Fertility studies on soils of the lower Burdekin area north Queensland. 2. Lower Burdekin River – Barratta Creek – Haughton River Area

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Abstract

Chemical analyses of soils of the lower Burdekin River–Barratta Creek–Haughton River area, showed low salt levels, acid to neutral pH, very low to high extractable phosphate, medium to high potassium and manganese, and medium zinc and copper levels. A composite of ten subsamples gave an acceptable representation of the extractable phosphate status of a site. Lucerne yield responses were obtained from the application of phosphorus, sulphur, lime, molybdenum, potassium and a mixture of micronutrients. Rice responded to applications of phosphorus and sulphur. Phosphorus sorption analysis showed marked differences among soils and between soil depths. Fertiliser phosphorus requirements were estimated from phosphorus sorption curves.

INTRODUCTION

Maltby and McShane (1988) reported on fertility studies on selected soils of the lower Burdekin River – Elliott River area. These studies related to the semi-detailed reconnaissance soil survey of Thompson (1977). A similar soil survey has been carried out by Reid and Baker (1984) on 80 000 ha of the Barratta Creek – Haughton River area. Mapping scale was 1:100 000 with a 3 740 ha reference area being surveyed at 1:25 000. The results of this survey gave an indication of the likely chemical properties of soils in the survey area. However, it was considered that more detailed information was required to adequately characterise the fertility of these soils.

To obtain this information an intensive soil sampling programme with subsequent laboratory analysis, pot trials (phosphorus rate and factorial design) and phosphorus sorption analysis was undertaken.

This paper reports the results of these experiments.

MATERIALS AND METHODS

Soils were selected on the basis of mapping area and suitability for irrigation cropping. Soils selected and their area (hectares) were: 2Uge 10609; 2Ugd 11030; 2Ugh 1915; 2Dyb 13570; 6Dbd 1926; 6Drb 964; 6Dyf 8470. For a detailed description of these soils see Reid and Baker (1984).

Soil sampling

The soils were sampled within the reference area of Reid and Baker (mapping scale 1:25 000). The sampling scheme was the same as that outlined in Maltby and McShane (1988) except that the sites were selected using a 100 m grid as distinct from the 250 m grid of that study.

For the pot trials bulk surface (0–100 mm) samples were taken for each soil as described previously (Maltby and McShane 1988).

Soil analysis

Methods used for soil analysis are described by Maltby and McShane (1988).

Pot experiments

The experimental design was described previously (Maltby and McShane 1988): phosphorus rate and factorial experiments using lucerne (*Medicago sativa* cv. Hunter River) and rice (*Oryza sativa* cv. Starbonnet) as test plants.

In the phosphorus rate experiments, seven rates (0, 10, 30, 50, 70, 90, 110 kg P/ha) were used for lucerne whereas for rice only six rates were used (0, 5, 10, 20, 40, 60 kg P/ha). Basal nutrient applications were as outlined by Maltby and McShane (1988).

For the factorial nutrient experiments lucerne treatments were the presence or absence of sulphur, lime, potassium, zinc, molybdenum, and copper plus manganese plus iron plus boron. Rates of application and nutrient compounds used were (kg/ha): S, 25 as sodium sulphate; $CaCO_3$, 847; K, 52 as potassium chloride; Zn, 7 as zinc chloride; Mo, 0.54 as ammonium molybdate; Cu, 5.6 as copper chloride, plus Mn, 4.2 as manganese chloride, plus Fe, 15 as ferric citrate. For rice, treatments (kg/ha) were: S, 25 as sodium sulphate; Ca, 50 as calcium chloride, plus Mg, 11 as magnesium chloride; K, 52 as potassium chloride; Zn, 15 as zinc chloride; Mo, 0.54 as ammonium molybdate; Cu, 5.6 as copper chloride, plus Mn, 4.2 as manganese chloride, plus Fe, 15 as ferric citrate, plus B, 1 as sodium borate.

All nutrients were added to the soil surface in solution apart from lime which was added as a powder and thoroughly mixed throughout the soil. Urea was added to the rice soils by injecting below the surface oxidised layer with syringes.

In terms of potting up procedures, the only changes to those described by Maltby and McShane (1988) for lucerne were in weights of soil used: 1600 g for soils 6Dbd, 6Dyf, 6Drb and 2Dyb; 1500 g for soils 2Ugd, 2Uge and 2Ugh. Changes in the rice pot experiments were 6 kg of soil (cf. 8 kg) added to each pot and plants in both the factorial and phosphorus rate experiments being harvested at the flowering stage of growth.

Plant oven dry weight (80°C) was recorded with plants from selected treatments being analysed for nitrogen, sulphur, phosphorus, calcium, molybdenum, zinc, copper, manganese, iron and boron (Methodology as per Maltby and McShane 1988).

RESULTS AND DISCUSSION

Soil chemical properties

Chemical analyses (Table 1) were interpreted using the criteria of Bruce and Rayment (1982) to assess their fertility status.

In all soils, surface pH (0–100mm) ranges from slightly acid to mildly alkaline and is considered suited to most crops. In five of these soils pH increases in the 100 to 200 mm depth. However, only in soil 2Ugh would the increase be considered a potential problem to plant growth.

The electrical conductivity and chloride levels in the 0 to 100 mm and 100 to 200 mm depths of all soils are low to very low and would not affect plant growth.

In the surface of 2Uge, 2Ugh, 2Ugd, 2Dyb and 6Dyf soil extractable phosphorus is low to very low, medium in 6Drb and high in 6Dbd. The high value in 6Dbd is considered to reflect the relatively younger age of this soil (Reid and Baker 1984). In all soils extractable phosphate decreases in the 100 to 200 mm depth.

Table 1. Means and Standard errors (SE) for soil chemical properties of the 0 to 100 mm and 100 to 200mm depth

Soil property	2Uge		2Ugh		2Ugd		2Dyb		6Dyf		6Dbd		6Drb	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
pH														
0–100 mm	6.7	0.1	7.5	0.05	6.2	0.1	6.6	0.05	6.5	0.04	6.6	0.05	6.7	0.1
100–200 mm	7.2	0.1	8.2	0.03	6.8	0.1	7.4	0.10	6.4	0.04	6.7	0.04	6.7	0.1
Electrical conductivity (mS/m)														
0–100 mm	0.038	0.002	0.085	0.015	0.030	0.001	0.044	0.006	0.025	0.001	0.025	0.001	0.030	0.006
100–200 mm	0.045	0.006	0.118	0.009	0.021	0.001	0.15	0.03	0.089	0.001	0.019	0.001	0.018	0.001
Chloride (mg/kg)														
0–100 mm	32	3	26	4	33	1	41	6	19	1	20	1	19	1
100–200 mm	21	3	18	0.2	18	0.5	183	32	19	0.5	20	1	18	0.5
Acid extractable phosphorus (mg/kg)														
0–100 mm	6	0.2	4	0.3	6	1	6	0.5	18	3	115	14	31	6
100–200 mm	2	0.2	2	0.4	5	1	4	0.5	3	0.4	95	13	9	2
Bicarbonate extractable phosphate (mg/kg)														
0–100 mm	10	1	7	0.6	12	2	7	1	13	1	33	4	21	2
100–200 mm	2	0.6	5	0.3	7	0.6	6	0.7	5	0.6	24	4	12	2
Exchangeable cations (meq per 100 g)														
Ca 0–100 mm	11	1	19	1	11	0.5	5	0.7	4	0.2	6	0.7	4	0.4
Mg 0–100 mm	10	0.6	12	0.3	11	0.5	4	0.3	2	0.1	2	0.2	2	0.1
Na 0–100 mm	0.35	0.05	0.46	0.03	0.32	0.02	0.55	0.09	0.07	0.01	0.09	0.02	0.05	0
K 0–100 mm	0.60	0.03	0.59	0.04	0.72	0.05	0.18	0.02	0.31	0.02	0.3	0.03	0.38	0.01
Extractable K (meq per 100 g)														
0–100 mm	0.53	0.03	0.48	0.02	0.66	0.04	0.21	0.02	0.37	0.01	0.44	0.04	0.43	0.02
100–200 mm	0.41	0.03	0.28	0.009	0.53	0.04	0.11	0.006	0.22	0.01	0.29	0.03	0.34	0.04
Organic carbon (%)														
0–100 mm	1.00	0.03	0.77	0.02	0.98	0.07	1.03	0.06	0.88	0.05	1.07	0.10	0.89	0.04
100–200 mm	0.51	0.02	0.47	0.005	0.42	0.02	0.70	0.04	0.46	0.04	0.37	0.04	0.42	0.03
Extractable zinc (mg/kg)														
0–100 mm	1	0.1	2	0.2	1	0.08	2	0.1	2	0.1	2	0.3	2	0.2
Extractable copper (mg/kg)														
0–100 mm	3	0.2	2	0.06	3	0.3	2	0.1	1	0.1	1	0.1	1	0.1
Extractable manganese (mg/kg)														
0–100 mm	52	7	19	2	71	5	55	5	62	0.2	57	12	71	5
Extractable iron (mg/kg)														
0–100 mm	40	10	5	0.7	54	9	98	16	79	4	71	6	59	6

Calcium is the dominant cation (cf. magnesium) in the 0 to 100 mm depth in all soils except 2Ugd. The levels found do not indicate any likely plant nutrition problems from these nutrients.

Levels of extractable and exchangeable potassium in all soils except 2Dyb are medium to high. In soil 2Dyb, levels are below 0.2 meq per 100 g, a figure associated with potassium deficiences (Piper and De Vries 1960). In all soils extractable potassium decreases in the 100 to 200 mm depth with levels still considered medium (excluding 2Dyb).

Organic carbon levels are low and decline in the 100 to 200 mm depth in all soils.

In all soils, surface zinc and copper levels are medium with no plant nutrition problems anticipated. The alkaline pH in the 100 to 200 mm depth of soil 2Ugh may

affect zinc availability; a problem that could occur if this soil is exposed during levelling for irrigation purposes.

Manganese levels range from medium to high, with neither deficiences nor toxicities considered a problem.

Soil 2Ugh has a markedly lower iron level compared with the other soils. No interpretive data is available to indicate if this will have any significant effect on plant nutrition.

The acid extractable (Table 2) phosphate values are similar for the two sampling methods. The result is the same as that found by Maltby and McShane (1988) and indicates: (1) Sampling, subsampling, sample preparation and analyses did not introduce large error terms; and (2) The chemical variability of the sites was small.

Table 2. Mean and standard deviation (SD) for acid extractable phosphate for 10 subsamples (true mean) and mean of the composite sample

Soil	Acid extractable P (µg/g)		
	True mean	SD	Mean of composite
2Uge	12	4.4	7
2Ugd	4	1.6	5
2Ugh	3	1.2	3
2Dyb	6	2.5	8
6Dbd	144	12.9	159
6Drb	26	5.4	25
6Dyf	25	10.8	25

Pot experiments

Chemical properties for the seven soils used in the pot experiments are shown in Table 3.

Lucerne dry matter production was increased by phosphorus addition on all soils. Dry matter yields on soils 2Ugh, 2Uge, 2Ugd, 2Dyb, 6Dyf, 6Drb and 6Dbd at nil phosphorus were 4, 10, 27, 26, 24, 29 and 64% of the respective maximum yield obtained. The amounts of phosphorus required for 90% maximum yield were estimated from quadratic regression equations (significant at $P<0.01$):

$$2Ugh \quad Y = -0.8 + 0.113x - .000463x^2$$

$$2Ugd \quad Y = 1.32 + 0.0491x - 0.000106x^2$$

$$2Uge \quad Y = 0.337 + 0.118x - 0.00049x^2$$

$$2Dyb \quad Y = 1.185 + 0.062x - 0.000245x^2$$

$$6Dyf \quad Y = 1.148 + 0.079x - 0.000488x^2$$

$$6Dbd \quad Y = 1.516 + 0.115x - 0.00819x^2$$

$$6Drb \quad Y = 2.05 + 0.084x - 0.000487x^2$$

Phosphorus required was 95 kg/ha 2Ugd, 75 to 85 kg P/ha 2Uge, 2Ugd, and 2Ugh and 50 to 55 kg P/ha 6Drb and 6Dyf. Plant phosphorus concentrations in all soils increased upon phosphorus addition. However, in soils 2Uge and 2Ugd, the plant phosphorus percentage was below the suggested critical percentage of 0.24% (Andrew and Robins 1969*a*) even at the highest phosphorus rate.

Rice dry matter production was increased by phosphorus addition in soils 2Uge and 2Ugh with yields for the zero phosphorus treatment being 82% and 6% of the respective maximum yield obtained. The amount of phosphorus required for 90% maximum yield was estimated from quadratic regression equations (2Uge $Y = 62.2 + 0.632x - 0.0089x^2$; 2Ugh $Y = 10.42 + 2.817x - 0.032x^2$) as 5 kg P/ha 2Uge and 25 kg P/ha 2Ugh. Plant nutrient analysis suggests that plant P%>0.1% indicates sufficiency; P%=0.1% possible deficiency; and P%<0.1% deficiency. This conclusion is supported by the results of subsequent pot trial work (J. E. Maltby and T. J. McShane unpub. data 1984).

Table 3. Chemical properties for soils 0 to 100 mm used in the pot experiments

Chemical property	2Uge	2Ugh	2Ugd	2Dyb	6Dyf	6Dbd	6Drb
pH	5.8	7.1	5.2	5.4	5.2	5.5	5.8
Electrical conductivity (m S/cm)	0.051	0.106	0.054	0.049	0.028	0.027	0.033
Acid extractable phosphorus (mg/kg)	6	6	15	11	8	121	17
Bicarbonate extractable phosphorus (mg/kg)	10	5	16	13	9	37	13
Exchangeable cations (meq per 100g)							
Ca^{++}	10.97	21.18	6.75	3.58	2.55	2.98	5.01
Mg^{++}	9.75	8.80	5.70	4.11	2.11	1.63	2.58
Na$^+$	0.57	0.36	0.39	0.63	0.14	0.13	0.13
K$^+$	0.74	0.61	0.70	0.32	0.33	0.41	0.50
CEC	34.0	38.0	29.8	22.2	12.7	10.0	16.5
Extractable boron (mg/kg)	0.5	0.4	0.4	0.3	0.3	0.14	0.3
Extractable sulphate (mg/kg)	4	7	6	4	3	2	3
Extractable zinc (mg/kg)	0.5	0.8	0.9	1.3	0.7	0.6	1.7
Extractable copper (mg/kg)	2.4	2.2	2.6	2.6	1.6	0.6	1.8
Extractable manganese (mg/kg)	101	40	130	235	132	79	119
Extractable iron (mg/kg)	69	24	191	153	110	69	78

Factorial experiments

Lucerne

Significant yield ratios for main effects and significant two factor interactions for lucerne are shown in Table 4.

Addition of sulphur increased lucerne dry matter yields in all soils. After accounting for possible effects of other nutrients, mean plant sulphur concentrations over all soils for nil sulphur treatments were 0.07% compared with 0.19% for sulphur treated plants. The suggested critical value is 0.20% (Andrew 1977). Plant sulphur concentrations were highly correlated with plant nitrogen concentrations (r=0.88, P<0.001).

The results are similar to those reported previously (Maltby and McShane 1988) where the pot data indicate potential sulphur deficiency over large areas in the lower Burdekin. Phosphate extractable sulphate sulphur levels in the pot soils (0–100 mm) ranged from 2 to 7 mg/kg. However, interpretation of plant response to surface sulphate

levels and pot trial results is difficult due to possible sulphur availability from subsoil sulphate.

Table 4. Significant yield ratios† for main effects and two factor interactions for lucerne and rice

Effect	2Uge	2Ugh	2Ugd	2Dyb	6Dyf	6Dbd	6Drb
Lucerne							
S	4.23**	4.74**	2.03**	2.12**	1.80**	2.73**	2.29**
Lime		1.35**	1.51**	1.27**	1.40**	1.18**	
Mo			1.63**	1.17**			
Cu Mn Fe B				1.09*	1.15*	1.16**	
K				0.92*			
S × Lime		**	**				
S × Mo			**	**			
S × CuMnFeB						**	
Lime × Mo			**			**	
Mean Yield (g/pot)	3.12	5.71	4.29	5.41	4.32	4.49	5.90
CV%‡	94	21.5	21.4	10.5	16.5	12.2	21.3
Rice							
S	1.13*	1.22*	1.11*				
Zn			0.907*				
Mean (g/pot)	32.72	25.37	39.37	44.08			
CV%	8.4	11.8	6.9	6.6			

* Mean yield of treated plants significantly different from that of untreated plants $P<0.05$.

** Mean yield of treated plants significantly different from that of untreated plans $P<0.01$.

†Yield ratio = $\dfrac{\text{mean yield of treated plants}}{\text{mean yield of untreated plants.}}$

‡CV Coefficient of variation.

Nevertheless it is considered that under a cropping regime of annual, relatively shallow-rooted crops grown under irrigation, sulphur deficiency is a distinct possibility in the soils studied.

The coefficient of variation for soil 2Uge is exceptionally high (Table 4). This is thought to be due to inefficient *Rhizobium* symbiosis reflected in a large range (1.09 to 3.26%) in nitrogen concentration for sulphur treated plants. This variability was also reflected in yields (1.22 g per pot to 10.24 g per pot). The reasons for this are unknown.

In soils 2Dyb, 6Dyf and 6Dbd a positive response to lime addition occurred in the absence of other nutrients, whereas in soils 2Ugh and 2Ugd the response to lime occurred only after the correction of sulphur deficiency. In these latter two soils there was an additive response to lime and sulphur addition.

Lime is thought to predominantly affect plant growth through its effects on pH, and the availability of calcium, manganese, aluminium and molybdenum (Munns and Fox 1977). However, in studies with lucerne, Crocker, Sheridan and Holford (1985) suggest that the mechanism of the beneficial effect of lime found in their experiments was due to increased root growth rather than increased nutrient availability or improved nodulation.

In the soils studied it is considered highly unlikely that lime was alleviating aluminium or manganese toxicities. It is possible that lime increased root growth leading to greater uptake of available nutrients although this was not reflected in plant nutrient analyses. Soil pH analyses indicated that the response in soils 2Ugd, 2Dyb, 6Dyf and 6Dbd could

be due to pH effects on host *Rhizobium* symbiosis. In these soils the pH before liming was <6.2 and in soils 2Ugd, 2Dyb and 6Dyf the pH after liming was still below this figure. The recommended pH range for lucerne is 6.2 to 6.7 (Andrew 1976). If this beneficial effect of lime addition was due to improved nodulation it was not reflected in plant nitrogen concentrations for soils 2Ugh, 2Dyb and 6Dyb with a mean of 3.43% N before liming and 3.29% N after liming. In soil 6Dyf mean plant nitrogen concentration increased from 2.8% to 3.6% upon liming. In soil 2Ugd plant nitrogen percentage increased from 2.4% to 2.6% after liming. This latter figure is considered low, and indicates that an increased rate of lime is required for optimum lucerne growth in this soil.

The response to lime may also have been due to an increase in calcium activity with mean plant calcium concentrations (over all responsive soils) increasing from 1.22% to 1.61% upon liming. However, a level of 1.22% before liming would be considered adequate when compared with the results of Andrew and Johnson (1976). Soil 2Ugd had mean plant calcium levels of 0.36% before and 0.44% after liming again highlighting that an increased rate of lime is required for this soil. However, there is no clear evidence to suggest what caused the beneficial effect of lime.

Soils 2Dyb and 2Ugd responded to molybdenum addition but only in the presence of sulphur. In both soils mean plant nitrogen and molybdenum concentrations in sulphur treated plants increased upon molybdenum addition: for soil 2Dyb, nitrogen increased from 2.59% to 3.15% and molybdenum from 0.50 mg/kg to 1.57mg/kg; for soil 2Ugd, nitrogen increased from 1.99% to 2.57% and molybdenum from 0.3 mg/kg to 0.4 mg/kg. The suggested critical molybdenum concentration for lucerne is 0.5 mg/kg (Melsted, *et al.* 1969).

It is known (Olsen 1972) that sulphur reduces molybdenum uptake and this could explain the sulphur by molybdenum interaction in these soils. Because molybdenum mainly affects nitrate reduction in plants (Hewitt and Nicholas 1964), the use of ammonium type fertiliser may mask any field molybdenum response in these soils.

In soils 6Dbd and 2Ugd, molybdenum addition increased yields in the absence of lime reflected in plant nitrogen increases of 10% and 68% respectively. With lime there was no yield increase. This molybdenum by lime interaction is similar to that found in previous work (Maltby and Webb 1983).

Positive yield responses to the treatment combining copper, manganese, iron and boron were recorded in soil 2Dyb, 6Dyf and 6Dbd with the response in 6Dbd occurring only after the correction of sulphur deficiency. Soil analyses (Table 3) indicated that these three soils would be rated as very low in terms of extractable boron, medium for extractable copper and medium to high for extractable manganese (Bruce and Rayment 1982). In the three soils, mean plant manganese and iron concentrations for plus and minus nutrient treatments were well above the suggested critical values of 25 mg/kg and 30 mg/kg for Fe and Mn respectively (Melsted, *et al.* 1969).

Mean plant copper concentrations for nil copper treatments were 4.6 mg/kg, 6.3 mg/kg and 11.1 mg/kg for soils 2Dyb, 6Dyf and 6Dbd respectively. This suggests deficiency in soils 2Dyb and 6Dyf when compared with the suggested critical value of 7 mg/kg (Melsted *et al.* 1969). Upon copper addition, plant copper concentrations in all soils were above this critical value. Mean plant boron concentrations over the three soils was 20.2 mg/kg (range 19.7 mg/kg to 26 mg/kg) before boron addition and 83.6 mg/kg (range 70 mg/kg to 94.2 mg/kg) after boron addition. This indicates deficiency and sufficiency respectively when compared with the suggested critical values of 22 mg/kg (Haddad and Kaldor 1982) and 30 mg/kg (Melsted *et al.* 1969).

The results indicate that the response in soil 6Dbd is due to boron deficiency whereas the response in soils 2Dyb and 6Dyf is most probably a combination of both copper and boron deficiency.

Soil analysis indicated that extractable zinc and potassium levels should be adequate for plant growth and no positive growth responses to addition of these nutrients was found. The slight growth depression upon addition of potassium in soil 2Dyb is thought due to chloride toxicity from the addition of potassium as the chloride salt. This has occurred in previous work (Webb *et al.* 1977).

Rice

Significant yield ratios for main effects in rice are shown in Table 4. No significant two factor interactions were found.

Application of sulphur significantly increased dry matter yields in soils 2Uge, 2Ugh and 2Ugd. Examination of soil extractable sulphate-sulphur levels would not have enabled pre-selection of the one soil which was not responsive to sulphur addition. This is in general agreement with Blair *et al.* (1978) who suggest that testing for sulphate status prior to flooding will be of little if any value since the sulphate status of flooded soil depends not only on the sulphur content but also on the degree of reduction in the soil.

The slight growth reduction upon zinc application in soil 2Ugd is unexplained. It could be due to chloride toxicity since zinc was added as the chloride salt and chloride is known to have specific toxicity to rice (Murty and Rao 1967).

Phosphorus sorption analysis

Soil phosphorus values for intensity (equilibrium phosphorus concentration), capacity (phosphorus buffer capacity) and phosphorus desorbed (0.01M $CaCl_2$) are shown in Table 5.

Table 5. **Phosphorus buffer capacity (PBC), equilibrium phosphorus concentrations (EPC), and phosphorus desorbed in 0.01 MCaCl2(PD) for each soil at two sampling depths**

Soil	Depth mm	PBC mL/g	EPC µg/mL	PD µg/g
2Uge	0–100	61	0.004	0.03
	100–200	66	0.003	0.02
2Ugh	0–100	56	0.008	0.03
	100–200	56	0.003	0.02
2Ugd	0–100	68	0.009	0.05
	100–200	64	0.003	0.03
2Dyb	0–100	48	0.012	0.05
	100–200	57	0.003	0.02
6Dyf	0–100	39	0.020	0.05
	100–200	33	0.014	0.04
6Dbd	0–100	36	0.118	0.57
	100–200	38	0.053	0.26
6Drb	0–100	38	0.042	0.15
	100–200	32	0.021	0.08

The results are similar to those reported previously (Maltby and McShane 1988), with marked differences in phosphate sorption among soils and between depths of the same soil. Dissimilar to Maltby and McShane (1988) is the wide range of buffer capacities between soils, or more precisely between groups of soils with the type 2 soils (2Uge, 2Ugd, 2Ugh, 2Dyb; soils of the major river flood plains) having much higher phosphate buffer

capacities than the type 6 soils (6Dbd, 6Drb, 6Dyf; miscellaneous alluvial deposits). This grouping of soils is based on apparent origin of parent material and position in the landscape (Reid and Baker 1984). Correlations between phosphate buffer capacity and percentage clay for the pot soils (the only soils for which percentage clay was measured in this experiment) showed that phosphate buffer capacity is positively correlated with percentage clay(r=0.89 P<0.01). The low phosphate buffer capacity of the type 6 soils suggests that after an initial period of high phosphorus fertility (high EPC) frequent small applications of phosphorus will be required to compensate for their expected limited capacity to buffer soil solution P against plant removal.

In all soils the phosphorus sorption curve for the 100 to 200 mm depth is shifted to the left of the 0 to 100 mm depth with soil 2Dyb showing the greatest relative shift. This result for 2Dyb is possibly due to the much larger increase in percentage clay in the 100 to 200 mm depth for this soil unit compared with the other soils (taken from Reid and Baker 1984). The shift of the phosphorus sorption curve for the 100 to 200 mm depth is also reflected in a lower level of intensity for these soil depths indicating that the concentrations of P in soil solution at these depths are more likely to be below a non-limiting soil solution P concentration for plant growth than in the surface soils.

The results for the 100 to 200 mm depths have important implications for agriculture. If these depths are exposed during levelling for irrigation purposes then additional amounts of fertiliser will have to be added compared with 0 to 100 mm depths. Estimated fertiliser P requirements for soybeans and maize for the two soil depths are shown in Table 6. These requirements, estimated from the P sorption curves assuming supernatant solution P concentrations of 0.01 µg P/mL for soybeans (from Moody *et al.* 1982) and 0.02 µg P/mL for maize (Peaslee and Fox 1978), were not limiting for plant growth.

Table 6. Phosphorus required to attain supernatant solution P concentrations of 0.01 µg P/mL and 0.02 µg P/mL for 0 to 100 mm and 100 to 200 mm soil depths

Soil	P required (kg/ha) to attain 0.01 µg/mL supernatant P concentrations		P required (kg/ha) to attain 0.02 µg/mL supernatant P concentrations	
	0%n100 mm	100%n200 mm	0%n100 mm	100%n200 mm
2Uge	34	51	59	81
2Ugh	7	44	31	69
2Ugd	5	50	34	80
2Dyb	0	42	14	66
6Dyf	0	0	0	6
6Dbd	0	0	0	0
6Drb	0	0	0	0

Field trials on a 2Ug type soil that had been levelled for irrigation indicated that maximum grain yield of maize was obtained at 50 to 60 kg P/ha (R. B. Brinsmead, pers. comm.); a figure which is in keeping with the estimated requirements of Table 6.

The P requirements shown in Table 6 must be viewed with the knowledge that, in general, P requirements estimated from sorption curves on fertilised soils correlate well with plant response data but not as well for untreated soils (Peaslee and Fox 1978). Probert (1982) found that concentrations of P in solution required for maximum plant yield were higher when estimated from unfertilised soil compared with fertilised soil again suggesting caution in interpreting P sorption data from unfertilised soils.

Acid extractable phosphate (P_A), bicarbonate extractable phosphate (P_B) and phosphorus desorbed were highly correlated with intensity ($P<0.01$) but not with buffer capacity.

These results confirm those found previously indicating that if intensity is the soil factor governing phosphorus availability in these soils then either P_A, P_B or P_D should adequately assess phosphorus availability.

Correlation of lucerne relative yield (yield at nil P addition/max. yield) with extractable phosphorus and phosphorus supply factors for the 0 to 100 mm depth showed that relative yield is significantly correlated with EPC, P_D, P_A and P_B ($P<0.01$) but not with PBC. These results reflect those found previously and suggest that bicarbonate extractable phosphorus would be a suitable method for predicting plant response to phosphorus (at least in pots).

Results for rice relative yield showed that within the limited number of data points available, bicarbonate extractable phosphorus was the only soil test significantly correlated with relative yield ($r=0.92$, $n=4$, $P<0.1$). This result agrees with Chang (1978) who states that the Olsen's test (0.5 M $NaHCO_3$, pH 8.5) is highly correlated with rice response to phosphorus. The results differ from Maltby and McShane (1988), where no soil test adequately predicted rice response to phosphorus addition.

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