A comparison of establishment and growth of two *Stylosanthes* species with eight grass species sown on cultivated and uncultivated seedbeds at three sites in the semi-arid tropics of the Northern Territory

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Abstract

Two legumes and eight grasses were evaluated in small plots as potential pasture species for three distinct areas of the Katherine region. In the two drier areas there had been little previous quantitative regional testing of legume or grass species. Sowings were made on cultivated and uncultivated land. Data were recorded as plant numbers in year 1 and dry matter in years 2 and 3 partitioned into legume leaf and stem, and green and dry fractions of grass. Surface seed reserves were also recorded each dry season. Over 3 average or better years it was shown that none of the grass species would establish on uncultivated seedbeds. However, with cultivation, the species *Bothriochloa pertusa* cv. Bowen and *Andropogon gayanus* cv. Kent out-performed the standard species of *Cenchrus ciliaris* cv. Gayndah and *Urochloa mosambicensis* cv. Nixon. *Stylosanthes scabra* cv. Fitzroy established and outyielded *S. hamata* cv. Verano. Both legumes persisted well after being sown on to uncultivated seedbeds following a burn in the early wet season. Reducing competition from native grasses, perhaps with grazing, may be necessary in environments similar to the Katherine Experiment Farm site, to improve establishment of legumes, especially Verano.

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Resumen

Se evaluó el potencial de dos leguminosas y ocho gramineas, en pequeñas parcelas, como especies de pasturas para tres areas importantes de la región Katherine. En las dos areas más secas se han realizado pocas pruebas regionales con especies de gramineas y leguminosas. Las siembras se realizaron en tierras cultivadas y no cultivadas. En el primer año se registró el número de plantas; en los años dos y tres se registró el rendimiento en materia seca, la cual fue dividida en hoja y tallo de leguminosa y fracciones verdes y secas de la gramínea. También se registraron las reservas de semillas en la superficie del suelo en cada estación seca. Se demostró que, en promedio de tres años o en los mejores años, ninguna de las gramineas se podría establecer en suelos sin cultivar. Sin embargo, en suelos cultivados, las especies Bothriochloa pertusa *cv. Bowen y* Andropogon gayanus *cv. Kent tuvieron un comportamiento superior a las especies* Cenchrus ciliaris *cv. Gayndah y* Urochloa mosambicensis *cv. Nixon comúnmente utilizadas.* Stylosanthes scabra *cv. Fitzroy se estableció mejor y tuvo un mejor rendimiento que* S. hamata *cv. Verano. Ambas species de leguminosas sembradas en camas no cultivadas persistieron bién despuès de haber sido quemadas al inicio de la època húmeda. A fin de mejorar el establecimiento de las leguminosas, especialmente Verano, en medios ambientes similares al de la Granja Experimental de Katherine, es necesario reducir la competencia de las gramineas nativas; esto se podría lograr por medio del pastoreo.*

Introduction

At the start of this study, the Victoria River District was the major beef producing area of the

Katherine Region and the Sturt Plateau area was undergoing accelerated pastoral and agricultural development. Both areas receive on average 300 mm less rainfall than Katherine, which was the only site at which extensive evaluation of improved pastures had been undertaken. Most of this was centred on Townsville stylo (*Stylosanthes humilis*) grown on the Tippera clay loams (Lucas *et al.* 1985) close to Katherine (Norman 1966; Norman and Begg 1973). Plant introduction sites had been established at other locations in the region but, with few exceptions, only qualitative data had been collated (Winter *et al.* 1985). Quantitative data on the performance of Verano (*S. hamata*) or the shrubby stylos (*S. scabra*) over a range of district environments were not available. Similarly, few evaluations of improved grasses had been made since the late 1950s and 1960s (Norman 1960a, 1960b, 1961, 1967; Fisher 1971). More recently, Winter *et al.* (1989a; 1989b) reported on the performance of *Stylosanthes* species under grazing on Tippera soils.

Establishment methods described by Stocker and Sturtz (1966) for Townsville stylo have proved suitable for Verano and the shrubby stylos (Winter *et al.* 1985). However the successful establishment of buffel (*Cenchrus ciliaris*), birdwood (*C. setiger*), and Sabi (*Urochloa mosambicensis*) relies on prior cultivation (Norman 1966). Cultivation increased the cost of establishment such that the sowing of grasses was precluded from most commercial situations. Since Norman's work was reported, a number of other grass species possibly adapted to the district became available. Gamba grass (*Andropogon gayanus* cv. Kent) had recently been released through the Northern Territory Herbage Plant Liaison Committee. *Bothriochloa insculpta* cv. Hatch and *B. pertusa* had performed well in similar environments in Queensland (Bisset and Graham 1978; Bisset 1980; Anning 1982). Callide rhodes (*Chloris gayana* cv. Callide) and signal grass (*Brachiaria decumbens*) had shown promise in seedling sown trials on Tippera clay loams near Katherine (W.H. Winter, personal communication).

Norman (1967) suggested that a companion grass species was a desirable feature of Townsville stylo pastures to increase total production, ensure stability, increase energy value and prevent weed invasion. Similarly, preliminary results from a grazing experiment at the CSIRO research site, Manbulloo, suggested that a perennial improved grass should be included with Verano stylo plantings to maintain sward stability and animal production (Winter *et al.* 1989b).

The study reported in this paper was designed to determine: potentially valuable species for various areas of the district; the ability of grasses to establish without cultivation; and the ability of the grasses to combine successfully with each of the two stylos.

Materials and methods

Sites

The experiment was sown at three sites in the Katherine district — the former Katherine Experiment Farm (KEF); the Victoria River Research Station, 'Kidman Springs' (KS); and 'Sunday Creek' (SC), a co-operating pastoral property near Daly Waters. Site descriptions are shown in Table 1. All sites carried a predominantly perennial grass native pasture typical of large areas of the Katherine district. Trees on the three trial sites were either cleared, or killed with Tordon 50D (Dow Australia Ltd) shortly before starting the experiment.

Experiment design and management

The trial at all sites was designed as a split-plot plaid, sub-sub plots being 3m x 3m in size. The four replications in blocks were each split for cultivation treatments which were:

(a) Burnt only
(b) Burnt and cultivated.

The trial was then further split for:

(a) *S. hamata* cv. Verano and
(b) *S. scabra* cv. Fitzroy.

Across these plots in a plaid design, eight grasses were sown:

(a) Buffel (*Cenchrus ciliaris* cv. Gayndah), (BUF)
(b) Birdwood (*Cenchrus setiger*), (BIR)
(c) Callide rhodes (*Chloris gayana* cv. Callide), (CAL)
(d) Gamba (*Andropogon gayanus* cv. Kent), (GAM)
(e) Creeping bluegrass (*Bothriochloa insculpta* cv. Hatch), (HAT)
(f) Indian bluegrass (*B. pertusa* cv. Bowen), (PER)
(g) Sabi (*Urochloa mosambicensis* cv. Nixon) (SAB) and

Table 1. Description of location, rainfall, soil type and vegetation type for three experimental sites in the Katherine district, Northern Territory.

Site Name	Sunday Creek	Kidman Springs	Katherine Experiment Farm
Location	133°10′E, 16°10′S	130°55′E, 16°10′S	132°10′E, 14°22′S
Average annual rainfall (mm)	662 (90 yrs) (Daly Waters)	680 (12 yrs)	970 (92 yrs) (Katherine Post Office)
Soil class (Northcote 1979)	'Sunday Creek' Red Earth[3] (Gn 2.12)	'Kidman Springs' Emu Red Earth[2] (Gn 2.16)	Krec Red Earth[1] (Gn 2.11)
Original vegetation			
Trees	*E. terminalis* *E. dichromophloia* *E. argillacea* *Erythrophleum chlorostachys*	*E. tectifica* *E. grandifolia* *Terminalia platyptera*	*Eucalyptus foelscheana* *E. tectifica*
Grasses*	*Sehima nervosum* *Chrysopogon fallax* *Themeda triandra* *Aristida browniana* *Dichanthium fecundum*	*Aristida inaequiglumis* *Heteropogon contortus* *Chrysopogon fallax* *Aristida browniana* *Enneapogon purpurescens*	*Sehima nervosum* *Chrysopogon fallax* *Sorghum plumosum* *Themeda triandra* *Heteropogon contortus*

[1]Lucas *et al.* (1985)
[2]Forster and Laity (1972)
[3]Day and Henderson (1985)
*Grass species are listed in decreasing order of abundance

(h) Signal (*Brachiaria decumbens* cv. Basilisk) (SIG).

Each site was fertilised at sowing with single superphosphate at 125 kg/ha. Trace minerals were applied using "Es-min-el" fertiliser mix at 11 kg/ha equivalent. All seed was germination tested prior to sowing and found to easily satisfy minimum standards for germination and purity (Humphreys 1980). Both legume species returned germination test results of approximately 75% (50% hard seed) following heat treatment. Legumes and grasses were broadcast at a rate of 2.5 kg/ha of each species following adequate rainfall in December 1979 and January 1980.

All plots were mown to a height of 10-20 cm in the late dry season each year with a reciprocating blade mower. Cut plant material was removed from the plots. No maintenance fertiliser was applied.

Measurements and analysis

Plant counts were undertaken using two 0.5 m x 0.5 m quadrats per plot at the end of the wet season in 1980. Seed production was estimated by collecting seeds from the soil surface within a 0.5 m x 0.5 m quadrat in the late dry season in 1980, 1981 and 1982. Sieving and flotation techniques were used to clean the seed. Numbers and weight of seed were determined. DM yields were estimated at the end of the wet season in 1981 and 1982 on cut samples from a 1 m x 0.5 m quadrat per plot. Yields were partitioned for species and for green and dry fractions. The Fitzroy stylo was partitioned for edible and inedible material, the division being made arbitrarily at a stem diameter of 0.5 cm. Observations on plant habit, flowering and retention of green leaf were taken throughout the year in all 3 years of the experiment.

Soil samples were taken from the top 10 cm of each legume plot and the surrounding area of virgin native pasture at the completion of the trial. Samples were analysed for nitrogen, phosphorus, potassium and sulphur.

Statistical analysis was undertaken using an analysis of variance for a split-plot plaid design (D. Ratcliff, personal communication).

Results

Climate

Monthly rainfall for all 3 sites is shown in Figure 1. The KEF and KS sites had above average rainfall in the establishment year. KS and SC received above average rainfall in the following 2 seasons while KEF rainfall was below average in the 1980/81 season.

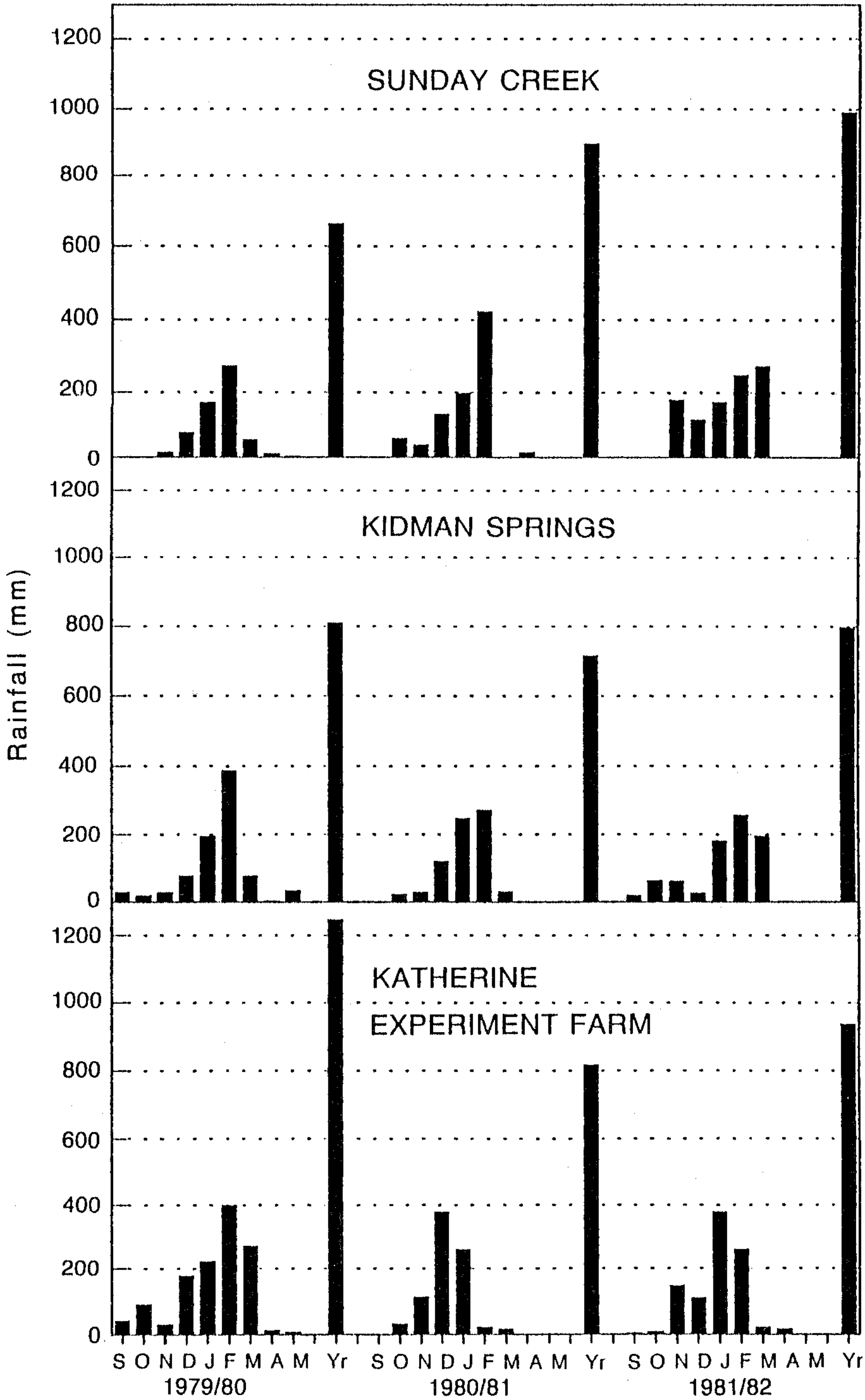

Figure 1. Monthly and seasonal rainfall totals for three experimental sites in the Katherine district, Northern Territory.

Effect of cultivation

All introduced grasses failed to establish on uncultivated plots at all sites. The effect of cultivation was not significant at KEF where there was poor grass establishment on cultivated plots as well. There was a significant positive effect of cultivation on legume establishment at SC ($P<0.05$). The effect remained evident for the 3 years of the experiment in terms of both total legume dry matter and legume leaf dry matter ($P<0.01$). While there was no significant effect of cultivation on native grass plant numbers in 1980, it reduced native grass DM yields at the SC site ($P<0.05$, after log transformation). Effects of cultivation on legume and native grass yields for 1982 are shown in Figure 2.

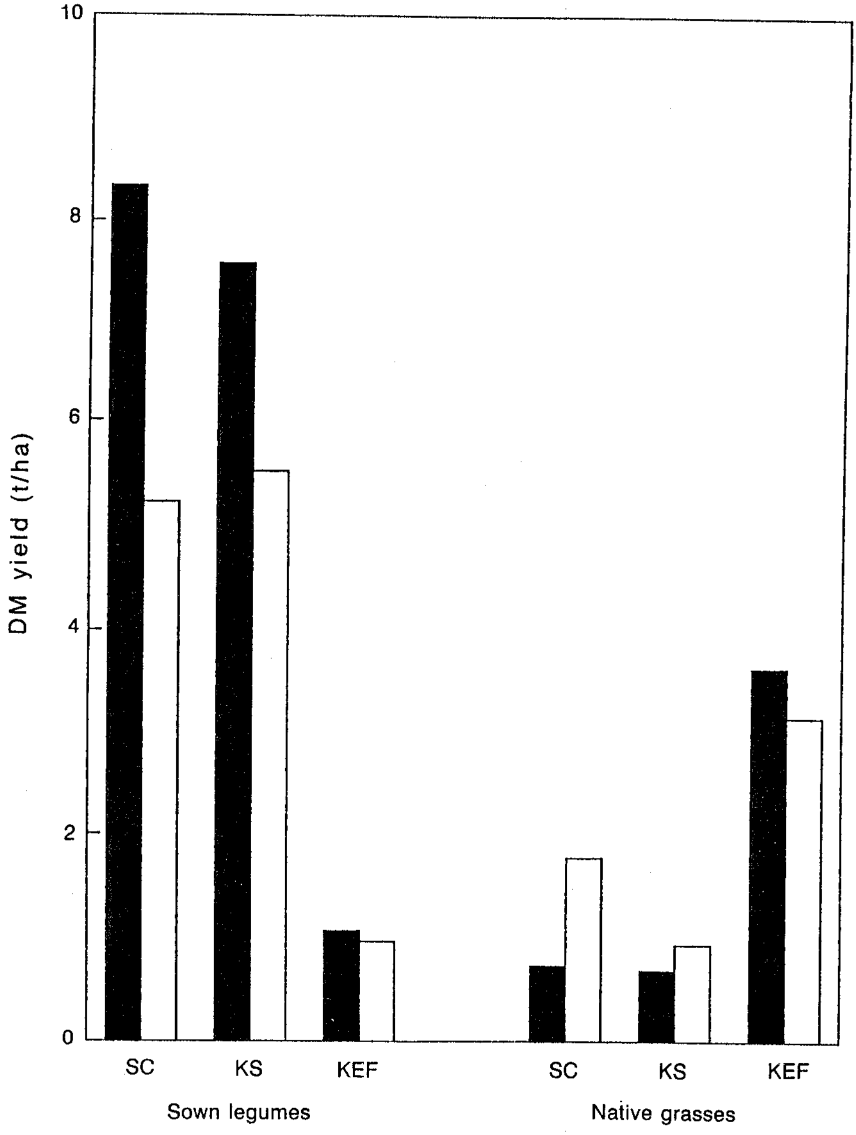

Figure 2. Effect of cultivation (■) or no cultivation (□) on DM yields of sown legumes and native grasses in 1982 at Sunday Creek (SC), Kidman Springs (KS) and Katherine Experiment Farm (KEF) in the Katherine district, Northern Territory.

Effect of legume

As measured by plant numbers, Fitzroy established significantly better than Verano at all sites ($P<0.01$). The legume treatment had no effect on plant numbers of either introduced or native grasses. There was however a significant effect on native grass yield at SC, where yields of 1052 and 1494 kg/ha were recorded for the Verano and Fitzroy treatments respectively in 1982 ($P<0.01$). Effects of treatment on legume establishment and DM yields are shown in Figure 3 while estimated legume seed yields are shown in Table 2. Fitzroy consistently outyielded Verano at all sites in years 2 and 3 in terms of both total yield and legume leaf yield ($P<0.05$). Recovered seed numbers of Verano at KS and KEF in 1980 were superior to those of Fitzroy ($P<0.05$) whereas Fitzroy yielded significantly higher ($P<0.01$) on the cultivated plots at SC in 1981.

Effect of introduced grass

Results for introduced grasses are presented for cultivated treatments only, except for KEF in 1980 where there were no significant effects of cultivation. There were significant treatment effects on introduced grass numbers in 1980 ($P<0.01$) (Table 3), and DM yield in 1981 ($P<0.05$) and 1982 ($P<0.01$) at all sites (Table 4). There were no significant correlations between number of viable seeds sown and subsequent numbers of plants established at any of the three sites.

Establishment, 1980. Gamba, Indian bluegrass and buffel ranked in the top 4 at all sites in 1980. At SC, buffel established significantly better than all other species except for Gamba and Callide rhodes ($P<0.05$). Birdwood was significantly worse than all other species ($P<0.05$). Indian bluegrass and Gamba were significantly superior to all grasses except buffel at KS ($P<0.05$). At

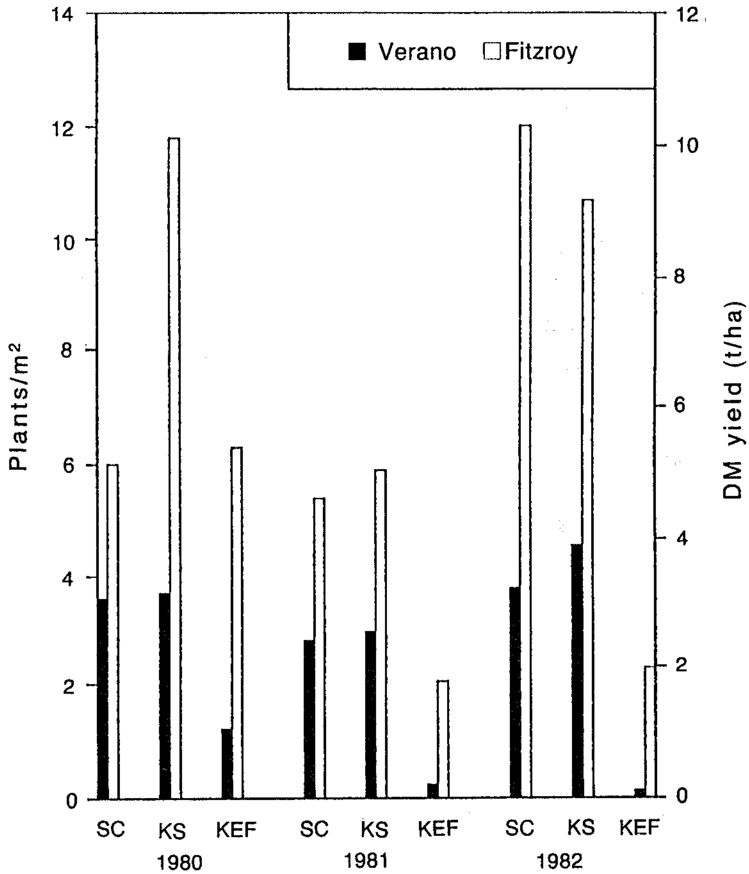

Figure 3. Number of legume plants in 1980, and DM yields in 1981 and 1982 at Sunday Creek (SC), Kidman Springs (KS) and Katherine Experiment Farm (KEF) in the Katherine district, Northern Territory.

Table 2. Estimated legume seed yields (kg/ha) recovered from the soil surface at Sunday Creek (SC), Kidman Springs (KS) and Katherine Experiment Farm (KEF) over 3 years.

	1980		1981		1982	
Site	Verano	Fitzroy	Verano	Fitzroy	Verano	Fitzroy
SC	1.6	0.1	2.6	70.0	188.0	66.0
KS	6.0	0.5	13.5	3.8	138.0	32.0
KEF	0.4	0.2	2.8	7.8	1.7	5.4

Table 3. Effect of grass species on plant numbers (plants/m^2) in 1980 of introduced grasses sown on to cultivated seedbeds with two legumes at three sites in the Katherine district, Northern Territory.

	Site			
Grass	Sunday Creek	Kidman Springs	Katherine Experiment Farm	Mean
Birdwood	0.1	1.6	0.4	0.7
Buffel	3.9	4.6	0.8	3.1
Callide rhodes	3.0	2.7	0.2	2.0
Gamba	3.0	6.7	3.6	4.4
Creeping bluegrass	1.2	0.8	0.2	0.7
Indian bluegrass	2.0	8.3	1.6	4.0
Sabi	2.0	2.3	0.9	1.7
Signal	1.5	0.6	0.4	0.8
Mean	2.1	3.4	1.0	

Table 4. Effect of grass species on DM yield (kg/ha) in 1981 and 1982 of eight pasture grasses sown with two legumes on to cultivated seedbeds at three sites, Sunday Creek (SC), Kidman Springs (KS) and Katherine Experiment Farm (KEF), in the semi-arid tropics of the Northern Territory.

	1981			1982		
Grass	SC	KS	KEF	SC	KS	KEF
Birdwood	0 ab[1]	67 ab	11 a	0 a	2 a	26 a
Buffel	57 ab	215 ab	301 ab	207 a	100 a	349 ab
Callide rhodes	582 c	61 a	55 a	2 a	0 a	0 a
Gamba	674 c	264 b	484 b	2028 b	87 a	845 b
Creeping bluegrass	256 bc	0 a	0 a	43 a	0 a	0 a
Indian bluegrass	440 bc	37 a	494 ab	340 a	592 b	634 ab
Sabi	429 bc	89 ab	78 ab	47 a	38 a	134 a
Signal	261 bc	0 a	16 a	78 a	0 a	444 a

[1] Within columns, means followed by a common letter are not significantly different (P>0.05).

KEF, Gamba plant numbers were significantly greater than all other species (P<0.05). Grass establishment was best at KS and worst at KEF.

DM yields, 1981–82. In 1981 at SC, Gamba and Callide rhodes yielded significantly higher than birdwood and buffel (P<0.05) with other species intermediate. Gamba yielded significantly higher than grasses other than buffel, sabi and birdwood at KS, while at KEF, Gamba was significantly superior to species other than Indian bluegrass, sabi and buffel (P<0.05). In 1982 Gamba was superior to all species at SC, and to all but Indian bluegrass and buffel at KEF (P<0.05). At KS, Indian bluegrass yielded significantly more than all other species (P<0.05).

Effect of site

Mean data for each of the sites are shown in Table 5. Values for soil nutrient levels in cultivated plots and surrounding areas of native pasture for KS and SC sites are shown in Table 6. SC and KS generally allowed better establishment and growth of legumes with SC showing much higher yields

Table 5. Site means of cultivated treatments for plant numbers in 1980, DM yields of Verano (VER), Fitzroy (FIT), introduced grasses (IG), and native grasses (NG), Fitzroy edible/inedible ratios (E/I), and green/dry ratios for native grass (G/D) in 1981 and 1982.

Year	Site	VER	FIT	IG	NG	E/I	G/D
		Plants/m²					
1980	SC	5.0	8.7	2.2	2.6	—	—
	KS	4.1	11.8	3.5	3.0	—	—
	KEF	1.4	6.5	1.0	6.0	—	—
		Dry matter (t/ha)					
1981	SC	2.4	4.6	0.3	0.9	2.9	0.2
	KS	2.6	5.1	0.1	1.0	2.2	0.6
	KEF	0.2	1.8	0.2	1.5	30.0	0.4
1982	SC	4.4	15.2	0.3	0.8	1.9	1.3
	KS	3.9	9.7	0.1	0.9	3.4	3.0
	KEF	0.1	2.0	0.3	3.8	—	0.5

Table 6. Soil nutrient levels (ppm) of sown areas (SN) and surrounding native areas (NAT) at the Sunday Creek (SC) and Kidman Springs (KS) sites in January 1983.

Site	SC		KS	
	SN	NAT	SN	NAT
Total N	772	637	357	284
Available P	<5	<5	<5	<5
K	277	232	92	104
S	<5	<5	<5	<5

of Fitzroy in 1982. Soil nitrogen levels during the wet season of 1983 were approximately 20% higher where legumes had been sown at both SC and KS. No data were available for KEF. Levels of P and S were low at both sites. Native grass DM yields were higher at KEF than the other sites, particularly in 1982. There were no significant interactions between legume and grass treatments at any site.

Discussion

None of the grass species tested showed any ability to establish without cultivation. While all previous testing of grass species in the area had relied on cultivation for establishment, Fisher (1971) postulated that sabi grass may be suitable for aerial sowing with stylos. The results from this experiment do not support this hypothesis.

The improved establishment of legumes on cultivated areas at SC differs from the results of Mott *et al.* (1976). The response at SC is thought to be due to the better response of the soil surface to cultivation compared with the soils at other sites in this experiment and those used by Mott *et al.* These soils are prone to rapid sealing after rainfall. Mott *et al.* also cultivated only between tussocks. In our study, practical cultivation techniques ensured some reduction in competition from grasses. Throughout the experiment, dry matter yields of native grass were lower at SC than at other sites.

At the two lower rainfall sites (SC, KS), both legume species established and produced well despite quite low plant numbers in the first year. The yields of Fitzroy at SC and KS in 1982 were excellent at 15.2 and 9.7 t/ha respectively. Anthracnose (*Colletotrichum gleosporioides*) poses little risk in this environment. Survey results (T.G.H. Stockwell, unpublished data) showed very low levels of anthracnose at SC and KS compared with wetter environments. Verano yields were similarly satisfactory at the SC (4.4 t/ha) and KS (3.9 t/ha) sites. Reduced establishment and subsequent yields, of Verano in particular (0.1 t/ha), at KEF are thought to be due to greater competition from the perennial grass species as evidenced by the higher grass DM yields at this site. While Mott *et al.*(1976) found reduced germination of heat treated *Stylosanthes scabra* compared with Verano, the opposite occurred in this experiment with Fitzroy and Verano, both similarly heat treated. While 15% of viable Fitzroy seed established successfully, only 5% of viable Verano seed established successfully. Fitzroy established better on both burnt and cultivated treatments at all sites.

The substantial yield of legumes and the recovery of substantial levels of seed by 1982 confirmed the adaptation of both species to these environments. Continued observations (to 1991) at the SC and KS sites confirm the persistence of both species. Fitzroy has shown a marked ability to spread, colonies being located up to 10 km from the original sowings. While Verano yields were much reduced during the below average rainfall years in the mid to late 1980's (Stockwell 1989), the cultivar has persisted strongly in both of the drier environments. The KEF site was burnt by wildfire in 1982 and ownership of the site lost.

Production of introduced grasses was generally poor. As all seed was tested to be of acceptable quality and there was no relationship between the number of viable seeds sown and plant establishment at any site, performance of the various grasses was considered to reflect adaptation to environment at the three sites. Birdwood grass was once the preferred standard species for the Katherine district (Norman 1967). While the surprisingly poor performance of this species is thought to have been due to preferential grazing by wallabies, this was not the case for the poor establishment and growth of Hatch and signal grass. Similarly, Callide did not persist despite having reasonable establishment. The widely grown district species, Gayndah buffel and sabi, were outperformed only by Kent and Bowen. Kent produced the best grass yield of 2 t/ha and seeded at all sites, while Bowen produced only moderate yields but seeded heavily and showed good spreading ability. Failure to establish without cultivation precludes the use of any of the grass species tested in low-cost sowings.

Anning (1982) argues that the high risk of failure of grasses to establish in the semi-arid tropics means that grasses must have the ability to colonise and spread. The apparent increase in soil nitrogen levels in the legume plots (Table 6) suggests that a more favourable environment for grass establishment may exist several years after sowing a legume. While the four most productive grasses may establish in, and spread from, cultivated strips in such a system, the cost involved will limit their use to pastures for special purposes or intensive use. Long-term studies by J. McIvor (personal communication) have suggested that on soils with much higher soil phosphorus levels, introduced grasses may establish in significant amounts 8–10 years after sowing. However in the environments used in this experiment, low soil phosphorus levels would reduce the chance of establishment of presently available introduced grass species.

The introduction of new grasses which may establish over the long term on low phosphorus soils would improve the chance of developing a stable grass–legume pasture in the semi-arid tropics.

It was found that both *Stylosanthes scabra* cv. Fitzroy and *S. hamata* cv. Verano could be successfully established in the districts typified by the SC and KS sites by burning in the early wet season immediately prior to sowing by broadcasting. More attention to control of competition from native perennial grasses, perhaps through grazing, is indicated for the KEF environment. While *Andropogon gayanus* cv. Kent and *Bothriochloa pertusa* cv. Bowen could be recommended as suitable species for sowing along with *Cenchrus ciliaris* cv. Gayndah and *Urochloa mosambicensis* cv. Nixon, their use appears to be restricted to special purpose pastures which may justify the added expense of cultivation. There was no difference in the ability of any of the grasses to combine with either of the legumes as companion species. Broadcasting seed of these grass species cannot be recommended as a successful establishment method.

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References

Anning, P. (1982) Evaluation of introduced grass species for pastures in the dry tropics of north Queensland. *Tropical Grasslands*, **16**, 136–145.

Bisset, W.J. and Graham, T.G. (1978) Creeping bluegrass finds favour. *Queensland Agricultural Journal*, **104**, 245–247.

Bisset, W.J. (1980) Indian bluegrass has special uses. *Queensland Agricultural Journal*, **106**, 507–517.

Day, K.J. and Henderson, R.L. (1985) Land resources of the Sunday Creek development area. *Conservation Commission of the Northern Territory Technical Memorandum No. 85/2.*

FISHER, M.J. (1971) Pasture species for the Tipperary area, Northern Territory. *CSIRO Division of Land Research Technical Paper No. 31.*

FORSTER, B.A. and LAITY, J.R. (1972) Report on the land units of the Victoria River Research Station, Kidman Springs. *Northern Territory Land Conservation Section Report.*

HUMPHREYS, L.R. (1980) *A Guide to Better Pastures for the Tropics and Sub-tropics.* 4th Edn. (Wright Stephenson and Company: Sydney).

LUCAS, S.J., DAY, K.J. and WOOD, B. (1985) Revised classification of earth soils of the Daly Basin, N.T. *Conservation Commission of the Northern Territory Technical Memorandum No. 85/5.*

MOTT, J.J., MCKEON, G.M. and MOORE, C.J. (1976) Effects of seed bed conditions on the germination of four *Stylosanthes* species in the Northern Territory. *Australian Journal of Agricultural Research,* **27,** 811-823.

NORMAN, M.J.T. (1960a) The establishment of pasture species on arable land at Katherine, NT. *CSIRO Division of Land Research and Regional Survey Technical Paper No. 18.*

NORMAN, M.J.T. (1960b) Performance of Buffel grass and Buffel grass — Townsville lucerne mixtures at Katherine, NT. *CSIRO Division of Land Research and Regional Survey Technical Paper No. 11.*

NORMAN, M.J.T. (1961) The establishment of pasture species with minimum cultivation at Katherine, NT. *CSIRO Division of Land Research and Regional Survey Technical Paper No. 14.*

NORMAN, M.J.T. (1966) Katherine Research Station 1956-64: A Review of Published Work. *CSIRO Division of Land Research Technical Paper No. 28.*

NORMAN, M.J.T. (1967) Companion grasses for Townsville lucerne at Katherine, N.T. *Journal of the Australian Institute of Agricultural Science,* **33,** 14-22.

NORMAN, M.J.T. and BEGG, J.E. (1973) Katherine Research Station: A Review of Published Work 1965-72. *CSIRO Division of Land Research Technical Paper No. 33.*

NORTHCOTE, K.H. (1979) *A Factual Key for the Recognition of Australian Soils.* 4th Edn. (Rellim Technical Publications: Glenside, South Australia).

STOCKER, G.C. and STURTZ, J.D. (1966) The use of fire to establish Townsville lucerne in the Northern Territory. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **6,** 277-279.

STOCKWELL, T.G.H. (1989) *The productivity of cattle and pastures in the semi-arid tropics of the Northern Territory.* Master of Agricultural Science Thesis, University of Queensland, Brisbane.

WINTER, W.H., CAMERON, A.G., REID, R., STOCKWELL, T.G.H. and PAIGE, M.C. (1985) Improved pasture plants. In: Muchow, R.C. (ed.) *Agro-research for the Semi Arid Tropics: North West Australia,* pp. 227-272. (University of Oueensland Press: Brisbane).

WINTER, W.H., MOTT, J.J., MCLEAN, R.W. and RATCLIFF, D. (1989a) Evaluation of management options for increasing the productivity of tropical savanna pastures. 1. Fertiliser. *Australian Journal of Experimental Agriculture,* **29,** 613-622.

WINTER, W.H., MOTT, J.J. and MCLEAN, R.W. (1989b) Evaluation of management options for increasing the productivity of tropical savanna pastures. 2. Legume species. *Australian Journal of Experimental Agriculture,* **29,** 623-630.

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