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(Accepted for publication January 5, 1978)

NUTRITION OF *STYLOSANTHES GUIANENSIS* ON TWO SANDY SOILS IN A HUMID TROPICAL LOWLAND ENVIRONMENT

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ABSTRACT

Fertilizer experiments with Stylosanthes guianensis *were conducted on two deep sandy soils in north Queensland. In experiment* 1, *cultivar Schofield was grown on a granitic sand with treatments of four phosphorus rates, four potassium rates and two lime rates. Two sources of phosphorus were also tested. In experiment* 2, *cultivar Endeavour was grown on a beach sand with treatments of four phosphorus rates, four potassium rates and two rates of boron plus molybdenum.*

In experiment 1, *maximum dry matter yields were achieved at* 25 *kg* ha^{-1} *P but yields were reduced by* 100 *and* 200 *kg* ha^{-1} *P. Yields were increased by potassium and lime, whereas monosodium orthophosphate gave higher yields than superphosphate.*

In experiment 2, 50 kg ha^{-1} *P and 56 kg* ha^{-1} *K gave maximum dry matter yields. Higher rates of phosphorus and potassium reduced yields. There was no effect of a boron plus molybdenum treatment.*

The ability of these soils to retain applied nutrients is discussed.

INTRODUCTION

Expansion of the beef industry in the humid tropical lowlands of Queensland led to the development of extensive areas of land previously regarded as unsuitable for agricultural development (Sloan *et al.* 1962). Some of the least fertile soils were sands, either from granitic parent material or of marine origin. A program based on glasshouse experiments and limited field experiments showed widespread deficiencies of phosphorus, potassium, calcium, sulphur, copper and zinc on both types of sand (Teitzel and Bruce 1971, 1973).

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Two sites (one representative of a sandy granitic soil and the other of a beach sand) were selected for field experiments to gain further information on the fertilizer requirements of *Stylosanthes guianensis* on these soils. Preliminary pot experiments from these two sites have been reported elsewhere. On the granitic sand phosphorus, copper and calcium increased dry matter yields of phasey bean (*Macroptilium lathyroides*); calcium increased seedling survival while copper increased seedling growth (Experiment 12, Teitzel and Bruce 1971). With the beach sand, phasey bean yields were increased by phosphorus, copper, calcium, potassium and a combined treatment of sulphur, magnesium, boron and manganese (Experiment 2, Teitzel and Bruce 1973). Two other pot experiments with the beach sand were inconclusive because phasey bean and stylo (*Stylosanthes guianensis* cv. Endeavour) were affected by phosphorus toxicity. The effect was more pronounced with stylo than with phasey bean (Experiments 3 and 13, Teitzel and Bruce 1973).

This paper reports the results of the two field experiments with stylo and associated soil and plant analyses. Dry matter yields from the first harvest on the beach sand were reported elsewhere (Experiment 14, Teitzel and Bruce 1973). These yields are included in this paper together with two subsequent harvests and detailed soil and plant analyses to enable further interpretation of the data and comparison of the two soils.

MATERIALS AND METHODS

Experimental sites

A site representative of a sandy granitic soil was chosen 5 km west of Tully and of a beach sand, 8 km south east of Cowley. Both sites supported a layered sclerophyll forest vegetation dominated by *Acacia* species. The two sites were about 50 km apart.

Experiment 1 (*granitic sand*). Four rates of phosphorus, two sources of phosphorus, four rates of potassium and two rates of calcium were combined in a full factorial array and laid out in a completely randomized design. The fertilizer treatments were:—

Ca-P	superphosphate
Na-P	monosodium orthophosphate
P_{25}	25 kg ha^{-1} P
P_{50}	50 kg ha^{-1} P
P_{100}	100 kg ha^{-1} P
P_{200}	200 kg ha^{-1} P
K_0	nil
K_{28}	28 kg ha^{-1} K as potassium chloride
K_{56}	56 kg ha^{-1} K ,, ,, ,,
K_{84}	84 kg ha^{-1} K ,, ,, ,,
L_0	nil
L_1	560 kg ha^{-1} $CaCO_3$

A basal application of copper and zinc sulphates, each at 10 kg ha^{-1}, was also applied. Sulphur was not included as it was not deficient in the pot experiment with soil from this site, and because it was thought that if a deficiency did occur it could be confirmed by chemical analysis of stylo from the two phosphorus sources.

The experiment began on 27th February 1969 when 4 m × 5 m plots were sown with stylo (cv. Schofield) at 10 kg ha^{-1} and the soil lightly raked by hand. Fertilizers were broadcast onto the soil surface. Dry matter yields were measured on 3rd July 1969, 22nd August 1969 and 14th May 1970. Five quadrats 1 m × 0.4 m were cut to ground level in each plot at the first sampling while two quadrats were cut per plot at subsequent samplings. All plots were mown and cut material raked off after each sampling.

Whole plant tops were sampled for chemical analysis on 24th March 1970. Soil samples from selected treatments were taken on 15th September 1969 and 3rd

February 1971. At the first sampling six 2.5 cm diameter cores to a depth of 15 cm were bulked per plot. At the second sampling 10 cores (2.5 cm diameter) were bulked for the 0-15 cm depth while three cores (5 cm diameter) were bulked for the 15-30, 30-60 and 60-90 cm depths.

Experiment 2 (*beach sand*). A full factorial combination of four phosphorus rates (as superphosphate), four potassium rates (as potassium chloride) and two trace elements rates, nil (T_0) or 5.6 kg ha^{-1} borax plus 0.55 kg ha^{-1} sodium molybdate (T_1), was laid out in a completely randomized design. Phosphorus and potassium treatments were similar to those in Experiment 1.

A basal application of copper and zinc sulphates, each at 10 kg ha^{-1} was also applied. Sulphur was not included as it was not deficient in the pot experiment. On 4th August 1969, after the first harvest, the plots were split and lime (560 kg ha^{-1} $CaCO_3$) was applied to half of each plot. Potassium treatments were reapplied on 8th January 1970.

Stylo (cv. Endeavour) was sown at 10 kg ha^{-1} on 11th February 1969. Harvests for dry matter yield were taken on 4th August 1969 and 5th May 1970 by cutting two quadrats (1 m × 0.4 m) per plot to ground level. Experimental procedures were the same as for Experiment 1.

Whole plant tops were sampled for chemical analysis on 8th August 1969, 12th May 1970 and 21st July 1970.

Soils were sampled on 8th August 1969, 12th May 1970 and 15th October 1970 from selected treatments. For 0-15 cm depth, sampling intensities with a 2.5 cm diameter tube were 10, 8, and 10 cores per plot respectively. At the final sampling date three 5 cm diameter cores were bulked per plot for the depths below 15 cm.

Soil and plant analyses

Soil samples were analyzed for pH in a 1:5 suspension in water; for extractable phosphorus by the method of Kerr and von Stieglitz (1938); for total phosphorus and potassium by x-ray fluorescence spectroscopy; for total nitrogen by a Kjeldahl method; for organic carbon by the method of Walkley (1947); for cation exchange capacity and exchangeable cations using normal ammonium chloride at pH 7; and for particle size analysis by a Bouyoucos hydrometer method.

Phosphorus and potassium soluble in boiling hydrochloric acid after ignition at 550°C for one hour was determined. This was expected to measure total phosphorus (Beckwith and Little 1963) but as higher results were obtained by x-ray fluorescence spectroscopy these values are referred to as acid digestible phosphorus and potassium.

Plant samples were analyzed for nitrogen by a microkjeldahl method. After dry ashing, phosphorus was determined by the colorimetric method of Cavell (1954); calcium and magnesium by E.D.T.A. titration; and potassium by flame photometry.

RESULTS

Soils

The beach sand and granitic sand belong to the Uc 4.2 and Gn 2.81 Principal Profile Forms of Northcote (1971) respectively. The Uc 4.2 profile has more than 90% sand throughout while the Gn 2.81 profile has more than 80% sand throughout with more than 90% sand in the top 30 cm. The proportions of coarse and fine sand are different in the two soils.

Analytical data for a soil profile from each site are given in Table 1. Both soils are strongly acid and have low levels of all the chemical attributes measured.

Rainfall

Annual rainfalls recorded in the vicinity of the two sites during 1969 and 1970 were: granitic sand—3142 and 3264 mm; and beach sand—2384 and 2500 mm respectively.

TABLE 1

Chemical analyses of soil profiles from unfertilized sites at Experiment 1 and 2

Depth cm	pH	C.S.	Particle size F.S. %	Si	C	C.E.C.	Exchangeable cations Ca m. equiv. 100 g^{-1}	Mg0	Na	K	P	Total K %	C	N	Acid extr. P ppm
Experiment 1															
0-15	5·1	61	32	5	2	5	0·6	0·1	0·05	0·09	0·014	0·03	1·3	0·06	15
15-30	5·0	65	27	6	2	5	0·4	0·1	0·05	0·02	0·007	0·02	0·9	0·05	9
30-60	5·5	66	22	2	10	3	0·2	0·1	0·05	0·02	0·005	0.03	0·6	0·03	4
60-90	6·0	61	23	2	14	2	0·1	0·1	0·05	0·02	0·011	0·09	0·4	0·02	2
Experiment 2															
0-15	5·2	32	62	3	3	8	2·2	1·2	0·12	0·11	0·026	0·04	1·4	0·09	12
15-30	5·0	28	67	1	4	7	0·9	0·6	0·05	0·02	0·016	0·03	0·7	0·04	5
30-60	5·3	27	69	2	2	4	0·3	0·1	0·05	0·02	0·010	0·03	0·6	0·02	2
60-90	5·6	28	70	1	1	3	0·2	0·1	0·05	0·02	0·007	0·03	0·5	0·02	2

Experiment 1

The trends in dry matter yields with treatments were consistent at each of the three harvests. Main effects are given in Table 2. Interactions were not statistically significant ($P > 0.05$), probably due to the wide range in yields from low to high phosphorus rates.

TABLE 2

Dry matter yields (kg ha^{-1}) of Schofield stylo at three sampling dates in Experiment 1

Treatment	Harvest date 3/7/69	22/8/69	14/5/70
S_1	619	1251	5924
S_2	1348	2658	8873
L.S.D. (p = 0·05)	233	540	2231
P_{25}	1315	2810	8633
P_{50}	1222	2134	7830
P_{100}	842	1608	8113
P_{200}	555	1267	5019
L.S.D. (p = 0·05)	330	763	3155
K_0	706	1527	6741
K_{28}	962	1885	7023
K_{56}	1024	1978	7299
K_{84}	1241	2428	8532
L.S.D. (p = 0·05)	330	763	3155
Ca_0	862	1717	6132
Ca_1	1104	2192	8665
L.S.D. (p = 0·05)	233	540	2231

Monosodium orthophosphate gave higher yields than superphosphate. Yields declined with increasing phosphorus application. This effect was most marked with superphosphate particularly at the 200 kg ha^{-1} P rate. At harvest 1 very few plants survived at this rate and dry matter yield was 30 kg ha^{-1}. By harvest 3 plant growth was good but yields were reduced because plant number was still low. Both lime and potassium increased yields.

Main effects of treatments on stylo chemical composition are given in Table 3. Plants fertilized with superphosphate had higher phosphorus and calcium percentages but lower magnesium and nitrogen percentages than plants fertilized with monosodium orthophosphate. Lime increased plant nitrogen and calcium percentages. Rates of phosphorus increased phosphorus percentages. Potassium rates increased plant potassium percentages but the effect was not significant ($P > 0.05$). Only selected treatments were analyzed for sulphur but results averaged 0.17% S for 25 kg ha^{-1} P superphosphate treatments and 0.18 for 100 kg ha^{-1} P monosodium orthophosphate treatments (data not presented).

Acid digestible phosphorus in 0-15 cm soil samples taken seven months after fertilizer application were 68 and 61 ppm P at the 25 kg ha^{-1} P rate for superphosphate and monosodium orthophosphate sources respectively. At the 200 kg ha^{-1} P rate the respective figures were 140 and 83 ppm P. There was little change at the sampling 24 months after fertilizer application except for superphosphate at 200 kg ha^{-1} P which declined from 140 to 90 ppm P. Results presented in Table 4 are averaged over both sources. There are some accumulations of phosphorus from the highest two rates particularly at the 0-15, 15-30 and 30-60 cm depths.

Exchangeable potassium was generally within the range 0.02 to 0.05 m. equiv. 100 g^{-1} regardless of treatment, sampling depth or sampling time (data not presented).

TABLE 3

Effect of fertilizer treatments on chemical composition of Schofield stylo sampled from Experiment 1 on 24th March, 1970

Treatment	N	P	K %	Ca	Mg
Ca-P	2·18	0·35	1·26	1·33	0·58
Na-P	2·35	0·31	1·26	1·16	0·69
L.S.D. ($p = 0{\cdot}05$)	0·15	0·03	0·16	0·12	0·07
L_0	2·11	0·34	1·25	1·13	0·67
L_1	2·42	0·32	1·27	1·35	0·61
L.S.D. ($p = 0{\cdot}05$)	0·15	0·03	0·16	0·12	0·07
P_{25}	2·27	0·29	1·27	1·17	0·64
P_{50}	2·28	0·30	1·19	1·21	0·62
P_{100}	2·26	0·34	1·23	1·29	0·67
P_{200}	2·26	0·40	1·34	1·30	0·62
L.S.D. ($p = 0{\cdot}05$)	0·22	0·05	0·23	0·17	0·10
K_0	2·27	0·33	1·16	1·25	0·67
K_{50}	2·27	0·35	1·23	1·23	0·62
K_{100}	2·28	0·33	1·30	1·33	0·62
K_{150}	2·25	0·31	1·35	1·23	0·60
L.S.D. ($p = 0{\cdot}05$)	0·22	0·05	0·23	—	—

TABLE 4

Effect of phosphorus rates on soil acid digestible phosphorus (ppm) at four depths at the final samplings of Experiments 1 and 2

	Depth (cm)			
Treatment	0-15	15-30	30-60	60-90
Experiment 1 (3/2/71)				
P_{25}	57	39	27	60
P_{50}	64	44	29	58
P_{100}	81	43	55	47
P_{200}	84	58	41	70
L.S.D. ($p = 0{\cdot}05$)	14			
Experiment 2 (15/10/70)				
P_{25}	38	19	6	6
P_{50}	40	18	10	17
P_{100}	45	16	11	12
P_{200}	46	17	12	12
L.S.D. ($p = 0{\cdot}05$)	19			

Experiment 2

At harvest 1 the P 50 K 56 treatment gave maximum dry matter yields. Higher rates of P and K reduced yields. At the 200 kg ha^{-1} P rate only an occasional plant survived. By harvest 2, at the end of the second summer, plant numbers had increased from self sown seed and yield differences were not significant. Main effects for phosphorus and potassium are given in Table 5. The other fertilizer treatment (boron plus molybdenum) did not affect yields, nor did the split plot application of lime applied after harvest 1.

Chemical analyses of plants sampled at harvest 1 and 2 are given in Table 5. Phosphorus percentages increased with phosphorus application at both samplings

TABLE 5

Dry matter yield and chemical composition of Endeavour stylo at two sampling dates of Experiment 2

Treatment	D.M. yield (kg ha^{-1}) 4/8/69	5/5/70	% N 8/8/69	12/5/70	% P 8/8/69	12/5/70	% K 8/8/69	12/5/70
P_{25}	2965	4432	1·21	1·03	0·31	0·14	0·81	0·84
P_{50}	3476	6276	1·22	1·21	0·32	0·16	0·80	0·90
P_{100}	1857	5489	1·28	1·27	0·39	0·19	0·78	0·84
P_{200}	199	5472	1·37	1·13	0·48	0·22	0·85	0·80
K_0	1665	4560	1·32	1·23	0·42	0·24	0·80	0·51
K_{28}	2124	6108	1·28	1·18	0·43	0·16	0·79	0·81
K_{56}	3286	6218	1·22	1·17	0·30	0·15	0·77	0·96
K_{84}	1422	4785	1·26	1·10	0·35	0·14	0·88	1·11
L.S.D. ($p = 0·05$)	822	2891						

but levels at harvest 2 were only about half those at harvest 1. Calcium concentrations also increased with phosphorus rate from 0.89 to 1.13% Ca at the first sampling and from 0.77 to 0.97 at the second sampling. Potassium concentrations were not affected by potassium rate at harvest 1 but were increased at harvest 2, reflecting the reapplication of potassium treatments between the two harvests. Where no potassium was applied % K decreased from 0.80% to 0.51%. Magnesium percentages were not affected by potassium rate at the first sampling (mean 0.54% Mg) but decreased with increasing potassium rate from 0.70 to 0.32% Mg at the second sampling. Nitrogen concentrations were very low (1.2 to 1.3% N) at both samplings. At a further sampling on 21st July 1970 nitrogen concentrations ranged from 0.9 to 1.7% N while sulphur concentrations ranged from 0.05 to 0.10% S. Nitrogen and sulphur percentages were correlated ($r = 0.90$, $P < 0.01$).

The effect of phosphorus rate could be detected by soil acid digestible phosphorus analyses only on 8th August 1969, six months after fertilizer application when phosphorus concentrations were 31, 38, 55, and 96 ppm P in the 0-5 cm depth for the 25, 50, 100 and 200 kg ha^{-1} P rates respectively. After 15 and 20 months there were no differences between rates at the 0-15 cm depths. Deeper sampling after 20 months did not indicate any appreciable residual phosphorus in the top 90 cm of soil. Results for the latter sampling are given in Table 4.

Acid digestible potassium analysis showed small increases from potassium treatments in 0-15 cm samples. Values for nil and 150 kg ha^{-1} K treatments were 0.03 and 0.05 m. equiv. 100 g^{-1} on 12th May 1970 (differences not significant), and 0.05 and 0.10 m. equiv. 100 g^{-1} on 15th October 1970 ($P < 0.05$). At the latter date there were no differences between treatments at any other depth where values ranged from 0.01 to 0.05 m. equiv. 100 g^{-1}.

The amounts of phosphorus and potassium in the plant material removed at the two harvests are given in Table 6 together with calculated apparent recoveries of fertilizer phosphorus and potassium. Overall recovery of potassium is high at the 56 kg ha^{-1} K rate but declines at the higher rates. Phosphorus recoveries (related back to the 25 kg ha^{-1} rate) are low at the 100 and 200 kg ha^{-1} P rates.

TABLE 6

Amounts of phosphorus and potassium removed in plant material summed over two harvests of Experiment 2 and calculated apparent recoveries of fertilizer phosphorus and potassium

Amount applied kg ha^{-1}	Amount removed kg ha^{-1}	Apparent recovery	
		kg ha^{-1}	%
Phosphorus			
25	15·4	—	—
50	21·1	5·7	23
100	17·6	2·2	3
200	13·0	—	—
Potassium			
0	26·6	—	—
56	66·3	39·7	71
112	85·0	58·4	52
168	65·6	39·0	23

DISCUSSION

The outstanding feature of both experiments was the failure of stylo to establish at high rates of phosphorus. This is in agreement with results of pot experiments (Teitzel and Bruce 1973) but has not been found in field experiments with other soils deficient in phosphorus (e.g. Teitzel 1969, Jamieson 1969, Teitzel and Bruce 1971). Symptoms similar to those described by Jones (1974) for phosphorus toxicity were observed on seedlings soon after emergence in 100 and 200 kg ha^{-1} P treatments in both experiments. While the mechanism of phosphorus toxicity is not fully understood (Jones 1974) the low phosphorus sorption capacity of siliceous sands would have led to high P concentration in the vicinity of seedlings. We believe that more rapid leaching of the completely soluble monosodium orthophosphate is the explanation for the less severe depression by this source of phosphorus in experiment 1. Recovery of surviving plants in both experiments and establishment of stylo from self sown seed in experiment 2 is thought to have occurred because of subsequent loss of phosphorus from the surface soil.

The mechanism of the lime response in experiment 1 is not clear. The main effect of lime was significant ($P < 0.05$) at harvests 1 and 3 and almost significant at harvest 2 ($P = 0.078$). Such a consistent response suggests that effects on calcium nutrition or nitrogen fixation would be more likely than effects on aluminium or phosphorus toxicity. However a nutritional effect of calcium appears unlikely as calcium percentages of stylo exceeded 1% in the absence of lime regardless of phosphorus source. Yields of dry matter and nitrogen were highest for the Na-P L_1 combination. Improved nitrogen fixation at the higher lime rate is the most likely explanation. This differs from the results of Munns *et al.* (1977) who found little effect of lime on the growth and nodulation of *Stylosanthes guianensis*, but their soil had higher pH and exchangeable calcium status than did ours.

Lime applied after harvest 1 in experiment 2 did not affect subsequent yields. Low nitrogen concentrations in this experiment appear to be due to sulphur deficiency and this could have prevented any effect of lime on nitrogen fixation from being reflected in increased plant protein.

Potassium deficiency symptoms were observed on stylo at low potassium rate treatments in both experiments and a response to applied potassium was predictable from the low exchangeable potassium analyses. The depression from the 84 kg ha^{-1} K treatment at harvest 1 in experiment 2 was unexpected and is perhaps due to chloride rather than potassium. Jones (1973) reported depressed yields of *Desmodium intortum* due to chloride toxicity.

In experiment 2 acid digestible phosphorus in the 0-15 cm depth of the 200 kg ha^{-1} P treatment decreased from 96 ppm P six months after fertilizer application to 46 ppm P after 20 months. Also, at the latter date, there was no evidence of phosphorus retention in the top 90 cm of soil. This, combined with the zero apparent recovery of applied phosphorus by stylo at this rate, is taken as evidence for leaching of phosphorus in this soil. There is also evidence of loss of phosphorus from the 0-15 cm depth of the high rate of superphosphate treatment in experiment 1 between the 7 and 24 month samplings. However, as deeper sampling revealed accumulations of phosphorus in sub-surface depths complete loss of phosphorus had not occurred in this soil. The increase in clay in the profile may be the reason for this retention.

Because only a small increase in acid digestible potassium could be measured in experiment 2 and no increase in exchangeable potassium could be found in experiment 1 it is likely that losses of potassium also occurred. However recoveries of potassium by plants were considerable in experiment 2 and leaching losses cannot be proven on the data available. Low sulphur percentages in stylo in experiment 2 suggest that sulphur applied in superphosphate has been leached also.

Where plants take up some of the applied nutrients and the remaining nutrients are leached the apparently anomalous situation can arise where plant analyses indicate adequate nutrition while soil analyses suggest deficiency. In time the plant concentrations should fall and a yield response should be obtained.

When formulating a fertilizer strategy for these sandy soils, the relatively narrow range between mineral deficiency and toxicity must be stressed. The policy of applying luxury amounts of any fertilizer likely to be required by infertile sandy soils could be worse than applying no fertilizer. Even if toxic conditions are not produced, considerable loss of nutrients could occur. Low rates of superphosphate and potassium chloride are recommended, particularly until plants are established. Annual maintenance applications would also be required.

ACKNOWLEDGEMENTS

We acknowledge the financial support of the Australian Meat Research Committee.

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(Accepted for publication December 1, 1977)