RESPONSE OF ESTABLISHED SIRATRO (*MACROPTILIUM ATROPURPUREUM* CV. SIRATRO) PASTURES IN SOUTH EAST QUEENSLAND TO PHOSPHORUS FERTILIZER

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ABSTRACT

Rates of calcium phosphate supplying up to 60 *kg P* ha^{-1} *were topdressed onto established, commercial, grass—Siratro* (Macroptilium atropurpureum *cv. Siratro*) *pastures in* 18 *experiments conducted during a three year period in south east Queensland. Siratro was the most responsive component but increases in dry matter yield were measured at only five sites. Its responsiveness did not appear to be influenced by the type of soil, associated grass, legume percentage or rainfall. Applied phosphorus increased phosphorus concentration in Siratro only at the responsive sites but increased grass phosphorus concentrations at almost all sites. The grasses appeared to have a competitive advantage over Siratro for topdressed phosphorus but nitrogen deficiency limited their dry matter yield response.*

Phosphorus concentration in Siratro from unfertilized plots was not correlated with Siratro relative yields. Soil total phosphorus was not correlated with relative yields of either Siratro or grass, nor were bicarbonate extractable phosphorus or acid extractable phosphorus correlated with relative yields of grass. However, results with both empirical extractants were significantly correlated with Siratro relative yield. Bicarbonate extraction of a 0-10 *cm sample gave the best separation of responsive and non responsive sites. Responses are likely below* 10 *ppm, unlikely above* 14 *ppm and uncertain between* 10 *and* 14 *ppm P.*

INTRODUCTION

Sown pastures based on the tropical legume Siratro (*Macroptilium atropurpureum* cv. Siratro) have been established in recent years throughout large areas of south east Queensland. The need for fertilizers, particularly superphosphate, when planting these and other tropical pastures has been shown in many experiments and has been emphasized in extension publications. On the other hand it has been widely assumed but not well confirmed that, once established, these pastures need continued inputs of phosphorus and other nutrients (Jones and Jones 1971). Few critical experiments dealing with the fertilization of established perennial pastures have been reported.

Jones (1966) fertilized a one-year-old Siratro/*Setaria anceps* pasture near Gympie and measured responses to superphosphate, urea and potassium chloride over three seasons. At Eskdale, 't Mannetje (1967) found that the effect of an establishment dressing of 250 kg ha^{-1} superphosphate on a Siratro/*Chloris gayana* pasture had largely disappeared after two years but that superphosphate at 125 kg ha^{-1} $year^{-1}$ maintained good growth. In north Queensland, Bruce (1974) reported responses to superphosphate in a one-year-old and two 2-year-old *Stylosanthes guianensis* based pastures, while Jones (1968) found that maintenance dressings of superphosphate increased dry matter yield of *Stylosanthes humilis* in the second and third years only where nil or 125 kg ha^{-1} superphosphate had been used at establishment.

Such experiments provide site specific information on a pasture's need for superphosphate but do not provide bases for extrapolation to other pastures, where soils and soil fertility status may be different, unless responses are related to soil and/or

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plant chemical analyses. Soil phosphorus analyses have been correlated with the response of newly planted tropical pastures to phosphorus (White and Haydock 1968; Bruce and Bruce 1972) but not with the response of established pastures. Critical concentrations of phosphorus have been published for some tropical pasture species (Andrew and Robins 1969, 1971, Jones 1968, Bruce 1974) but have not been widely checked as indicators of the responsiveness to phosphorus of grazed grass-legume pastures.

A program of pasture topdressing experiments was begun in 1973 in south east Queensland to obtain data on the relationship between pasture yield responses and soil and plant analyses. This paper reports results of 18 of these experiments with established commercial pastures where Siratro was the only legume.

METHODS

Site and pasture characteristics

Details of location, soil, pasture composition, age, fertilizer history and rainfall for the 18 experimental sites are given in Table 1. Soil chemical properties (0-10 cm samples) are given in Table 3.

Treatments and design

Experimental design at all sites was a randomized block with 3 replicates of 8 (1973/74), 9 (1974/75) or 10 (1975/76) treatments. Phosphorus (P) was applied as mono calcium phosphate at the following rates:—

1973/74 0, 20, 40 and 60 kg P ha^{-1}
1974/75 0, 10, 20, 40 and 60 kg P ha^{-1}
1975/76 0, 10, 20, 30, 40 and 60 kg P ha^{-1}

All phosphorus rate treatments received basal applications of potassium chloride at 50 kg K ha^{-1}, gypsum at 25 kg S ha^{-1}, copper chloride at 2.05 kg Cu ha^{-1}, zinc chloride at 1.82 kg Zn ha^{-1}, and sodium molybdate at 0.10 kg Mo ha^{-1}.

The remaining treatments were the presence or absence of potassium chloride and gypsum in the presence of phosphorus (40 kg P ha^{-1}) and trace elements (rates the same as above). Only the results from the phosphorus rate treatments are reported here.

Field procedure

At each location an experimental area was selected according to pasture uniformity and mown to a height of approximately 7.5 cm. Cut material was immediately removed and 2 m × 2 m plots pegged out. Guard rows of 1 m width separated the replicates. Soil samples were taken with a tube type sampler to a depth of 10 cm. In 1973/74 and in 1974/75, 12 composite soil samples (each a composite of eight cores) were taken in a systematic manner across each site. In 1975/76, 15 composite samples were taken. One profile to 1 m in 10 cm increments was also sampled at each site.

After soil sampling, fertilizer treatments were broadcast by hand and basal trace elements applied in dilute aqueous solution. Experiments were fenced to exclude grazing animals.

Hand shears were used for harvesting, at a cutting height of approximately 7.5 cm. A 1 m^2 quadrat was cut from the centre of each plot and all harvested material was hand separated into component species. After separation, the samples (termed uptake samples) were dried, weighed and bulked by treatment across replications for subsequent chemical analyses.

Fertilizers were applied to the various sites from mid-September to mid-February and harvests made from early January to mid-May. The time between fertilizer application and first harvest averaged 88 days (range 63 to 155). Second harvests were taken at sites 3, 16 and 20.

TABLE 1

Details of experimental sites and pasture.

Site No.	Season	Location	Soil Classification	Pasture grasses	Siratro* content %	Age of pasture years	Superphosphate history establishment kg ha^{-1}	Superphosphate history maintenance kg ha^{-1}	Rainfall mm
3	1973-74	Wacol	Solodic,† Db1‡	Rhodes,** green panic§ setaria‖	48	3	375	500	300
4	1973-74	Gympie	Non calcic brown, Dr2	Rhodes	86	4	625	some	820
15	1974-75	Woodgate	Gleyed podozolic, Gn3	Setaria	31	3	500	250	670
16	1974-75	Rosedale	Solodic, Dy3	Rhodes	29	1	250	nil	440
20	1974-75	Beaudesert	Prairie, Uf	Setaria	13	3	500	some	340
22	1974-75	Goomeri	Earthy sand (gritty), Uc	Native grasses	52	3	nil	nil	390
23	1974-75	Wooroolin	Solodic, Dy2	Green panic	17	3	nil	nil	490
24	1974-75	Booubijan	Soloth, Dy3	Rhodes	43	3	nil	nil	450
30	1975-76	Gunalda	Soloth, Dy3	Setaria, plicatulum§§	37	1	400	nil	480
32	1975-76	Beaudesert	Solodic, Dy3	Setaria	39	2	375	nil	380
33	1975-76	Gayndah	Siliceous sand, Uc	Native grasses	43	2	125	nil	320
37	1975-76	Mundubbera	Red earth, Gn2	Green panic	51	3	375	nil	310
38	1975-76	Mundubbera	Solodic, Dy2	Green panic, native	75	2	250	nil	330
39	1975-76	Malarga	Soloth, Dy3	Setaria	39	1	nil	nil	520
41	1975-76	Undulla	Siliceous sand, Uc	Setaria	80	4	375	250	300
42	1975-76	Coominya	Soloth, Dy2	Native grasses	74	2	375	nil	270
43	1975-76	Rosedale	Yellow earth, Dy2	Rhodes	46	3	250	nil	390
44	1975-76	Berajondo	Siliceous sand, Uc	Green panic	11	4	187	250	390

† Great soil group (Stace *et. al.* 1968).
‡ Northcote (1971).
* Percentage by weight in nil phosphorus plot at harvest.
** *Chloris gayana.*
§ *Panicum maximum* var. *trichoglume.*
¶ Rainfall at nearest recording station during period of the experiment.
‖ *Setaria anceps.*
§§ *Paspalum plicatulum.*

At a majority of sites in the 1973/74 and 1975/76 seasons, 'diagnostic' Siratro tissue samples were also collected for chemical analyses. These were as described by White and Haydock (1970).

Chemical analyses

Soil analyses included total P by X-ray fluorescence, acid extractable P (Kerr and von Stieglitz 1938), bicarbonate extractable P (Colwell 1963), exchangeable K (neutral N NH_4 Cl), pH (1:5 soil/water) and total N (Kjeldahl).

After Kjeldahl digestion plant samples were analysed for nitrogen (N) and phosphorus by an Auto Analyzer procedure (Roofayel, unpublished) based on the ammonia-phenate-hypochlorite reaction for N and sulphuric-molybdate-A.N.S.A. method for P.

Statistical methods

Yields of Siratro, grass and total pasture from each site were analysed by two-way analyses of variance. In addition linear, quadratic and square root quadratic models were fitted to yield and phosphorus rate. The best fitting model was used to estimate maximum yields and yields in the absence of phosphorus for each site. Relative yields for legume, grass and total pasture were then calculated, relative yield being the yield in the absence of phosphorus as a percentage of the maximum yield.

The relationships between relative yields and site mean soil phosphorus analyses were determined using the discontinuous model of Cate and Nelson (1971) and four continuous models (Mitscherlich, linear, quadratic and square root quadratic). Also determined were the relationships between the relative yield of Siratro and the percentage phosphorus in Siratro (both uptake and diagnostic samples) from the corresponding nil phosphorus treatment.

RESULTS

Climatic conditions

Climatic conditions were generally suited to the growth of Siratro based pastures. No frosts were reported and rainfall during each experiment averaged 422 mm (range 270 to 820 mm) over the 18 sites (Table 1). The site which received 270 mm was at field capacity during establishment.

Dry matter yields

Total pasture production was satisfactory at all sites in all years. Mean dry matter yields (from single harvests over phosphorus rates and sites) for the three growing season 1973/74, 1974/75 and 1975/76 were 3376, 4018 and 3228 kg ha^{-1} respectively.

For Siratro yields, F tests in the analyses of variance indicated that only at sites 16 and 33 was a significant ($P < 0.05$) response obtained from phosphorus fertilizer applications. In addition regressions of Siratro yield against phosphorus fertilizer rate gave significant ($P < 0.05$) positive quadratic response trends for sites 37, 39 and 44. These five sites were the only ones with relative yields of Siratro less than 70%.

For the grass component, F tests were significant ($P < 0.05$) at only two sites and at these the response was either small (84% relative yield at site 43) or not sustained at a second harvest (site 3). None of the regressions of grass yield against phosphorus fertilizer rate gave significant positive quadratic or linear response trends.

For the purpose of comparison, sites 16, 33, 37, 39 and 44 have been grouped as responsive sites and the remaining 13 sites as non-responsive. Mean yields of Siratro and grass for these groupings and for each common phosphorus rate are given in Table 2. No correlation between responsiveness to phosphorus and yield was apparent as the range of total yields for each group was similar. There were only minor changes in grass yields with increasing phosphorus rate for both groupings. This resulted in an increase in Siratro percentage with increasing phosphorus rate in the responsive group but no change in the non-responsive group.

TABLE 2

Influence of phosphorus rate on mean legume percentages and pasture component mean yields (kg ha^{-1} dry matter) for responsive and non-responsive sites.

Group	Component	P rate (kg ha^{-1})				
		nil	10	20	40	60
P responsive (5 sites)	Siratro	1206	1556	1721	1976	2152
	grass	2080	2105	2149	2217	2251
	% legume	36·7	42·5	44·5	47·1	48·9
P non-responsive (13 sites)	Siratro	1586	1616	1642	1671	1648
	grass	1713	1806	1839	1839	1751
	% legume	48·1	47·2	47·2	47·6	48·5

Plant chemical composition

Phosphorus concentration in the grass component at harvest was measured in 1974/75 and 1975/76 seasons. In 14 of these 16 sites, phosphorus concentration increased markedly with increasing phosphorus rate. Averaged over all 16 sites the phosphorus percentages for the 0, 10, 20, 40 and 60 kg P ha^{-1} rates were 0.22, 0.23, 0.27, 0.29 and 0.32 respectively. Corresponding nitrogen percentages were 0.88, 0.86, 0.86, 0.86 and 0.82. The two sites (22 and 30) which failed to show an increase in phosphorus concentration with phosphorus rate had site mean values of 0.24 and 0.18% P compared with an overall site mean value of 0.27% P.

Phosphorus concentrations in Siratro uptake samples at harvest increased with increasing phosphorus rate at the five responsive sites, mean values being 0.15, 0.15, 0.16, 0.18 and 0.19% P for phosphorus rates of 0, 10, 20, 40 and 60 kg ha^{-1} respectively. No marked trend was evident in the mean values of the unresponsive group where phosphorus concentrations ranged from 0.16 to 0.17%. Within each group there was little apparent change in nitrogen percentage with phosphorus rate. Mean value for the responsive group was 2.26% while the remaining sites averaged 2.43% N.

Phosphorus uptake

Figure 1 shows the mean phosphorus uptake by Siratro and grass for each grouping at five phosphorus fertilizer rates. The increase in phosphorus uptake by Siratro at the responsive sites is the most obvious feature but is it also apparent that the grass component, irrespective of grouping, accounts for more phosphorus than the associated legume. Only at sites 33, 37, 38, 41 and 42 where Siratro accounted for more than 50 per cent of the dry matter yield at harvest did phosphorus uptake by Siratro equal or exceed that of the grass component. Recovery of applied phosphorus was low.

Correlation of Siratro relative yield with Siratro phosphorus concentration

Phosphorus concentrations in the uptake samples at nil phosphorus ranged from 0.10 to 0.23% (mean 0.16% P) while in the diagnostic samples, which were not available from all sites, they ranged from 0.13 to 0.27% (mean 0.20%). Neither was significantly correlated ($P > 0.05$) with the relative yield of Siratro. A significant linear relationship $Y = 0.029 + 0.74X$ ($R^2 = 0.72$; $P < 0.01$) (where Y = uptake % P and X = diagnostic % P) was found between the two types of Siratro samples taken from the same plots at a number of experimental sites including some outside the scope of this paper.

Correlation of relative yield with soil phosphorus

Soil chemical properties and relative yields of Siratro, grass and total pasture are given in Table 3.

TABLE 3

Site soil chemical properties and relative yields of Siratro, grass and total pasture.

Site No.	Soil chemical properties (0–10 cm)						Relative yields		
	pH	total N%	exch K m. equiv 100 g^{-1}	Acid P ppm P	Bicarb P ppm P	Total P ppm P	Siratro	Grass	Total pasture
3	6·6	0·11	0·21	23	18	430	73	67	69
4	5·4	0·17	0·19	64	32	540	100	55	90
15	5·5	0·04	0·12	22	13	100	75	91	90
16	5·7	0·15	0·49	10	7	370	44	90	72
20	5·7	0·10	0·34	25	15	220	100	66	73
22	6·6	0·12	0·85	151	60	1250	100	88	100
23	4·6	0·11	1·09	42	39	800	95	100	98
24	6·3	0·13	1·23	16	22	1050	94	100	92
30	5·7	0·13	0·28	22	14	300	100	88	100
32	5·8	0·09	0·22	17	13	150	94	100	100
33	6·7	0·05	0·18	8	5	220	55	97	74
37	7·0	0·05	0·60	17	7	280	69	100	88
38	6·8	0·10	0·38	13	13	270	73	69	73
39	5·9	0·15	0·52	10	13	590	57	82	84
41	6·2	0·05	0·34	34	18	310	89	59	82
42	5·6	0·05	0·06	50	30	120	100	90	100
43	6·1	0·10	0·11	9	10	440	82	84	84
44	6·3	0·09	0·31	17	11	320	50	67	69

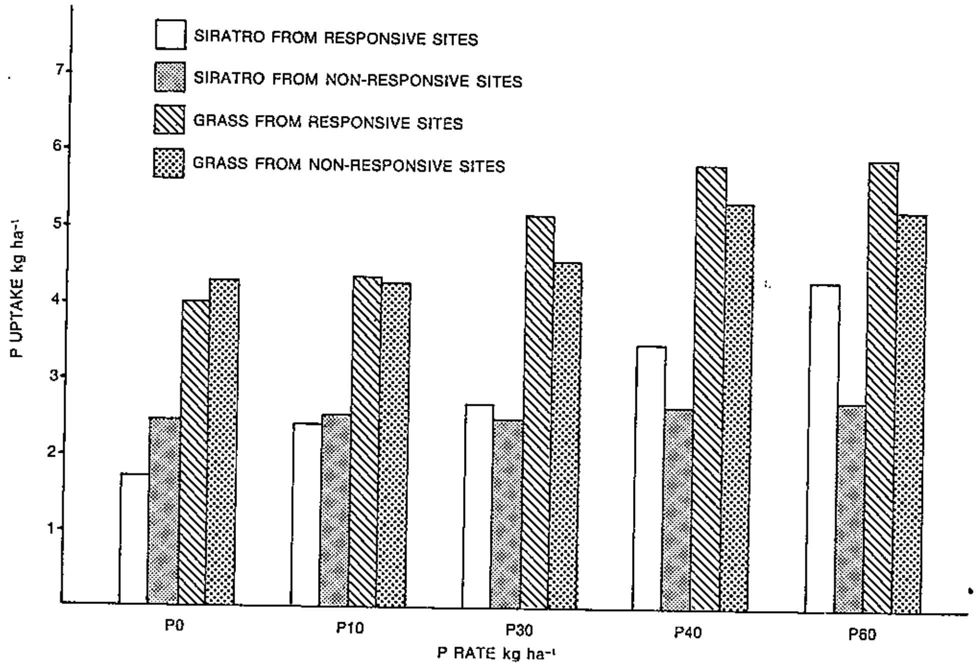

FIGURE 1

The influence of phosphorus rate on the mean phosphorus uptake of Siratro and grasses from responsive and non-responsive sites.

Relative yield of grass was not significantly correlated with any of the three phosphorus analyses. Siratro relative yields were significantly correlated ($P < 0.05$) with both extractable soil phosphorus tests but not with total phosphorus analyses. Of the continuous models, the Mitscherlich equations were preferred because they had the highest R^2 values (Table 4). These are plotted in Figure 2 together with the best Cate and Nelson separations. Coefficients of determination for the Cate and Nelson separations were 0.52 ($P < 0.01$) and 0.49 ($P < 0.01$) for the bicarbonate and acid extractable soil phosphorus tests respectively.

TABLE 4

Regression equations and coefficients of determination (R^2) for the regression of Siratro relative yield against soil phosphorus analyses

Soil test	Model	Regreesion equation	R^2
Acid P	linear	$Y† = 71{\cdot}07 + 0{\cdot}29X‡$	0·27*
	quadratic	$Y = 54{\cdot}6 + 1{\cdot}25X - 0{\cdot}006X^2$	0·50**
	square root quadratic	$Y = 11{\cdot}62 + 19{\cdot}76X^{\frac{1}{2}} - 1{\cdot}03X$	0·53**
	Mitscherlich	$Y = 101{\cdot}49 - 70{\cdot}66 \exp(-0{\cdot}061X)$	0·54**
Bicarbonate P	linear	$Y = 64{\cdot}1 + 0{\cdot}84X$	0·36**
	quadratic	$Y = 45{\cdot}01 + 2{\cdot}72X - 0{\cdot}031X^2$	0·51**
	square root quadratic	$Y = -8{\cdot}79 + 32{\cdot}42X^{\frac{1}{2}} - 2{\cdot}40X$	0·54**
	Mitscherlich	$Y = 100{\cdot}43 - 79{\cdot}78 \exp(-0{\cdot}095X)$	0·54**

† Y = Siratro relative yield.
‡ X = soil phosphorus.

* Significant at the 5% level.
** Significant at the 1% level.

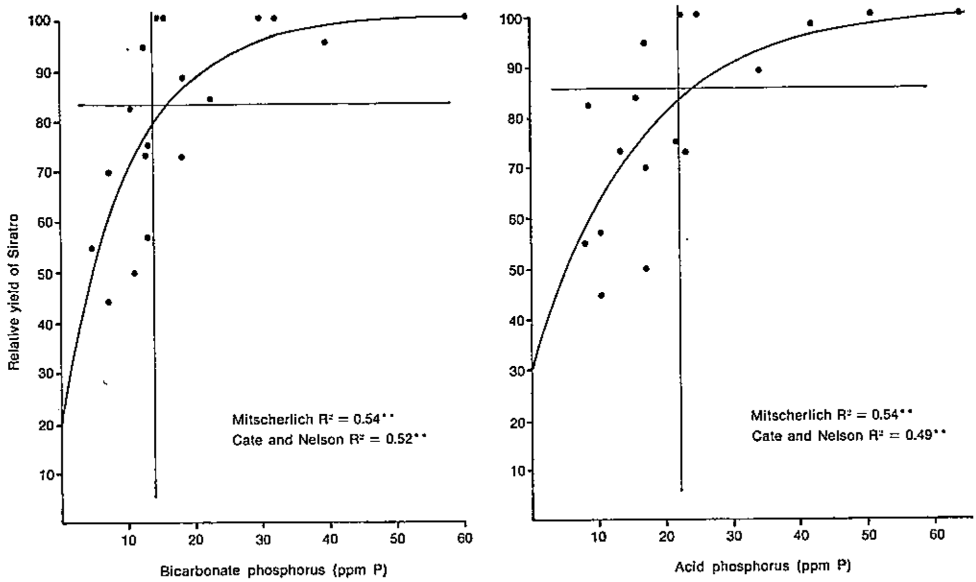

FIGURE 2

Cate and Nelson separations and Mitscherlich response curves of Siratro relative yield data and bicarbonate and acid extractable soil phosphorus tests.

For relationships between relative yields of total pasture and soil phosphorus analyses, low R^2 values ($P < 0.05$) were obtained by the Cate and Nelson procedure with both acid ($R^2 = 0.29$) and bicarbonate ($R^2 = 0.33$) extractions and by a linear correlation with bicarbonate extraction ($R^2 = 0.30$).

DISCUSSION

The experiments reported were conducted over three seasons of variable but generally adequate rainfall on a range of soils with pastures of varying age, grass species and initial and maintenance fertilizers (Table 1). Overall there was a low incidence of dry matter yield responses by these established Siratro-grass pastures to topdressed phosphorus fertilizer at rates up to 60 kg P ha^{-1}. This contrasts with a widespread requirement for relatively high rates of phosphorus at the establishment phase of similar pastures in the same area (White and Haydock 1968, Truong, Andrew and Skerman 1967 and others).

Where positive responses to phosphorus were measured these were generally associated with the legume component rather than the companion grass. This is in general agreement with the findings of Jones (1966), 't Mannetje (1967), and Bruce (1972) who worked with established legume-grass pastures based on Siratro, Siratro and *Stylosanthes guianensis* respectively. Further, the companion grass appeared to have no control over the percentage legume in the pasture or the ability of the legume component to respond to phosphorus. Grass nitrogen concentrations at harvest averaged 0.86% N over all sites and phosphorus rates. Considering the yield and age of grass harvested, this is low and suggests that nitrogen deficiency could be more limiting for grass production in these Siratro based pastures than phosphorus. Jones, Griffiths Davies and Waite (1967) found that grass associated with Siratro rarely fell below 1% N and that nitrogen transfer from legume to grass tended to increase with time. Apparently a build up and transfer of mineral nitrogen had not occurred to any measurable extent in the pastures studied. Longer term experimentation would be required to determine whether fixation and transfer of nitrogen by Siratro in future seasons could enable the grass component to become more responsive to phosphorus.

The heterogeneous nature of the legume-grass mixture in grazed pastures makes it difficult to measure small changes in yield of component species using the classical techniques of field experimentation employed in this investigation. High coefficients of variation result in large necessary differences for significance in F and t tests of individual site data. In this series of trials, coefficients of variation averaged 20 and 30% for Siratro and grass yields respectively. As a consequence an increase in legume yield of about 40% was often needed for a significant response. Alternative experimental techniques and designs which increase precision are required. Factors such as plot size, sampling technique, number of replications and number of treatments warrant investigation.

Under the experimental conditions Siratro took up very little of the applied phosphorus. Only where dry matter yields increased were there measurable increases in phosphorus uptake. On the other hand, grass phosphorus concentrations increased with applied phosphorus even in the absence of yield changes and were well above, sometimes double, the concentrations given by Andrew and Robins (1971) as adequate. This suggests that the companion grasses, apparently irrespective of species, compete strongly for the available phosphorus from the applied fertilizer even when nitrogen supply probably limits their ability to produce dry matter yield responses.

The concentrations of phosphorus in Siratro were comparatively insensitive to phosphorus supply. This has also been noted by White and Haydock (1968), and Blunt and Humphries (1970) and is apparent from the data of Jones (1966). White and Haydock (1968) found that a plot of relative yield of Siratro against phosphorus concentration was only of limited value in the diagnosis of phosphorus deficiency in pure swards of establishing Siratro. Similarly phosphorus concentrations in both uptake and diagnostic samples from unfertilized plots bore no relation to relative yields of Siratro in these experiments.

The Cate and Nelson technique gave a reasonable separation of the bicarbonate extractable phosphorus-Siratro relative yield data with only two points in the negative quadrants (Figure 2; Cate and Nelson, 1971). With acid extractable phosphorus the points were more scattered and consequently the separation was not as sharp. Critical levels were at 13.7 and 22 ppm P for the bicarbonate and acid extractions respectively.

When continuous models are fitted to relative yield—soil test data, the soil test value at some arbitrarily chosen relative yield, often 90% is taken as the critical level. Because of the variation associated with much of the yield data reported, 90% relative yield gives a poor separation of responsive from non-responsive sites. As 70% relative yield separated the five sites previously considered responsive (see Results) this is the most reliable basis for setting a soil test limit below which responses should be obtained. This corresponds to 10 ppm and 13 ppm P for bicarbonate and acid extractions respectively from the appropriate Mitscherlich curves (Figure 2).

The Cate and Nelson critical level effectively separates non-responsive sites from those where response is less clear. From our data we would suggest that the best interpretation is to consider the soil test at 70% relative yield as a lower limit, the Cate and Nelson critical value as an upper limit and the range between the two as a zone of uncertain response. For bicarbonate extraction, responses are likely below 10 ppm, unlikely above 14 ppm and uncertain from 10 to 14 ppm P. Corresponding acid extractable phosphorus values are 13, 22 and 13 to 22. Because of its narrower range of uncertainty the bicarbonate method is more reliable and its use is recommended at present. However, consideration of other soil properties and additional experimentation may further improve these soil phosphorus/plant response relationships.

A soil test range of 10 to 14 ppm bicarbonate extractable phosphorus in surface (0-10 cm) samples is considered low and as bicarbonate extractable phosphorus status also decreased with increasing profile depth at all sites except 22 (data not presented) it indicates that established Siratro plants can obtain their phosphorus requirements from soils of low phosphorus status. This could be because the root system of established Siratro plants is able to exploit a large soil volume and/or is more efficient at extracting soil phosphorus. In this connection the finding of Fox *et al.* (1974) in Hawaii that *Desmodium aparines* has a lower phosphorus requirement for regrowth than for establishment is relevant. White (1972) also suggested that Siratro was efficient at utilizing phosphorus because its low growth rate allowed more time for retranslocation of phosphorus within the plant. Alternatively grass competition for the available phosphorus supply could have prevented Siratro from obtaining sufficient phosphorus for response, giving an impression of low requirement. It is also possible that on the non-responsive sites there is some other factor limiting yield, but this seems unlikely.

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