Population dynamics of Siratro and shrubby stylo in south-east Queensland as affected by phosphorus, soil type, stocking rate and rainfall

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Abstract

The effects of P application and stocking rate on the persistence of Siratro (*Macroptilium atropurpureum* cv. Siratro) and shrubby stylo (*Stylosanthes scabra* cv. Fitzroy) were monitored in 2 experiments over 9 years on 2 soil types in subcoastal, subtropical Queensland. Experiment 1 examined the effects of 2 stocking rates (0.8 and 1.2 steers/ha) and annual rates of P application, ranging from 0–15 kg/ha P, on Siratro. Experiment 2 compared the response of Siratro and Fitzroy to a restricted range of P and S treatments.

Phosphorus application increased the yield of both legumes, but had only a negligible effect on the survival of the original plants. However, P application to Siratro resulted in the soil seed bank of the treatment receiving 15 kg/ha P (P15) being some 5 times higher than in the treatment receiving no P (P0).

This in turn led to more recruitment of Siratro in the P-fertilised plots and a 3-fold higher plant density in the P15 treatment compared with the P0 treatment at the end of the experiment. However, the density of Siratro decreased with time as recruitment of new plants did not compensate for death of older plants. The lower than median rainfall may have adversely affected Siratro recruitment. There was very little effect of stocking rate or soil type (red earth or yellow podzolic) on Siratro persistence.

Fitzroy density increased with time whereas Siratro density declined. This is attributed to the higher seed set of Fitzroy which lead to reserves of soil seed being more than 100 times those of Siratro after 9 years and to the successful recruitment of stylo plants from seedling strikes. Appreciable quantities of viable seed of Fitzroy were excreted in cattle dung.

Introduction

Over the last 3 decades there has been increasing interest in the use of legumes as a means of increasing the productivity of pastures in subtropical and tropical Queensland. With this has come the recognition that there are frequently difficulties in achieving long-term persistence of legumes, particularly in the subtropics. This in turn has led to an interest in the demography of pasture legumes with an emphasis on improving persistence by management (Jones and Carter 1989). Most studies have focussed on the role of stocking rate. For example, Jones and Bunch (1988a; 1988b) showed that a sustained, high stocking rate on Siratro (*Macroptilium atropurpureum*) depressed survival of plants, seed set and seedling recruitment. However, there is very little information on the effect of fertiliser application on the demography of tropical legumes.

Consequently, the opportunity was taken to study the effect of fertiliser on the demography of Siratro and shrubby stylo (*Stylosanthes scabra* cv. Fitzroy) within 2 grazing experiments. Both experiments examined the effect of phosphorus application on pasture and animal productivity and, in the case of Siratro, the effect of stocking rate was also examined.

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Materials and methods

Description of site and grazing experiments

Descriptions of the site and experimental treatments are given by Kerridge and McLean (1989) and Kerridge *et al.* (1992). In brief, 2 experiments were established on a low fertility soil, with 5 ppm bicarbonate extractable P in the top 10 cm, at the Narayen Research Station in subtropical, subcoastal Queensland (25° 41 'S, 150° 52' E). The site was formerly dominated by spotted gum (*Eucalyptus maculata*). The experiments were sown in January 1981 with a basal dressing of 5 kg/ha P applied as monoammonium phosphate.

Experiment 1. Experiment 1 investigated the effect of 4 levels of maintenance fertiliser (0, 2.5, 5 and 15 kg/ha/year of both P and S) on a Siratro-buffel grass (*Cenchrus ciliaris* cv. Biloela) pasture. The effects of S and possible P x S interactions were examined in other treatments. As there were no significant effects of S on pasture or animal production (P.C. Kerridge and R.W. McLean, unpublished data), the treatments are simply referred to as P0, P2.5, P5 and P15.

Two stocking rates were used: all fertiliser treatments were grazed at 0.8 yearling steers/ha but only P5 and P15 pastures were grazed at 1.2 steers/ha. All pastures were individually fenced and set-stocked year-long, although hay was fed on pastures at the higher stocking rate for short periods of time towards the end of the experiment.

Grazing commenced in September 1982 and ceased in May 1989. Paddock size was 1.2 ha at the lighter stocking rate and 0.8 ha at the heavier stocking rate. There were 4 replicates of each fertiliser x stocking rate combination: 2 were on a gradational red earth (Dr 5.61 , Northcote 1977) and 2 on a yellow podzolic (Dy 5.61).

Experiment 2. Experiment 2 investigated the effect of 4 levels of maintenance fertiliser on 2 pasture types: Siratro-buffel grass and shrubby stylo-buffel grass. The pastures were sown in January 1981 with a basal dressing of 5 kg/ha P applied as monoammonium phosphate. The 4 fertiliser levels were:

P5S0 — 5 kg/ha P applied annually as triple superphosphate
P0S5 — 5 kg/ha S applied annually as gypsum
P5S5 — 5 kg/ha P and S applied annually
P20S5 — 20 kg/ha P applied in 1982 and 1986, 5 kg/ha S annually

There were 2 replicates of each treatment in a randomised block layout. The 0.25 ha plots were grazed by a single yearling steer during the growing season (usually January–May) at a stocking rate equivalent to 2 yearling steers/ha. The steers alternated between the replicates every 2 weeks. Grazing commenced in January 1983 and ended in May 1989.

Measurements

Experiment 1. Four 80 x 80 cm fixed quadrat positions were pegged out in the year of sowing in each paddock. All Siratro plants were marked prior to application of maintenance fertiliser or stocking rate. Plant survival was monitored each spring and any new crowns, resulting from seedling recruitment in the previous growing season, were also marked and mapped. A plastic-coated wire ring was placed around the crown of each plant, using different colours for each cohort, and the position in the quadrat was recorded on a plan. The late spring counts were made only after there had been adequate rain and all surviving crowns had produced new shoots. Any seedlings present were also marked, although these would obviously not represent total seedling emergence over the growing season. Soil seed reserves were measured at the end of each winter. Thirty cores of 7 cm diameter were taken in the 1.2 ha paddocks and 20 in the 0.8 ha paddocks, to a depth of 5 cm. Siratro seed was recovered by the technique of Jones and Bunch (1988c). The last measurements of plant survival and soil seed were taken in December 1990 and June 1989, respectively.

Experiment 2. The densities of Siratro and Fitzroy plants were measured annually, usually in late spring or early summer, in 12 fixed 80 x 80 cm quadrats in each plot. No counts were made over the 1983/84 growing season. New seedlings and plants which had survived through the previous winter were recorded separately.

Recordings of the survival of individual plants of Fitzroy were commenced in 6 of these fixed quadrats per plot in February 1983. At this observation, plants were categorised as those which emerged in the year of sowing (late summer-autumn 1981), those resulting from seedling emergence in the 1981/82 season, and young plants which emerged in the 1982/83 season. Plants were recorded at least twice a year after good rain, in late spring and autumn. If there was a strike of new seedlings, the total number of seedlings was counted, and up to 10 were tagged and their positions marked on the plan. All major strikes of seedlings were recorded and seedlings counted until November 1989, but no seedlings were marked after May 1986. The survival of all tagged plants was monitored until November 1989, when the tap root diameters of plants of different ages were measured.

Soil seed reserves were measured at the end of winter from 1983–1989, by taking 10 cores of 7 cm diameter to a depth of 5 cm in each paddock. The seed was recovered using the procedure employed in Experiment 1. The last measurements of plant density and soil seed were taken in December 1990 and July 1989, respectively.

Over the January-June grazing period in 1987, fresh faecal samples were collected on 8 occasions from the stylo pastures at the end of each grazing period. Approximately 250 g was taken from each of 3 dung pats in each paddock and the concentration of stylo seeds was measured by the technique of Jones and Bunch (1988c). Recovered seed was classed as either black (soft) or yellow (mainly hard), in or out of pod, and sound or unsound (shrivelled or malformed).

Results

Rainfall

Monthly rainfall recorded on the experimental site from 1981–1990 is given in Table 1. Annual rainfall was above decile 4 rainfall in 3 of the first 4 years, but below decile 4 in 5 of the 6 following years. The experimental period was characterised by relatively poor rainfall in late summer and early autumn, with February rainfall being below decile 4 in 7 out of 10 years and March rainfall in 6 out of 10 years. The driest growing seasons were in 1982/83, 1987/88 and 1989/90.

Experiment 1 — Persistence, recruitment and soil seed reserves of Siratro

Plant survival and recruitment. The survival of the original Siratro plants and successful recruitment of new plants from seedlings, averaged over all treatments, are listed in Table 2. Up to 1986/87, recruitment was of little consequence compared with survival of the original plants, whereas after 1988/89 the population was dominated by recent recruitment. This recruitment maintained the population at a density of *c.* 2 plants/m^2. The overall pattern of all original plants dying by 1990 and of the failure of recruitment to maintain plant density at the initial level was common to all treatments.

Table 1. Monthly and annual rainfall (mm) for the years 1981–1990, with the 104 year mean and decile 4 rainfall. Figures in bold/underline type are below decile 4.

	Rainfall												
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	92	284	**40**	104	45	62	79	31	**0**	39	113	146	985
1982	165	**29**	153	**8**	20	**0**	**18**	**5**	47	**30**	**4**	**44**	**523**
1983	149	**12**	52	286	158	40	35	38	**4**	172	91	**62**	1099
1984	242	**5**	**13**	64	**2**	**17**	169	21	57	56	56	90	792
1985	76	**13**	**20**	26	**11**	61	32	30	31	64	**44**	141	**549**
1986	**63**	63	**4**	**2**	47	**0**	37	26	47	158	84	78	**609**
1987	161	**27**	**25**	**8**	34	**7**	31	16	**13**	**29**	**52**	**39**	**442**
1988	**24**	**30**	**25**	89	23	32	63	107	18	**0**	**33**	125	**569**
1989	133	89	58	161	59	39	46	44	**2**	72	103	**48**	854
1990	**14**	**4**	72	96	72	44	**19**	**2**	27	**34**	**48**	**52**	**484**
Mean	107	91	70	41	40	36	38	27	33	57	76	99	714
Decile 4	76	48	49	22	19	20	21	14	17	36	56	72	636

Decile 4 used as an indicator of dry conditions rather than below average (Gibbs and Maher 1967)

Table 2. Life table of Siratro, averaged over all treatments, based on the plants/m^2 of different ages as measured early in the growing season from 1981/82–1990/91 (Experiment 1).

Year of emergence	Year of measurement									
	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91
1980/81	11.5[1]	10.6	8.1	7.7	5.7	1.4	0.9	0.1	0.1	0
1981/82	(2.2)[2]	1.0	0.3	0.2	0.2	0	0	0	0	0
1982/83		(2.2)	0.3	0.2	0.1	0	0	0	0	0
1983/84			(0.6)	2.4	0.2	0	0	0	0	0
1984/85				(0)	0	0	0	0	0	0
1985/86					(7.2)	0.6	0.3	0.1	0	0
1986/87						(2.8)	0.6	0.1	0	0
1987/88							(0.9)	1.7	1.5	0.9
1988/89								(1.9)	0.7	0.3
1989/90									(0.5)	0.3
Total (excluding seedlings)	11.5	11.6	8.7	10.5	6.2	2.0	1.8	2.0	2.3	1.5

[1] Plants from original sowing into a cultivated seedbed.
[2] Numbers in brackets are seedling numbers when annual plant counts were made and do not show total seedling emergence over the growing season.

Soil type, stocking rate and fertiliser had no effect on survival of the original plants until 1986 and 1987, after which there were minor but significant effects. There were more ($P<0.05$) of these plants on the red earth than the yellow podzolic in 1986 (2.0 *vs* 0.9/m^2) and 1987 (1.3 *vs* 0.3 plants/m^2). In 1987 there were also significantly ($P<0.05$) more original plants at the lower stocking rate (1.2/m^2) than at the higher stocking rate (0.2/m^2). By January 1989, none of the original plants remained in fixed quadrats in the P5 and P15 treatments, whereas there were low densities on the P0 (0.2 plants/m^2 or 2% survival) and P2.5 (0.3 plants/m^2 or 3% survival). Half of the original plants survived until they were almost 5 years old (November 1985) but heavy mortality in the following year reduced the residual population by 75%. Averaged over all treatments, the original plants had a half-life of 48 months from 1981/82–1985/86, but only 7 months from 1985/86–1988/89.

In December 1990, plant density was higher ($P<0.05$) in the P15 treatment, at both the lower (2.1 plants/m^2) and the higher (2.9 plants/m^2) stocking rate, than in the P0 (0.6 plants/m^2) and P2.5 (0.7 plants/m^2) treatments at the lower stocking rate. Densities in the P5 treatment were intermediate. In contrast to the better survival of original plants on the red earth, total plant density in 1990 was higher on the yellow podzolic (1.8 plants/m^2) than on the red earth (1.3 plants/m^2) though the difference was not significant.

The total numbers of seedlings recorded in the fixed quadrats when the annual counts were made from 1981–1990 are given in Table 3. These values do not give the total emergence of seedlings throughout the experiment. Seedling numbers were significantly lower in the P0 treatment than in 2 of the 3 fertilised treatments and significantly higher in the yellow podzolic soil than the red earth.

Soil seed reserves. Averaged over all treatments, soil seed reserves of Siratro at the end of each winter from 1982–1989 were 42, 18, 285, 109, 63, 32, 13 and 11 seeds/m^2. The only substantial seed input occurred during the 1983/84 growing season, and thereafter there was a progressive run down in soil seed reserves. Following the seed input in 1984 there was a significant increase in soil seed reserves with P application, with a near 5-fold increase in reserves from P0 to P15 (Table 3). There was a small but significant ($P<0.05$) depression of seed reserves at the higher stocking rate during 1986/87. Seed reserves were significantly ($P<0.05$) higher on the yellow podzolic than on the red earth in 1984/85.

Experiment 2 — Persistence, recruitment and soil seed reserves of Siratro and Fitzroy stylo

Plant and seedling density. Initially Siratro density (9 plants/m^2) was higher than that of Fitzroy (3.8 plants/m^2) (Table 4). However, this changed within 2 years and from 1982/83 onwards the density of Fitzroy always exceeded that of Siratro. Siratro density steadily declined so that by 1989 the Fitzroy: Siratro density ratio was 100:1. There were few Siratro seedlings when the annual counts were made at the start of each growing season but many Fitzroy seedlings. Fertiliser treatment had no significant effect on the density of Fitzroy and on only one occasion in 1988 was Siratro density significantly ($P<0.05$) higher on the P5S5 treatment.

Survival of Fitzroy plants. The survival of tagged Fitzroy stylo plants is summarised in Table 5. Fertiliser treatment did not affect survival. Seedling numbers were highest with the later cohorts (8, 9 and 10). Major seedling strikes were also recorded in April 1988 (average 700/m^2), November 1989 (59/m^2) and April 1990 (263/m^2). Survival of the seedlings emerging prior to 1987 was considered in 2 phases: the first 12 months after emergence (the establishment year) and all subsequent years (survival as plants). Of the 7 seedling strikes which had an initial density > 1 seedling/m^2, the average half-life of seedlings over the first 12 months was 10 months for cohorts 3–7 (range 9–14) but only 3.4 months for cohorts 8–10 (range 2.5–5.3). After the establishment year, the half-life of older plants from the different cohorts up to March 1989 ranged from 13–49 months. At the last measurement there was a significant relationship between tap root diameter (y, in mm) and age (x, in years) of $y = 1.48x$ ($P<0.01$).

Excluding young plants that were less than 12 months old, density was dominated by the original cohort up to June 1984, by cohort 4 from January 1985–April 1985, by cohort 6 from April 1985–November 1986 and by cohort 9 after November 1986. The high total densities recorded in September and November 1986 (Table 5), and also at the start of the 1986/87, 1987/88 and 1988/89 growing seasons (Table 4) were composed mainly of young, small plants. Major plant mortality occurred between March 1989–November 1989 (Tables 4 and 5), although there was better survival of smaller plants resulting from seedlings which emerged after 1986. These younger plants made up the density of 29 plants/m^2 recorded in December 1990 (Table 4).

Soil seed reserves. Soil seed reserves were always higher with Fitzroy than Siratro (Table 4). The reserves of Siratro seed steadily declined from 55/m^2 in 1983/84 to zero in 1989. In contrast, Fitzroy reserves reached a peak of 4030/m^2 in 1986/87 before declining to 756/m^2 in 1989.

Table 3. Soil seed reserves of Siratro and total numbers of seedlings/m^2 as affected by 4 P levels (comparison within lighter stocking rate), stocking rate (comparison within P5 and P15 fertiliser levels) and soil type (comparison over all 6 fertiliser x stocking rate treatments). Annual data has been pooled into 4 time periods (Experiment 1).

	Soil seed levels				Total seedlings
	1982–83	1984–85	1986–87	1988–89	1981–1990
	(numbers/m^2)				
P level (kg/ha/year)					
0	28	47 (1.56)	19 (1.21)	2 (0.24)	6 (0.71)
2.5	30	167 (2.16)	35 (1.53)	6 (0.83)	19 (1.20)
5.0	46	263 (2.34)	54 (1.72)	21 (1.29)	17 (1.15)
15.0	17	311 (2.41)	83 (1.84)	18 (1.24)	14 (1.00)
LSD ($P=0.05$)[2]	ns[1]	(0.41)	(0.36)	(0.48)	(0.35)
Stocking rate (head/ha)					
0.8	31	287	69 (1.79)	20	16 (1.07)
1.2	37	281	44 (1.2)	17	25 (1.26)
LSD ($P=0.05$)	ns	ns	(0.18)	ns	(0.18)
Soil type					
Red earth	28	149 (2.00)	34	10	10 (0.91)
Yellow podzolic	37	301 (2.37)	59	17	25 (1.28)
LSD ($P=0.05$)	ns	(0.26)	ns	ns	(0.10)

[1] ns = no significant differences.
[2] Least significant differences relate to transformed values ($\log x+1$) given in brackets.

Table 4. Plant and seedling numbers of Fitzroy stylo and Siratro early in the growing season and reserves of soil seed in the winter following that growing season, averaged over all fertiliser treatments (Experiment 2).

Growing season	Mature plants			Seedlings			Soil seed		
	Siratro		Fitzroy	Siratro		Fitzroy	Siratro		Fitzroy
	(plants/m²)			(plants/m²)			(seeds/m²)		
1980/81	9.0	**[1]	3.8	0		0	—		—
1981/82	6.1		4.1	0		0	—		—
1982/83	7.6	**	3.3	0	***	0.4	29	***	292
1983/84	—[2]		—	—		—	55	**	587
1984/85	4.6	**	9.5	0	***	9.2	43	**	1260
1985/86	4.3	**	14.7	0		5.1	31	**	1550
1986/87	1.3	***	40.9	0.5	***	89.2	29	***	4030
1987/88	0.7	***	38.6	0.1	***	10.9	2	**	1160
1988/89	0.6	***	120.6	0.1	***	5.3	5	**	1300
1989/90	1.0	***	14.1	0.3	***	53.0	0	***	756
1990/91	0.3	***	29.6	0		0	—		—

[1] **, *** = significantly different at $P<0.01$ and $P<0.001$, using log $(x+1)$ transformation as appropriate.
[2] — indicates not measured.

Averaged over all samplings, fertiliser treatment had a significant effect on seed reserves with seed levels of Siratro and Fitzroy at the lowest fertility level (P0S5) averaging only 30% of the corresponding levels at higher fertility treatments (P5S5 and P20S5). From 1985–1988 there was a significant linear relationship (either $P<0.05$ or $P<0.01$) between the late winter soil seed reserves of Fitzroy and major seedling strikes in the following year. Usually the major seedling strikes accounted for only some 10% of the soil seed reserves.

Seed of Fitzroy stylo in faeces. When averaged over all treatments, the concentration of seeds recovered in faeces increased from January to February and then declined to low levels in June (Table 6). The average seed content from January–June 1987 was 8 seeds/g of oven dry faeces. Concentrations tended to be higher at the higher fertility levels, but differences were not significant. In the January sampling only half the recovered seed was sound, the remainder being shrivelled or malformed. However, the percentage of unsound seed declined throughout the growing season, as did the proportion of seed that was recovered in pods. The highest proportion of black seed, which was always "soft", was recovered in the first sampling. Two-thirds of the yellow seed was still "hard" after recovery.

Discussion

P application had only a minor adverse effect on the survival of individual plants of Siratro in Experiment 1 and had no effect on Fitzroy in Experiment 2. This contrasts with the typical 3-fold increases in presentation yield of Siratro in the P15 compared with the P0 treatment (Kerridge and McLean 1989) and the 35% higher yield of Fitzroy in the P5S5 compared with the P0S5 treatment (Kerridge *et al.* 1992). It is possible that any potential benefits of P on survival may have been offset by competition from the more vigorous grass growth resulting from P application and, indirectly, through high N levels attributable to enhanced legume growth (Kerridge and McLean 1989; Kerridge *et al.* 1992). In a study in the dry tropics of Australia on a soil with 3ppm bicarbonate extractable P, Mott *et al.* (1989) also found that survival of original perennial stylo plants (predominantly shrubby stylo) was not affected by P fertilisation. However, at another site with 2ppm available P, survival of shrubby stylo (cv. Seca) was enhanced by P application (Coates *et al.* 1990).

However, the density of Siratro at the end of Experiment 1 was higher on treatments receiving the higher levels of P. This is attributed to the higher Siratro yield which produced higher seed set and soil seed levels in these treatments, and

Table 5. Life table of Fitzroy stylo, meaned over fertiliser treatments, showing survival up to 1990 of original plants sown in 1981, and of seedling recruitment up to November 1986 (Experiment 2).

		Date of count																	
Cohort	Date of emergence	2.83	5.83	12.83	6.84	1.85	4.85	12.85	5.86	9.86	11.86	5.87	11.87	4.88	9.88	3.89	11.89	4.90	12.90
		(plants/m²)																	
1	2.81	5.8	5.6	4.7	4.4	1.8	1.7	1.1	0.9	0.8	0.7	0.7	0.4	0.3	0.3	0.3	0	0	0
2	81/82	0.9	0.9	0.8	0.7	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
3	1.83	8.6	4.7	3.6	3.1	2.5	2.4	2.2	2.2	2.1	2.1	2.0	1.6	1.5	1.4	1.2	0	0	0
4	4.83	—	(25.2)[1]	15.6	10.0	8.2	7.6	6.4	6.1	6.0	5.9	5.8	4.7	4.5	4.5	4.1	0.1	0	0
5	11.83	—	—	(1.6)	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0	0	0
6	6.84	—	—	—	(20.2)	14.4	9.5	7.9	7.6	6.9	6.4	6.3	5.4	5.0	5.0	3.8	0.1	0	0
7	4.85	—	—	—	—	—	(0.4)	0.4	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0	0	0
8	12.85	—	—	—	—	—	—	(35.4)	3.4	2.0	1.9	1.9	1.3	1.3	1.3	1.2	0.1	0	0
9	5.86	—	—	—	—	—	—	—	(254.4)	133.9	90.5	48.1	27.9	24.5	22.6	18.2	0.3	0.1	0.1
10	11.86	—	—	—	—	—	—	—	—	—	(167.1)	28.9	7.0	5.7	5.6	5.5	0.2	0.1	0
Total plants		15.3	11.2	24.7	18.9	27.9	22.1	18.6	21	152.4	108.2	94.4	NA[2]	NA	NA	NA	NA	NA	NA

[1] Seedling counts (in brackets) are excluded from totals.
[2] Not applicable.

Table 6. Numbers and type of Fitzroy stylo seeds per g of oven dried faeces excreted by cattle grazing stylo-buffel grass pastures from mid-summer to early winter 1987. Mean of all fertiliser treatments (Experiment 2).

Month of grazing	Sound seeds						Unsound seeds	
	Seeds/g faeces		Out of pod		In pod			
	Mean	Range[1]	Yellow	Black	Yellow	Black	Seeds/g	As % of all seed
			(%)	(%)	(%)	(%)		
January	6	(03–13)	66	4	20	10	5	48
February	24	(11–35)	75	3	19	3	11	32
March	10	(07–17)	85	1	13	1	4	26
April	7	(05–10)	82	6	11	0	2	20
May	3	(01–06)	82	7	11	0	<1	14
June	1	(00–04)	88	6	6	0	<1	15

[1] Range over fertiliser treatments.

enabled more recruitment. These higher soil seed levels of Siratro can be attributed primarily to seed set in the 1983/84 growing season. The average seed level in 1984 (285/m^2) was at the higher end of the range normally recorded in Siratro pastures (Mannetje and Jones 1990). By 1989, the average level of 11 seeds/m^2 was typical of pastures where Siratro had run down and was unlikely to recover (Mannetje and Jones 1990). Without this 1984 seed set, there would have been negligible Siratro in the pastures by 1990. Although there was inadequate recruitment of new Siratro plants to maintain a desirable density of *c.* 5 plants/m^2 (Jones and Bunch 1988a), long-term maintenance of Siratro density was still enhanced by P application. Similar effects of P in increasing seed banks and hence plant density have been measured in *S. hamata* and *S. scabra* in north Queensland and the Northern Territory (Coates *et al.* 1990).

In general, rainfall in the second half of the study period was below decile 4, particularly in the summer/early autumn period which is critical for successful seeding and recruitment of Siratro (Mannetje and Jones 1990). It is possible that Siratro density at the end of Experiment 1 may have been higher given some years with more favourable mid-and late season rainfall. In a more favourable rainfall environment, Jones and Bunch (1988a) documented a case where adequate Siratro density was maintained by successful recruitment for *c.* 7 years after the original population had ceased to be of consequence. However, the population then declined to below 2 plants/m^2, 16 years after sowing.

Stocking rate had little effect on the persistence of Siratro in this experiment. This is attributed to the generally over-riding effects of rainfall which limited the growth and seeding of Siratro. In the one year with major seed input (1984), which had the important role in maintaining long-term Siratro density, stocking rate had no effect on seed set or on subsequent plant recruitment. High stocking rates have adversely affected the survival and recruitment of Siratro at sites with a higher rainfall than Narayen (Jones and Bunch 1988a; 1988b) or in favourable years at Narayen (Mannetje and Jones 1990). However, these stocking rates were in excess of 1.2 yearlings/ha. In these favourable sites or years, stocking rates of 1.2 yearlings/ha (the higher stocking rate used in this experiment) have not adversely affected survival or recruitment. However, spelling heavily grazed Siratro pastures during late summer and autumn of years with favourable rainfall may improve long-term persistence of Siratro through an increased seed set.

The finding that long-term persistence of Siratro was limited by inadequate recruitment confirms previous studies (Mannetje and Jones 1990). It also reinforces the suggestion that recruitment may be aided by rough cultivation or renovation provided seed banks are adequate (Bishop *et al.* 1983; Mannetje and Jones 1990). Such disturbance can stimulate emergence and reduce competition to establishing seedlings.

The poor recruitment of Siratro contrasts with the much greater recruitment of Fitzroy and the implications of this are considered by McIvor *et al.* (1993). Fitzroy seeded much more freely and its seed reserves were some 100-fold higher than those of Siratro and, to a lesser extent, exceeded the reserves of shrubby stylo measured by Mott *et al.* (1989). Consequently, there was more seedling emergence of Fitzroy than of Siratro. Furthermore, comparison of data for the period 1982–1987 (Tables 2 and 5) shows that Fitzroy plants which survived their first winter subsequently persisted better than equivalent plants of Siratro. Even so, there was considerable mortality of Fitzroy seedlings and young plants in the later years of the experiment which we attribute to soil moisture stress. This is reflected in the shorter half-life of seedlings in cohorts 8-10 compared with cohorts 3–7. Recruitment of shrubby stylo in this experiment was more successful than that measured in a very stressful dry tropical environment in the Northern Territory (Mott *et al.* 1989), although there was effective recruitment of Seca shrubby stylo in less extreme dry tropical environments in north (Gardener 1984) and central (Orr and Paton 1993) Queensland. The importance of maintaining adequate seed banks which can effectively result in the recruitment of new plants must be recognised when evaluating and managing herbaceous perennial legumes, just as it is for annual legumes (Jones and Carter 1989).

There was widespread death of Fitzroy plants during the 1989 winter which followed a period of above-average rainfall and very wet conditions in late autumn and early winter. Although anthracnose was present, we consider that it was not the primary cause of this death. This view is substantiated by the higher deaths of both Fitzroy and Seca shrubby stylos in 3 other experiments on Narayen Research Station during the same period, even though Seca is relatively resistant to anthracnose. Plant death was not obvious during winter as there is always appreciable or complete death of top growth over this period as a result of frosting. The increasing incidence of rainfall during late autumn and winter with increasing latitude may limit the adaptation of shrubby stylo in addition to cool season temperatures *per se*.

An important characteristic of shrubby stylo is that ripened seed is retained on the plant (Gardener 1993). This means appreciable quantities of hard seed are ingested which can survive passage through the digestive tract (Simao Neto *et al.* 1987). If 3 kg of dung (oven dry basis) was excreted by each animal every day over the 5.5 months grazing period of our experiment, then each animal excreted approximately 4 million seeds. This is equivalent to 8 million seeds or 19 kg/ha within the experiment. However, the dissemination of stylo seed through faeces into other stylo-free areas by strategic grazing of established stylo pastures (Gardener 1993) is of greater practical importance than the further deposition of seed into existing stylo pastures.

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