Sward evaluation of fifteen *Stylosanthes hamata* accessions in twenty dry tropical environments

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Abstract

Forty-four *S. hamata* accessions were grown in association with volunteer species (mainly native grasses) for 3 to 5 years in small swards in 20 dry tropical environments, 18 of which were considered marginal for the existing cultivar Verano because of low rainfall (8), cool temperatures (5) or soil type (5).

The objectives were to find accessions superior to Verano for marginal environments. Results are presented for the 15 *S. hamata* tetraploids which were grown in all environments, and for the diploid CPI 61670 which was grown in 10 environments.

In spite of low rainfall, the stylos established and survived in 15 of the 20 environments. The stylos were adapted to a wide range of soil types including solodics and red and yellow earths but not grey cracking clays and a shallow solodic with impeded drainage.

Cultivar Amiga (CPI 55822) was significantly better than Verano in perenniality in 2 out of 3 years and dry matter yield in 2 out of 4 years when averaged over all environments, and maintained higher seedling densities than Verano. In Timur, CPI 61670 showed marked environmental specificity and gave higher yields than Amiga and Verano on an alkaline clay soil with pH 8.6 and an average annual rainfall of 1200 mm.

Resumen

Durante 3 a 5 años se cultivaron 44 accesiones de S. hamata *en asociación con especies voluntarias (principalmente gramíneas nativas) en pequeñas parcelas úbicadas en 20 ambientes tropicales secos, 18 de los cuales fueron considerados marginales para el cultivar Verano existente debido a la baja precipitación (8), a las temperaturas bajas (5) o al tipo de suelo (5).*

Los objetivos fueron encontrar accesiones superiores al Verano en ambientes marginales. Se presentan los resultados de 15 tetraploides de S. hamata *cultivados en todos los ambientes y del diploide CPI61670 el cual fue cultivado en 10 ambientes.*

Los stylos se establecieron y sobrevivieron en 15 de los 20 ambientes, a pesar de las reducidas lluvias. Los stylos se adaptaron bién a un amplio rango de suelos incluyendo los solódicos y los de tierra roja y amarilla pero no en los suelos de arcilla gris fracturable o en los suelos delgados solódicos con drenaje restringido.

El cultivar Amiga (CPI55822) fue significativamente más perenne que Verano en 2 de cada 3 años y tuvo un mayor rendimiento en 2 de cada 4 años cuando se promediaron todos los ambientes, y mantuvo mayor densidad de plántulas que Verano. En Timur, CPI61670 mostró una marcada especificidad por el ambiente y produjo mayores rendimentos que Amiga y Verano en los suelos alcalino arcillosos con pH 8.6 y un promedio anual de lluvias de 1200 mm.

Introduction

S. hamata cv. Verano is an important pasture legume for seasonally dry tropical environments. It has been used widely in pasture improvement

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programs in northern Australia since it was released in 1973 (Oram 1990). Practical experience since then suggested that Verano is poorly adapted to regions with < 760 mm annual rainfall and to cooler environments with > 300 m altitude and/or > 20° latitude. However, Strickland and Greenfield (1988) showed that Verano survived 4 to 5 years in environments with < 760 mm rainfall at latitudes of c. 24 °S when established on cultivated seed beds, but the competition from volunteer species in terms of dry matter yield was not recorded. Strong competition from volunteer species may eliminate Verano in marginal environments.

Verano was the only tetraploid form of the species evaluated in Australia when it was released. By 1982, the total tetraploid collection had been increased to 43 accessions. This collection together with the diploid CPI 61670 was evaluated in small sward experiments in 19 dry tropical environments across northern Australia and 1 in Indonesia. Within *S. hamata* tetraploids, only data for the 15 accessions grown in all environments are presented because this subset contains the highest yielding and most persistent accessions.

The objective of the evaluation was to see if there were any *S. hamata* accessions superior to Verano in environments that may be marginal for Verano. This paper records the research that led to the selection and release of cv. Amiga and compares Verano and Amiga (CPI 55822) over a range of environments.

Materials and methods

Sites

There were 16 sites and 8 soil types (Table 1) within the tropics between latitudes 10° and 23 °S. Two experiments (a and b) were commenced in different years at 4 sites giving a total of 20 environments.

Natural grasslands occurred on the grey cracking clay soils at Wrotham Park and Bing Bong; the remaining sites carried open *Eucalyptus, Melaleuca* or *Acacia* woodlands. All woodland sites except Forest Home and Highbury were cleared before the experiments commenced. Native grasses dominated the ground flora except at 3 sites. At these sites the ground flora was dominated by introduced grasses *viz. Cenchrus pennisetiformis* (Cloncurry strain) at Corella Park, *Urochloa mosambicensis* at Lansdown and *C. setiger* at Inkata. The soil pH at Besi Pae was alkaline (pH 8.6); the remaining soils were moderately acid (pH 5.6 to 6.9).

The average annual rainfall for each site ranged from 429 to 1200 mm (Table 2). All sites experienced a marked dry season ranging from 4 to 9 months each year.

Only 2 environments, the Wrotham Park yellow earth and Lansdown were considered highly favourable for Verano. The remaining 18 environments were considered marginal for Verano because of low average annual rainfalls < 760 mm (5a, 5b, 7a, 7b, 9a, 9b, 14 and 16)

Table 1. Location, altitude, soil type, pH and phosphorus levels of the experimental sites

No.	Site	Approximate locality	Lat. (°S)	Long. (°E)	Alt. (m)	Soil type and Northcote (1971) classification		pH	P (acid) (ppm)	P (bicarb) (ppm)	Applied P[1] (kg/ha)
1	Springmount	Mareeba, Qld	17°14′	145°18′	580	Non-calcic brown soil	Dr2.12	6.4	3.0	<2.0	20
2	Wrotham Park	Chillagoe, Qld	16°37′	143°59′	160	Yellow earth	Gn2.61	5.6	3.0	<2.0	20
3a,3b	Wrotham Park	Chillagoe, Qld	16°34′	143°59′	180	Grey clay	Ug5.2	6.5	6.0	3.0	20
4	Besi Pae	Timur, Indonesia	10°13′	123°38′	2	Black earth	-	8.6	10.0	-	20
5a,5b	Corella Park	Cloncurry, Qld	20°40′	140°30′	189	Red earth	Gn2.12	6.8	49.8	16.0	nil
6	Lansdown	Townsville, Qld	19°40′	146°51′	61	Solodic	Dy3.43	5.9	5.0	3.6	10
7a,7b	Forest Home	Georgetown, Qld	18°13′	143°01′	200	Solodic	Dy3.42	5.9	5.0	2.0	20
8	Tirrabella	Mt Garnet, Qld	17°53′	145°14′	600	Red earth	Gn2.12	6.7	-	20.0	20
9a,9b	Prairie	Prairie, Qld	20°54′	144°36′	432	Red earth	Gn2.11	6.5	6.0	-	20
10	Kunwarara	Rockhampton, Qld	22°55′	150°08′	15	Red earth	Gn2.11	6.7	2.3	4.0	30
11	Glen Geddes	Rockhampton, Qld	22°52′	150°18′	60	Solodic	Dy3.4	6.9	4.8	2.5	30
12	Pinnarendi	Mt Garnet, Qld	18°03′	142°53′	740	Red earth	Dr2.51	6.4	-	6.0	20
13	Highbury	Chillagoe, Qld	16°28′	143°12′	100	Solodic	Dy3.43	6.0	-	4.0	20
14	Inkata	Derby, WA	17°59′	124°11′	44	Solodic	Dy2.4	6.4	5.5	-	10
15	Bing Bong	Borroloola, NT	15°37′	136°20′	15	Grey clay	Ug5.28	6.1	9.0	-	20
16	McArthur River	Borroloola, NT	16°26′	136°05′	42	Red earth	Gn2.12	6.6	10.0	-	20

[1] P Applied as superphosphoate. [2] Data not available.

Table 2. Annual rainfall (October to September) at the experimental sites

No.	Site	Date sown	Year 1	Year 2	Year 3	Year 4	Mean	Long-term average
					(mm)			
1	Springmount	3.12.83	**553**[1]	**645**	1038	**535**	**693**	804
2	Wrotham Park Y.E.	22.11.83	1041	**901**	**774**	**722**	**860**	937
3a	Wrotham Park G.C.	21.11.83	1041	**901**	**774**	**722**	**860**	937
3b	Wrotham Park G.C.	20.11.85	**774**	**722**	**742**	X[2]	**746**	937
4	Besi Pae	30.11.83	1222	**1016**	1564	X	1267	1200
5a	Corella Park	15.12.83	511	**278**	**253**	**379**	**355**	429
5b	Corella Park	11.12.85	**253**	**379**	**235**	**248**	**279**	429
6	Lansdown	20.12.83	**559**	**687**	**655**	**399**	**575**	869
7a	Forest Home	18.12.84	**259**	**363**	**545**	**470**	**409**	752
7b	Forest Home	11.12.85	**363**	**545**	**470**	X	**459**	752
8	Tirrabella	11.12.84	**466**	917	**541**	**575**	**625**	760
9a	Prairie	29.11.84	**308**	**373**	**392**	**283**	**339**	432
9b	Prairie	12.12.85	**373**	**392**	**283**	**426**	**368**	432
10	Kunwarara	19.12.84	**809**	**698**	**454**	X	**654**	970
11	Glen Geddes	10.12.84	**809**	**698**	**454**	X	**654**	915
12	Pinnarendi	31.12.85	1253	**375**	**554**	X	**727**	882
13	Highbury	18.11.85	**622**	**749**	**656**	X	**676**	1074
14	Inkata	7.1.86	**692**	**478**	**239**	X	**470**	500
15	Bing Bong	7.11.86	**622**	951	1734	X	1102	790
16	McArthur	18.11.86	**604**	**636**	1145	X	795	749

[1] Rainfalls in bold type are less than the average. [2] Experiment terminated.

(Table 2), unsuitable soil types such as heavy clays (3a, 3b, 4 and 15) or an extremely shallow solodic soil (13) and the cooler environments with an altitude > 500 m (1, 8, and 12) or a latitude > 20 °C (10 and 11) (Table 1).

Accessions

The 44 accessions included in the experiments (Table 3) were evaluated in 2 to 20 environments. Results are presented for the 15 *S. hamata* tetraploids which were grown in the 20 environments and the diploid 61670 which was grown in 10 environments (Table 4).

Table 3. List of *S. hamata* accessions evaluated

No.	CPI No.	No.	CPI No.	No.	CPI No.
1	Verano*	16	65365	31	75167
2	46588	17	65367	32	75168*
3	55812*	18	65368	33	75169*
4	55820*	19	65371	34	75171
5	55821*	20	65962	35	75172
6	55822*	21	65963	36	92412
7	55823*	22	65965	37	92415
8	55824*	23	65966	38	92671
9	55825	24	68837	39	92698
10	55826	25	68838	40	92715
11	55827	26	68840	41	92720
12	55828*	27	75162*	42	92749
13	55830*	28	75163*	43	99665
14	55831*	29	75164	44	61670
15	61672(B)	30	75166*		

* Accessions included in the data presented.

Experimental procedure

The experiments were commenced over 4 years, 1983–84 to 1986–87, were sown between November and January before the wet season commenced (Table 2) and were terminated by June 1989.

The seed of all accessions was produced at Lansdown, mainly during 1982–83, and tested for germination and hardseededness. Accessions with an appreciably and significantly higher or lower hard seed content than Verano (46%), expressed as a percentage of viable seed, were 75169 (78%), 55830 (80%), 55828 (80%), 55824 (8%) and 55821 (17%) (LSD = 22%, $P < 0.05$). The sowing rate per plot was 5 g dehulled plus 10 g podded seed which was equivalent to 5 kg/ha of dehulled seed. The seed was not scarified or inoculated with *Rhizobium* before sowing.

Experimental design was a randomized block with 3 replications, and a plot size of 4 m x 5 m or 5 m x 5 m. The experimental areas were lightly disced before sowing to reduce grass competition except at Forest Home and Highbury, where the areas were burnt but not cultivated.

Superphosphate was applied at 10 to 30 kg/ha P (Table 1) except at Corella Park which had a high soil P level (16 ppm bicarbonate extractable P). The high soil P at Tirrabella (20 ppm bicarbonate extractable P) resulted from superphosphate applied to a previous peanut crop. At Pinnarendi, a response was obtained in year 2 to

Table 4. Attributes recorded each year in each environment

No.	Environment	Attributes recorded[1] Year 1		Year 2			Year 3			Year 4		
1	Springmount	S	—	S	P	Y	S	P	Y	S	P	Y
2	Wrotham Park YE	S	Y	S	P	Y	—	—	—	—	—	Y
3a	Wrotham Park GC	S	—	S	P	—	F	F	F[3]	F	F	F
3b[D2]	Wrotham Park GC	S	—	—	—	—	F	F	F	F	F	F
4[D]	Besi Pae	S	Y	—	—	Y	—	—	Y	—	—	—
5a	Corella Park	S	Y	S	P	Y	S	P	—	F	F	F
5b[D]	Corella Park	S	—	—	P	Y	F	F	F	F	F	F
6	Landsown	S	—	—	P	Y	—	—	—	S	P	Y
7a	Forest Home	S	—	S	P	—	S	P	Y	S	P	Y
7b[D]	Forest Home	S	—	S	P	Y	S	P	Y	—	—	—
8	Tirrabella	S	Y	S	P	Y	—	—	Y	S	—	Y
9a	Prairie	S	Y	S	P	Y	S	P	Y	S	P	Y
9b[D]	Prairie	S	Y	S	P	Y	S	P	Y	—	—	—
10	Kunwarara	S	Y	S	P	Y	—	—	Y	—	—	—
11	Glen Geddes	S	Y	S	P	Y	—	—	Y	—	—	—
12[D]	Pinnarendi	S	Y	S	P	Y	S	P	Y	—	—	—
13[D]	Highbury	S	—	—	P	Y	F	F	F	F	F	F
14[D]	Inkata	S	—	S	P	Y	S	P	Y	—	—	—
15[D]	Bing Bong	S	Y	S	—	Y	—	—	—	—	—	—
16[D]	McArthur River	S	Y	—	P	Y	—	—	—	—	—	—
	Total number	20	11	14	17	17	8	8	11	5	4	6

[1] S = seedlings, P = perennials, Y = yield, – = not sampled.
[2] D = environments where the diploid CPI 61670 was sown.
[3] F = failed to survive.

7 kg/ha zinc sulphate, following observations of Zn deficiency symptoms in year 1.

The swards were grazed during the dry season and/or defoliated by mowing before the commencement of each growing season. At some sites, the experiments were grazed for 1 or 2 months after the wet season commenced before excluding stock to record dry matter yields for the remainder of the growing season.

Data recorded

Stylo plant counts were made in nine or ten 0.25 m^2 quadrats per plot to measure the initial seedling establishment 3 or 4 weeks after suitable rains had fallen. In subsequent years the number of perennating stylos and surviving seedlings (i.e. first year plants) were counted towards the end of the growing season when the plots were harvested for dry matter yield.

The dry matter yield of *Stylosanthes* accessions and other species was usually determined by cutting four 0.25 m^2 quadrats per plot. At some sites and occasions, the dry matter yield was estimated on a scale of 1 to 10 and the scale was standardised by quadrat cuts. With one exception dry matter yields were determined in April, May or June each year depending on the seasonal conditions. The exception was Besi Pae where 2 harvests were taken in both the 2nd and 3rd year.

It was not always possible to sample all attributes and all environments because of severe drought or accidental grazing. The attributes recorded each year in each environment are given in Table 4.

Numerical methods

Analyses of variance. The data for the 15 tetraploid accessions were transformed using a fourth root transformation in order to make the variances homogeneous before analyses of variance using the statistical package GENSTAT 5 (Payne 1987). Where the site by accession interaction was significant, contrasts between accessions and Verano were extracted in an attempt to simplify the interpretation. This assisted in interpreting the interaction between the accessions and sites.

Ranking procedures. A ranking procedure was used to summarize the performance of the 15 tetraploid accessions in years 2, 3, and 4; year 1 was excluded to eliminate differences between the accessions during the establishment phase. The accessions were ranked 1 maximum to 15 minimum on fourth root transformed means averaged over all environments for the 9 attributes recorded. The total of the 9 ranks was then ranked 1 to 15.

Results

Rainfall

Rainfall during the experiment (Table 2) was well below average in the majority of years for all sites, except Besi Pae and Bing Bong where it was above average for 2 of the 3 years. The annual rainfall was often less than 500 mm with the lowest recording of 235 mm at Corella Park during 1985–86. The drought which occurred at most sites during the experiment was reflected in the low stylo plant counts and dry matter yields (Tables 5, 6 and 7).

Adaptation

The accessions established, seeded and perennated in all environments but failed to survive after year 3 at Wrotham Park (3a and 3b), Corella Park (5a and 5b) and Highbury (Table 4). The heavy clay soils at Wrotham Park (3a and 3b) and the solodic at Highbury were unsuitable for stylos. The latter soil differed from the other solodic soils (Table 1) in having an impermeable subsoil close to the surface and poor water holding capacity. At Corella Park, the accessions failed to survive the moisture stress during the long dry season; the mean annual rainfall during the 2 experiments was 317 mm. Prairie was the lowest rainfall region where the accessions survived; the mean annual rainfall during the 2 experiments was 356 mm.

Seedling establishment

Excluding 5 environments, the initial seedling establishment was low due to poor seasonal conditions: the mean seedling densities over all accessions ranged from 3.3 to 11.6 plants/m^2. The exceptions were the higher rainfall environments Besi Pae, Kunwarara, Glen Geddes and Pinnarendi together with Corella Park (5a) which experienced favourable rainfall conditions for stylo establishment: the mean seedling densities in these 5 environments ranged from 23.3 to 56.5 plants/m^2. Subsequent germination events after the first 3 or 4 weeks increased the seedling densities in the first year at most sites. Seedling densities in years 2, 3 and 4 were also generally low due to poor seasonal conditions. In the first year, the mean seedling density was higher ($P < 0.05$) for 8 accessions when averaged over all environments than Verano; in years 2, 3 and 4 there were no accessions higher ($P < 0.05$) than

Table 5. Number of environments where the seedling density of each *S. hamata* accession exceeded that of Verano (#) and mean seedling density averaged over all sites (fourth root transformed means of No./20 m^2)

Accession CPI No.	Year 1 #	Year 1 Mean all sites	Year 2 #	Year 2 Mean all sites	Year 3 #	Year 3 Mean all sites	Year 4 #	Year 4 Mean all sites
Verano	—	3.47	—	2.23	—	2.82	—	3.08
55812	14/20	3.79**[1]	6/13	2.12	0/7	1.89**	2/5	2.80
55820	14/19	3.77**	8/13	2.43	2/7	2.60	1/5	2.58
55821	12/20	3.68*	6/12	2.23	2/7	2.65	4/5	3.67
55822	16/20	3.86***	8/14	2.46	4/7	2.95	4/5	3.72
55823	13/20	3.71*	4/12	1.66*	1/6	1.98*	0/4	2.73
55824	9/20	3.50	5/11	1.92	3/7	2.53	3/5	3.56 I
55828	12/20	3.56	7/14	2.29 I[2]	3/8	2.44	1/5	2.78 I
55830	13/20	3.75*	7/14	2.50 I	3/8	2.56	4/5	3.17
55831	16/20	3.87***	9/14	2.49	3/7	2.70	4/5	3.52
75162	12/20	3.70*	5/12	2.00	5/6	3.06	4/5	3.78
75163	8/20	3.51	7/13	2.06	2/7	2.48	2/4	3.35
75166	8/20	3.51	7/13	2.22	2/7	2.82	2/5	2.98
75168	10/20	3.59	5/12	2.02	2/7	1.96*	1/5	2.52
75169	8/20	3.32	5/11	2.11	6/8	3.05	2/5	2.93 I
Accession x environment		n.s.		***		n.s.		*
Accession		***		*		**		**
Seedling plant density[3] (plants/m^2)								
Verano		7.2		1.2		3.2		4.5
55822		11.1		1.8		3.8		9.6
Mean all accessions		8.8		1.2		2.2		4.9

[1] The asterisks against the means refer to the level of the significant difference from Verano.
[2] I indicates an interaction between environments and the Verano and accessions means.
[3] Back-transformed means.

Table 6. Number of environments where the density of perennial plants of each *S. hamata* accession exceeded that of Verano (#) and mean perennial plant density averaged over all environments (fourth root transformed means of No./20 m²)

Accession CPI No.	Year 2 #	Year 2 Mean all sites	Year 3 #	Year 3 Mean all sites	Year 4 #	Year 4 Mean all sites
Verano	—	3.37	—	2.54	—	2.59
55812	7/17	3.36	4/7	2.54	1/4	2.76 I[2]
55820	8/17	3.38	4/7	2.70	1/4	2.72 I
55821	9/17	3.42	6/7	2.66	4/4	3.26*
55822	12/16	3.72**[1]	6/7	2.75	4/4	3.50**
55823	11/17	3.35	5/7	2.68	2/4	2.71
55824	6/17	3.24	6/7	2.62	3/4	2.87
55828	7/17	3.06*	5/8	2.52	2/4	2.60
55830	10/17	3.51	7/8	2.64	3/4	3.08
55831	14/17	3.60	2/7	2.32	4/4	3.65**
75162	11/17	3.45	5/8	2.71	4/4	3.16
75163	6/17	3.32	3/7	2.39	4/4	3.30*
75166	9/17	3.30	4/7	2.42	2/4	2.50
75168	6/17	3.26	5/8	2.42	1/4	2.34
75169	6/17	3.15	5/8	2.47	2/4	2.47 I
Accession x environment		n.s.		n.s.		*
Accession		***		n.s.		***
Perennial plant density[3] (plants/m²)						
Verano		6.4		2.1		2.2
55822		9.6		2.8		7.6
Mean all accessions		6.4		2.1		3.5

[1] The asterisks against the means refer to the level of the significant difference from Verano.
[2] I indicates an interaction between environments and the Verano and accessions means.
[3] Back-transformed means.

Verano over all environments (Table 5). Accession 55822 gave consistently high seedling numbers being ranked 2, 3, 3 and 2 in years 1 to 4, respectively, and exceeded Verano in the majority of environments in each year.

Perennial plants

The mean density of perennial plants was higher ($P < 0.05$) than Verano for 55822 in years 2 and 4, and for 55821, 55831 and 75163 in year 4 only when averaged over all environments; there were no significant differences in year 3 (Table 6). Accession 55822 gave consistently high perennial plant densities being ranked 1, 1 and 2 in years 2 to 4 respectively and exceeded Verano in the majority of environments in each year.

Stylo yield

In year 1 there were no accessions with significantly higher yields than Verano; 4 accessions had lower yields ($P < 0.05$). Accessions with higher yields ($P < 0.05$) than Verano in the subsequent years were 75162 in year 2 and 55822 in years 2 and 4. In year 3 there were no accessions with significantly higher yields than Verano (Table 7). Although Verano did well in year 1, its yield relative to the other accessions declined in the subsequent years being ranked 5, 11, 12 and 10 in years 1 to 4 respectively. Accession 55822 gave consistently high yields being ranked 2, 1, 1 and 1 in years 1 to 4 (Tables 7 and 8).

The stylo yields for each environment showed that the greatest differences between Verano and 55822 occurred at 2 of the 3 high altitude sites *viz.* Tirrabella in years 2, 3 and 4 and Springmount in years 2 and 4 (Appendices, 1, 2 and 3). The accession x site interaction was significant in years 3 and 4 but not in years 2 (Table 7).

Performance

The ranks for all accessions for seedling establishment, number of perennials and yield in years 2 to 4 are shown in Table 8. The performance of the accessions is summarized by ranking the accessions on the total of the 9 attributes recorded during years 2 to 4. The highest ranked accession was 55822; it gave higher ($P < 0.05$) perennial plant numbers and yield than Verano in 2 out of

Table 7. Number of environments where the yield of each *S. hamata* accession exceeded that of Verano (#) and mean yield averaged over all environments (fourth root transformed means kg/ha)

Accession CPI No.	Year 1 #	Year 1 Mean all sites	Year 2 #	Year 2 Mean all sites	Year 3 #	Year 3 Mean all sites	Year 4 #	Year 4 Mean all sites
Verano	—	4.43	—	5.20	—	4.30	—	4.70
55812	2/11	3.86**[1]	9/17	5.28	5/11	4.30	2/6	4.69
55820	2/11	3.93*	8/17	5.27	7/11	4.38	3/6	4.74
55821	8/11	4.48	9/17	5.24	7/11	4.24	4/6	4.97
55822	6/11	4.66	13/17	5.76**	9/10	4.77	5/6	5.32*
55823	5/11	4.34	10/17	5.37	8/11	4.58	2/6	4.70
55824	3/11	3.96*	9/17	5.34	8/11	4.52	3/6	4.81
55828	6/11	4.40	9/17	5.06	5/11	4.16	2/6	4.48
55830	2/11	3.83**	10/16	5.19	7/11	4.59	2/6	4.74
55831	8/11	4.72	13/17	5.54	7/11	4.53	5/6	5.13
75162	5/11	4.61	14/17	5.64*	7/11	4.66	2/6	4.78
75163	4/11	4.27	12/16	5.40	6/11	4.43	4/6	4.92
75166	3/11	4.18	8/17	5.05	7/11	4.36	3/6	4.59
75168	4/11	4.06	10/16	5.24	6/11	4.34	3/6	4.58
75169	5/11	3.78 I[2]	9/17	5.10	6/11	4.31	2/6	4.35
Accession x environment		***		n.s.		*		*
Accession		***		*		n.s.		*
Yield[3] (kg/ha)								
Verano		385		733		343		488
55822		474		1100		516		800
Mean all accessions		321		796		385		516

[1] The asterisks against the means refer to the level of the significant difference from Verano.
[2] I indicates an interaction between environments and the Verano and accessions means.
[3] Back-transformed means.

3 years and had consistently high seedling numbers in all 3 years. Accessions 75162 and 55831, ranked second and third, showed only a small difference in total rank but, with a low rank for at least one attribute, they did not perform as consistently as 55822. Verano was ranked ninth.

Accession 61670

Accession 61670, which was sown in 10 environments (Table 4) was the only accession in this experiment with a notable specific environmental adaptation. At Besi Pae, 61670 gave higher ($P < 0.05$) yields than Verano and 55822 in years

Table 8. Accession ranked from 1 to 15 on transformed means for attributes recorded in years 2, 3 and 4 (from Tables 5, 6 and 7)

Accession CPI No.	Seedling No. Yr 2	Seedling No. Yr 3	Seedling No. Yr 4	Perennial No. Yr 2	Perennial No. Yr 3	Perennial No. Yr 4	Yield Yr 2	Yield Yr 3	Yield Yr 4	Total	Rank
Verano	7	4	8	7	8	12	11	12	10	79	9
55812	9	**15**[1]	11	8	9	8	7	13	11	91	11
55820	4	8	14	6	3	9	8	8	7	67	6
55821	6	7	3	5	5	**4**	10	14	3	57	5
55822	3	3	2	**1**	1	**2**	**1**	1	**1**	15	1
55823	**15**	**13**	13	9	4	10	5	4	9	82	10
55824	14	10	4	13	7	7	6	6	5	72	8
55828	5	12	12	**15**	10	11	14	15	14	108	14
55830	1	9	7	3	6	6	12	3	8	55	4
55831	2	6	5	2	15	**1**	3	5	2	41	3
75162	13	1	1	4	2	5	**2**	2	6	36	2
75163	11	11	6	10	14	**3**	4	7	4	70	7
75166	8	4	9	11	12	13	15	9	12	93	12
75168	12	**14**	15	12	13	15	9	10	13	113	15
75169	10	2	10	14	11	14	13	11	15	100	13

[1] Ranks in bold type differ from Verano ($P \leqslant 0.05$), based on analyses in Tables 5, 6 and 7.

1, 2 and 3 with a mean yield of 6.56 t/ha compared with 4.14 and 3.66 t/ha for Verano and 55822, respectively. In 2 of the remaining environments which were sampled each year (Prairie 9b and Pinnarendi) the mean yield over 3 years of 61670 was 0.36 t/ha compared with 1.03 and 1.46 t/ha for Verano and 55822 respectively.

Yield of volunteer species

The mean yield of volunteer species for each environment in years 2, 3 and 4 are given in Appendices 1, 2 and 3 respectively; year 1 yields were comparable to year 2. There was strong grass competition for the stylos at all sites in all years except at Besi Pae which was hand weeded in years 1 and 2 and at Forest Home and Prairie where the soils are infertile and grow little grass even in good seasons.

Discussion

Cultivar selection

Accession 55822 was consistently superior to the cultivar Verano in seedling and perennial plant density and in yield. It was released as the cultivar Amiga by the Queensland Herbage Plant Liaison Committee in August 1988 after consideration of the environment x year data presented in this paper was available. The main reasons for the selection and release of Amiga are given below.

For pasture plants in general, it seems more desirable to select accessions with adaptability to a wide range of seasonal and edaphic conditions and high and low yielding environments rather than to select accessions for specific sites. In this experiment 61670 was the only accession with specific environmental adaptation: it was originally collected in Venezuela from an environment very similar to Besi Pae in rainfall, soil texture and pH (Table 1).

Under the experimental conditions a number of *S. hamata* accessions appeared superior to the existing cultivar Verano over a range of environments which experienced below average rainfall. These environments were largely selected because they were considered marginal for Verano. Under more favourable environmental conditions and different management systems of defoliation or grazing, it is possible that the ranking order would differ. However, the prime objective of the experiment was to see if there were accessions superior to Verano in marginal environments.

The most promising accession from these experiments was Amiga. In the second and subsequent years it ranked higher than Verano in perenniality, seedling establishment and yield at the majority of sites although the difference from Verano was not always statistically significant. Other promising accessions were 55831 and 75162 which were also highly ranked for perenniality and yield in most years.

Seedling establishment

Verano behaves predominantly as an annual after the second year and largely re-establishes from seed in subsequent years. Despite this, Verano is a highly persistent legume in the long term owing to its consistently high seed yields, hardseededness and large seed reserves in the soil (Gardener 1981). Although seed yields were not measured in this experiment, the 15 accessions were compared in a spaced plant experiment at Lansdown and 55812 (114 g/plant) and Amiga (103 g/plant) had higher ($P < 0.05$) seed yields than Verano (68 g/plant). Seed yield differences could partly explain the differences in plant numbers between accessions in this experiment.

The annual cycle of seedling establishment and survival is equally important in the long term persistence of *S. hamata*. Although significant differences in seedling numbers between accessions and/or accession by site interactions occurred in each year of the experiment (Table 5) it was only in the first year that there were accessions with higher ($P < 0.05$) seedling densities than Verano. In stylo evaluation experiments using comparable seed, significant differences in seedling establishment 3 to 4 weeks after the first germination are common particularly when the seed has not been dehulled or scarified before sowing and even when the seed has been dehulled and scarified (Edye and Cameron 1975; Edye *et al.* 1975; Edye *et al.* 1976).

The differences in initial seedling density are most likely due to differences in the rate of hardseed breakdown and possibly disappeared during subsequent germination events. To a lesser extent, they could be partly due to seed size differences in the dehulled seed and to differences in the percentage of pods without seed or with non-viable seed. With one exception, the accessions did not differ in the number of perennial plants in year 2 which suggests that the differences in initial seedling density had largely disappeared. The exception was Amiga which perennated better than Verano in 2 out of 3 years (Table 6). In this experiment it is not possible to partition the contribution of seedling density in year 1 and the percentage survival of first year plants to the perennial plant density in year 2 because the plant density at the end of year 1 was not determined.

Perenniality

Perenniality in *S. hamata* is a highly desirable attribute particularly for adaptation to low rainfall environments. Perennial plants will survive 'false breaks' of the dry season then grow rapidly and set a lot of seed early in the second growing season before the plants die. *S. hamata* plants have a potential for perenniality particularly in the second year; young plants of Verano with virtually no flowering or seed set during the first growing season had a survival rate of 93% (Gardener 1981).

Any plants which survived into the following year were regarded as perennial plants in our experiment. The accessions that were significantly better than Verano in perenniality were Amiga in 2 out of 3 years and 55821, 55831 and 75163 in 1 year only.

Gardener (1981) studied the longevity and regeneration of Verano over a 9 year period of above average rainfall at Lansdown and showed that in every year except years 2 and 5, the population consisted predominantly of first year plants which died in the seedling year. Only 0.03% of seedlings survived to the end of the third year. In years 2 and 5 the density of perennial plants was 22.0 and 27.0 plants/m^2 respectively. In our experiment with below average rainfall, perennial plants predominated in years 2 and 4 at Lansdown and the densities were 30.0 and 27.7 plants/m^2 for Verano and 40.0 and 63.0 plants/m^2 for Amiga; there were no perennial plant counts in year 3. Verano appears to be more strongly perennial when the growth is restricted by a short growing season and/or heavy grazing.

Yield

The significant differences in initial seedling densities had little effect on dry matter yield in the first and subsequent years. There were no accessions with significantly higher yields than Verano in year 1 and accessions 55812, 55820 and 55830 with higher ($P < 0.05$) initial seedling densities than Verano gave lower ($P < 0.05$) dry matter yields. The accessions that gave significantly higher dry matter yields than Verano were Amiga in 2 out of 4 years and 75162 in 1 year only.

Gardener (1981) showed that Verano achieved maximum yields at densities around 50 plants/m^2, but yields in excess of 3000 kg/ha occurred between 10 and 100 plants/m^2 with 91% perennial and 100% first year plants, respectively. In this experiment, the plant densities averaged over all sites were below the densities required for maximum yield and were reflected in the low mean yields that were recorded in each year (Table 7). In years 2 and 4 Amiga had perennial plant densities of 9.6 and 7.6 plants/m^2 and gave relatively high yields of 1100 and 800 kg/ha respectively compared with Verano with perennial plant densities of 6.4 and 2.2 plants/m^2 and yields of 733 and 488 kg/ha. Yields < 600 kg/ha appear to limit cattle liveweight gains in continuously grazed pastures (Gillard *et al.* 1980).

In environments that are marginal for *S. hamata*, adequate plant densities for high dry matter and seed yields must occur regularly to ensure the long-term persistence of the species and for it to retain its potential to colonize new areas during favourable seasonal conditions. In spite of low rainfall, Verano performed well in 15 of the 20 environments where all accessions survived. After the establishment year, Amiga was the only accession to give significantly higher perenniality and dry matter yield than Verano in years 2 and 4 when averaged over all environments; in year 3 there was an extreme drought in all environments except Springmount and Besi Pae and Amiga did not differ significantly from Verano.

The objective of the study was to find accessions superior to Verano for marginal environments. Environments were considered to be marginal on account of low rainfall, cool temperatures or soil type. The overall superiority of Amiga was clearly established across the set of 15 environments where *S. hamata* survived, in particular, as shown by the ranking procedure. Considering the ecological complexity of growth and survival of *S. hamata* over a 4 year period in marginal environments receiving well below average rainfall in most years, it seems unlikely that an initial advantage in seedling density in year 1 after 3 to 4 weeks growth can explain the differences between Amiga and Verano in the subsequent years. The accession x environment interactions showed that the greatest differences between Amiga and Verano occurred at 2 of the 3 higher altitude tropical sites.

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Appendix 1. Mean yield of *S. hamata* accessions and volunteer species in each environment in year 2

Accession CPI No.	1 Spr	2 Wro	4 Bes	5(a)[1] Cor	5(b)[1] Cor	6 Lan	7(b) For	8 Tir	9(a) Pra	9(b) Pra	10 Kun	11 Gle	12 Pin	13 Hig	14 Ink	15 Bin	16 McA	Mean
									(t/ha)									
Verano	0.33	0.30	8.01	0.06	0.03	1.19	0.52	1.19	0.89	0.74	1.65	2.30	2.00	0.46	2.91	2.04	0.02	1.45
55812	0.21	0.65	6.70	0.08	0.14	1.09	0.76	**3.36**	1.61	0.81	2.88	1.38	1.54	0.34	2.92	1.14	0.01	1.51
55820	0.48	**0.96**[2]	5.76	0.04	0.05	0.72	0.54	**5.41**	0.71	1.52	3.36	1.48	2.08	0.52	1.39	0.97	0.01	1.53
55821	0.53	0.78	4.53	0.04	0.09	0.96	0.48	**3.27**	1.10	1.10	2.06	1.58	1.54	0.46	1.15	2.60	0.02	1.31
55822	**1.40**	**0.84**	7.91	0.07	0.16	1.41	1.08	**4.18**	1.03	1.43	2.87	3.68	2.27	0.92	1.49	1.22	0.01	**1.88**
55823	**1.14**	0.46	6.56	0.14	0.04	1.44	0.52	**4.44**	1.07	1.21	3.44	1.49	1.81	0.78	1.39	0.99	0.01	1.58
55824	0.85	0.60	7.05	0.10	0.01	0.91	0.61	3.06	1.67	1.22	2.62	2.27	1.45	0.46	2.41	1.63	0.01	1.58
55828	0.33	0.52	8.39	0.16	0.06	1.26	0.48	2.64	2.57	1.54	0.39	0.67	1.81	0.50	1.63	1.04	0.02	1.41
55830	0.42	0.75	10.95	0.15	0.09	1.58	0.52	1.65	0.85	1.17	1.65	0.72	2.00	0.64	1.58	0.68	0.01	1.49
55831	**1.10**	**1.02**	8.49	0.12	0.05	1.24	0.69	**4.02**	1.34	1.00	2.47	3.09	1.54	0.32	0.75	2.24	0.02	1.74
75162	**1.16**	**1.35**	8.44	0.07	0.07	1.37	1.04	**4.18**	1.21	1.48	1.33	3.25	2.08	0.38	3.15	1.20	0.01	**1.87**
75163	0.38	0.41	8.70	0.12	0.04	1.27	0.43	2.87	1.05	1.41	2.22	2.09	2.00	0.39	1.52	2.35	0.01	1.60
75166	0.51	0.31	6.62	0.12	0.07	1.51	0.28	**3.33**	0.77	1.59	1.78	1.96	1.81	0.42	0.87	1.92	0.01	1.40
75168	0.34	0.53	4.11	0.11	0.20	1.25	0.46	**3.76**	0.79	1.23	2.46	0.61	2.00	0.78	1.39	1.30	0.05	1.26
75169	0.05	0.40	6.01	0.12	0.16	1.36	0.37	1.35	1.15	1.29	3.05	1.03	2.18	0.24	2.43	1.71	0.01	1.35
Mean	0.62	0.66	7.22	0.10	0.08	1.24	0.58	3.25	1.19	1.25	2.28	1.84	1.87	0.51	1.80	1.54	0.02	1.53
Vol. spp.	1.06	3.57	0.00	—	1.77	1.11	0.60	3.32	0.20	0.03	4.36	1.81	1.66	0.90	1.28	3.99	—[3]	1.71

[1] Grazed during the first month of the wet season.
[2] Yields in bold type differ from Verano ($P < 0.05$).
[3] Yield not determined.

Appendix 2. Mean yield of *S. hamata* accessions and volunteer species in each environment in year 3

Accession CPI No.	1 Spr	4 Bes	7(a) For	7(b) For	8 Tir	9(a) Pra	9(b) Pra	10 Kun	11 Gle	12 Pin	14 Ink	Mean
						(t/ha)						
Verano	1.35	1.60	0.43	0.20	1.35	0.47	0.01	0.06	1.11	1.96	0.01	0.78
55812	1.02	1.50	0.74	0.16	1.45	0.73	0.01	0.01	0.65	2.57	**0.06**[1]	0.81
55820	1.67	0.54	0.91	0.20	1.93	0.66	0.02	0.02	1.26	2.79	0.01	0.91
55821	0.83	1.04	1.00	0.24	1.45	1.30	0.02	0.06	0.09	1.86	0.02	0.72
55822	1.50	1.46	0.95	0.28	**2.61**	0.59	0.03	0.05	1.14	2.99	0.01	1.06
55823	1.60	1.05	0.52	0.11	1.64	0.70	0.02	0.24	0.86	2.20	**0.09**	0.82
55824	1.42	0.99	0.56	0.24	1.84	**2.07**	0.02	0.07	1.34	1.97	0.02	0.96
55828	2.08	1.00	0.35	0.18	2.13	**1.55**	0.02	0.00	0.49	3.19	0.01	1.00
55830	0.96	**2.68**	**1.17**	0.09	1.45	0.71	0.01	0.04	0.70	3.13	0.03	1.00
55831	1.69	1.97	0.87	0.22	1.64	0.49	0.01	0.03	0.75	2.46	0.01	0.92
75162	1.34	1.91	0.48	0.31	2.22	0.95	0.04	0.03	1.02	1.80	0.02	0.92
75163	0.82	2.36	0.74	0.13	2.13	0.78	0.01	0.03	1.00	3.06	0.00	1.01
75166	1.20	1.52	0.61	0.13	1.84	0.55	0.02	0.05	0.53	1.86	0.02	0.76
75168	0.86	1.30	0.65	0.11	1.45	0.58	0.01	**0.15**	0.57	1.82	0.03	0.68
75169	0.20	1.17	0.78	0.20	1.16	**1.02**	0.01	0.13	1.20	2.66	0.01	0.78
Mean	1.24	1.47	0.72	0.19	1.75	0.88	0.02	0.06	0.85	2.42	0.02	0.87
Vol. spp.	0.63	4.85	0.60	0.60	1.84	0.12	0.22	3.46	2.00	1.43	—[2]	1.58

[1] Yields in bold type differ from Verano ($P < 0.05$).
[2] Yield not determined.

Appendix 3. Mean yield of *S. hamata* accessions and volunteer species in each environment in year 4

Accession CPI No.	1 Spr	2 Wro	6[1] Lan	7(a) For	8 Tir	9(a) Pra	Mean
				(t/ha)			
Verano	0.40	3.75	0.57	0.20	1.29	0.01	1.04
55812	0.19	4.50	0.60	0.22	**2.19**[2]	0.01	1.28
55820	0.26	**5.70**	0.52	0.35	1.44	0.01	1.38
55821	**1.01**	4.00	0.48	0.33	1.36	0.02	1.20
55822	**1.08**	3.62	0.90	0.33	**2.28**	0.02	**1.37**
55823	0.31	4.88	0.81	0.16	0.96	0.01	1.19
55824	**0.84**	3.88	0.41	0.20	0.97	0.02	1.05
55828	0.37	3.62	0.29	0.13	1.41	0.02	0.98
55830	0.40	4.75	0.49	0.38	0.98	0.01	1.17
55831	**1.03**	3.88	0.49	0.33	1.63	0.02	1.23
75162	**1.06**	3.50	0.42	0.20	1.40	0.02	1.10
75163	0.81	3.38	0.52	0.29	**2.08**	0.01	1.18
75166	**1.05**	2.88	0.44	0.28	1.55	0.01	1.03
75168	0.45	4.10	0.36	0.20	1.56	0.01	1.11
75169	0.22	3.12	0.43	0.37	0.71	0.01	0.81
Mean	0.63	3.97	0.52	0.26	1.45	0.01	1.14
Vol. spp.	1.23	—[3]	0.82	0.60	4.63	0.29	1.51

[1] Grazed during the first month of the wet season.
[2] Yields in bold type differ from Verano ($P < 0.05$).
[3] Yield not determined.

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