Pasture legume adaptation to six environments of the seasonally dry tropics of north Queensland

T.J. HALL[1] AND R.W. WALKER[2]
[1]*Department of Primary Industries and Fisheries, Roma, and* [2]*Atherton, Queensland, Australia*

Abstract

Production, regeneration and persistence of summer-growing pasture legumes were studied in plots (26 accessions) in 3 sub-coastal environments (>600 m elevation) and in rows (92 accessions) in 3 inland environments (<200 m elevation) in the seasonally dry tropics of north Queensland. In the plots, the annuals *Aeschynomene americana* and *Centrosema pascuorum* and the perennials *Stylosanthes scabra*, *S. hamata* and *Chamaecrista rotundifolia* were most productive, yielding up to 4.5 and 7.6 t/ha DM, respectively, on grey and red earths and a red duplex soil. Annuals regenerated poorly in low rainfall years, but populations and production of the *Stylosanthes* species and *C. rotundifolia* cv. Wynn remained adequate for commercial pastures in all years, and increased in a high rainfall year. *Macroptilium gracile* cv. Maldonado was planted at only one site and produced a peak yield of 6.2 t/ha DM and had most spread (>30 m) during the experiment.

In the row experiments, legume establishment and production were restricted by drought on the red earth and grey clay soils, and by waterlogging on a hard-setting solodic soil. After 4 years of drought and grazing, none of the 72 legumes sown on the fertile red earth had survived, although there was subsequent regeneration from seed. *Desmanthus* species and *Clitoria ternatea* were most productive and persistent, over 15 years, on the cracking clay soil, and *Stylosanthes scabra* cv. Seca and *S. hamata* cv. Verano were the only survivors on the solodic soil. Environmental limitations of the current pasture legume cultivars have been identified and legume genera are suggested for further evaluation and development under commercial grazing management and for special purpose pastures in these environments.

Correspondence: Trevor Hall, Department of Primary Industries and Fisheries, PO Box 308, Roma, Qld 4455, Australia. E-mail: trevor.hall@dpi.qld.gov.au

Introduction

The cattle production benefits from introducing well adapted legumes into low-quality, grass-dominant pastures have been well demonstrated across tropical Australia and the animal production from sown *Stylosanthes* pastures has been reviewed by Hall and Glatzle (2004). Introducing *Stylosanthes* spp. in the seasonally dry tropics of north Queensland usually improved annual growth rates of cattle by 30–60 kg/hd (Coates *et al.* 1997), with a 3-fold increase in animal production per hectare. In the dry tropics, Winks (1973) reported liveweight gains of 190 kg/head on superphosphate-fertilised Townsville stylo (*Stylosanthes humilis*), compared with around 80 kg/head on native pasture, at a stocking rate of 1 beast/2.4 ha, between January and August. Cattle lost weight in the dry season, between August and December on both pastures. Increasing stocking rate reduced both wet season and annual liveweight gains on Townsville stylo pastures.

The low reproductive rates and relatively high death rates of beef cattle in the region are also improved by the better nutrition offered by sown legumes. Holroyd *et al.* (1983) reported that, in some years, cows grazing fertilised stylo-grass pasture in the dry tropics can have higher conception rates and earlier calving dates, and generally retain better body condition and are heavier, while their calves grow faster to weaning than those on native pasture alone. Also, fertilised stylo-grass pastures can produce a 2.4-fold increase in cow and calf liveweight per unit area over that of native pasture. Branding-rate increases of 20–30% are achievable with the better weaner-management options available on sown legume pastures (Partridge *et al.* 1996).

Verano (*S. hamata*) and Seca (*S. scabra*) stylos are the major tropical legumes being sown in tropical Australia (Walker and Weston 1990) and, with added superphosphate, have already had an impact on light soils of the inland low-elevation (<200 m) dry tropics to the north and west of the eastern uplands, but pasture development has been more slowly accepted by graziers in the subcoastal more elevated (>600 m) areas of Queensland. This could be because Verano has poor persistence at the mild temperatures experienced at flowering late in the wet season (Williams and Gardener 1984), or plants are frosted in this environment. There are now at least 600 000 ha of sown *Stylosanthes* pastures in northern Australia, contributing some $20 M annually to beef production through higher cattle turnoff weights, improved weaner and heifer nutrition and reduced drought risk (Miller *et al.* 1997). Evaluation of Wynn cassia (*Chamaecrista rotundifolia*), a forage legume which has increased annual cattle liveweight gain by 35 kg/hd in south-east Queensland (Partridge and Wright 1992), has been limited in north Queensland.

Clements (1996) reported that constraints to the future use of sown tropical pasture plants included the limited availability of well adapted legumes in some areas, instability of legume-based pastures, and the high cost of establishing and maintaining improved pastures. The selection of environmentally well adapted and vigorous legumes with an ability to spread under grazing in the dry tropics will help alleviate these constraints. Potential weediness in ungrazed environments has to be considered in any species selection.

In the low-elevation inland tropics, suitable sown legumes are not available for all environments, because existing cultivars lack adaptation to some soil types, including infertile light-textured soils, heavy cracking clays and seasonally waterlogged duplex soils, and/or the rainfall is too low. Even where soils are fertile and support productive introduced grass, such as Cloncurry buffel (*Cenchrus pennisetiformis*) (Hall 1978), the variable and low (<500 mm) rainfall limits legume performance (Edye *et al.* 1991). Screening legume species in these environments to select accessions for more detailed evaluation is warranted.

In the higher and more reliable rainfall (>750 mm) environments of the more elevated subcoastal areas of the eastern highlands near Mt Garnet, evaluation of commercial cultivars of tropical legumes on soils that are being used for more intensive agricultural development has been limited. Gilbert *et al.* (1987) assessed the fertility of the red and yellow earths and duplex soils and diagnosed phosphorus deficiency for sown pasture production in this area.

Our experiments were designed to evaluate the adaptation and production of accessions of introduced tropical pasture legumes and commercial legume cultivars in 6 environments in the seasonally dry tropics of north Queensland.

Materials and methods

Sites

Six experiments to evaluate pasture legume accessions were conducted in plots (swards) or spaced rows across north Queensland. Three plot experiments were located on major soil types of the elevated (600–740 m) subcoastal Mt Garnet area of the eastern highlands, and 3 spaced-row experiments were at low-elevation (<200 m) inland sites. These locations represent a range of soil and climatic environments in the southern Peninsula and lower Gulf regions of Queensland. The site locations, soils, vegetation, frost risk and establishment details are shown in Table 1. The experimental sites were in grass-dominant native pasture communities with a range of desirable and less desirable grasses present. At Ben Avon, main grasses were: *Aristida, Arundinella, Brachiaria, Chloris, Digitaria* and *Heteropogon* spp.; and at Tirrabella, *Aristida, Chloris, Chrysopogon, Digitaria, Heteropogon* and *Themeda* spp. were common. A diverse range of forbs and native legumes (*e.g. Crotalaria, Glycine, Desmodium, Galactia, Indigofera* and *Rhynchosia* spp.) also occurred at these sites.

Site preparation

All sites, except Highbury, which had a low and scattered population of 3–4 m high broadleaf teatree (*Melaleuca viridiflora*) trees, were cleared of woody vegetation. Tall and dense stands of *Eucalyptus* species were cleared by pulling and stick-raking at Ben Avon, Tirrabella and Pinnarendi. The low and scattered population of western grey box trees (*Eucalyptus argillacea*) was pushed by bulldozer from the site at Corella Park, and bauhinia (*Lysiphyllum* spp.)

Table 1. Locations, soil and vegetation descriptions, sites and details of legume establishment at 6 experimental sites.

	Experimental sites					
	Plot experiments			Row experiments		
	Ben Avon	Tirrabella	Pinnarendi	Wrotham Park	Highbury	Corella Park
Nearest town	Ravenshoe	Mt Garnet	Mt Garnet	Chillagoe	Chillagoe	Cloncurry
Latitude (°S)	17°48′	17°53′	18°03′	16°34′	16°28′	20°31’
Longitude (°E)	145°20′	145°14′	142°53′	143°59′	143°12′	140°14’
Elevation (m)	640	600	740	175	100	195
Soil type	grey earth	red earth	red duplex	heavy, cracking, grey clay	hard-setting, yellow duplex	deep, loamy red earth
Soil classification[1]	Gn 2.74	Gn 2.12	Dr 2.51	Ug 5.22	Dy 3.43	Gn 2.11
Soil surface (0–10 cm) — unfertilised						
pH	5.9	7.5	6.4	6.3	6.0	7.0
P (ppm) (bicarb.)	2	8	6	3	1	16
NO_3-N (ppm)	12	30	4	9	1	2
Extr. K (m.eq.%)	0.28	0.44	0.53	0.45	0.09	0.57
Cl^- (ppm)	20	10	10	21	14	10
E.C. (mS/cm)[2]	0.047	0.095	0.032	0.034	0.013	0.018
Vegetation type	woodland	open forest	woodland	low, open woodland	open woodland	low, open woodland
Main trees	*Eucalyptus alba* *Eucalyptus leptophleba*	*Eucalyptus tetrodonta* *Eucalyptus leptophleba*	*Eucalyptus crebra* *Eucalyptus polycarpa*	*Lysiphyllum cunninghamii* *Terminalia chillagoensis*	*Melaleuca viridiflora*	*Eucalyptus argillacea* *Eucalyptus terminalis*
Main grasses	*Heteropogon contortus* *Themeda triandra* *Heteropogon triticeus*	*Chloris virgata* *Melinis repens* *Themeda triandra*	*Themeda triandra* *Eragrostis brownii*	*Astrebla squarrosa* *Eragrostis tenellula*	*Aristida hygrometrica* *Schizachyrium fragile* *Eriachne mucronata*	*Cenchrus pennisetiformis* *Chrysopogon fallax* *Enneapogon polyphyllus*
Frost risk	high	high	moderate	nil	nil	nil
History	native pasture, cleared 1984, buffel pasture	peanut/sorghum cultivation	native pasture, cleared 1985	native pasture, cleared 1985	native pasture, trees undisturbed	naturalised Cloncurry buffel, cleared 1985
Seedbed preparation	cultivated (6 cm)	cultivated (12 cm)	light disturbance (2 cm)	lightly disced strips (5 cm)	lightly disced strips (5 cm)	disc-cultivated (10 cm)
Establishment date	19.12.1984	11.12.1984	31.12.1985	21.11.1985	19.11.1985	11.12.1985
Superphosphate applied (kg/ha)	200	100	200	200	200	nil

[1] Soil classification (Northcote 1979).

[2] Electrical conductivity.

and terminalia (*Terminalia* spp.) trees were also pushed from the Wrotham Park site. Three sites (Ben Avon, Tirrabella and Corella Park) were fully cultivated with a scarifier producing a fine loose seedbed before sowing. The Pinnarendi site was lightly disturbed to 3 cm by stick-raking during tree clearing immediately prior to sowing and was not otherwise cultivated. At Wrotham Park and Highbury, the sown rows were lightly disced, producing a loose surface 1 m wide and 5 cm deep, alternating with 1 m wide strips of undisturbed native grass. The pasture at these 2 sites had been heavily grazed and burnt, respectively, prior to establishing the experiments.

Accessions

The legumes studied were selected from established and recently released tropical cultivars and from species collected from similar soils or climatic environments in mainly South American countries. Other experimental (unreleased) accessions had shown potential in evaluation experiments in north Queensland. There was sufficient seed of *Macroptilium gracile* (previously *M. longipedunculatum* and subsequently released as cv. Maldonado) to plant only a single plot at one site (Ben Avon). The collection origins and site details of the accessions have been published in the *Australian Plant Introduction Review*.

Design and treatments

The 6 experiments were a randomised block design. The treatments of the 3 spaced row experiments were 72–81 accessions (Table 2), sown in rows 20 cm wide × 2 m long, with 4 replications. These rows were 2 m apart and there was 1 m spacing between accessions within each row. The 3 plot experiments had 15–22 accessions (Table 2) sown in plots of 5 m × 5 m with 3 replications. In both experimental designs, the plots and rows within each replication were set in a parallel design to obtain a near square or compact rectangular layout. Where recommended sown pasture cultivars existed, they were included as controls to provide a comparison with the new accessions.

Soil sampling and fertility

Undisturbed and unfertilised soil profiles were sampled by 50 mm diameter cores to 1 m and analysed for chemical composition before the experiments commenced (Table 1). This showed very low to moderate phosphorus levels for sown pasture growth at all sites except Corella Park, which was naturally high in plant-available phosphorus (16 ppm P_B). Soil surface (0–10 cm) phosphorus levels were reanalysed during the experiments after superphosphate fertiliser had been applied to all sites at establishment, except at Corella Park. There was adequate phosphorus for sown pasture growth in all years of the plot experiments at Tirrabella (range 6–20 ppm) and Pinnarendi (6–13 ppm), but it remained deficient (2–4 ppm) at Ben Avon. At the row experiment sites, available soil phosphorus levels were: Highbury 1–3 ppm; Wrotham Park 3–4 ppm; and Corella Park remained at 16 ppm. The seasonally waterlogged solodic soil at Highbury had a pH of 9.3 in the yellow subsoil clay at 90 cm.

Experimental procedures

The plot experiments were sown at 5 kg/ha of seed, which was dehulled and scarified before hand-broadcasting with the basal superphosphate fertiliser. The row experiments were sown at 2–5 g/row of scarified seed, depending on seed size, and the superphosphate was hand-broadcast over the whole experimental area. Inoculum was not applied to seed because seed was surface-sown and the high temperatures on the dry soil would probably have killed the rhizobium. No additional maintenance fertiliser was applied during the experiments. Cattle were excluded only during the first 2 growing seasons, but all sites were well grazed each dry season.

The Ben Avon site was sprayed with the post-emergence selective herbicide, Fusillade (active ingredient 212 g/L fluazifop-P, present as the butyl ester in a 685 g/L hydrocarbon solvent; Crop Care Australasia Pty Ltd) on February 5, 1985 at a rate of 1 L/ha, to control annual grasses and reduce competition with establishing seedlings. *Setaria pumila* remained competitive with the sown legumes, while *Brachiaria, Digitaria* and *Eragrostis* species were controlled.

The Tirrabella site was slashed twice to 10 cm in the first wet season to control broad-leafed weeds (especially *Acanthospermum hispidum)* and the grass *Chloris virgata*. Ungrazed material was slashed at the end of the first and second dry seasons. The dense plots of *Aeschynomene*

Table 2. Pasture legume accessions and cultivars sown, established (1986) and persisting (1989) in the 3 row experiments at Wrotham Park (WP), Highbury (H) and Corella Park (CP), and accessions and cultivars sown in the 3 plot experiments at Ben Avon (BA), Tirrabella (T) and Pinnarendi (P).

Species	Accession[1]/ Cultivar	Row experiments									Plot experiments		
		Sown 1985			Established 1986			Persisting 1989			Sown 1984–85		
		WP	H	CP	WP	H	CP	WP	H	CP	BA	T	P
Aeschynomene americana	CPI 58522	x	x	x	x						x		
Aeschynomene americana	Glenn	x	x	x	x	x	x				x	x	x
Aeschynomene sp.	P 6814	x	x	x									
Aeschynomene uniflora	CPI 60164	x	x	x	x								
Alysicarpus aff. *ovalifolius*	CPI 49663	x	x	x									
Alysicarpus sericea	CPI 30042	x	x	x									
Alysicarpus vaginalis	CPI 33216	x	x	x									
Alysicarpus vaginalis	Katherine	x	x	x	x		x				x	x	x
Chamaecrista rotundifolia	Wynn	x	x	x	x	x	x				x	x	x
Centrosema brasilianum	CPI 55696	x	x	x			x						
Centrosema brasilianum	CPI 55698	x	x	x							x	x	
Centrosema pascuorum	CPI 55697	x	x	x	x	x	x				x	x	x
Centrosema pascuorum	Bundey	x	x	x	x	x	x				x	x	x
Centrosema pascuorum	Cavalcade	x	x	x	x						x	x	x
Centrosema pascuorum	Ex Myuna[2]	x	x	x									
Centrosema pascuorum	Q 10050	x	x	x	x		x						
Centrosema pascuorum	Q 9855	x	x	x									
Centrosema plumieri	CPI 60477	x	x	x	x	x	x						
Centrosema schottii	CPI 65967	x	x	x			x				x	x	
Centrosema virginianum	CPI 78361	x	x	x			x						
Clitoria ternatea	CPI 47187	x											
Clitoria ternatea	CPI 48337	x											
Clitoria ternatea	Milgarra	x	x	x	x		x	x			x	x	x
Cyamopsis senegalensis	CPI 50375	x											
Desmanthus acuminatus	CPI 78380		x								x	x	
Desmanthus bicornutus	CPI 90813	x	x	x	x			x					
Desmanthus bicornutus	CPI 91162	x	x	x	x		x	x					
Desmanthus covillei	CPI 84972	x	x	x									
Desmanthus covillei	CPI 90826	x	x	x			x						
Desmanthus covillei	CPI 90843	x	x	x	x								
Desmanthus covillei	CPI 90848	x	x	x	x								
Desmanthus covillei	CPI 90877	x	x	x	x			x					
Desmanthus covillei	CPI 90883	x	x	x	x			x					
Desmanthus fruticosus	CPI 84960	x	x	x	x		x	x					
Desmanthus fruticosus	CPI 84973	x	x	x	x		x	x					
Desmanthus fruticosus	CPI 84974	x	x	x			x						
Desmanthus fruticosus	CPI 84975	x	x	x									
Desmanthus fruticosus	CPI 84990	x	x	x			x						
Desmanthus fruticosus	CPI 84991	x	x	x									
Desmanthus leptophyllus	CPI 55719	x	x	x	x			x					
Desmanthus leptophyllus	CPI 92722	x	x	x	x			x					
Desmanthus tatuhyensis	CPI 90362		x										
Desmanthus virgatus	CPI 33201	x	x	x	x						x	x	x
Desmanthus virgatus	CPI 40071	x	x	x	x						x	x	
Desmanthus virgatus	CPI 67643	x	x	x	x			x			x	x	
Desmanthus virgatus	CPI 85172	x	x	x	x			x					
Desmanthus virgatus	CPI 91326	x	x	x	x			x					
Desmanthus virgatus	CPI 91335	x	x	x	x			x					
Desmanthus virgatus	CPI 91486	x	x	x	x			x					
Desmanthus virgatus	CPI 91491	x	x	x	x			x					
Desmanthus virgatus	CPI 91493	x	x	x	x			x					
Desmanthus virgatus	Marc	x	x	x	x			x					
Desmanthus sp.	CPI 33426		x										
Galactia sp.	CPI 91323	x	x	x									
Macroptilium atropurpureum	CPI 73477	x	x	x	x		x	x					
Macroptilium atropurpureum	CPI 84988	x										x	
Macroptilium atropurpureum	CPI 84989	x	x	x									

Species	Accession[1]/ Cultivar	Row experiments									Plot experiments		
		Sown 1985			Established 1986			Persisting 1989			Sown 1984–85		
		WP	H	CP	WP	H	CP	WP	H	CP	BA	T	P
Macroptilium atropurpureum	CPI 90337	x	x	x								x	
Macroptilium atropurpureum	CPI 90338	x	x	x	x		x						
Macroptilium atropurpureum	CPI 90821	x			x								
Macroptilium atropurpureum	CPI 90844	x	x	x	x	x	x						
Macroptilium atropurpureum	CPI 90847	x	x	x			x						
Macroptilium atropurpureum	CPI 90850	x	x	x	x		x						
Macroptilium atropurpureum	CPI 91315	x	x	x									
Macroptilium atropurpureum	CQ 1382	x	x	x	x		x					x	x
Macroptilium atropurpureum	CQ 1398	x	x	x	x								
Macroptilium atropurpureum	Siratro	x	x	x	x							x	
Macroptilium lathyroides	CPI 55779	x	x	x	x		x						
Macroptilium gracile	CPI 91485	x	x	x	x	x	x						
Macroptilium gracile	Maldonado										x		
Macrotyloma axillare	Archer	x	x	x									
Rhynchosia minima var. *falcata*	CPI 60335	x											
Rhynchosia minima var. *minima*	CPI 32963	x											
Rhynchosia minima var. *minima*	CPI 36696	x	x	x									
Rhynchosia minima var. *minima*	CPI 81386	x	x	x									
Rhynchosia minima var. *nuda*	CPI 78473	x											
Stylosanthes guianensis	Graham										x		x
Stylosanthes hamata	CPI 55828		x			x							
Stylosanthes hamata	CPI 57247	x	x	x									
Stylosanthes hamata	CPI 70364	x	x	x									
Stylosanthes hamata	CPI 75162		x			x							
Stylosanthes hamata	CPI 75166	x	x	x		x							
Stylosanthes hamata	Amiga											x	x
Stylosanthes hamata	Verano	x	x	x	x	x	x		x		x	x	x
Stylosanthes scabra	CPI 63466	x	x	x									
Stylosanthes scabra	CPI 93116										x		x
Stylosanthes scabra	mix L85[3]												x
Stylosanthes scabra	Q 10042										x	x	x
Stylosanthes scabra	Seca	x	x	x		x			x		x	x	x
Stylosanthes sympodialis	CPI 67704	x	x			x							
Teramnus labialis	CPI 60377	x	x	x									
Vigna unguiculata	CPI 52826	x	x	x	x								
Vigna unguiculata	CPI 60442	x	x	x			x						
Number of accessions	92	82	79	73	43	13	27	18	2	0	20	22	15
Number of species	33	20	31	28	17	9	17	8	2	0	12	12	9
Number of genera	14	14	13	13	9	5	9	3	1	0	8	8	7

[1]CPI = Commonwealth Plant Introduction Number (CSIRO, Australia); CQ = CSIRO Queensland Plant Identification Number; P = Plant Introduction Number New South Wales; Q = Queensland Department of Primary Industries Plant Introduction Number.
[2]Unidentified accession surviving in a clay soil legume evaluation nursery 1982, 'Myuna', north Queensland.
[3]Genetic composite from *Stylosanthes scabra* accessions in the seed-increase nursery 1985, Lansdown, north Queensland.

americana cv. Glenn were cut and removed before seeding in May 1986 to prevent spread into adjacent grain crops. In 1987, cattle grazed all plots in the dry season and all material was consumed by November.

The Pinnarendi experiment was grazed during the early wet season to reduce competition from perennial tussock grasses, mainly kangaroo grass (*Themeda triandra*), which was not removed by the light soil disturbance when the site was stick-raked prior to sowing.

The row experiments were continuously grazed by cattle after the first 2 growing seasons, with heavy grazing occurring each year after sampling during the mid-dry season.

Data recording

Plot experiments. Dry matter yields (from harvesting a single 1 m^2 quadrat per plot at 5 cm height or by visual ranking with standards clipped, dried and weighed to produce a regression of yield rank on dry matter yield), plant counts of seedlings and perennials (from nine 0.25 m^2 quadrats per plot), colour rating (1-dark healthy green to 5-'dead' yellow), plant height (cm) and reproductive stage rating (1-vegetative, 2-flowering, 3-green seed, 4-ripe seed, 5-shed seed) were recorded at the end of each growing season (April–May). Grazing acceptability by cattle and leaf retention were monitored during the dry seasons.

Row experiments. Plant populations, yield rating, distance spread, height and reproductive stage of growth were recorded at the end of each growing season.

Statistical analysis

Transformed data from the seedling and perennial population counts and from the dry matter yields were analysed by analysis of variance (one-way ANOVA in randomised blocks) for individual sites, each year.

Results

Climate

The 6 sites were in seasonally dry areas receiving more than 83% of their annual rainfall in the main pasture growing months of November–March. Rainfall during the experiments was well below average in most years, with extended drought conditions experienced at Corella Park (Figure 1).

At Pinnarendi, mean minimum monthly temperatures were 11.8–14.7°C for May–September and were below 19.6°C all year. Mean monthly maximum temperatures ranged from 23.9°C (June) to 34.0°C (December). Temperature range at Corella Park (near Cloncurry) was greater with summer mean monthly maximum of 39°C and winter mean monthly minimum of 10°C (Figure 2). Cloncurry and Pinnarendi represent the range of environments (harshest and most favourable, respectively). Temperatures at Ben Avon and Tirrabella are similar to those at Pinnarendi, and temperatures at Wrotham Park and Highbury approach those at Cloncurry.

Population dynamics

Plots. In the first season at Ben Avon, seedling establishment was good (4–37 plants/m^2) for all lines, except *Desmanthus virgatus* accessions (<3 plants/m^2). At Tirrabella, seedling numbers in the establishment year were generally lower (<10 plants/m^2 for most accessions), amongst dense grass (*Chloris virgata* over 1m tall) and weeds in this old cultivation area. At Pinnarendi in the first year, seedling populations were adequate

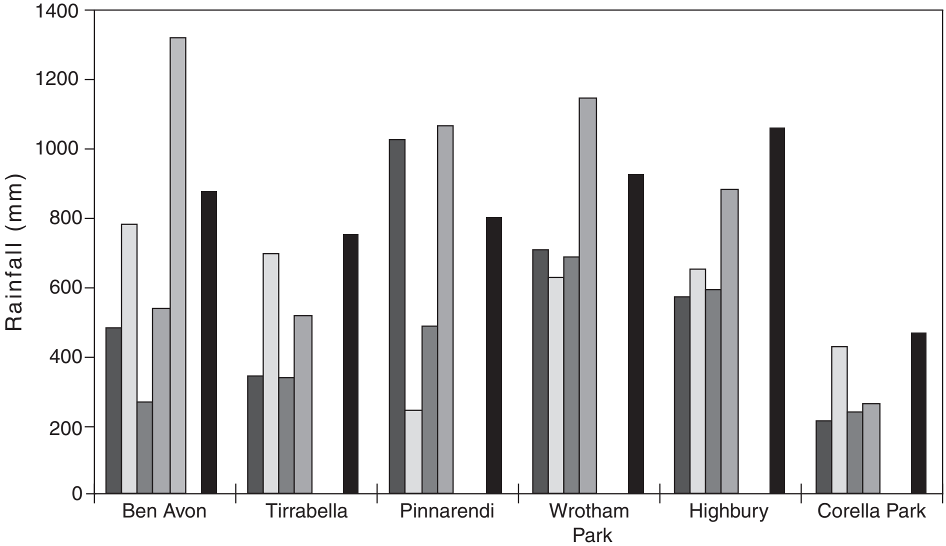

Figure 1. Annual (July–June) rainfall (mm) during the experiments (Years 1 to 4 or 5 shaded) and long-term mean (black) in 6 environments.

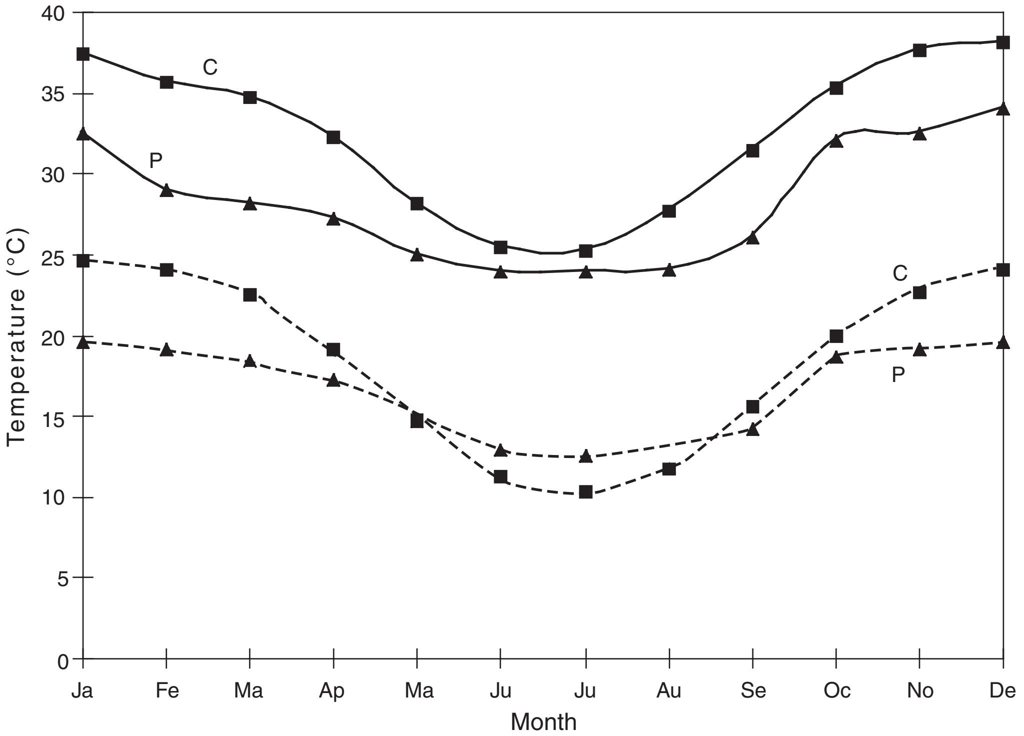

Figure 2. Mean monthly maximum (solid) and minimum (dashes) temperatures (°C) at Corella Park (C) and Pinnarendi (P), representing the harshest and most favourable environments for the 6 sites, respectively.

(>10 plants/m^2) for all lines, except *Centrosema* spp. and *Macroptilium atropurpureum* accessions. The *Stylosanthes* accessions and *Chamaecrista rotundifolia* cv. Wynn produced the most seedlings (>30 plants/m^2).

After the poor rainfall of 1987–88, there was negligible seedling survival in May 1988 at these 3 sites, but accessions regenerated from seed in the high rainfall summer of 1988–89. The annuals, *Aeschynomene americana* and *Alysicarpus vaginalis,* plus the perennials Wynn cassia and the *Stylosanthes* accessions regenerated best. No *Centrosema pascuorum* accessions were present in 1988, but seedlings emerged in 1989 from hard seed produced in earlier years (Table 3). Native species competed with sown legume seedlings at all sites. For example, at Tirrabella, 14 grasses, 8 native legumes and 14 other forb species were present across the experiment.

Perennial plant populations of Wynn cassia and the *Stylosanthes* spp. remained adequate, up to 30 plants/m^2, for a commercial pasture each year at the 3 sites.

Long-term species persistence recording at Ben Avon in 1991 showed Wynn cassia, *C. pascuorum*, Verano, Maldonado and Glenn were still present and spreading at the site, with most spread off the site by Glenn. By 2001 at Pinnarendi, Verano and the *S. scabra* lines still persisted, while both the Ben Avon and Tirrabella sites had been regularly cultivated for cropping.

Rows. No lines survived the combination of grazing and the initial 4 drought years at Corella Park, while at Highbury, only *S. scabra* and *S. hamata* persisted, although populations declined, on the waterlogged solodic soil; and at Wrotham Park on the heavy clay soil, *Desmanthus* spp., including *D. virgatus, Clitoria ternatea* and *Macroptilium atropurpureum* were the main survivors, with *Desmanthus* spp. having highest populations (>30 plants/m^2) and most spread (2 m) (Table 2).

Long-term persistence recording at these 3 row sites in 2001, showed a *Vigna* accession and Verano had regenerated from seed after the drought and were present at Corella Park; there was no legume survival on the solodic soil at

Table 3. Legume seedling populations (no/m^2, maximum count of 40/m^2) and ranking in the final year in the 3 plot experiments at Ben Avon, Tirrabella and Pinnarendi, and perennial populations at Pinnarendi.

Species	Accession[1]/ Cultivar	Ben Avon			Tirrabella			Pinnarendi					
		Seedlings			Seedlings			Seedlings			Perennials		
		1985	1989	Rank	1985	1987	Rank	1987	1989	Rank	1987	1989	Rank
Ae. americana	CPI 58522	13	0										
Ae. americana	Glenn	20	40	1	9	1	9	2	40	1	0	0	
Al. vaginalis	Katherine	37	40	1	16	1	9	2	36	5	0	0	
Ch. rotundifolia	Wynn	14	40	1	15	10	1	18	40	1	30	30	3
Ce. brasilianum	CPI 55698	5	1	10	1	1	9						
Ce. pascuorum	CPI 55697	9	0		8	1	9	0	9	10	1	0	
Ce. pascuorum	Bundey	8	7	8	9	1	9	2	17	8	0	0	
Ce. pascuorum	Cavalcade	7	3	9	9	1	9	5	17	8	0	0	
Ce. schottii	CPI 65967	0	0		1	0							
Cl. ternatea	Milgarra	9	0		1	2	6	0	0		6	19	4
De. virgatus	CPI 33201	3	0		10	1	9	1	0		6	2	9
De. virgatus	CPI 40071	2	0		10	3	3						
De. virgatus	CPI 67643	1	0		1	1	9						
De. virgatus	CPI 78380	3	0		8	1	9						
Ma. atropurpureum	CPI 84988				7	1	9						
Ma. atropurpureum	CPI 90337				3	1	9						
Ma. atropurpureum	CQ 1382				2	2	6	0	0		3	2	9
Ma. atropurpureum	Siratro				31	1	9						
Ma. gracile	Maldonado	nr[2]	nr										
St. guianensis	Graham	4	0		7	0							
St. hamata	Amiga				13	6	2	65	40	1	36	40	1
St. hamata	Verano	24	40	1	7	3	3	61	40	1	27	40	1
St. scabra	CPI 93116	18	15	7				1	0		13	12	6
St. scabra	mix L85[3]							26	25	6	40	3	8
St. scabra	Q 10042	20	20	5	3	3	3	4	0		20	16	5
St. scabra	Seca	18	16	6	2	2	6	42	20	7	40	7	7
Mean population		11	12		8	2		15	19		15	11	
LSD (P = 0.05)		9	na[4]		8	3		15	na		na	na	

[1]CPI = Commonwealth Plant Introduction Number (CSIRO, Australia); CQ = CSIRO Queensland Plant Identification Number; Q = Queensland Department of Primary Industries Plant Introduction Number.
[2]nr = not recorded (only one plot sown).
[3]Genetic composite from *Stylosanthes scabra* accessions in the seed-increase nursery 1985, Lansdown, north Queensland.
[4]na = not statistically analysed (1989 counts were from Replication 1 only).

Highbury; and at Wrotham Park, *Desmanthus* accessions (including CPI 67643 and an unidentified *D. virgatus* type) and Milgarra butterfly pea (*C. ternatea*) had survived and spread.

Dry matter production

Plots. In the establishment year, the highest legume dry matter yield of 2.7 t/ha was produced at Ben Avon by *A. americana* and at Tirrabella by *Centrosema pascuorum* cv. Cavalcade on cultivated seedbeds, while the highest yield on the lightly disturbed soil at Pinnarendi was 1.5 t/ha by *Stylosanthes hamata* cv. Amiga. *S. scabra* and *S. hamata* accessions were consistently productive at the 3 plot sites, with Seca yielding to 6.2 t/ha, and Amiga consistently out-yielding Verano (mean 2.7 *vs.* 1.5 t/ha over 3 years at 2 sites). *S. guianensis* cv. Graham had poor yields except when there was good summer and autumn rain. The extended growing season of 1989 suited its growth pattern and it produced 7.6 t/ha at Ben Avon (Table 4).

Wynn cassia produced little dry matter initially, but increased significantly (to 4.2 t/ha at Pinnarendi in 1989) during the study. *A. americana* cv. Glenn (jointvetch) was productive only in higher rainfall years, and tops wilted early in the dry season before plants flowered, in the drier years. *Centrosema pascuorum* accessions were most productive in the establishment year, but competed poorly with the native species and had low populations and poor yields in subsequent years. At Ben Avon, *M. gracile* cv. Maldonado grew over the native pasture, flowering commenced in late autumn, and growth continued with autumn rain after grasses had matured. This cultivar was palatable and selectively grazed by cattle, although ungrazed material was frosted in winter. It spread more than other accessions, extending more than 30 m from the original plot.

Pests and diseases did not affect legume yields during the experiment. However, late autumn and winter rain, in May and June of 1989, induced severe anthracnose damage, including leaf fall, on dense ungrazed plots of *S. hamata* accessions at Pinnarendi, and fungal leaf spots on Wynn cassia were caused by *Cercospora* sp., *Glomerella* sp. and *Phomopsis* sp. (R. Trevorrow, personal communication).

Native grass yields exceeded 3.3 t/ha each year on the cultivated red earth of Tirrabella, but were less than 2 t/ha at Ben Avon, and less than 0.8 t/ha at Pinnarendi, where grazing was more frequent and occurred in the early wet season. The yield of native grass was not affected by the presence of legumes, except in the dense *S. scabra* and Amiga stylo plots at Pinnarendi and in *S. scabra* plots at Ben Avon, where grass production was reduced.

Plant height, colour, reproduction, grazing acceptability and leaf retention

Plant heights exceeded 1 m in the plots in 1989, a good rainfall year. The *S. scabra* lines grew to

Table 4. Annual dry matter yield (g/m^2) and ranking in the final year of legumes and mean grass yield in the 3 plot experiments at Ben Avon, Tirrabella and Pinnarendi.

Species	Accession[1]/ Cultivar	Ben Avon				Tirrabella				Pinnarendi			
		1985	1986	1989	Rank	1985	1986	1987	Rank	1986	1987	1989	Rank
Ae. americana	CPI 58522	257	43	0									
Ae. americana	Glenn	260	131	449	7	5	415	–[2]		122	63	101	10
Al. vaginalis	Katherine	138	16	88	10	17	0	2	19	9	18	42	14
Ch. rotundifolia	Wynn	23	155	300	8	16	205	48	6	72	190	423	4
Ce. brasilianum	CPI 55698	1	8	0		204	10	19	11	84	9	111	9
Ce. pascuorum	CPI 55697	72	142	47	13	27	6	6	16				
Ce. pascuorum	Bundey	218	22	40	14	133	1	4	18	87	27	70	13
Ce. pascuorum	Cavalcade	295	3	58	12	269	45	4	18	104	36	100	11
Ce. schottii	CPI 65967	0	0	0		8	0	0					
Cl. ternatea	Milgarra	116	52	84	11	13	111	29	8	17	54	92	12
De. virgatus	CPI 33201	2	0	475	5	4	25	13	13	9	45	115	8
De. virgatus	CPI 40071	1	7	0		21	156	39	7				
De. virgatus	CPI 67643	1	0	0		0	3	12	14				
De. virgatus	CPI 78380	0	0	0		2	25	17	12				
Ma. atropurpureum	CPI 84988					32	5	6	16				
Ma. atropurpureum	CPI 90337					28	8	8	15				
Ma. atropurpureum	CQ 1382					13	50	27	9	84	82	24	15
Ma. atropurpureum	Siratro					80	10	21	10				
Ma. gracile	Maldonado[3]	250	620	454	6								
St. guianensis	Graham	74	35	759	1	37	287	68	5				
St. hamata	Amiga					155	418	261	1	153	227	412	5
St. hamata	Verano	205	48	227	9	63	120	135	4	84	199	268	7
St. scabra	CPI 93116	70	234	670	2					12	172	451	3
St. scabra	mix L85[4]									50	199	528	1
St. scabra	Q 10042	100	230	500	4	131	304	261	1	66	245	317	6
St. scabra	Seca	99	272	616	3	125	118	193	3	42	208	497	2
Mean legume yield		109	101	238		109	106	53		66	118	237	
LSD (P = 0.05)		127	140	na[5]		92	189	50		66	50	128	
Mean native grass yield		129	198	85		436	332	370		65	20	77	

[1] CPI = Commonwealth Plant Introduction Number (CSIRO, Australia); CQ = CSIRO Queensland plant identification number; Q = Queensland Department of Primary Industries Plant Introduction Number.
[2] Glenn was removed prior to seeding in 1986 (because of a potential invasion into surrounding cultivation).
[3] Maldonado was not included in statistical analyses (data were from one plot only).
[4] Genetic composite from *Stylosanthes scabra* accessions in the seed-increase nursery 1985, Lansdown, north Queensland.
[5] na = not statistically analysed (yield harvests were from one replication of all lines).

120 cm over one good wet season, while *Desmanthus* spp. and Glenn jointvetch were more than 1.3 m tall. At Ben Avon, the early maturing annual accession *A. vaginalis* and the perennials *C. ternatea* and Wynn cassia were pale green in colour, appearing nitrogen-deficient, by the end of each growing season (April–May). Other species remained green until they reached maturity or suffered moisture stress in the dry season. There was little variation in leaf colour between accessions at Tirrabella, but *A. vaginalis* was first to mature and shed leaf. All accessions remained green to the end of the growing season in 1987.

Alysicarpus vaginalis (Katherine strain) and Wynn cassia were the most advanced accessions reproductively, producing seed during the wet season in the establishment year, while the other species were still in a vegetative growth phase. In subsequent years, all accessions had seeded by the early dry season (March–April).

Mild winters were experienced during the experiments and only light frosts occurred at the 3 more elevated subcoastal sites in June and July, when legumes were mature. Cattle grazed all accessions, with Maldonado selected early in summer and the stylos, especially *S. scabra* lines, normally grazed later, towards the end of the wet season. The *S. scabra* lines showed the best ability to retain leaf late in the dry season, and could provide green leaf for grazing until frosts occurred.

Discussion

Species

These experiments have identified a number of introduced tropical legume species, especially from the genera *Stylosanthes, Chamaecrista, Desmanthus, Clitoria, Centrosema, Macroptilium* and *Aeschynomene* that are well adapted to some environments of the seasonally dry tropics of north Queensland. They also showed that, in low rainfall (<450 mm) areas and on some duplex soil types, pasture improvement with current legume cultivars might not be feasible.

The severe rainfall constraints during this study eliminated some species, especially in the row experiments, with potential under better rainfall conditions. However, the successful accessions have shown a tolerance to adverse climatic conditions and warrant more widespread testing in large plots under controlled grazing.

Stylosanthes species, especially *S. scabra* accessions, were productive throughout the study and were the best-adapted species in the experiments. Regenerating seedlings of Seca at the more elevated sites produced flowers earlier in summer than did seedlings of CPI 93116 (a vigorous Colombian selection). That accession remained late-flowering (mid to late autumn), and anthracnose-resistant throughout the experiment, becoming more productive with time. The *S. scabra* accessions were the only species that retained green leaf throughout the dry season, except when frosted at Ben Avon. This indicates they will provide feed of higher quality to cattle than the other species at this critical time when protein is deficient in native pastures. Seca stylo is now the main perennial legume recommended for commercial sowing in the dry tropics. It was the most anthracnose-resistant and one of the most productive of the *S. scabra* accessions evaluated in 5 dry tropical environments in north Queensland (Hall *et al.* 1995), and it has provided a significant long-term benefit for cattle producers in this region (Bethel 1996). Where it is well adapted, grazing management and fire can be required to maintain a grass-legume balance in the pasture (Cooksley *et al.* 2003).

Amiga stylo proved more suited to the more elevated subcoastal environment than Verano. Amiga was selected for its ability to grow in more adverse environments than Verano (Edye *et al*. 1991), but insufficient seed was available to include it in the row experiments to test the lower limits of its adaptation. The autumn rain-induced anthracnose problems we observed are less likely to occur in grazed pastures, and current anthracnose strains are not expected to have adverse effects on pasture production in the seasonally dry tropics.

Wynn cassia showed good adaptation and has potential to complement the stylos in north Queensland. It established on a range of soil types, and plant populations and production increased during the experiments. The early and continuous seeding habit of Wynn suggests it could survive low rainfall years and complement stylo (*e.g.* Seca) pastures, where it would produce a ground layer. The decline in yield of Wynn in plots at Tirrabella, which were ungrazed during the wet season and had strong grass competition, indicates less aggressive grass pastures or some grazing in the growing season will be required to maintain a productive Wynn component in a mixed pasture in more favourable soil and climatic environments. Cattle selectively graze green grass in preference to Wynn in summer and early autumn, so summer grazing in a mixed grass-Wynn cassia pasture will reduce grass competition on the legume (Clements *et al.* 1996). Like Seca, too much wet season grazing can lead to Wynn dominance, especially on sandy soils (K. Shaw, personal communication). The main value of Wynn could be in maintaining a higher quality diet through autumn and into winter in normal rainfall years. Wynn also improves the nitrogen concentration in the companion grass, both with and without applied fertiliser (Partridge and Wright 1992).

At Pinnarendi, stems of Wynn became red and leaves wilted, curled and externally were also red in colour in early autumn in low rainfall years. Leaf fall occurred at this time, when native grasses had also matured and were drying-off. Although the leaves of *S. scabra* lines were wilting, the upper leaves were retained on plants and remained green in colour.

Centrosema pascuorum accessions showed good establishment, rapid growth and high yields on cultivated soil in the year of sowing and appeared suitable for hay production or short-term grazing in a ley pasture phase in crop rotations in the subcoastal environments. However, their poor regeneration, even where grass competition was reduced by grazing, suggests they have limited use as a permanent pasture legume for grazing in these environments.

While the high yields and good spread of Maldonado at Ben Avon indicate it could be a useful pasture legume in the higher rainfall environments of the seasonally dry tropics, it requires more evaluation in north Queensland. Despite flowering late in autumn, Maldonado regenerated and spread with the mild winters, possibly as a result of geocarpic seed set in late autumn, and regrowth in summer from the tuberous root was rapid. Management of grazing times and intensity would be required to maintain this species in a pasture because of its high palatability. Commercial seed harvesting may not be possible in this environment as little above-ground seed was produced before mid-winter, when frosts killed plant tops.

Glenn jointvetch was productive only in high rainfall years. This equates with its proven value as a component of sown pastures in higher rainfall coastal areas (Bishop *et al.* 1985). It may be a useful pasture component in the seasonally dry tropics only in wet swampy sites or in high rainfall years, if sufficient hard seed can survive the low rainfall years. Mid to late autumn flowering, early dry season wilting and autumn leaf loss make it unsuitable as a permanent pasture in the dry tropics, although summer-flowering, perennial accessions could have more widespread use (H.G. Bishop, personal communication).

On cracking clay soils, where legume establishment and regeneration are recognised problems, *Desmanthus* spp. and *Clitoria ternatea* were the best-adapted species and have the most potential as pasture legumes. *D. virgatus* (cv. Marc) has been persistent in trials on cracking clay soils in north-eastern Queensland (Clem and Hall 1994), and selection within *Desmanthus* introductions could produce improved lines for grazing evaluation. There is a good prospect of success as the *Desmanthus* species are a highly polymorphic group exhibiting a wide range of characteristics, including the ability to thrive and spread on heavier vertosol soils (Gardiner and Burt 1995). *Desmanthus* generally performed poorly on the light-textured soils. The combination of competition from the native grass *Setaria pumila* and the acidic soil proved unsatisfactory for this species, which is understandable as *Desmanthus* accessions have been introduced from neutral-alkaline soils. *C. ternatea* is adapted to other clay soils in north Queensland (Hall 1985; Hall *et al.* 1987) and central Queensland (Clem and Hall 1994), and appropriate grazing management must be refined to make economic use of its environmental adaptation. A differential environmental adaptation by *C. ternatea* and *D. virgatus* has been reported on a red-brown clay with a surface pH of 5.0 in West Java (Yuhaeni and Ivory 1994), where *C. ternatea* was recommended for further evaluation, while productivity and persistence of *D. virgatus* were poor and no further testing was considered.

Macrotyloma axillare cv. Archer failed to establish in the harshest 3 environments in these experiments, suggesting it is not adapted to the inland dry tropics. It is adapted to higher rainfall (>1000 mm) and frost-free environments (McCosker and Middleton 1975; Cameron 1986) and to an area of fertile soils on the Atherton Tableland, where it has become naturalised (Blumenthal and Staples 1993). These authors also suggested that other species of the genus (*M. uniflorum, M. africanum* and *M. daltonii*) might have a role in northern Australia. Representatives of these species should be included in future legume evaluations.

Establishment

Cook *et al*. (1993) reported that sowing methods, which provide good soil-seed contact and place the seed at an optimum depth in the soil, can maximise germination and emergence and provide for efficient use of seed. The successful accessions and cultivars in these experiments established following surface or shallow sowing. The seed germinated and sufficient seedlings established and competed with native pasture species to form legume-dominant plots. All sites have high evapotranspiration over summer and the seedlings have to rely on follow-up rainfall to establish. Some of the species sown in these experiments, especially larger-seeded accessions, may have been disadvantaged by the shallow sowing method employed.

The remoteness of the locations meant emergence counts could not be made, and seedlings were well established when counted. Establishment of a sward can be divided into 2 phases: seed germination and emergence; and subsequent seedling growth and survival to maturity. The length of the initial emergence phase varies, *e.g. Stylosanthes hamata* can take 2–3 days and podded seed of *S. scabra* can take 8–10 days (Mott *et al.* 1976). In the harsher environments of these experiments, rainfall conditions and soil moisture may not have been adequate for a sufficient time to allow germination and establishment of some species. For forage legume species to be commercially viable on these infertile soils on extensive beef properties at this time, the legumes must establish from surface-sowing techniques with limited soil disturbance. Survival of seedlings and mature plants is influenced by grazing pressure, *e.g. Desmanthus* seedling recruitment is higher under grazing than in ungrazed mixed grass-legume swards (Burrows and Porter 1993). The single grazing management regimen imposed on each site may not have been optimum for the different species in this study, but is likely to represent the norm for commercial practice.

Environments

The range of environments included in this study was representative of the pasture environments of the main cattle grazing country of north Queensland, covering the main grass-dominant pasture types where sown legumes are required to improve the nutrition of grazing cattle. Unfortunately, the rainfall experienced during the study was not representative of the long-term range. Below average rainfall at all sites, especially Corella Park, would have reduced establishment, production, seeding and persistence of all legumes. Only those with a good ability to tolerate the variable rainfall summers with short growing seasons could persist.

Selections

Unavailability of seed prevented the inclusion of some species and accessions in these experiments, *e.g.* for the *Teramnus* genus only one accession of *T. labialis* was included. This species exhibits a great deal of variability, and there are 275 accessions of *Teramnus* in the Australian collection, which has been classified by Pengelly and Eagles (1996). As this accession failed to establish at the 3 sites sown, the evaluation was inconclusive for this pan-tropical genus. Any species that established and grew well in 1986 should be included in future legume evaluation studies, even though they may not have survived the continuous drought and periodic grazing to 1989. The dry conditions were so severe that, at Corella Park, the naturalised and well adapted Cloncurry buffel grass tussocks were dying at the experimental site during this extreme climatic period.

Alternative uses for the more successful pasture legumes could be in hay making for feeding to weaners and stock in the live cattle export trade, and in short-term crop rotations as a ley phase in the more favourable environments. The *Alysicarpus* and *Centrosema* genera could be evaluated for these roles.

On the flat site at Highbury, with hard-setting and shallow yellow duplex soil, short-term seasonal flooding occurs each year, even in low-rainfall summers, but the alkaline clay subsoil holds little water and was not penetrated by legume roots during this evaluation.

The cool late-summer temperatures at the 3 higher sites (minimum to 15°C in February at Pinnarendi) would reduce plant demand for water and help alleviate, but not negate, effects of poor rainfall on legume growth. The cool night temperatures late in the growing season (minimum below 14°C in April) could reduce flowering and seed set of some species. At Ben Avon, moisture remained in the subsoil clay for extended periods after rain due to lateral moisture movement within the profile from higher up the slope, which could increase the growing period for plants at this site.

Long-term persistence

The persistence of *Stylosanthes, Clitoria, Desmanthus* and *Chamaecrista* lines at some of these sites for over 15 years shows they are strongly adapted to the environments. Management strategies to obtain animal production benefits from their inherently higher nutritive value than the associated grasses need to be refined. Better grazing ecotypes may be available within the collections of these genera. For example, both fine leafy and coarse stemmy forms of *Desmanthus* are persisting on the Wrotham Park clay soil site.

Conclusion

These experiments have shown the broad adaptation, high productivity and commercial potential of some tropical legume species and cultivars across a range of seasonally dry environments in north Queensland, with most potential in the higher-altitude, subcoastal environments. They have also demonstrated the ability of other pasture legume species to establish and persist, as well as produce yields in excess of 4 t/ha, in more favourable environments in the seasonally dry tropics. This high degree of environmental adaptation and dry matter production reinforce the promotion of sown pasture legumes for improving cattle production in north Queensland. Accessions from *Aeschynomene* and *Centrosema* (annuals) and *Stylosanthes, Desmanthus, Clitoria, Chamaecrista* and *Macroptilium* (perennials) showed adaptation and are worth further evaluation for animal performance and developing management systems under commercial grazing across a wider range of environments in the more favoured rainfall areas. No species was successful under drought conditions experienced in the semi-arid inlands, although the most fertile soil studied occurred here (Corella Park), showing establishment rainfall is critical for sown pasture success, irrespective of soil type.

The development of the live cattle trade from north Queensland has provided cattle producers with greater management flexibility, improved financial resources and increased opportunities to introduce higher-quality, sown pastures. The demand for younger and better-conditioned animals for this trade (Winter *et al.* 1996) has increased the need for more intensive management and higher quality pastures, which may be provided from researching the genera identified in this study.

Any subsequent evaluation program for the seasonally dry tropics should include a wider range of accessions with representatives from groups that have shown an ability to establish and persist in these experiments, and also accessions from the recommendations from the State-wide pasture species evaluation program (Pengelly and Staples 1996). Identifying species and accessions for special purpose pastures, such as for weaner feeding, hay production, preparing cattle for the live export trade, rehabilitation of degraded landscapes, crop rotations and alternative legumes to stylos, may be more beneficial than evaluating for more widespread adaptation under grazing across the tropics, especially with the current environmental concerns and restricted financial support for new introduced pasture species.

There is potential to include a wider range of environments in future evaluation programs across the dry tropics, such as in higher-rainfall areas in Cape York Peninsula and also on the more fertile, medium to heavy-textured soils in the marginal rainfall areas of the inland. For effective legume evaluation in these drier environments, at least average rainfall is required in the establishment year. Using new climate forecasting technology, such as the SOI, could improve legume establishment prospects by selecting seasons to commence future evaluation research when there is a higher probability of above-average rainfall.

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