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Fertility studies on soils of the lower Burdekin area north Queensland. 1. Lower Burdekin River - Elliot River area

J. E. Maltby[1] and T. J. McShane[2]

[1]Department of Primary Industries, PO Box 538, Bowen, Q. 4805, Australia.

[2]Department of Primary Industries, PO Box 591, Ayr, Q. 4807, Australia.

Abstract

Chemical analyses, nutrient pot experiments and phosphate sorption analyses were carried out on selected soils of the lower Burdekin River Elliot River area, north Queensland.

Chemical analyses showed low soluble salts in the majority of soils, high pH in the 100 to 200 mm depth of some soils, generally very low extractable phosphorus, low to medium extractable zinc levels and adequate copper and manganese levels. Combining ten subsamples into one composite sample at each sampling site gave an acceptable representation of the sites extractable phosphate status.

Lucerne yield responses were obtained from the application of phosphorus, sulphur and molybdenum whereas rice responded to phosphorus and zinc applications only. No difference in nutrient response with lucerne was found using undisturbed cores and conventional sampling.

Marked differences in phosphorus sorption were found between soils with subsoils invariably sorbing more phosphorus than surface soils.

Fertiliser phosphorus requirements were estimated for the different soil depths from phosphorus sorption curves.

INTRODUCTION

Construction of the Burdekin Falls dam will provide some 1.75 million megalitres of water for agricultural and urban use. Development of the irrigation scheme will involve the resumption of up to 140 000 ha of land enabling some 45 125 ha to be irrigated annually (Queensland Water Resources Commission 1980). Little is known of the suitability of these soils for irrigation cropping.

Thompson (1977) provided information on the chemical and physical properties, distribution, and suitability for irrigation cropping of 92 000 hectares of soils on the right bank of the Burdekin River.

It was considered, however, that more detailed information was needed to adequately characterise the fertility of this extensive group of soils. This information would provide the basis for fertiliser recommendations and for designing future field experiments.

To obtain this information, the following experiments, were undertaken on selected soils:

- Intensive soil sampling and analyses to determine the range and variability in chemical properties.

- Nutrient pot experiments on phosphorus rates and 26 half-factorial nutrient trials, using lucerne and rice as indicator plants.

- Phosphorus sorption analysis.

This paper reports the results of these experiments.

MATERIALS AND METHODS

Soils were selected on the basis of their mapping area and suitability for irrigation cropping. Soils selected and their areas(hectares)were: 1Uga 2630; 1Ugd 6870; 3Ugd 4610; 5Dra 14425; 5Dyb 1985; 6Ufc 5200; and 1Dya 20 (included because of its frequent occurrence) For a detailed description see Thompson (1977).

Soil sampling

Intensive sampling for laboratory analyses

The soils were sampled within Thompson's (1977) four reference areas (mapping scale 1:25 000) with each soil mapping unit being divided on a 250 m grid. At a mapping scale of 1:25 000 the mapping units should be 70% pure; hence for each marked grid site the soil profile class was identified to determine if the site was representative of the mapping unit. Ten representative sites were then sampled and analysed within each mapping unit. At each site 10 subsamples were taken, one at a centre point and nine radially spaced from this point. If the soil contained gilgai microrelief, sampling was adjusted so that all samples came from mound areas. Cores were divided into 0 to 100 mm and 100 to 200 mm depths, with the depth increments being bulked to make a composite 0 to 100 mm and 100 to 200 mm depth sample per site. At one sampling site in each soil mapping unit a small subsample from the 0 to 100 mm depth for each of the ten samples was taken for separate analysis before bulking. This was done to measure the variability between samples at a site. All samples were taken with a 44 mm diameter steel tube knocked manually 200 mm into the ground.

Bulk sampling for pot trials

For the pot trials, bulk surface (0–100 mm) samples were taken for each soil at one sampling site. For one soil (5 Dyb), an additional thirty-two undisturbed soil cores 100 mm × 100 mm were taken by a hydraulic soil sampler.

The sampling bit is designed to receive an internal aluminium pipe of slightly greater internal diameter than that of the cutting edge. The core is then removed from the sampler.

Soil analysis

Soil parameters measured were: pH, electrical conductivity, chloride, acid and bicarbonate-extractable phosphorus, exchangeable cations, CEC, organic carbon, extractable potassium, boron, sulphate-sulphur, zinc, copper, manganese and iron. Analytical methods are given by Bruce and Rayment (1982).

Phosphate sorption curves were determined on each of the soils used in the pot experiments and on a 100 to 200 mm sample for each soil; this sample was obtained by subsampling and bulking the 100 to 200 mm depth samples for the ten sampling sites of the initial soil sampling programme. The sorption curves were obtained by shaking 3 g soil end-over-end for 18 hours in 30 mL 0.01M$CaCl_2$ containing phosphate (KH_2PO_4) concentrations equivalent to 0, 10, 20, 40, 70, 100 μgP/g soil. Solutions were then centrifuged and filtered, and phosphate remaining in solution (supernatant P) determined colorimetrically by the method of Murphy and Riley (1962) with a spectrophotometer and a 40 mm flow cell. Curves were drawn by plotting phosphorus sorbed against supernatant P concentration. Phosphorus desorbed (P_D) is as taken as the phosphorus extracted at zero phosphorus addition. The soils phosphate buffer capacity and equilibrium phosphorus concentration (intensity) were determined from the phosphate sorption curves as described by Moody *et al.* (1983).

Pot experiments

Soils were ground, sieved and thoroughly mixed. For each soil a phosphorus rate experiment and a $1/2 \times 2^6$ factorial nutrient experiment was carried out. For all soils lucerne *(Medicago sativa* cv. Hunter River) was used as the indicator plant. Additional trials were carried out on soils 1Uga, 1Ugd, 1Dya and 3Ugd using rice *(Oryza sativa* cv. Starbonnet) as the indicator plant. These soils were selected on the basis of their suitability for rice growth.

The phosphorus rate experiments comprised seven rates of phosphorus: 0, 10, 30, 50, 70, 90, 110 kg P/ha for lucerne and 0, 2.5, 5, 10, 20, 40, 60 kg P/ha for rice. The nutrient was added as $NaH_2PO_4.2H_20$ with rates calculated on an area basis. For lucerne, the experiment was a completely randomised design with three replications, whereas for rice the experiment was a randomised block design with three replications. A basal application of all nutrients used in the factorial experiments was added to each pot.

For the factorial experiments with lucerne, the treatments and rates of application of nutrients (kg/ha) were S, 25 as sodium sulphate; B, 1.25 as sodium borate; K, 52 as potassium chloride; Zn, 7 as zinc chloride; Mo, 0.326 as ammonium molybdate; and Cu, 5.6 as copper chloride, plus Mn, 4.2 as manganese chloride, plus Fe, 1 as ferric citrate. For the factorial experiments with rice, the treatments and rates of application of nutrients (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. A basal application of phosphorus (90 kg P/ha)was added to all lucerne pots. For rice, phosphorus was added at 60 kg P/ha with nitrogen added as urea at a rate equivalent to 60 kg urea/ha/month.

All nutrients were added to the soil surface in solution, except urea which was added to the rice soils by injecting below the surface oxidised layer with syringes.

For the lucerne experiments, 1400 to 1600 g soil was used in polystyrene 150 mm diameter pots. *Rhizobium* inoculant was added to the soil, plants were thinned to six plants per pot. The pots were watered daily to field capacity with deionised water and the plants harvested when 50% of the flower buds had opened.

For the rice experiments, 8 kg of soil was placed in 240 mm diameter black polythene buckets with drain holes. The pots were placed in concrete bays and the soil surface kept moist with frequent watering. Plants were thinned to 10 per pot and permanently flooded to a depth of 30 mm when 60 mm tall. Plants were harvested at maturity and separated on a dry matter and panicle (grain) basis for the factorial experiment. For the phosphorus rate experiment, rice plants were harvested at the flowering stage of growth.

Plant oven dry weight (80°C) for all pots was recorded. Dried and ground plant material from selected treatments of the factorial experiments and from bulked replicates of the phosphorus rate experiments were analysed for nitrogen using a micro Kjeldahl digestion and a modification of the Berthelot (1859) reaction using a calorimetric autoanalyser finish. Phosphorus, sulphur, zinc, copper, manganese and iron were determined by x-ray fluorescence spectroscopy. Molybdenum was determined by ashing the sample,dissolving in acid then complexing the molybdenum with oxine prior to solvent extraction and determination by ICPES.

RESULTS AND DISCUSSION

Soil chemical properties

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

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

Soil property	1Uga		1Ugd		1Dya		3Ugd		5Dra		5Dyb		6Ufc	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
pH														
0–100 mm	7.1	0.04	7.5	0.1	7.5	0.1	6.9	0.1	6.6	0.04	6.7	0.05	6.7	0.05
100–200 mm	7.8	0.1	8.2	0.1	8.6	0.1	7.6	0.1	6.6	0.04	6.7	0.02	6.9	0.1
Electrical conductivity (dS/m)														
0–100 mm	0.05	0.01	0.07	0.01	0.26	0.05	0.04	0.006	0.02	0.002	0.02	0.001	0.04	0.003
100–200 mm	0.10	0.02	0.10	0.01	0.76	0.12	0.06	0.01	0.02	0.001	0.02	0.006	0.03	0.003
Chloride (mg/kg)														
0–100 mm	<18		34	4	242	70	23	1	<18		<18		28	4
100–200 mm	19	3	36	6	795	168	19	1	<18		<18		25	3
Acid extractable phosphorus (mg/kg)														
0–100 mm	7	1	6	1	6	0.5	7	0.5	12	1	8	1	220	19
100–200 mm	5	0.5	3	0.3	3	0.5	4	0.4	5	1	4	0.4	181	22
Bicarbonate extractable phosphorus (mg/kg)														
0–100 mm	10	1.2	3	0.7	7	0.6	9	0.5	9	1	6	1	55	4.4
100–200 mm	6	0.45	2	0.6	5	0.4	6	0.7	4	0.4	3	0.2	39	4.8
Exchangeable cations (meq per 100g)														
Ca 0–100 mm	16	2	12	1	9	2	25	1	6	0.2	7	0.5	15	0.8
Mg 0–10 0 mm	17	1	16	0.5	10	1	22	1	3	0.2	4	0.3	10	1
Na 0–100 mm	0.29	0.03	0.91	0.1	2.54	0.83	0.47	0.09	0.06	0.01	0.07	0.01	0.42	0.16
K 0–100 mm	0.21	0.03	0.25	0.02	0.14	0.01	0.36	0.05	0.27	0.03	0.20	0.06	0.60	0.09
Replaceable K (meq per 100g)														
0–100 mm	0.24	0.03	0.26	0.02	0.17	0.01	0.35	0.04	0.25	0.03	0.19	0.04	0.74	0.08
100–200 mm	0.21	0.03	0.20	0.03	.14	0.01	0.28	0.04	0.23	0.04	0.16	0.03	0.59	0.07
Organic carbon (%)														
0–100 mm	1.06	0.04	0.51	0.02	0.6	0.04	0.82	0.03	1.08	0.08	1.32	0.09	2.25	0.15
100–200 mm	0.57	0.03	0.37	0.009	0.48	0.03	0.57	0.01	0.57	0.06	0.74	0.08	2.02	0.18
Extractable zinc (mg/kg)														
0–100 mm	0.5	0.06	0.5	0.05	0.7	0.1	1	0.1	2	0.2	2	0.2	5	0.6
Extractable copper (mg/kg)														
0–100 mm	1.8	0.1	1.7	0.1	1.4	0.1	2.3	0.15	2	0.1	2	0.1	3	0.3
Extractable manganese (mg/kg)														
0–100 mm	33	7	31	7	30	6	45	9	121	8	118	5	106	6
Extractable iron (mg/kg)														
0–100 mm	13	4	5	1	7	2	10	3	57	7	72	9	79	11

The pH values of the 0 to 100 mm depth for all soils are neutral to mildly alkaline and are considered suited to most crops. However, problems may be encountered with strongly alkaline soils at 100 to 200 mm depth in soils 1Uga, 1Ugd, 1Dya and 3Ugd, especially if the subsoils are exposed during levelling. This may occur in soils 1Uga, 1Ugd, and 3Ugd because these soils exhibit gilgai microrelief.

The electrical conductivity and chloride levels for all soils apart from 1Dya range from low to very low and should pose no problems for crop growth. The chloride levels in the 100 to 200 mm depth for 1Dya are medium to high and could cause problems, especially for rice.

All soils (apart from 6Ufc) are considered low to very low in extractable phosphorus for all crops apart from rice. In all soils the 100 to 200 mm depth has lower extractable phosphorus than the 0 to 100 mm sample. The range of values obtained was much lower than that found by Thompson (1977).

In soils 3Ugd, 5Dra, 5Dyb and 6Ufc, calcium is the dominant cation whereas in soils 1Uga, 1Ugd, and 1Dya magnesium is the dominant cation. The values obtained do not indicate any likely plant nutrition problems. The dominance of magnesium and sodium in soil 1Dya could indicate poor physical properties.

Values for exchangeable and extractable potassium are high in soil 6Ufc, medium in soils 1Uga, 1Ugd, 3Ugd, 5Dra, and low in soils 1Dya and 5Dyb. In these latter two soils, levels are below 0.2 meq per 100 g, a figure associated with deficiencies (Piper and DeVries 1960).

Organic carbon levels in the surface 100 mm depth for all soils except 6Ufc are low and decrease in the 100 to 200 mm depth.

Zinc levels in soils 1Uga, 1Ugd, and 1Dya are low. The high pH in the 100 to 200 mm depth of these soils would also reduce zinc availability. Levels in the 0 to 100 mm depth for remaining soils are medium. Copper levels in all soils are medium and should not reduce plant growth. Manganese levels range from medium to high indicating deficiencies should not be a problem. No interpretative data are available for iron.

The acid extractable phosphate values for mean of ten subsamples compared with mean of a composite sample (Table 2) are generally comparable for the two sampling methods. This indicates that these soils may be quite homogenous for acid extractable P and an adequate estimate of the P status of these soils can be obtained from a composite sample.

Table 2. Mean and standard error (SE) for acid extractable phosphate for 10 subsamples and mean of the composite sample

Soil	Acid Extractable P (μg/g)		
	Mean (10 subsamples)	SE	Composite
1Uga	5	0.5	9
1Ugd	7	1.4	9
1Dya	10	0.7	7
3Ugd	7	0.3	7
5Dra	12	1.7	8
5Dyb	8	0.3	9
6Ufc	265	5.6	255

Pot experiments

Chemical properties for the seven soils used in the pot experiments are shown in Table 3. Notable differences to results in Table 1 were in soils 1Uga and 1Ugd where pH and electrical conductivity values suggest that soil from 100 to 200 mm depth was included in the sample.

Phosphorus rate experiments

Dry matter production of lucerne was increased by phosphorus addition on all soils except 6Ufc. Dry matter yields on soils 3Ugd, 1Ugd, 1Uga, 1Dya, 5Dra and 5Dyb at nil phosphorus were 9, 8, 10, 12, 48 and 30% of the respective maximum yields attained. Significant ($P<0.01$) quadratic regression equations were determined for all phosphorus responsive soils:

$$1\text{Uga}\quad Y = 0.056 + 0.0967\,x - 0.000507\,x^2$$

$$\text{1Ugd } Y = 0.293 + 0.0816\,x - 0.00037\,x^2$$

$$\text{5Dyb } Y = 0.556 + 0.0467\,x - 0.00027\,x^2$$

$$\text{3Ugd } Y = 0.471 + 0.0492\,x - 0.00015\,x^2$$

$$\text{5Dra } Y = 1.492 + 0.0565\,x - 0.00035\,x^2$$

$$\text{1Dyd } Y = 0.339 + 0.0444\,x - 0.00017\,x^2$$

These equations were used to calculate the amount of phosphorus required for 90% maximum yield: 50 kg P/ha for soil 5Dra, 65 to 75 kg P/ha for soils 5Dyb, 1Uga and 1Ugd, and 90 kg P/ha for soils 1Dya and 3Ugd. Plant phosphorus concentrations increased in all soils with increasing phosphorus applied. However, in soils 1Ugd and 1Uga, the phosphorus concentration was below the suggested critical level 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 1Uga, 1Ugd and 1Dya. Yields for the zero phosphorus treatment were 1, 3 and 88% of the respective maximum yield obtained. The amount of phosphorus required for 90% maximum yield was estimated from quadratic regression equations:

$$\text{1Ugd } Y = 4.996 + 1.764\,\text{x} - 0.0222\,x^2$$

$$\text{1Uga } Y = 2.623 + 1.754\,x - 0.0196\,x^2$$

$$\text{1Dya } Y = 45.82 + 0.223\,x - 0.00199\,x^2$$

Phosphorus required was 25 kg P/ha for 1Uga, 20 kg P/ha for 1Ugd and 5 kg P/ha for 1Dya. In soil 3Ugd, there was no significant ($P<0.05$) yield response to phosphorus addition.

Table 3. Chemical properties of soils (0 to 100 mm) used in the pot experiments

Chemical property	1Uga	1Ugd	1Dya	3Ugd	5Dra	5Dyb	6Ufc
pH	7.9	8.1	6.5	6.0	6.0	6.0	6.2
Electrical conductivity (mS/cm)	0.193	0.16	0.12	0.08	0.06	0.05	0.10
Acid extractable phosphorus (mg/kg)	7	6	6	5	22	8	239
Bicarbonate extractable phosphorus(mg/kg)	8	4	8	7	18	11	48
Exchangeable cations (meq per 100g)							
Ca^{++}	25	25	6.5	30	9.7	8.2	23
Mg^{++}	16	14	9.1	22	4.4	3.5	6.5
Na^{+}	0.44	0.61	2.1	0.65	<0.1	<0.1	0.10
K^{+}	0.37	0.27	0.20	0.42	.44	.25	0.88
CEC	40	37	23	60	22	18	39
Extractable boron (mg/kg)	0.2	0.3	0.6	0.3	0.3	0.3	0.3
Extractable sulphate (mg/kg)	5.0	3.5	5.7	4.5	3.0	4.0	3.0
Extractable zinc (mg/kg)	0.4	0.3	0.6	0.7	3.4	1.2	2.7
Extractable copper (mg/kg)	1.7	2.1	2.2	2.3	1.7	1.6	2.2
Extractable manganese (mg/kg)	17	24	100	95	125	119	146
Extractable iron (mg/kg)	15	19	63	37	49	36	43

Factorial experiments

Lucerne

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

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

Effect	3Ugd	1Ugd	1Uga	1Dya	5Dra	5Dyb	6Ufc	5Dyb[u]‡
Lucerne experiments								
S	2.19**	2.74**	2.14**		2.52**	1.19*	2.28**	1.99**
Mo	2.48**				1.35**	1.29**		1.50**
Cu Mn Fe					0.89**			
S × Mo	**				**	**		**
Mean Yield (g/pot)	2.26	3.61	3.01	2.65	2.66	1.61	2.97	1.01
CV%§	23	16	10	29	9	16	12	23
Rice experiments								
Zn		1.08**	1.08**					
S×Zn			*					
Mean Yield (g/pot)	39.29	31.39	30.78	46.17				
CV%	6	8	6	11				

* 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 plants $P<0.01$.

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

‡u = Undisturbed cores.

§CV = Coefficient of variation.

Addition of sulphur increased lucerne dry matter yields on all soils except 1Dya. Mean plant sulphur percentage for sulphur treated plants was 0.24% (range 0.20 to 0.31%) compared with 0.09% (range 0.08 to 0.19%) for nil sulphur addition. The suggested critical value is 0.20% (Andrew 1977). Sulphur deficient plants were a much paler green in colour than sulphur sufficient plants, which is indicative of both sulphur and nitrogen deficiency. Plant sulphur concentrations were found to be highly correlated with plant nitrogen concentrations (r=0.91, $P<0.001$).

The pot data indicate potential sulphur deficiency over large areas of the Burdekin River–Elliot River area. Phosphate extractable sulphate-S levels in the 0 to 100 mm soil depth ranged from 3 to 5 mg/kg for sulphur deficient soils while the one non sulphur responsive soil (1Dya) had a level of 5.7 mg/kg.

These results must be viewed in conjunction with possible sulphur availability from subsoil sulphate under field conditions. Jones (1970) concluded that subsoil sulphur accounted for the lack of lucerne response to sulphur applications, while White *et al.* (1981) suggested a critical soil level of 3.5 mg/kg in the 0 to 800 mm zone for lucerne. Grundon *et al.* (1985) suggested that inconsistency between glasshouse and field response to sulphur may be caused by pot experimentation exhausting mineral sulphur, thereby increasing the number of sulphur deficiencies determined in pot trials.

Nevertheless since shallow rooted annual crops will be grown under irrigation on the soils studied, sulphur deficiency is a distinct possibility.

Plant growth responded to molybdenum addition in soils 3Ugd, 5Dra and 5Dyb. In soil 5Dra, the response to molybdenum occurred only after correction of sulphur deficiency, while the response to sulphur occurred irrespective of molybdenum addition. In soils 3Ugd and 5Dyb no response to molybdenum or sulphur occurred unless both nutrients were applied. After correcting for sulphur deficiency plant nitrogen concentrations increased from a mean value of 1.96% to 3.1% upon addition of molybdenum indicating the response to molybdenum may have been essentially a nitrogen response; as shown by Johansen *et al.* (1977).

Molybdenum deficiency often occurs on acid soils (Lucas and Knezek 1972) and care should be taken when cropping these soils to prevent any decrease in soil pH. The responses obtained here should be viewed in the knowledge that a legume such as lucerne will normally have a higher molybdenum requirement for nodulation than for host plant growth. Molybdenum levels in these soils may be sufficient for non legumes.

Hot water extractable boron in the soils studied was very low to very low (Rayment and Bruce 1984), but no response to boron was noted in the pot experiments. However, boron deficiency is known to occur in vegetable crops within the area.

Soil analyses indicate that extractable copper levels should be adequate for plant growth, whereas for zinc, soils 1Uga and 1Ugd would be considered deficient. Mean plant nutrient concentrations in this experiment of 12.6 mg/kg for copper and 32 mg/kg for zinc indicate sufficiency when compared with the suggested critical values of 7 mg/kg for copper and 15 mg/kg for zinc (Melsted *et al.* 1969).

The slight growth reduction due to copper plus manganese plus iron addition in soil 5Dra is unexplainable; plant analyses showed similar nutrient concentrations between plus and minus nutrient treatments indicating nutrient toxicity was not depressing growth.

The results for soil 5Dyb indicate that there is no advantage in terms of nutrient response between taking undisturbed cores compared with the conventional method of collecting a disturbed 0 to 100 mm sample for pot trials. Both techniques showed the same nutrient responses with the undisturbed technique having a slightly higher coefficient of variation (23% vs. 16%). In terms of manpower operations, the conventional technique of taking a disturbed soil sample is far superior to taking undisturbed cores.

Rice

Significant yield ratios for main effects and significant two factor interactions for yield of rice straw are shown in Table 4. There were no significant responses to treatments applied on panicle yields.

Yields of rice straw were significantly increased by the addition of zinc on soils 1Uga and 1Ugd, with a sulphur by zinc interaction in soil 1Uga. Plant zinc concentrations ranged from 15 to 21 mg/kg for nil zinc treatments compared with 22 to 26 mg/kg for zinc treated plants. These results indicate deficiency and sufficiency respectively (Mikkelsen and Kuo 1976). Also, the DTPA extractable zinc levels in soils 1Uga and 1Ugd are less than the critical value of 0.51 mg/kg quoted as deficient for rice growth by Xie Zhen-chi *et al.* (1981).

It is noteworthy that the two soils responding to zinc application are the only soils with alkaline pH (Table 3). Zinc deficiencies are common in alkaline or calcareous soils with pH of 7.4 or higher (Mikkelsen and Kuo 1976). The pH of the 0 to 100 mm depth of 1Uga and 1Ugd were lower in the intensive field sampling (Table 1) than in the soil collected for the pot experiment (Table 3). This suggests that the sampling depth for these two pot soils may have been greater than 0 to 100 mm. The zinc response could also have been accentuated by the rate of phosphorus addition per pot (equivalent to 60 kg P/ha), a rate that has induced zinc deficiency in rice (Xie Zhen-chi *et al.* 1981).

Even though panicle yields did not increase when zinc was applied the results indicate a potential zinc deficiency in these soils, especially if alkaline subsoils are exposed. This problem has already occurred in rice crops following land levelling in the Burdekin area (J. E. Maltby and T. J. McShane unpub. data 1982).

Phosphorus sorption analysis

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

Table 5. Phosphorus buffer capacity (PBC), Equilibrium phosphorus concentration (EPC), and phosphorus desorbed in 0.01M$CaCl_2$(P_D) for each soil at two sampling depths

Soil	Depth mm	PBC L/g	EPC ug/mL	P_D ug/g
3Ugd	0–100	50	0.008	0.020
	100–200	49	0.007	0.020
1Ugd	0–100	52	0.025	0.060
	100–200	51	0.012	0.020
1Uga	0–100	59	0.009	0.037
	100–200	53	0.004	0.020
1Dya	0–100	43	0.018	0.040
	100–200	44	0.018	0.050
5Dra	0–100	46	0.045	0.260
	100–200	45	0.006	0.010
5Dyb	0–100	47	0.014	0.050
	100–200	49	0.004	0.010
6Ufc	0–100	57	0.407	2.61
	100–200	47	0.161	1.01

The results indicate a relatively narrow range of phosphate buffer capacities among soils, and that the 0 to 100 mm and 100 to 200 mm samples for a particular soil have phosphate buffer capacities. This shows that for each soil the P sorption curve for the 100 to 200 mm depth has the same slope as the 0 to 100 mm depths. Fox, Yost, and Memon (1981) stated that a useful characteristic of phosphate sorption curves is that the curve is shifted to the right by phosphate fertiliser additions to the soil. For all soils apart from 3Ugd and 1Dya, the 100 to 200 mm curve is shifted to the left of the 0 to 100 mm curve with a greater relative shift for the duplex (5D) soils. This result indicates that if the 100 to 200 mm soil depths are exposed when levelling for irrigation purposes, then the rate of fertiliser needed to attain a non limiting soil solution P concentration for plant growth will be higher than those needed for the 0 to 100 mm depth. That there is a difference between the two soil depths is shown by the lower EPC and PD in the 100 to 200 mm depth for all soils apart from 3Ugd and 1Dya. It is assumed that the 100 to 200 mm depth of these latter two soils will behave similarly in terms of P sorption to the 0 to 100 mm depth.

Estimated fertiliser P requirements for the 0 to 100 mm and 100 to 200 mm depths are shown in Table 6. These requirements were estimated from the P sorption curves assuming supernatant 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 non limiting concentrations for plant growth. As expected requirements are highest for the 100 to 200 mm depths.

Field trials by departmental officers (unpublished) on a 5Dra soil indicated that 15 kg P/ha was required for maximum growth of soybeans. Estimated fertiliser requirement for the 100 to 200 mm depth in thissoil is 12 kg/ha (Table 6). No data is available for maize growth on these soils.

Acid extractable phosphate (P_A), bicarbonate extractable phosphate (P_B) and phosphorus desorbed (P_D) were highly correlated with intensity ($P<0.01$) but not with buffer capacity. These results are similar to those of Moody, *et al.* (1983), who considered the correlation of PA and PB with intensity to be an artifact of their suite of soils.

Relative yield (yield at nil P addition/max yield) for lucerne is correlated with EPC, P_D, P_A and P_B ($P<0.01$) for 0 to 100 mm depths but not with PBC. However, it is considered that the spread of data points is not large enough for any definitive comment to be made regarding the most suitable method of predicting response to phosphorus; at least in pots. Relative yield of rice was not significantly correlated with EPC, PBC, P_D, P_A and P_B measured on air dry soil. This tends to indicate that the measurement of phosphate availability on air dry soil did not provide a good representation of phosphorus availability under reduced conditions. These being dependent on changes in the sorption properties of the soil as well as the solubility of iron phosphates (Holford and Patrick Jr. 1979).

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

Soil	P required (kg/ha) to attain 0.01 µg/mL supernatant P concentration		P required (kg/ha) to attain 0.02 µg/mL supernatant P concentration	
	0–100 mm	100–200 mm	0–100 mm	100–200 mm
1 Uga	5	30	28	53
3 Ugd	7	12	26	31
1 Ugd	0	0	0	16
1 Dya	0	0	3	5
5 Dyb	0	25	8	44
5 Dra	0	12	0	31
6 Ufc	0	0	0	0

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