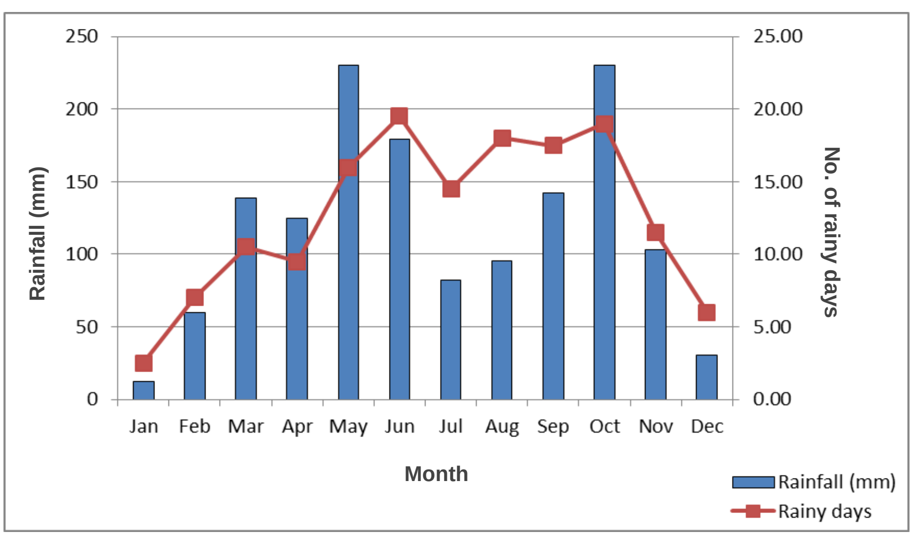

Figure 1. Mean monthly rainfall for the study period (2009 and 2010).

Forage sampling and determination of species composition

Forage sampling for the determination of species composition was done within the first three months of the rainy season (March – May) in year 1. At monthly intervals a quadrat measuring 50 cm x 50 cm was thrown 6 times at random across the field (at distances of at least 30 m apart) and forage within the quadrat harvested. Clipping was done at approximately 2 cm from ground level, and the harvested material was placed in paper bags. Each sample was weighed, separated according to species and individual species weighed. Dry matter (DM) of each species was determined by drying in a forced-draught oven at 65 ºC for 48 h. The dry weight of the total sample was calculated from the mean DM of the individual species. The contribution of each species to the total sample biomass was calculated according to the formula below:

$$A = {}^{Da}\!/_{Dt}$$

$$Dt = \sum(Da + ... + Dn)$$

where:
A is contribution of species A;
Da is DM (g) of species A per quadrat;
Dt is total DM (g) of forage per quadrat; and
Dn is DM (g) of the nth species per quadrat.

Chemical composition

Samples of all species of forage selected by sheep were taken between 09.00 and 11.00 h once a month for 3 months in each season for 2 years (2009 and 2010). For shrubs, samples were made up of leaves and twigs of not more than 5 mm in thickness. For grasses and forbs, samples were taken by harvesting at about 2 cm above ground level. The samples were oven-dried at 60 $^{\circ}$C for 48 h to determine DM, milled through a 1.0 mm screen and bulked on monthly basis (combining the 2 years). Total N was determined by the Kjeldahl method (AOAC 1990) and CP was calculated as % N x 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and their components were determined according to Goering and Van Soest (1970).

Data analysis

Data on chemical composition were subjected to analysis of variance using the General Linear Model (GLM) as in JMP-SAS (SAS Institute 2009) according to the model:

$$Y = u + S + e$$

where:
Y is the response variable such as DM, CP, NDF or ADF;
S is the effect due to season; and
e is the residual error.

Means were compared using Tukey-Kramer HSD (Honestly Significant Difference) as in JMP-SAS.

Results

Species identified

Ten species were identified under the plantation canopy, while 5 species were identified as growing only at the fringes of the tree canopy and in areas in the orchard where some trees had been felled, creating a break in the canopy (Table 1). In addition to the listed forages, sheep also consumed leaves of orange trees within their reach.

Table 1. Forage species selected by sheep in a citrus plantation in Ghana.

Species	Plant family	Forage type
Under the trees		
Asystasia gangetica	Acanthaceae	Forb
Centrosema molle (formerly: *C. pubescens*)	Leguminosae, (Papilionoideae)	Forb
Pueraria phaseoloides	Leguminosae, (Papilionoideae)	Forb
Axonopus compressus	Poaceae	Grass
Oplismenus burmanii	Poaceae	Grass
Panicum repens	Poaceae	Grass
Combretum sp.	Combretaceae	Shrub
Ficus exasperata	Moraceae	Shrub
Griffonia simplicifolia	Leguminosae, (Papilionoideae)	Shrub
Mallotus oppositifolius	Euphorbiaceae	Shrub
Only at fringes or in the open		
Ageratum conyzoides	Asteraceae	Forb
Aspilia africana	Asteraceae	Forb
Melanthera scandens	Asteraceae	Forb
Mimosa pudica	Leguminosae, (Mimosoideae)	Forb
Synedrella nodiflora	Asteraceae	Forb
Panicum maximum	Poaceae	Grass

Contribution of species to forage biomass

The species contributing most to forage biomass under the tree canopy was *Panicum repens*, which contributed

46.1% to the total forage biomass (Table 2). Although *Ficus exasperata* was identified under the tree canopy, it was not captured in the sampling due to its low frequency of occurrence.

Table 2. Mean contribution of species to available forage (n = 3).

Species	kg DM/ha/yr	%
Panicum repens	511.0	46.1
Combretum sp.	331.1	22.7
Mallotus oppositifolius	105.2	8.6
Oplismenus burmanii	93.5	8.4
Pueraria phaseoloides	46.8	4.7
Griffonia simplicifolia	36.8	2.5
Asystasia gangetica	20.2	2.3
Centrosema pubescens	22.6	1.7
Axonopus compressus	2.7	0.2
Miscellaneous species[1]	33.9	2.9
Total	1,204	100

[1]Parts of plants that could not be identified.

Chemical composition

Dry matter and CP concentrations of selected forages for the 2 seasons are presented in Table 3. Average DM % was higher in the dry season (37.4–54.3%) than in the rainy season (28.8–50%) ($P<0.05$). In both seasons, *Asystasia gangetica* had the lowest DM percentage. Overall average CP concentration was not affected ($P>0.05$) by season. However, some species, such as *Asystasia gangetica* and *Mallotus oppositifolius*, had higher CP concentrations in the dry season than in the rainy season, whereas for other species, such as *Griffonia simplicifolia* and *Panicum repens*, the reverse occurred.

Season had no significant effect ($P>0.05$) on the overall means for both NDF and ADF (Table 4).

Table 3. Seasonal effects on dry matter and crude protein concentrations of forage species in a citrus plantation (n = 3 per season).

Species	Dry matter (%)			Crude protein (% DM)		
	Dry season	Rainy season	s.e.m.	Dry season	Rainy season	s.e.m.
Asystasia gangetica	37.4	28.8	1.85	20.6	16.9	1.63
Centrosema molle	45.4	44.1	2.56	18.7	19.0	1.15
Citrus leaves	50.2	50.0	1.18	12.8	13.0	0.27
Combretum sp.	54.3	49.2	1.44	19.9	18.2	1.02
Griffonia simplicifolia	47.3	49.6	2.12	17.9	20.1	1.46
Mallotus oppositifolius	43.3	43.4	2.30	17.1	15.6	0.80
Oplismenus burmanii	47.8	39.1	2.71	7.5	10.7	1.28
Panicum repens	46.5	38.8	1.14	8.9	10.8	0.68
Pueraria phaseoloides	43.5	34.8	2.11	18.5	17.5	0.81
Mean	46.2a[1]	42.0b		15.8a	15.5a	

[1]Means followed by different letters are significantly different ($P<0.05$).

Table 4. Seasonal effects on neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations in forage species in a citrus plantation (n = 3 per season).

Species	NDF (% DM)			ADF (% DM)		
	Dry season	Rainy season	s.e.m.	Dry season	Rainy season	s.e.m.
Asystasia gangetica	41.7	43.6	0.95	31.3	33.0	1.46
Centrosema molle	55.2	60.4	0.68	33.4	36.3	2.11
Citrus leaves	45.2	46.8	1.26	27.2	31.1	2.07
Combretum sp.	68.1	67.8	0.63	38.0	45.3	2.25
Griffonia simplicifolia	55.5	57.7	1.16	32.4	35.5	1.48
Mallotus oppositifolius	44.5	45.8	1.14	22.4	27.0	1.50
Oplismenus burmanii	64.4	66.8	2.17	37.2	36.6	1.96
Panicum repens	62.6	68.3	1.73	36.2	36.4	0.70
Pueraria phaseoloides	55.9	61.1	1.53	34.2	37.6	1.34
Mean	54.8a[1]	57.5a		32.5a	35.8a	

[1]Means followed by different letters are significantly different ($P<0.05$).

Table 5. Seasonal changes in cellulose and hemicellulose concentrations of forages in a citrus plantation (n = 3 per season).

Species	Cellulose (% DM)			Hemicellulose (% DM)		
	Dry season	Rainy season	s.e.m.	Dry season	Rainy season	s.e.m.
Asystasia gangetica	18.6	21.5	1.43	10.5	10.6	1.22
Centrosema molle	18.2	22.9	1.53	21.8	24.1	0.52
Citrus leaves	15.7	20.9	2.17	18.0	15.7	1.34
Combretum sp.	21.8	23.7	1.42	30.2	22.5	1.71
Griffonia simplicifolia	16.7	16.8	0.96	23.1	22.2	1.32
Mallotus oppositifolius	14.2	21.3	1.68	22.2	18.8	1.88
Oplismenus burmanii	27.1	25.7	1.58	27.2	30.2	0.88
Panicum repens	24.8	26.1	0.92	26.5	31.9	1.88
Pueraria phaseoloides	23.7	25.7	1.03	21.7	23.5	0.53
Mean	20.1a[1]	23.0a		22.3a	22.2a	

[1]Means followed by different letters are significantly different (P<0.05).

For the full range of forages selected by sheep, season had no effect (P>0.05) on cellulose and hemicellulose concentrations in the forage (Table 5). However, for some species, such as *Mallotus oppositifolius*, cellulose levels were higher in the rainy season than in the dry season.

Lignin concentrations were as follows: grasses - range 3.6–17.6%, mean 7.5%; shrubs - 4.6–26.0%, mean 14.0%; and forbs - range 3.2–18.0%, mean 11.3%. Silica concentrations in forbs and shrubs were similar (P>0.05) but both were lower (P<0.05) than for grasses (Table 6).

Discussion

This study has provided useful information on the seasonal changes in nutrient concentrations in forages selected by sheep in a citrus orchard in Ghana. The data indicate that forage quality, particularly CP, would not be a limiting factor for production and that DM availability is more likely to determine how well sheep perform in these situations.

Since the period of active growth for most forage species is the rainy season, it is often assumed that CP concentrations fall and fiber levels increase as the season advances from the rainy season towards the dry season. Studies based on a few planted species have supported this idea. However, in natural pastures with diverse forage species, this may not be the case. Results of this and other studies show that different species can respond differently to changing seasons. This is important for grazing ruminants because it provides an opportunity to select forage species in such a way as to minimize variations in their nutrient intake as the seasons change. Development of mixed pastures, therefore, may be a strategy to mitigate the effects of the dry season on ruminant production.

Table 6. Seasonal changes in lignin and silica concentrations in forages in a citrus plantation (n = 3 per season).

Species	Lignin (% DM)			Silica (% DM)		
	Dry season	Rainy season	s.e.m.	Dry season	Rainy season	s.e.m.
Asystasia gangetica	9.2	11.2	1.04	0.5	0.9	0.43
Centrosema molle	11.8	12.5	0.90	1.6	1.0	0.20
Citrus leaves	9.2	9.8	0.86	0.1	2.4	0.98
Combretum sp.	14.7	17.2	1.04	1.6	3.6	1.15
Griffonia simplicifolia	14.2	18.2	1.62	0.4	0.6	0.23
Mallotus oppositifolius	6.8	6.5	0.35	0.3	0.9	0.23
Oplismenus burmanii	10.0	8.3	0.49	4.7	4.8	0.38
Panicum repens	8.9	7.3	0.57	2.1	3.3	0.27
Pueraria phaseoloides	9.8	11.6	0.92	0.8	1.3	0.62
Mean	10.5a[1]	11.0a		1.4a	2.1a	

[1]Means for each parameter followed by different letters are significantly different (P<0.05).

Differences in response to season by different forage species have been reported in the literature. Although several studies have indicated a decline in forage CP concentrations in the dry season (Fianu et al. 1972; Crowder and Chheda 1982; Peters 1992), others have reported an increase in CP during the dry season for some species (Larbi et al. 1998; Sottie et al. 1998; Sarkwa et al. 2011). In a study involving 7 grasses, Evitayani et al. (2004a) observed similar CP concentrations in 4 species in both dry and rainy seasons.

Although shade has been reported to have a negative effect on forage CP levels (Johnson et al. 2002), the average CP concentrations for forages under citrus trees of 15.5% and 15.8% for the dry and rainy seasons, respectively, were still high compared with the maintenance requirement of 6–7% CP for ruminants (Smith 1992). As animals can actively select for leaf, the CP concentrations in the diet selected would certainly be higher than these mean values for whole plant samples.

The higher NDF levels in grasses (*Oplismenus burmanii* and *Panicum repens*) during the dry season than in the rainy season were similar to earlier reports (Khan et al. 1999; Evitayani et al. 2004a; Waterman et al. 2007). However, for broad-leaved plants, responses varied. Work by Sottie et al. (1998) indicated no seasonal effect on the NDF levels of some browses in the Accra plains, while Larbi et al. (1998) and Sarkwa et al. (2011) observed decreases in both NDF and ADF concentrations in browse species in the dry season.

Similar seasonal changes in forage DM content to those observed in this study have also been reported in the literature. Sottie et al. (1998) reported DM increases averaging about 32% in selected forages as the season changed from the major rainy season to the dry season in the coastal savannah area of Ghana. The lower variation in DM content of forages in the current study may be due to the shorter dry season in the study area and the effect of high humidity resulting from a combination of the higher rainfall and the tree crop canopy. The higher variation in DM content of grasses than browses is in consonance with a report by Peters et al. (1997) that the effect of season on DM content of shrubs is less drastic than the effect on grasses.

The overall absence of an effect of season on forage lignin concentration agrees with the observations of Adejumo (1992). This lack of a significant overall effect of season is due to variation in the response by individual species, as reported by Evitayani et al. (2004b) and Sottie et al. (1998). The concentrations of silica, which is known to be an anti-nutritional factor and a digestibility depressant (Smith and Urquhart 1975), were also not affected by season. The wide range of values for lignin concentration in forages in this study (6.5–18.2%) is probably due to the diversity in the forage species in the study area, but the range is lower than the range of values (6–35%) reported in the literature (Khanal and Subba 2001; Kumar and Sharma 2003; Ogunbosoye and Babayemi 2010).

Conclusions

The range of species selected by sheep in this citrus plantation and the overall lack of change in nutrient concentrations in the forage throughout the year should present a situation where low quality of forage would not be a limiting factor to production. Considering that ruminants are selective in feeding, it may be expected that they would select forages in such a way as to minimize variation in nutrient intake during the dry season provided forage availability is adequate.

References

Adejumo JO. 1992. Effect of plant age and harvest date in the dry season on yield and quality of *Gliricidia sepium* in southern Nigeria. Tropical Grasslands 26:21–24.

AOAC (Association of Official Analytical Chemists). 1990. Official Methods of Analysis. 15th Edn. AOAC, Washington, DC, USA.

Crowder LV; Chheda HR. 1982. Tropical Grassland Husbandry. Longman, London and New York.

Evitayani; Warly L; Fariani A; Ichinohe T; Fujihara T. 2004a. Seasonal changes in nutritive value of some grass species in West Sumatra, Indonesia. Asian-Australasian Journal of Animal Sciences 17:1663–1668.

Evitayani; Warly L; Fariani A; Ichinohe T; Abdulrazak SA; Fujihara T. 2004b. Comparative rumen degradability of some legume forages between wet and dry season in West Sumatra, Indonesia. Asian-Australasian Journal of Animal Sciences 17:1107–1111.

Fianu FK; Attah-Krah MK; Koram K. 1972. Some aspects of dry season nutrition of ruminants in Ghana. Proceedings of the V Ghana Animal Science Symposium 51:289–293.

Fianu FK; Addae PC; Adjorlolo LK. 1994. Sheep rearing under tree crop plantations in Ghana's forest zone: Problems and prospects. Proceedings of the III Biennial Conference of the African Small Ruminant Research Network, UICC, Kampala, Uganda. p. 85–91.

Goering HK; Van Soest PJ. 1970. Forage fiber analysis. Agriculture Handbook No. 379. USDA, Washington, DC, USA.

Hirata M; Hasegawa N; Takahashi T; Chowdappa R; Ogura S; Nogami K; Sonoda T. 2008. Grazing behaviour, diet selection and feed intake of cattle in a young tree plantation in southern Kyushu, Japan. Tropical Grasslands 42:170–180.

Johnson SE; Sollenberger LE; Andrade IF; Benne JM. 2002. Nutritive value of Rhizoma Peanut growing under varying levels of artificial shade. Agronomy Journal 94:1071–1077.
Khan RI; Alam MR; Amin MR. 1999. Effect of season and fertilizer on species composition and nutritive value of native grasses. Asian-Australasian Journal of Animal Sciences 12:1222–1227.
Khanal RC; Subba DB. 2001. Nutritional evaluation of leaves from some major fodder trees cultivated in the hills of Nepal. Animal Feed Science and Technology 92:17–32.
Kumar A; Sharma SD. 2003. Nutritive evaluation of some fodder tree leaves for ruminants in Tarai Region of Uttaranchal. Indian Journal of Animal Nutrition 20:161–167.
Larbi A; Smith JW; Kurdi IO; Adekunle IO; Raji AM; Ladipo DO. 1998. Chemical composition, rumen degradation, and gas production characteristics of some multipurpose fodder trees and shrubs during the wet and dry seasons in the humid tropics. Animal Feed Science and Technology 72:81–96.
Ogunbosoye DO; Babayemi OJ. 2010. Potential values of some non-leguminous browse plants as dry season feed for ruminants in Nigeria. African Journal of Biotechnology 9(18):2720–2726.
Owusu-Benoah E; Awadzi TW; Boateng E; Krogh L; Breuning-Madsen H; Borggaard OK. 2000. Soil properties of a toposequence in the moist semi-deciduous forest zone of Ghana. West African Journal of Applied Ecology 1:1−10.
Peters M. 1992. Evaluation of tropical pasture legumes for fodder banks in subhumid Nigeria. Ph.D. Thesis. Justus-Liebig-Universitãt, Giessen, Germany.
Peters M; Tarawali SA; Alkämper J. 1997. Dry season performance of four tropical pasture legumes in subhumid West Africa as influenced by superphosphate application and weed control. Tropical Grasslands 31:201–213.
Sarkwa FO; Adogla-Bessa T; Timpong-Jones EC; Adjorlolo LK. 2011. Preliminary assessment of the nutritional value of eight browse species in the Coastal Savanna. Proceedings of the XVII Biennial Conference of the Ghana Society of Animal Production, University of Ghana, Ghana, July 2011.
SAS Institute. 2009. Statistical Analysis Systems Procedures guide, release 8.0.2. SAS Institute Incorporated, Cary, NC, USA.
Smith OB. 1992. Small ruminant feeding systems for small-scale farmers in humid West Africa. In: Stare JES; Said AN; Kategile JA, eds. The complementarity of feed resources for animal production in Africa. Proceedings of the Joint Feed Resources Networks Workshop, Garborone, Botswana. p. 363–376.
Smith GS; Urquhart NS. 1975. Effect of Sodium Silicate Added to Rumen Cultures on Digestion of Siliceous Forages. Journal of Animal Science 41:882–890.
Sottie ET; Agyei-Henaku AAO; Amaning-Kwarteng K; Fleischer JE. 1998. Effect of season on the chemical composition and in vitro digestibility of some browse and shrubs in Ghana. Ghana Journal of Agricultural Science 31:99–105.
Wahab HA. 2001. Forages in oil palm and rubber plantations in Malaysia. In: Moog FA; Reynolds SG; Maaruf K, eds. Forage development in Southeast Asia: Strategies and impacts. Proceedings of the 7th Meeting of the Regional Working Group on Grazing and Feed Resources, Manado, Indonesia, July 2001. FAO - University of Sam Ratulangi, Manado, North Sulawesi, Indonesia. http://goo.gl/o10MSX
Waterman RC; Grings EE; Geary TW; Roberts AJ; Alexander LJ; MacNeil MD. 2007. Influence of seasonal forage quality on glucose kinetics of young beef cows. Journal of Animal Science 85:2582–2595.
Wattanachant C; Dahlan I; Alimon AR; Rajion MA. 1999. Sheep-oil palm integration: grazing preference, nutritive value, dry matter intake estimation and digestibility of herbage. Asian-Australasian Journal of Animal Sciences 12:209–214.
Wong CC; Moog FA. 2001. Forage, livestock and tree crop integration in Southeast Asia: Present position and future prospects. In: Moog FA; Reynolds SG; Maaruf K, eds. Forage development in Southeast Asia: Strategies and impacts. Proceedings of the 7th Meeting of the Regional Working Group on Grazing and Feed Resources, Manado, Indonesia, July 2001. FAO - University of Sam Ratulangi, Manado, North Sulawesi, Indonesia. http://goo.gl/llmgP7

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Tolerancia de leguminosas herbáceas estivales a condiciones de anegamiento temporal

Tolerance of herbaceous summer legumes of temporary waterlogging

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Palabras clave: Leguminosas forrajeras, inundación, *Aeschynomene americana*, *Desmanthus virgatus*, *Macroptilium lathyroides*, Nordeste de Argentina.

Keywords*: Forage legumes, flooding,* Aeschynomene americana, Desmanthus virgatus, Macroptilium lathyroides, *Northeast Argentina.*

Resumen

El objetivo del presente trabajo fue evaluar la adaptación de 4 leguminosas herbáceas de ciclo estival a condiciones de anegamiento temporal. En condiciones de casa de malla de la Facultad de Ciencias Agrarias de la Universidad Nacional del Nordeste (UNNE) en Corrientes, Argentina, fueron evaluadas la especies *Desmanthus virgatus* y *Aeschynomene americana* en fase vegetativa y *Macroptilium lathyroides* y *M. atropurpureum* tanto en fase vegetativa como reproductiva. El diseño experimental fue de bloques al azar con cinco repeticiones. Los tratamientos fueron: T0 testigo (riego diario); T1 saturación de suelo por ascenso capilar del agua, colocando las macetas con plantas en recipientes de 5 L de capacidad con un nivel de 10 cm de agua permanente; y T2 inundación, manteniendo una lámina de agua de 5 cm sobre el nivel del suelo, para lo cual las macetas se colocaron en recipientes de 10 L de capacidad. El período de anegamiento fue de 7 días. Los resultados mostraron que el anegamiento no tuvo efecto en la producción de biomasa aérea y radical ni en la nodulación de *A. americana*, mientras que *D. virgatus* presentó la mejor producción de materia seca en condiciones de suelo saturado. *Macroptilium lathyroides* mostró en fase reproductiva mayor tolerancia a inundación que en fase vegetativa, probablemente debido a la gran cantidad de raíces adventicias y tejido aerenquimático que formó. *Macroptilium atropurpureum* mostró adaptación a las condiciones de inundación temporal. La supervivencia y rápida recuperación de estas especies confirmarían su potencial forrajero para zonas bajas en el Nordeste de Argentina.

Abstract

A greenhouse study to evaluate adaptation of 4 herbaceous summer legumes to temporary waterlogging was conducted. Species evaluated were *Desmanthus virgatus* and *Aeschynomene americana* in their vegetative stage, and *Macroptilium lathyroides* and *M. atropurpureum* in both vegetative and reproductive stages. The experimental design was randomized blocks with 5 replications and treatments were: T0, control; T1, saturation by capillary movement placing pots in buckets of 5 L with 10 cm of permanent water; and T2, flooding, placing pots in buckets of 10 L and a layer of water 5 cm above the soil. The duration of the water treatments was 7 days. Waterlogging did not affect shoot or root biomass production nor nodulation in *A. americana*, whereas *D. virgatus* had its highest dry matter production in saturated soil (T1). In *M. lathyroides* flooding tolerance was more evident in the reproductive than in the vegetative stage, probably due to more production of adventitious roots and formation of aerenchymatic tissue. *Macroptilium atropurpureum* showed adaptation to temporary flooding. Survival and quick recovery of these species would confirm their potential as forages for temporarily waterlogged soils.

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Introducción

La inundación del suelo y la defoliación de las plantas son algunos de los factores ambientales y de manejo que afectan el rendimiento de las plantas en muchos ecosistemas pastoriles del mundo (McNaughton 1983; Soriano 1991; Loreti et al. 1994) y por tanto tienen un papel relevante como factor de selección natural (Vignolio et al. 1994).

En la región del Nordeste argentino existe una alta proporción de suelos con horizontes de baja permeabilidad o áreas deprimidas que provocan problemas de drenaje permanente o temporal (Ligier 2002). En los últimos años los problemas de anegamiento e inundaciones en amplias zonas del territorio nacional son cada vez más graves. A nivel de campo, en los lotes con exceso de agua se observan reducciones entre 50 y 100% en la producción de forraje debido a la asfixia de las raíces (Ciparicci et al. 2014). En la provincia de Corrientes, los campos bajos o humedales ocupan alrededor de 30% de la superficie, lo que representa aproximadamente 5 millones de hectáreas (Escobar et al. 1996; Canevari et al. 1999; Ligier 2002). Estos ambientes tienen aptitud ganadera y en ellos se encuentran pastizales sobre suelos hidromórficos, gramillares de bajos, cañadas y malezales (Carnevali 1994; Arbo et al. 2002; Schinini et al. 2004).

En los pastizales de la región predominan gramíneas y ciperáceas con baja presencia de leguminosas (5−10% como aporte a la biomasa total) (Hack et al. 2009). No obstante, una mayor presencia de leguminosas mejoraría la calidad de la dieta, además de aportar nitrógeno al sistema. Existen especies de gramíneas cultivadas y nativas adaptadas a suelos con drenaje deficiente como *Brachiaria mutica* (pasto pará), *B. arrecta* (pasto tanner), *Acroceras macrum* (pasto Nilo), *Echinochloa* spp. y *Paspalum repens*, entre otras (Skerman y Riveros 1992; Mannetje y Jones 1992; Carnevali 1994; Schinini et al. 2004; Cook et al. 2005). En cuanto a leguminosas herbáceas, es reconocida la tolerancia a anegamiento de los géneros *Aeschynomene*, *Macroptilium*, *Desmodium*, *Centrosema* y *Stylosanthes* (Whiteman et al. 1983; McIvor 1976; Schinini et al. 2004; Cook et al. 2005) y en particular, de las especies *Lotus pedunculatus*, *Vigna parkeri*, *Trifolium semipilosum*, *Aeschynomene americana* y *Medicago sativa* (Shiferaw et al. 1992) y *Lotus tenuis* (Vignolio et al. 1994; Striker et al. 2007).

El anegamiento se caracteriza por condiciones de deficiencia de oxígeno en la rizósfera de las plantas (Loreti et al. 1994; Jackson y Colmer 2005) y cambios de características morfológicas y anatómicas a nivel de raíz y tallo, lo que les permite a las plantas adaptarse y sobrevivir en esas condiciones (Baruch y Mérida 1995; Dias-Filho y Carvalho 2000; Voesenek et al. 2004). Estas alteraciones pueden ser, entre otras: elongación de tallo (Javier 1985; Grimoldi et al. 1999; Voesenek et al. 2004); formación de tejido aerenquimático (Evans 2003; Parent et al. 2009) y en el caso de leguminosas, nodulación en hipoxia (Goormachtig et al. 2004). Baruch y Mérida (1995) observaron en raíces formadas bajo condiciones de exceso de agua incremento del diámetro, reducción del número de los pelos absorbentes, acortamiento y ramificación de las raíces, disminución del peso radical e incremento de la lignificación y suberización de la pared celular.

En general, el anegamiento temporal influye de manera adversa en la fisiología y el crecimiento de las plantas, causando disminución en la absorción de nutrientes, reducción en la proporción de raíces y tallos, cierre de estomas y consecuentemente limitaciones fotosintéticas, clorosis foliar, senescencia y muerte (Krizek 1982; López 2009).

En el norte de la provincia de Corrientes, Argentina, en un ensayo de campo en suelo arcilloso, al evaluar la tolerancia de las leguminosas *Stylosanthes guianensis* (cv. Graham y accesión CIAT 184) y *Arachis pintoi* (accesiones CIAT 17434 y 18748) a condiciones de anegamiento temporal, se observaron incrementos en la producción de macollos y en *A. pintoi* inducción de la floración (Ciotti et al. 2006).

Las precipitaciones en la región del Nordeste argentino tienen una marcada estacionalidad, con picos en marzo y en el periodo octubre - noviembre. El exceso de lluvias afecta negativamente las especies estivales. Por tanto, encontrar especies forrajeras estivales que toleren excesos hídricos facilitaría la incorporación de una extensa área con drenaje deficiente a la ganadería regional. *Desmanthus virgatus*, *Aeschynomene americana* y *Macroptilium lathyroides*, especies que fueron utilizadas en este ensayo, son nativas de los pastizales en la región y su presencia se registra tanto en suelos arenosos como en suelos de drenaje deficiente (Burkart 1952; Fernández et al. 1983; Schinini et al. 2004). *Macroptilium atropurpureum* se encuentra naturalizada en esta región donde se presenta de forma espontánea en las partes más altas de los campos (lomadas arenosas). Estas especies resultan de interés por su potencial para ser incorporadas a otros sitios con anegamiento temporal

El objetivo del presente trabajo fue evaluar la tolerancia y el potencial de producción de biomasa forrajera de 4 leguminosas herbáceas de ciclo estival a condiciones de anegamiento temporal.

Materiales y Métodos

El ensayo se realizó en casa de malla con especies de ciclo estival en la Unidad Experimental de la Cátedra de Forrajicultura, ubicada en el predio de la Facultad de Ciencias Agrarias de la Universidad Nacional del Nordeste (UNNE) en Corrientes, Argentina (27º28' N, 58º16' O; 56 msnm).

El suelo utilizado es arcilloso y fue tomado en una zona que presenta normalmente encharcamiento y anegamiento temporal, perteneciente a la serie Paso de la Patria, clasificado como Albaqualf Vértico. Presenta severas limitaciones para el uso de cultivos por la susceptibilidad al anegamiento, drenaje deficiente, capa arable poco profunda y bajo contenido de materia orgánica (Escobar et al. 1996).

Se evaluaron 4 especies de uso potencial en suelos anegables: *Aeschynomene americana*, *Desmanthus virgatus*, *Macroptilium lathyroides* y *M. atropurpureum*. Para el establecimiento de las tres primeras especies se utilizaron semillas recolectadas en poblaciones localizadas en campos bajos de la región, mientras que para *M. atropurpureum* se empleó semilla cosechada de plantas de origen no conocido existentes en el jardín de introducción de la UNNE. Todas las especies fueron inoculadas con una solución acuosa de *Bradyrhizobium* sp. preparada en el Instituto Agrotécnico Pedro Fuentes Godo de la UNNE. Para la siembra de los materiales se utilizaron macetas de 4 L de capacidad y 20 cm de altura, que fueron llenadas con 4 kg de suelo. En cada maceta se sembraron 8 semillas y se dejaron 5 plantas en cada una de ellas.

Se utilizó un diseño experimental de bloques al azar con cinco repeticiones. Los tratamientos fueron los siguientes: T0, testigo (riego diario); T1, saturación por ascenso capilar colocando las macetas en baldes de 5 L con 10 cm de agua permanente; y T2, inundación colocando las macetas en baldes de 10 L con agua de manera que el nivel del agua superara en forma permanente 5 cm el nivel del suelo. El período de anegamiento fue de 7 días, con un tiempo de recuperación de 10 días cuando se cosecharon las plantas y se hicieron las evaluaciones. En los suelos de la región el período de permanencia del agua varía entre 5 y 10 días (Ligier 2002).

En *D. virgatus* y *A. americana* se aplicaron los tratamientos T0, T1 y T2 en fase vegetativa, cuando las plantas tenían 12 cm de altura (aproximadamente 13 días después de emergencia). En *M. lathyroides* y *M. atropurpureum* los tratamientos fueron T0 y T2, aplicados tanto en fase vegetativa, cuando las plantas tenían 12 cm de altura (aproximadamente 13 días después de emergencia), como en fase reproductiva, cuando en todas las repeticiones se observó por lo menos una flor. En todos los casos se evaluaron: la producción de materia seca (MS) total; el peso seco de la parte aérea; el peso seco de raíces; y nodulación. Para las determinaciones de la producción de MS las plantas fueron cosechadas y secadas a 60 ºC antes de determinar su peso seco. Después del corte las raíces fueron sumergidas en agua durante 12 h antes de tratarlas durante 8 h con una solución dispersante orgánica de hexametafosfato de sodio. Finalmente fueron lavadas con agua abundante, pesadas y llevadas a estufa para determinar el peso seco (g/maceta). La evaluación de la nodulación se hizo utilizando la escala propuesta por Bradley (1982) que combina cantidad, tamaño y color de los nódulos, de la forma siguiente: Pobre: entre 0 y 50 nódulos/maceta, tamaño <3 mm, color rosa claro; Buena: entre 51 y 150 nódulos, tamaño entre 3 y 7 mm y color rosa intenso; Excelente: más de 150 nódulos/maceta, tamaño >7 mm y color rosa intenso. En forma cualitativa se evaluó además el vigor de las plantas, utilizando una escala de 1 (mínimo) a 5 (máximo). Se registraron la cantidad de hojas/planta con síntomas de clorosis y la presencia de hojas senescentes.

En *M. lathyroides* se hizo un análisis anatómico del cuello (intersección tallo-raíz) y raíces. Para ello se utilizó material fijado en FAA (alcohol 70º, ácido acético y formol, 90:5:5) con inclusión en parafina según la técnica propuesta por Johansen (1940), modificada por González y Cristóbal (1997). Se realizaron cortes seriados con micrótomo rotativo, de 12 µm de espesor y se empleó doble tinción safranina-Astra blue (Luque et al. 1996).

Los resultados cuantitativos fueron sometidos a un análisis de varianza (ANOVA) para cada especie y fase fenológica, según el diseño experimental. Las diferencias entre las medias se comprobaron con la prueba de Tukey utilizando el paquete Infostat 2006 (Di Rienzo et al. 2006) con un nivel de significancia $P<0.05$.

Cuando fue necesario se controlaron plagas y enfermedades. En la fase vegetativa se observó un ataque leve de orugas (*Spodoptera frugiperda*) y en inundación se detectó un ataque de pulgón negro (*Toxoptera aurantii*). Ambas plagas fueron controladas con Avamectina al 1.8%.

Resultados

Producción de materia seca

En el Cuadro 1 se presenta la producción de la MS aérea y de raíces de *Aeschynomene americana* y *Desmanthus virgatus.*

En *A. americana* no se observaron diferencias (P>0.05) entre tratamientos en la producción de MS de la parte aérea y de las raíces, ni en carácteres morfológicos como coloración y vigor de hojas, así como como presencia de síntomas de estrés.

En *D. virgatus* las producciones de MS de la parte aérea y de las raíces fueron mayores en el T1 (saturación) que en el T2. En el T1 se observó un mayor desarrollo del xilopodio, órgano radical fibroso-leñoso que tiene un tejido de reserva (Burkart 1952). El desarrollo radical tanto de raíces caulinares como adventicias fue menor (P<0.05) en T2.

La altura de las plantas de *A. americana* al momento del corte fue diferente (P<0.05), siendo, respectivamente, los tratamientos saturación (T1) e inundación (T2) 20 y 40% superiores al testigo (T0). En *D. virgatus*, por el contrario, no se detectaron diferencias (P>0.05) en altura de plantas entre los tratamientos testigo (T0) e inundación (T2). En el tratamiento de saturación (T1) la altura promedio fue 38.4 cm, siendo diferente (P<0.05) a los demás tratamientos (Cuadro 1).

En el Cuadro 2 se presenta la producción de MS aérea y de raíces de *M. lathyroides* y *M. atropurpureum* en fase vegetativa y reproductiva.

Cuadro 1. Producción de materia seca de la parte aérea y raíces, altura de plantas y número de nódulos en *Aeschynomene americana* y *Desmanthus virgatus* en respuesta a 7 días de anegamiento en la fase vegetativa.

***Table 1**: Dry matter yield of shoot and root biomass, plant height and nodule number of* Aeschynomene americana *and* Desmanthus virgatus *in response to 7 days waterlogging during the vegetative stage.*

Especie y tratamiento de anegamiento	MS aérea (g/maceta)	MS raíces (g/maceta)	Altura (cm)	Nódulos (No./maceta)
Aeschynomene americana				
T0 (testigo)	6.8a[1]	5.2a	24.6c	130a
T1 (saturación)	7.7a	4.9a	29.4b	140a
T2 (inundación)	7.9a	5.3a	34.9a	135a
DLS (P<0.05)[2]	3.0	2.48	2.1	15
Desmanthus virgatus				
T0 (testigo)	2.5ab	4.1ab	28.1b	9a
T1 (saturación)	3.7a	4.8a	38.4a	12a
T2 (inundación)	2.1b	1.5b	30.8b	10a
DLS (P<0.05)	1.5	3.2	6.9	4

[1]Valores seguidos por letras iguales en las columnas dentro de especies no difieren significativamente (Tukey P>0.05).
[2]DLS: Diferencia límite de significación.

Cuadro 2. Producción de materia seca de la parte aérea y raíces y número de nódulos en *Macroptilium lathyroides* y *M. atropurpureum* en respuesta a 7 días de inundación en fase vegetativa y reproductiva.

***Table 2**. Dry matter yield of shoot and root biomass and nodule number of* Macroptilium lathyroides *and* M. atropurpureum *in response to 7 days flooding in the vegetative and reproductive stages.*

Especie	Fase	Tratamiento	MS aérea (g/maceta)	MS raíces (g/maceta)	Nódulos (No./maceta)
M. lathyroides	Vegetativa	T0 (testigo)	3.3a[1]	5.0a	12.0a
		T2 (inund.)	2.3b	4.3a	16.2a
		DLS (P<0.05)[2]	1.04	0.3	9.5
	Reproductiva	T0 (testigo)	9.55a	8.9a	155a
		T2 (inund.)	10.1a	11.0a	175a
		DLS (P<0.05)	1.6	2.5	20.4
M. atropurpureum	Vegetativa	T0 (testigo)	14.77b	21.0a	36.3a
		T2 (inund.)	17.88a	19.2a	15.2b
		DLS	2.5	1.5	24.5
	Reproductiva	T0 (testigo)	33.5a	30.5a	55.0a
		T2 (inund.)	31.8a	26.6a	35.8b
		DLS	18	38	10.6

[1]Valores seguidos por letras iguales en las columnas, dentro de especies y fases, no difieren significativamente (Tukey P>0.05).
[2]DLS: Diferencia límite de significación.

En *Macroptilium lathyroides* se observó una reducción en la producción de MS de la parte aérea cuando fue sometido a inundación en fase vegetativa, pero no se observó lo mismo en la fase reproductiva. Los cambios en la morfología de la planta se comenzaron a observar al tercer día después de la inundación, con clorosis progresiva, engrosamiento del tallo a nivel del agua y senescencia de hojas basales. Las plantas mantuvieron su vigor máximo (vigor 5) hasta el quinto día, cuando comenzaron a perderlo alcanzando valores medios (vigor 3) (datos no presentados).

Al cuarto día de inundación se observó ensanchamiento en el cuello o zona donde comienza la parte aérea de la planta, causado por la hiperplasia del tejido parenquimático, que llegó hasta 3 cm por encima del cuello, de coloración blanquecina. En esta parte de la planta *M. lathyroides* desarrolla rápidamente un crecimiento secundario el cual presenta una estructura típica, con presencia de peridermis y escaso tejido suberoso (Figura 1, A-B). En condiciones de inundación, la respuesta inmediata de la planta es la formación de tejido aerénquimatico (Figura 1, C-D). Este tejido se origina a partir del felógeno, que por divisiones periclinales forma células las cuales rápidamente desarrollan espacios intercelulares, desplazando el súber hacia el exterior.

Macroptilium lathyroides es reportada como una especie de día neutro para floración la cual es afectada por condiciones húmedas (Jones y Mannetje 1992a). En este ensayo las plantas comenzaron la floración 35 días después de la siembra y fructificaron normalmente (datos no presentados).

Macroptilium atropurpureum mostró adaptación a condiciones de anegamiento temporal. En la fase vegetativa el incremento de MS aérea fue significativo (P<0.05) mientras que en la etapa reproductiva no se detectaron diferencias entre tratamientos. El desarrollo del tejido aerenquimático en esta especie fue menos evidente que en *M. lathyroides*.

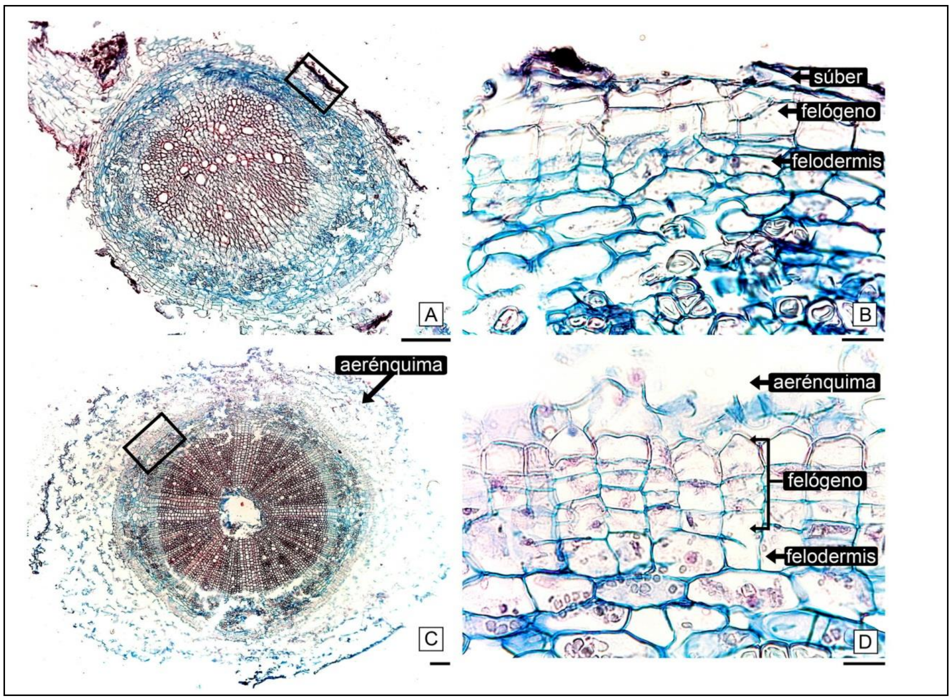

Figura 1. Cortes transversales de la zona del cuello de una planta de *M. lathyroides* de 30 días de edad, mostrando los efectos de la inundación. A: área no inundada. B: detalle señalado en A, mostrando los estratos de la peridermis con desarrollo normal. C: área sometida a inundación, nótese el abundante aerénquima formado. D: detalle señalado en C, mostrando felógeno en división originando parte del aerénquima. Escalas A, C: 0.25 mm; B, D: 20 µm.

Figure 1*. Cross sections of the root-shoot intersection zone of a 30-day-old* M. lathyroides *plant showing the effects of flooding. A: non-flooded zone. B: detail of the area indicated in A, showing the periderm layers with normal development. C: zone under flooding; note the abundant aerenchyma formed. D: detail of the area indicated in C, showing dividing phellogen cells generating part of the aerenchyma. Bars under letters A and C represent 0.25 mm; and under B and D represent 20 µm.*

Nodulación

En *A. americana* la nodulación fue buena y similar entre tratamientos (Cuadro 1). Se observó un número alto de nódulos tanto en la raíz principal como en las adventicias. En la primera el tamaño promedio fue de 6 mm y en las segundas de 4 mm. La coloración fue rosa intenso.

En *D. virgatus* la nodulación fue pobre con un número de nódulos similar entre tratamientos. En promedio se encontraron 10 nódulos por maceta (Cuadro 1) localizados en las raíces secundarias, con un tamaño promedio de 2.8 mm y coloración rosa claro.

En *M. lathyroides* la nodulación fue buena, con un tamaño promedio de 7 mm durante todo el ciclo y coloración rosa intenso. En la etapa vegetativa el número fue bajo (14 en promedio) y en la etapa reproductiva fue alto (160 en promedio) (Cuadro 2).

En *M. atropurpureum* la nodulación fue pobre durante todo el ciclo. El tamaño de los nódulos fue, en promedio, de 5 mm y la coloración rosa claro. El número de nódulos se redujo significativamente como efecto de la inundación, tanto en la fase vegetativa como en la reproductiva (Cuadro 2).

Discusión

Krizek (1982) determinó que en condiciones de exceso de agua las plantas presentan una secuencia de cambios morfológicos y fisiológicos que afectan la adaptación y la producción de biomasa de las especies. La capacidad de las plantas para soportar períodos de inundación o saturación temporal está relacionada con el desarrollo de sistemas radicales adventicios y de tejidos porosos; ambas estructuras mejoran el sistema de aireación de las plantas. En este ensayo la respuesta a condiciones de anegamiento temporal fue variable, dependiendo de las características de cada especie.

Producción de materia seca

La producción de MS de *A. americana* no se vio afectada por la inundación. Resultados similares encontraron Ross y Cameron (1991) en suelos arcillosos sujetos a inundaciones estacionales. En *D. virgatus*, en cambio, se observó una disminución de las biomasas aérea y radical después de 7 días de inundación. Esta reducción estuvo asociada con clorosis, caída de hojas basales y menor tamaño de folíolos, manifestaciones que se pueden atribuir a la deficiencia de nitrógeno, debido a los fenómenos de lixiviación y denitrificación que suceden tanto en condiciones de inundación como en saturación del suelo (Krizek 1982; Mommer y Visser 2005). La reducción del peso de raíces, junto con la suberización y lignificación de las paredes celulares, como consecuencia del anegamiento, fueron mencionados por Baruch y Mérida (1995).

Macroptilium lathyroides en fase vegetativa igualmente mostró una reducción significativa de la producción de biomasa aérea, siendo esta respuesta temprana normal bajo condiciones de anegamiento (Vignolio et al. 1994). No obstante, la recuperación fue rápida, lo que coincide con los resultados de Ross y Cameron (1991).

Contrario a lo esperado, *M. atropurpureum*, una especie que crece y produce mejor en suelos sin problemas de drenaje, en este ensayo produjo más MS aérea en el tratamiento con inundación en etapa vegetativa. La producción radical en fase vegetativa y la producción aérea y radical en fase reproductiva no fueron afectadas por la inundación, lo que indicaría su tolerancia a esta condición. Este resultado es contrario a los de otros autores (Mannetje y Jones 1992b; Cook et al. 2005) y debe ser corroborado a nivel de campo.

Modificaciones anatómicas de tallos y raíces

En *A. americana* la elongación del tallo en los tratamientos de saturación e inundacion fue, respectivamente, 20 y 40% superior al testigo. La altura de plantas es una respuesta morfológica que permite depositar biomasa foliar sobre el nivel del agua posibilitando la captura de oxígeno atmosférico y la continuación de la fijación de carbono (Javier 1985; Grimoldi et al. 1999; Voesenek et al. 2004).

En *M. lathyroides* se observó un mayor desarrollo de raíces adventicias, que comenzaron a formarse a las 72 h después del comienzo de la inundación. En condiciones de inundación, las raíces adventicias reemplazan funcionalmente a las raíces basales. Estas raíces especializadas aparecen cuando el sistema radical pierde la capacidad de absorber agua y nutrientes para uso por las plantas. Las raíces adventicias se forman generalmente cerca de la base del tallo y su crecimiento es lateral, paralelo a la superficie del agua. La produccción de raíces adventicias está asociada con el aumento de la tolerancia a inundaciones (Krizek 1982).

Otra respuesta a la inundación, tal vez la más evidente, es el desarrollo de espacios lacunares gaseosos (aerénquima) en la corteza de la raíz (Evans 2003; Parent 2009). La formación de aerénquima inducido por la escasa aireación del suelo es la primera respuesta de tipo anatómico manifestada por *M. lathyroides*. En este caso, el aerénquima se origina a partir del meristema secundario y se forma por el proceso de esquizogénesis que consiste en la separación celular ocasionada por crecimiento diferencial de las células, sin que involucre muerte celular. La formación de aerénquima inducido por hipoxia es un mecanismo común en las Eudicotiledoneae (Evans 2003; Parent et al. 2009). El aerénquima facilita el transporte de oxígeno desde el tallo hacia la raíz, ayudando así a restaurar el suministro de oxígeno a los tejidos sumergidos (Bradford y Hsiao 1982; Shiferaw et al. 1992; Crawford 1993; Viesser y Voesenek 2005). La diferencia de sensibilidad al estrés hídrico entre *M. lathyroides* y *M. atropurpureum* está relacionada con diferencias anatómicas. El mayor desarrollo de tejido aerenquimático en *M. lathyroides* sugiere que existe correlación entre el incremento de este tejido y la tolerancia a inundación de esta especie (Krizek 1982).

En *D. virgatus*, el órgano de reserva típico denominado xilopodio presentó un mayor desarrollo en el tratamiento con saturación (T1). Esto le permite crecer y nodular en estas condiciones (Burkart, 1952). En Australia esta especie resultó muy persistente a condiciones de inundación estacional en un suelo arcilloso pesado de características similares a las del presente ensayo (Peacock y Smith 1992).

Nodulación

Las leguminosas tolerantes a inundación tienen bacterias con mecanismos especiales para invadir las raíces y establecer la fijación simbiótica de N_2 en esas condiciones: En las raíces inundadas los rizobios entran en la corteza a través de fracturas en las raíces laterales basales, mientras que en las raíces bien aireadas la invasión ocurre por el encurvado de los pelos radicales (Goormachtig et al. 2004).

Aeschynomene americana presentó una buena nodulación bajo condiciones de anegamiento. Su tolerancia a la inundación fue previamente citada por Bishop et al. (1985) y puede estar relacionada con su capacidad de producir numerosas raíces adventicias que nodulan bien en condiciones de estrés hídrico.

En *D. virgatus* la nodulación no fue afectada por el anegamiento temporal. Ismaili et al. (1983) en condiciones similares a las de este ensayo y con la misma especie, no observaron formación de nódulos lo cual fue atribuido a la muerte de los microorganismos.

En *M. lathyroides* la adaptación a condiciones de anegamiento temporal se evidenció con la rápida producción de raíces adventicias que se formaron en los tallos sumergidos y con la rápida nodulación de éstas y otras raíces. Numerosos autores mencionan estos cambios morfológicos que se manifiestan en las plantas por efecto del anegamiento (Krizek 1982; Whiteman et al. 1983; Viesser y Voesenek 2005, López 2009). La nodulación se mantuvo alta durante el período reproductivo, lo que sugiere que esta especie podría mantener un nivel de oxígeno favorable en sus raíces a lo largo del ciclo productivo (Whiteman et al. 1983; Javier 1985). La buena adaptación de *M. lathyroides* a condiciones de anegamiento temporal y su potencial uso en los ambientes de malezal ya habían sido previamente reconocidas por Ciotti (1992). Esta especie durante la fase reproductiva no es afectada por la presencia de agua, con lo cual contribuye a su persistencia en los ecosistemas pastoriles.

Conclusiones

La supervivencia y rápida recuperación de las especies evaluadas en este trabajo confirmarían su potencial como forrajeras para las pasturas del Nordeste argentino, en suelos con drenaje deficiente que se inundan por períodos cortos. Se deberían realizar estudios en campo para evaluar la siembra de estas leguminosas, solas o asociadas, analizando su persistencia y producción bajo condiciones de inundación. Esto podría generar pautas de manejo para el aprovechamiento de áreas con potencial utilización para ganadería en zonas con problemas de drenaje.

Referencias

Arbo MM; López MG; Schinini A; Piesco G. 2002. Las plantas hidrófilas. En: Arbo MM; Tressens SG, eds. Flora del Iberá. Editorial de la Universidad Nacional de Nordeste, Corrientes, Argentina. p. 9−10.

Baruch Z; Mérida T. 1995. Effects of drought and flooding on root anatomy in four tropical forage grasses. International Journal of Plant Science 156:514−521.

Bishop HG. 1992. *Aeschynomene americana* L. En: Mannetje L‘t; Jones RM, eds. Plant Resources of South-East Asia No. 4. Forages. Pudoc Scientific Publishers, Wageningen, Países Bajos. p. 37−39.

Bishop HG; Ludke DH; Rutherford MT. 1985. Glenn jointvetch: A new pasture legume for Queensland coastal areas. Queensland Agricultural Journal 111:241−245.

Bradford KJ; Hsiao TC. 1982. Stomatal behaviour and water relations of water logged tomato plants. Plant Physiology 70:1508−1513.

Bradley RS. 1982. Manejo de las leguminosas forrajeras para los estudios de fijación de nitrógeno por *Rhizobium*. En: Toledo JM, ed. Manual para la Evaluación Agronómica. Red Internacional de Evaluación de Pastos Tropicales (RIEPT). Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. p. 83−89.

Burkart A. 1952. Las leguminosas argentinas silvestres y cultivadas. Ediciones ACME, Buenos Aires, Argentina.

Canevari P; Blanco DE; Bucher E; Castro G; Davidson I, eds. 1999. Los humedales de la Argentina: Clasificación, situación actual, conservación y legislación. Wetlands International Publicación No. 46. Buenos Aires, Argentina.

Carnevali R. 1994. Fitogeografía de la provincia de Corrientes. Gobierno de la Provincia de Corrientes, Instituto Nacional de Tecnología Agropecuaria (INTA), Corrientes, Argentina.

Ciotti EM. 1992. *Macroptilium lathyroides*: Un recurso forrajero para áreas anegadas. Gaceta Agronómica (Argentina) Vol. XII(65):27−33.

Ciotti EM; Castelán ME; Berg CH. 2006. Efecto del encharcamiento temporario sobre el rendimiento y la nodulación de *Stylosanthes guianensis* y *Arachis pintoi*. Pasturas Tropicales 28(1):52−56.

Ciparicci P; Candelero O; Reyna J. 2014. Excesos de agua: a cada problema, una solución. Sitio Argentino de Producción Animal, Boletín Todoagro N° 456. http://goo.gl/DJCqQB

Cook BG; Pengelly BC; Brown SD; Donnelly JL; Eagles DA; Franco MA; Hanson J; Mullen BF; Partridge IJ; Peters M; Schultze-Kraft R. 2005. Tropical forages: An interactive selection tool. [CD-ROM], CSIRO, DPI&F (Qld), CIAT and ILRI, Brisbane, Australia.

Crawford RMM. 1993. Plant survival without oxygen. Biologist 40(3):110−114.

Dias-Filho MB; Carvalho CJ. 2000. Physiological and morphological responses of *Brachiaria* spp. to flooding. Pesquisa Agropecuária Brasileira 35:1959−1966.

Di Rienzo JA; Balzarini M; Casanoves F; González L; Tablada M; Robledo CW. 2006. Infostat Profesional. Versión 2006. Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Córdoba, Argentina.

Escobar EH; Ligier HD; Melgar R; Matteio H; Vallejos O. 1996. Mapa de suelos de la provincia de Corrientes. Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental Agropecuaria Corrientes, Corrientes, Argentina.

Evans DE. 2003. Aerenchyma formation. New Phytologist 161:35−49.

Fernández JG; Benítez CA; Royo Pallarés O. 1983. Principales forrajeras nativas del Medio-Este de la Provincia de Corrientes. Serie Técnica No. 23. Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental Agropecuaria Mercedes, Corrientes, Argentina.

González AM; Cristóbal CL. 1997. Anatomía y ontogenia de semillas de *Helicteres lhotzkyana* (Sterculiaceae). Bonplandia 9:287−294.

Goormachtig S; Capoen W; Holsters M. 2004. Rhizobium infection: lessons from the versatile nodulation behaviour of water-tolerant legumes. Trends in Plant Science 9:518−522.

Grimoldi AA; Insausti P; Roitman GG; Soriano A. 1999. Responses to flooding intensity in *Leontodon taraxacoides*. New Phytologist 141:119−128.

Hack CM; Ciotti EM; Castelán ME; Porta M; Tomei CE. 2009. Efecto de dos sistemas de pastoreo en la producción de materia seca y la composición florística en un pastizal de *Andropogon lateralis*. Agrotecnia 19: 19−24.

Ismaili M; Briske DD; Weaver RW. 1983. Nitrogen fixing activity of water stressed Siratro. Agronomy Journal 75:649−653.

Jackson MB; Colmer TD. 2005. Response and adaptation by plants to flooding stress. Annals of Botany 96:501−505.

Javier RR. 1985. Effect of flooding on seven species of tropical pasture legumes. Annals of Tropical Research 5: 91−101.

Johansen DA. 1940. Plant Microtechnique. McGraw-Hill Book Co., New York, USA.

Jones RM; Mannetje L´t. 1992a. *Macroptilium lathyroides* (L.) Urban. En: Mannetje L´t; Jones RM, eds. Plant resources of South-East Asia, No. 4: Forages. Pudoc Scientific Publishers, Wageningen, Países Bajos. p. 158-159.

Jones RM; Mannetje L´t. 1992b. *Macroptilium atropurpureum* (DC.) Urban. En: Mannetje L´t; Jones RM, eds. Plant resources of South-East Asia, No. 4: Forages. Pudoc Scientific Publishers, Wageningen, Países Bajos. p. 155-157.

Krizek DT. 1982. Plant response to atmospheric stress caused by waterlogging. En: Christiansen MN; Lewis CF, eds. Breeding plants for less favorable environments. John Wiley & Sons, New York, USA. p. 293−335.

Ligier D. 2002. Análisis ambiental productivo de sistemas alternativos a la ganadería en la provincia de Corrientes. XIX Reunión de Grupo Técnico en Forrajeras del Cono Sur − Zona Campos. FAO – PROCISUR, Mercedes, Corrientes, Argentina. p. 60−66

López OR. 2009. Fisiología y ecología de comunidades arbóreas en hábitats inundables. Acta Biologica Panamensis 1:68−86.

Loreti J; Oesterheld M; León R. 1994. Efectos de la interacción del pastoreo y la inundación sobre *Paspalum dilatatum*, un pasto nativo de la pampa deprimida. Ecología Austral 4:49−58.

Luque R; Sousa HC; Kraus JE. 1996. Métodos de coloração de Roeser (1972) − modificado − e Kropp (1972) visando a substituição do azul de astra por azul de alcião 8 GS ou 8 GX. Acta Botanica Brasilica 10:199−212.

Mannetje L‘t; Jones RM, eds. 1992. Plant resources of South-East Asia, No. 4: Forages. Pudoc Scientific Publishers, Wageningen, Países Bajos.

McIvor JG. 1976. The effect of waterlogging on the growth of *Stylosanthes guianensis*. Tropical Grasslands 10: 173−178.

McNaughton SJ. 1983. Compensatory plant growth as a response to herbivory. Oikos 40:329−336.

Mommer L; Visser EJW. 2005. Underwater photosynthesis in flooded terrestrial plants: A matter of leaf plasticity. Annals of Botany 96:581−589.

Parent C; Capelli N; Berger A; Crevecoeur M; Dat J. 2009. An overview of plant responses to soil waterlogging. Plant Stress 2:20−27.

Peacock A; Smith FT. 1992. Evaluation of pasture legumes on a seasonally flooded heavy clay soil in south-east Queensland. Australian Plant Introduction Review 23:20−31.

Ross BJ; Cameron AG. 1991. Pasture legume evaluation on seasonally flooded soils in Northern Territory. Tropical Grasslands 27:32−36.

Schinini A; Ciotti EM; Tomei CE; Castelán ME; Hack CM. 2004. Especies nativas de campos bajos con potencial valor forrajero. Agrotecnia 12:18−22.

Shiferaw W; Shelton HM; So HB. 1992. Tolerance of some subtropical pasture legumes to waterlogging. Tropical Grasslands 26:187−195.

Skerman PJ; Riveros F. 1992. Gramíneas Tropicales. Colección FAO: Producción y Protección Vegetal No. 23. Food and Agriculture Organization of the United Nations (FAO), Roma, Italia.

Soriano A; León RJC; Sala OE; Lavado RS; Deregibus VA; Cahuepé MA; Scaglia OA; Velázquez CA; Lemcoff JH. 1992. Rio de la Plata Grasslands. En: Coupland RT, ed. Ecosystems of the World 8A. Natural Grasslands. Introduction and Western Hemisphere. Elsevier New York, USA. p. 367−407.

Striker GG; Insausti P; Grimoldi AA. 2007. Efectos de la inundación en la recuperación post-defoliación de *Lotus tenuis* y *Paspalum dilatatum*. Lotus Newsletter 37(1):26.

Viesser EJW; Voesenek LACJ. 2005. Acclimation to soil flooding − sensing and signal transduction. Plant and Soil 254:197−214.

Vignolio OR; Maceira NO; Fernández ON. 1994. Efectos del anegamiento en invierno y verano sobre el crecimiento y la supervivencia de *Lotus tenuis* y *Lotus corniculatus*. Ecología Austral 4:19−28.

Voesenek LACJ; Rijnders JH; Peeters AJ; van de Steeg HM; de Kroon H. 2004. Plants hormones regulate fast shoot elongation under water: From genes to communities. Ecology 85:16−27.

Whiteman PC; Seitlheko M; Siregar ME. 1983. Comparative flooding tolerance of tropical pasture legumes. Proceedings of the XIV International Grassland Congress, Lexington, KY, USA, 1981. p. 393−395.

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Collecting Venezuelan *Stylosanthes* species

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Abstract

A report on recent activities to collect representative germplasm samples of *Stylosanthes* species native to Venezuela is presented. The main objective was to obtain original seeds for phylogenetic studies and, at the same time, to contribute to safeguarding *Stylosanthes* diversity, in view of the increasing danger of genetic erosion. Seeds of 33 samples, comprising all 11 Venezuelan *Stylosanthes* species, were collected: *S. angustifolia, S. capitata, S. gracilis, S. guianensis, S. hamata, S. humilis, S. scabra* and *S. viscosa* plus the endemic and little-known *S. falconensis, S. sericeiceps* and *S. venezuelensis*. Populations of the latter 3 species were small and difficult to locate; these species must be considered endangered and require further attention by genetic resources specialists. Furthermore, assessment of their agronomic and forage potential, in particular, *S. falconensis* and *S. sericeiceps,* is warranted.

Resumen

Se presenta un informe sobre unas recientes actividades para recolectar muestras representativas de germoplasma de las especies venezolanas de *Stylosanthes*. El objetivo principal fue obtener semillas originales para ser usadas en estudios filogenéticos y, al mismo tiempo, contribuir a salvaguardar la diversidad de *Stylosanthes*, en vista del creciente peligro de erosión genética que afecta también a este género. Como resultado, se recolectaron un total de 33 muestras de semillas que comprenden las 11 especies venezolanas de *Stylosanthes*: *S. angustifolia*, *S. capitata*, *S. gracilis*, *S. guianensis*, *S. hamata*, *S. humilis*, *S. scabra*, *S. viscosa* y las endémicas y poco conocidas *S. falconensis*, *S. sericeiceps* y *S. venezuelensis*. Las poblaciones de las tres últimas especies fueron difíciles de localizar y pequeñas; por lo tanto, estas especies deben ser consideradas como en peligro y requieren una mayor atención por parte de los especialistas en recursos genéticos. Además ameritan ser evaluadas respecto a su potencial agronómico y forrajero, en particular *S. falconensis* y *S. sericeiceps*.

Introduction

Stylosanthes is considered one of the most important tropical forage legume genera (Burt et al. 1983; Chakraborty 2004). Primarily because most of its species are adapted to infertile soils and drought, it has received considerable attention by tropical pasture scientists and is well represented in the major forage genetic resources collections (Stace and Edye 1984; Cook et al. 2005).

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Venezuela is an important center of diversification of *Stylosanthes*; 11 species have been reported, 3 of them being endemic to the country (Calles and Schultze-Kraft 2010a). During 1973−1986, a significant collection of more than 600 accessions of Venezuelan *Stylosanthes* germplasm was assembled (Schultze-Kraft 1991).

A recent study of diversity of Venezuelan *Stylosanthes* (Calles 2012) has shown the convenience of molecular marker analyses to further describe genetic variation and species boundaries and relationships. For this, original seed samples (those collected at the original sites) should be used, rather than material that has undergone various cycles of seed multiplication in gene bank plant nurseries, with the concomitant risk that genetic integrity of the accession may be distorted (Chebotar et al. 2003).

This risk was recently pointed out by Garcia et al. (2013) for several *Stylosanthes* species, which usually are considered to be predominantly self-pollinating. They reported outcrossing rates of up to 31%. The Venezuelan diversity study also highlighted the increasing destruction of native habitats due to land use changes in the country, and subsequent endangerment of *Stylosanthes* populations.

This paper reports on recent (2006–2008) collecting activities in Venezuela to obtain representative germplasm samples of all 11 Venezuelan *Stylosanthes* species, with the objective of: (1) making original seeds available for phylogenetic analyses; and, at the same time, (2) safeguarding *Stylosanthes* diversity in view of the danger of genetic erosion.

Methodology

Three collection sites for each Venezuelan *Stylosanthes* species were predefined, based on exhaustive herbarium studies using specimens from 13 international and 22 Venezuelan herbaria (Calles and Schultze-Kraft 2010a). In order to cover as much intraspecific diversity as possible, the sites identified were in environments as contrasting as possible and/or with the largest possible geographic distance between them.

At each site, we collected as many mature seeds as possible from the target populations; if possible, 10 or more plants per population were sampled and the seeds bulked. Soil samples from the 0–10 cm horizon were taken and analyzed to determine texture, pH and phosphorus (P) content.

Geographical location and elevation were recorded with a GPS device and later refined using the geographical information program Google Earth (http://earth.google.com). Climatic information (i.e. mean annual rainfall, number of dry months and annual mean temperature) at collection sites was obtained from the software DIVA-GIS (Hijmans et al. 2005); a month with less than 60 mm of rainfall was considered dry. Vegetation/ecozone classification at collection sites was performed by locating the collection sites manually on the vegetation map of Venezuela (Huber and Alarcón 1988).

In compliance with national regulations governing access to Venezuelan plant genetic resources, a collection permit was obtained from the Ministry of Environmental Affairs (MINAMB, its Spanish acronym).

Results and Discussion

General

A total of 33 seed samples were collected. Except for *S. capitata*, *S. scabra* and *S. sericeiceps* (4 samples each), *S. viscosa* (2 samples) and *S. venezuelensis* (1 sample), 3 samples of each Venezuelan species were obtained as intended. The samples were incorporated in the collection of the Venezuelan Genebank for Forage Legumes (BGLFV, its Spanish acronym) at INIA-Anzoátegui, El Tigre; it is intended to deposit a duplicate at the Genetic Resources Program of CIAT, Cali, Colombia. Furthermore, at least 2 voucher herbarium specimens from plants with flowers and fruits were taken from each population and deposited at the Herbario Nacional de Venezuela (VEN). Passport data of the collected material are provided in Table 1.

Climate, soil and vegetation

Collections were made from an elevation range of 10–1,871 masl, with the only exception being a site at 2,481 masl, where a population of *S. sericeiceps* (CAL014) was collected in the Andes region, municipality of Mérida (Table 1). Most sampled populations were in areas with mean annual rainfall (MAR) ≥1,000 mm (Table 2) and with a dry season of up to 6 months. Interestingly, all populations of *S. falconensis* and one *S. viscosa* population (CAL005) were collected in areas with MAR as low as 781 and 312 mm, respectively. Moreover, at the collection site of sample CAL005, no month registered more than 60 mm rainfall. Most species were collected in areas with annual mean temperature (AMT) between 20 and 28 °C (Table 2), but it is noteworthy that some samples of *S. guianensis* (CAL030, CAL032), *S. hamata* (CAL012), *S. scabra* (CAL028, CAL031) and all samples of *S. sericeiceps* were collected in areas with AMT <20 °C.

Savanna was the original vegetation type, where the largest number of samples originated (12 samples), followed by: thorn forest and semi-deciduous forest (5 samples each); deciduous forest (4 samples); littoral vegetation and evergreen forest (3 and 2 samples, respectively); and gallery and cloud forests (1 sample each). In many cases, habitat destruction, as a consequence of land use changes, was observed.

Table 1. Passport data of *Stylosanthes* germplasm samples collected in Venezuela.

Collector number	Species	Collectors	State	km loc.	Locality	Lat. (°)	Long. (°)	Elev. (m)	Date	Herbarium specimen
CAL001	*S. venezuelensis* Calles and Schultze-Kr.	T. Calles, R. Schultze-Kraft, O. Guenni, Y. Espinoza	Distrito Capital		Caracas	10.495	-66.891	895	10.02.06	*Calles et al. 1001*
CAL002	*S. hamata* (L.) Taub.	T. Calles, E.M. Walle	Falcón	1 NW	La Luisa	10.868	-68.314	202	08.04.07	*Calles & Walle 1014*
CAL003	*S. angustifolia* Vogel	T. Calles, E. Colmenares	Guárico	31 SE	Calabozo	8.703	-67.297	78	25.04.07	*Calles & Colmenares 1015*
CAL004	*S. angustifolia* Vogel	T. Calles, E. Colmenares	Apure		Fundo Picachón	7.022	-67.668	49	26.04.07	*Calles & Colmenares 1016*
CAL005	*S. viscosa* (L.) Sw.	T. Calles, J. García	Sucre	0.5 SW	Tacarigua	10.569	-64.171	10	06.05.07	*Calles & García 1017*
CAL006	*S. hamata* (L.) Taub.	T. Calles	Sucre		Cumaná	10.430	-64.194	18	12.05.07	*Calles 1018*
CAL007	*S. falconensis* Calles and Schultze-Kr.	T. Calles	Falcón	0.6 SW	Carrizalito	11.130	-69.757	1,169	23.07.07	*Calles 1019*
CAL008	*S. falconensis* Calles and Schultze-Kr.	T. Calles	Falcón	0.4 NW	La Peña	11.108	-69.750	910	24.07.07	*Calles 1020*
CAL009	*S. falconensis* Calles and Schultze-Kr.	T. Calles	Falcón		Cucaire	11.124	-69.760	1,165	25.07.07	*Calles 1021*
CAL010	*S. humilis* Kunth	T. Calles	Portuguesa	7 NW	Guanare	9.066	-69.810	259	14.12.07	*Calles 1022*
CAL011	*S. sericeiceps* S.F. Blake	T. Calles	Mérida	3 NW	Lagunillas	8.515	-71.412	1,363	17.12.07	*Calles 1023*
CAL012	*S. hamata* (L.) Taub.	T. Calles	Mérida		La González	8.504	-71.326	819	17.12.07	*Calles 1024*
CAL013	*S. sericeiceps* S.F. Blake	T. Calles	Mérida		La González	8.502	-71.320	762	17.12.07	*Calles 1025*
CAL014	*S. sericeiceps* S.F. Blake	T. Calles	Mérida	4 NW	El Morro	8.471	-71.209	2,481	18.12.07	*Calles 1026*
CAL015	*S. humilis* Kunth	T. Calles, R. Schultze-Kraft	Guárico		Palo Seco	9.057	-67.238	141	06.02.08	*Calles & Schultze-Kraft 1027*
CAL016	*S. gracilis* Kunth	T. Calles, R. Schultze-Kraft	Guárico	6 NW	El Mejo	8.620	-66.434	139	06.02.08	*Calles & Schultze-Kraft 1028*
CAL017	*S. angustifolia* Vogel	T. Calles, R. Schultze-Kraft	Guárico	6 NW	El Mejo	8.620	-66.434	139	06.02.08	*Calles & Schultze-Kraft 1029*
CAL018	*S. capitata* Vogel	T. Calles, R. Schultze-Kraft	Guárico	17 S	Santa Rita	7.974	-66.238	53	06.02.08	*Calles & Schultze-Kraft 1030*
CAL019	*S. guianensis* (Aubl.) Sw.	T. Calles, R. Schultze-Kraft	Anzoátegui	6 NW	Santa Juana	8.946	-64.758	214	07.02.08	*Calles & Schultze-Kraft 1031*
CAL020	*S. scabra* Vogel	T. Calles, R. Schultze-Kraft	Anzoátegui	6 NW	Santa Juana	8.946	-64.758	214	07.02.08	*Calles & Schultze-Kraft 1032*
CAL021	*S. gracilis* Kunth	T. Calles, R. Schultze-Kraft	Anzoátegui	6 NE	Caracol	8.919	-64.608	343	07.02.08	*Calles & Schultze-Kraft 1033*
CAL022	*S. capitata* Vogel	T. Calles, R. Schultze-Kraft	Anzoátegui	14 NE	Santa Clara	8.610	-64.557	191	08.02.08	*Calles & Schultze-Kraft 1034*
CAL023	*S. scabra* Vogel	T. Calles, R. Schultze-Kraft	Sucre	5 SW	Santa Fe	10.232	-64.424	248	09.02.08	*Calles & Schultze-Kraft 1035*
CAL024	*S. capitata* Vogel	T. Calles, R. Schultze-Kraft	Monagas	4 S	Chaguaramas	8.690	-62.774	71	11.02.08	*Calles & Schultze-Kraft 1038*
CAL025	*S. viscosa* (L.) Sw.	T. Calles, R. Schultze-Kraft	Bolívar		La Ceiba	7.678	-63.508	143	11.02.08	*Calles & Schultze-Kraft 1040*
CAL026	*S. capitata* Vogel	T. Calles, R. Schultze-Kraft	Bolívar		Cardozo	8.000	-63.546	106	12.02.08	*Calles & Schultze-Kraft 1042*
CAL027	*S. humilis* Kunth	T. Calles, R. Schultze-Kraft	Bolívar		Cardozo	8.000	-63.546	106	12.02.08	*Calles & Schultze-Kraft 1043*
CAL028	*S. scabra* Vogel	T. Calles, T. Beuchelt	Táchira		Lobatera	7.933	-72.241	1,010	19.02.08	*Calles & Beuchelt 1044*
CAL029	*S. sericeiceps* S.F. Blake	T. Calles, T. Beuchelt	Mérida	1 SW	Higuerones	8.522	-71.282	868	20.02.08	*Calles & Beuchelt 1045*
CAL030	*S. guianensis* (Aubl.) Sw.	T. Calles, T. Beuchelt	Mérida	5 S	Mérida	8.535	-71.180	1,871	20.02.08	*Calles & Beuchelt 1046*
CAL031	*S. scabra* Vogel	T. Calles, T. Beuchelt	Lara	1 SE	Humocaro Alto	9.599	-69.982	1,024	23.02.08	*Calles & Beuchelt 1047*
CAL032	*S. guianensis* (Aubl.) Sw.	T. Calles, T. Beuchelt	Lara	1 SE	Humocaro Alto	9.599	-69.982	1,024	23.02.08	*Calles & Beuchelt 1048*
CAL033	*S. gracilis* Kunth	T. Calles, T. Beuchelt	Zulia	3 S	La Raya	9.848	-70.878	48	27.02.08	*Calles & Beuchelt 1 050*

All species were growing on extremely acid to slightly acid soils (Table 3), except for *S. falconensis* and *S. venezuelensis* (slightly alkaline to neutral). It is noteworthy that *S. angustifolia*, *S. capitata*, *S. gracilis* [formerly known as *S. guianensis* var. *gracilis* (Kunth) Vogel; Calles and Schultze-Kraft 2010b] and *S. humilis* consistently came from very strongly acid soils (classification according to SSDS 1993). Soil P content was low in most cases, except for *S. guianensis*, *S. hamata* and *S. sericeiceps* (medium to high P content). It was significant that only *S. scabra* was growing on a heavier textured soil (clay loam).

In general, climatic and soil conditions at collection sites are in agreement with what is known about ecological conditions where *Stylosanthes* species occur (Stace and Edye 1984). We draw attention to the very high site elevation of sample CAL014 (the endemic *S. sericeiceps*; above 2,400 masl; Figures 1A, B & C) and the very low rainfall at the site of CAL005 (*S. viscosa*; GIS-DIVA calculated MAR of 312 mm). Both are quite unusual for *Stylosanthes* species and germplasm from those sites might be a particularly interesting resource for selection and/or breeding projects concerned with cold- and drought-tolerance, respectively.

Table 2. Climatic characteristics (ranges) and vegetation types at collection sites of Venezuelan *Stylosanthes* species.

Species	MAR[1] (mm)	Dry months[2] (No.)	AMT[3] (°C)	Vegetation type[4] (Collector number)
S. angustifolia	1,297–1,868	4–5	26.7–27.9	SA (003, 017), GF (004)
S. capitata	943–1,512	4–6	26.2–27.8	SA (018, 022, 024), SF (026)
S. falconensis	781	5	23.5	DF (007, 008, 009)
S. gracilis	1,035–1,378	3–5	26.5–26.8	SA (016, 021, 033)
S. guianensis	1,052–1,214	3–5	15.8–26.9	SA (019), CF (030), EF (032)
S. hamata	1,089–1,141	2–5	15.8–26.6	LV (002, 006), TF (012)
S. humilis	943–1,597	4–6	27.3–27.8	SF (010, 027), SA (015)
S. scabra	925–1,223	3–5	18.8–26.9	SA (020), SF (023), TF (028), EF (031)
S. sericeiceps	1,088–1,127	3–4	14.5–16.4	TF (011, 013, 029), DF (014)
S. venezuelensis	1,003	5	20.0	SF (001)
S. viscosa	312–1,164	4–12	27.1–27.4	LV (005), SA (025)

[1]Mean annual rainfall; [2]months with <60 mm rainfall; [3]annual mean temperature; [4]according to Huber and Alarcón (1988): SA, savanna; GF, gallery forest; SF, semi-deciduous forest; DF, deciduous forest; CF, cloud forest; EF, evergreen forest; LV, littoral vegetation; TF, thorn forest.

Table 3. Some soil characteristics (mean values) at collection sites of Venezuelan *Stylosanthes* species.

Species	Texture[1] (Collector number)	pH[2] (±SD)	Phosphorus[3] (±SD) (ppm)
S. angustifolia	loamy sand (003), sand (004), loam (017)	4.8 (0.7)	6.3 (5.8)
S. capitata	sand (018, 022), sandy loam (024), loamy sand (026)	4.4 (0.2)	4.0 (0.0)
S. falconensis	sandy loam (007, 008, 009)	7.4 (0.3)	5.7 (4.6)
S. gracilis	loam (016), sand (021)	4.6 (0.6)	3.0 (0.0)
S. guianensis	loamy sand (019, 030), silt loam (032)	5.9 (1.0)	43.3 (68.2)
S. hamata	sandy loam (002, 006), loam (012)	6.3 (2.0)	34.3 (46.5)
S. humilis	sandy loam (010), silt loam (015), loamy sand (027)	4.6 (0.2)	4.7 (2.1)
S. scabra	loamy sand (020, 023), clay loam (028, 031)	5.7 (1.3)	11.0 (13.6)
S. sericeiceps	sandy loam (011, 013), loam (014), loamy sand (029)	6.2 (0.9)	108 (74.2)
S. venezuelensis	sandy loam (001)	7.3	15.0
S. viscosa	sandy loam (005), loamy sand (025)	4.8 (0.4)	3.5 (0.7)

Methodology: [1]Bouyoucos; [2]Water 1:1; [3]Mehlich I.

Figure 1. *Stylosanthes sericeiceps* (sample CAL014): **A** collection site; **B** overgrazed old plant; **C** flowering branches. *Stylosanthes falconensis* (sample CAL009): **D** collection site; **E** adult plant; **F** flowering branch. *Stylosanthes venezuelensis* (sample CAL001): **G** plants at collection site; **H** flowering branch. Photos A, B, C, G & H by R. Schultze-Kraft; D–F by T. Calles.

Endemic species

During our collecting activities we observed that the 3 endemic *Stylosanthes* species (*S. falconensis*, *S. sericeiceps* and *S. venezuelensis*) have very restricted distributions. Populations occurred in areas, where human intervention is negatively affecting their habitats, and were rather small and difficult to find. All 3 species must be considered rare. At collection sites, *S. falconensis* (a new species, closely related to *S. hamata*; Calles and Schultze-Kraft 2010c; Figures 1D, E & F) showed vigorous growth and plants were evidently grazed by livestock. This suggests that the forage potential of this species is worthy of evaluation. We observed apparent fertility problems at all 3 sites for that species; while plants were flowering profusely, there was very little seed set. The same was observed with 1 of the 3 *S. sericeiceps* populations (CAL011).

The third endemic species, *S. venezuelensis* (closely related to *S. scabra*; Calles and Schultze-Kraft 2009; Figures 1G & H), is particularly rare. In spite of our intensive search, we found only 1 small population in strongly intervened vegetation within the Caracas urban area.

Continued collecting of germplasm of these endemic species is required in order to safeguard their genetic diversity. In the case of *S. venezuelensis*, protection measures might be needed to avoid the extinction of the species. An initial step would be to multiply the collected material and disperse the seed into the species' native habitats.

Conclusion and Outlook

Original seed of all Venezuelan *Stylosanthes* species is now available for the intended phylogenetic studies. With the material collected, we might have made only a minor contribution to increased genetic diversity within the 8 non-endemic species, since, with the exception of *S. angustifolia*, they had been fairly well sampled in the 1970s and 1980s (Schultze-Kraft 1991). Rather, the significance of the collection reported here lies in the fact that germplasm of the 3 endemic species, *S. falconensis*, *S. sericeiceps* and *S. venezuelensis*, is available for the first time. These species are rare and must be considered endangered. Efforts to collect more material to safeguard genetic diversity are indicated, particularly in view of the destruction of the species' habitats.

Assessment of the agronomic and forage potential of the endemic species, particularly of *S. falconensis* and *S. sericeiceps,* is suggested.

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References

Burt RL; Rotar PP; Walker JL; Silvey MW, eds. 1983. The role of *Centrosema*, *Desmodium* and *Stylosanthes* in improving tropical pastures. Westview Press, Boulder, CO, USA.

Calles T. 2012. Diversity of Venezuelan *Stylosanthes* (*Leguminosae*). Cuvillier Verlag, Göttingen, Germany.

Calles T; Schultze-Kraft R. 2009. Una nueva especie venezolana de *Stylosanthes* (*Leguminosae*: *Papilionoideae*: *Dalbergieae*). Acta Botánica Venezuelica 32:153–157.

Calles T; Schultze-Kraft R. 2010a. *Stylosanthes* (*Leguminosae*, *Dalbergieae*) of Venezuela. Willdenowia 40:305–329.

Calles T; Schultze-Kraft R. 2010b. Re-establishment of *Stylosanthes gracilis* (*Leguminosae*) at species level. Kew Bulletin 65(2):233–240.

Calles T; Schultze-Kraft R. 2010c. *Stylosanthes falconensis* (*Leguminosae*: *Papilionoideae*: *Dalbergieae*), a new species endemic to Venezuela. Kew Bulletin 65(1):73–76.

Chakraborty S, ed. 2004. High-yielding anthracnose-resistant *Stylosanthes* for agricultural systems. ACIAR Monograph No. 111. Australian Centre for International Agricultural Research (ACIAR), Canberra, ACT, Australia.

Chebotar S; Röder MS; Korzun V; Saal B; Weber WE; Börner A. 2003. Molecular studies on genetic integrity of open-pollinating species rye (*Secale cereale* L.) after long-term genebank maintenance. Theoretical and Applied Genetics 107:1469–1476.

Cook BG; Pengelly BC; Brown SD; Donnelly JL; Eagles DA; Franco MA; Hanson J; Mullen BF; Partridge IJ; Peters M; Schultze-Kraft R. 2005. Tropical forages: An interactive selection tool. [CD-ROM], CSIRO, DPI&F(Qld), CIAT and ILRI, Brisbane, Qld, Australia.

Garcia M; Vigna BBZ; Sousa ACB; Jungmann L; Cidade FW; Toledo-Silva G; Francisco PM; Chiari L; Carvalho MA; Karia CT; Faleiro FG; Godoy R; Dall'Agnol M; Pagliarini SS; Souza FHD; Souza-Chies TT; Jank L; Resende RMS; Valle CB; Zucchi MI; Souza AP. 2013. Molecular genetic variability, population structure and mating system in tropical forages. Tropical Grasslands–Forrajes Tropicales 1:25–30.

Hijmans RJ; Guarino L; Jarvis A; O'Brien R; Mathur P; Bussink C; Cruz M; Barrantes I; Rojas E. 2005. DIVA-GIS, Version 5.2 [Computer Software]. Centro Internacional de la Papa (CIP), Lima, Peru and Bioversity International, Rome, Italy.
Huber O; Alarcón C. 1988. Mapa de Vegetación de Venezuela. Ministerio del Ambiente y de los Recursos Naturales (MARN), Caracas, Venezuela.
Schultze-Kraft R. 1991. La colección de forrajeras tropicales del CIAT. 2. Catálogo de germoplasma de Venezuela. Documento de trabajo No. 85. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.
SSDS (Soil Survey Division Staff). 1993. Soil survey manual. Soil Conservation Service, US Department of Agriculture, Washington, DC, USA.
Stace HM; Edye LA, eds. 1984. The biology and agronomy of *Stylosanthes*. Academic Press, Sydney, NSW, Australia.

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