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Soil phosphorus tests and grain yield responsiveness of maize (*Zea mays*) on Ferrosols

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Abstract

The grain yield response of maize (*Zea mays*) to various rates of applied phosphorus (P) was measured at each of 17 sites in the South Burnett region of south-eastern Queensland. The soils at all sites were Ferrosols. Relative grain yield of the nil applied P treatment [100×(yield at nil applied P/maximum yield)] was related to Colwell (0·5 M $NaHCO_3$) extractable P (P_B), $CaCl_2$-extractable P, and equilibrium P concentration and P buffer capacity calculated from P sorption curves. Of these P measurements, P_B was most highly correlated with relative grain yield ($R^2 = 0\cdot94$ for a linear response and plateau fit, $R^2 = 0\cdot92$ for a Mitscherlich fit), and the P_B values at 90% maximum grain yield were 20 mg/kg for the linear response and plateau model and 32 mg/kg for the Mitscherlich equation.

Additional keywords: corn, oxisols.

Introduction

Red, Brown, and Yellow Ferrosols (Isbell 1996) [classified as Oxisols by the US Taxonomy (Soil Survey Staff 1992)] occur extensively in the South Burnett region of south-eastern Queensland, and maize (*Zea mays*) is the principal summer grain crop grown on these soils in rotation with peanut (*Arachis hypogeae*) and soybean (*Glycine max*). Maize is also extensively grown on Ferrosols in other areas of Australia, and band applications of nitrogen (N), phosphorus (P), and potassium (K) fertilisers are typically applied at planting. Ferrosols have a high P sorption capacity (Moody 1994), and so it is essential that the P status of the soil is known for the formulation of fertiliser requirements. Correlations of soil P tests with soybean grain yield response to applied P fertiliser on these soils found that 0·01 M $CaCl_2$ extractable P best reflected soil P availability (Moody *et al.* 1983). This indicates that, of the soil P supply factors which describe P supply to the plant (i.e. quantity, intensity, and buffer capacity), the intensity factor (i.e. the concentration of P in the soil solution) is the most important for soybean (Moody *et al.* 1990). Phosphorus extracted by 0·5 M $NaHCO_3$ (Colwell 1963), which can be considered to reflect the quantity factor (Dalal and Hallsworth 1976), was only poorly correlated with soybean grain yield responsiveness. The soil P test (and by inference, the soil P supply factor) that is best correlated with maize grain yield response to P on Ferrosols of the South Burnett region is unknown. In field experiments in the USA, relative grain yield of maize has been correlated with the Bray 1, Bray II, and Mehlich extractants. For example, Beegle and Oravec (1990) found that the Mehlich 3 extractant allowed the best

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separation of responsive from non-responsive soils in Pennsylvania, and Locke and Hanson (1991) obtained critical values at 95% relative grain yield for Bray I, Bray II, and Mehlich 2 extractable P for one soil in Missouri.

The aim of this work was to measure the soil P supply factors of Ferrosols of the South Burnett region by the use of appropriate extractants, and to correlate these extractants with grain yield responsiveness of maize.

Materials and methods

Sites

During 1985–91, 17 field experiments were carried out on Ferrosols in the South Burnett region of south-eastern Queensland. Some properties of the soils are indicated in Table 1.

Table 1. Some properties of the 17 field site soils, and relative grain yield of maize in the control (nil applied phosphorus) plots

Pc, $0 \cdot 01$ M $CaCl_2$ extractable P; P_B, $0 \cdot 5$ M $NaHCO_3$ extractable P; EPC, equilibrium P concentration; PBC, P buffering capacity

Site	pH (1 : 5 water)	Organic C (%)	Clay (%)	P_C (μg/kg)	P_B (mg/kg)	EPC (μg/L)	PBC (L/kg)	Relative yield (%)
1	7·3	1·8	61	71	45	12	68	85
2	6·7	1·9	62	57	37	10	68	90
3	5·8	1·3	73	46	57	8	62	92
4	5·9	1·5	73	47	46	8	63	94
5	6·5	2·7	57	91	49	18	59	108
6	6·7	2·5	51	47	22	7	45	88
7	5·8	2·3	48	43	33	7	54	85
8	6·0	1·1	n.d.	28	29	5	58	92
9	5·5	2·1	40	35	30	9	51	87
10	5·5	2·8	43	19	30	4	72	89
11	5·6	2·7	45	44	34	10	59	88
12	6·5	2·2	30	21	14	6	38	66
13	6·2	1·7	59	20	17	4	81	80
14	5·9	1·6	60	19	14	4	50	63
15	6·2	1·0	55	20	7	2	74	22
16	5·5	1·4	n.d.	25	11	4	117	38
17	5·8	1·2	n.d.	23	4	3	41	21

n.d., not determined.

Experimental detail

Treatments comprised 0, 20, 40, and 80 kg P/ha band-applied as diammonium phosphate (DAP) (20% P) at planting. There were 4 replicates in a randomised block layout. Plots were 4 plant rows, $0 \cdot 9$ m apart and 20 m long, with the 2 centre rows used as datum rows. Maize cv. Pioneer 3270 was sown in December each year and hand-thinned to 30 000 plants/ha. Potassium (as KCl) was band-applied with the DAP at 50 kg/ha, and N (band-applied as urea) was balanced across all treatments at the rate of 57 kg/ha. The fertiliser band was 5 cm to the side of, and 5 cm below, the seed. Cobs were harvested with a 2-row autoheader and grain yield was expressed on a 14% moisture basis.

Soil measurements

Composite 0–10 cm soil samples (comprising 20 cores) were taken from each block immediately prior to planting. Samples were air-dried (40°C for 48 h), passed through a 2-mm sieve, and analysed for pH and electrical conductivity (1 : 5 soil : water), organic C (Walkley–Black uncorrected; Nelson and Sommers 1982), and clay content. The following soil

P parameters were determined: equilibrium P concentration (EPC) and P buffer capacity (PBC) from P sorption curves (4 g soil: 40 mL 0·01 M $CaCl_2$, 18 h shake at 25°C) (Moody *et al*. 1983), 0·5 M $NaHCO_3$ extractable P (P_B) (Colwell 1963), and 0·01 M $CaCl_2$ extractable P (P_C) (Moody *et al*. 1983).

Statistical analysis

At those sites where analysis of variance indicated that there was a significant ($P < 0{\cdot}05$) grain yield response to applied P, maximum grain yield was calculated by fitting Mitscherlich equations to the yield *v*. rate of applied P data. At the non-responsive sites, maximum grain yield was calculated as the mean yield of all the applied P treatments. Relative grain yield of the control (nil applied P) treatment of each site was calculated as 100×(yield at nil applied P/maximum yield). Relative yield was then regressed against each of EPC, P_C, and P_B using Mitscherlich and linear response and plateau equations of best fit.

Results and discussion

Phosphorus buffer capacity ranged from 38 to 117 L/kg with a mean of 62 L/kg. For the Ferrosols of this region used to calibrate soil P tests against the yield responsiveness of soybean, Moody *et al*. (1983) reported a range of 40–109 L/kg with a mean of 68 L/kg. The ranges in EPC, P_B, and P_C in Table 1 are also similar to those of the soils used in the earlier soil P test calibration with soybean. We conclude that the suite of Ferrosols used in the current study is essentially equivalent in terms of range in P sorption properties and P status to that of the soybean study.

Interrelationships between soil phosphorus measurements

Linear correlation coefficients between the soil phosphorus measurements are presented in Table 2. Calcium chloride extractable P is highly correlated with EPC, verifying the usefulness of the former as an estimate of P intensity (cf. Moody *et al*. 1983, 1990). Colwell extractable P was also significantly correlated with EPC, but the inclusion of PBC with EPC in a multiple step-up regression equation did not explain any more of the variation in P_B. These results indicate that the range observed in PBC across Ferrosols of the South Burnett is not sufficiently great to result in PBC having a significant effect on the relationship between quantity and intensity factors. Such an effect would be expected over a wider range of soil types and therefore PBC values.

Table 2. Correlation coefficients between soil phosphorus parameters

Parameter	P_B	EPC	P_C
PBC	−0·05	−0·15	−0·08
P_C	0·75***	0·94***	
EPC	0·75***		

*** $P < 0{\cdot}001$.

Relationships between soil phosphorus measurements and relative grain yield of maize

Of the soil P parameters, P_B accounted for 92 and 94% of the variance in relative grain yield by Mitscherlich and linear response and plateau fits, respectively, and the relationships are presented in Fig. 1. The values of P_B at 90% relative grain yield are 32 mg/kg for the Mitscherlich fit and 20 mg/kg for the linear response and plateau fit. The difference in these 2 soil test values reflects the different shapes of the 2 regression lines as maximum yield is approached (Fig. 1). Rayment *et al.* (1980) reported similar differences when attempting to derive critical soil P test values for *Desmodium intortum* cv. Greenleaf/grass pastures using several different response equations. We suggest that because the linear response and plateau model is a better fit to the current maize data than the Mitscherlich equation, a critical value of 20 mg/kg be used for diagnostic purposes.

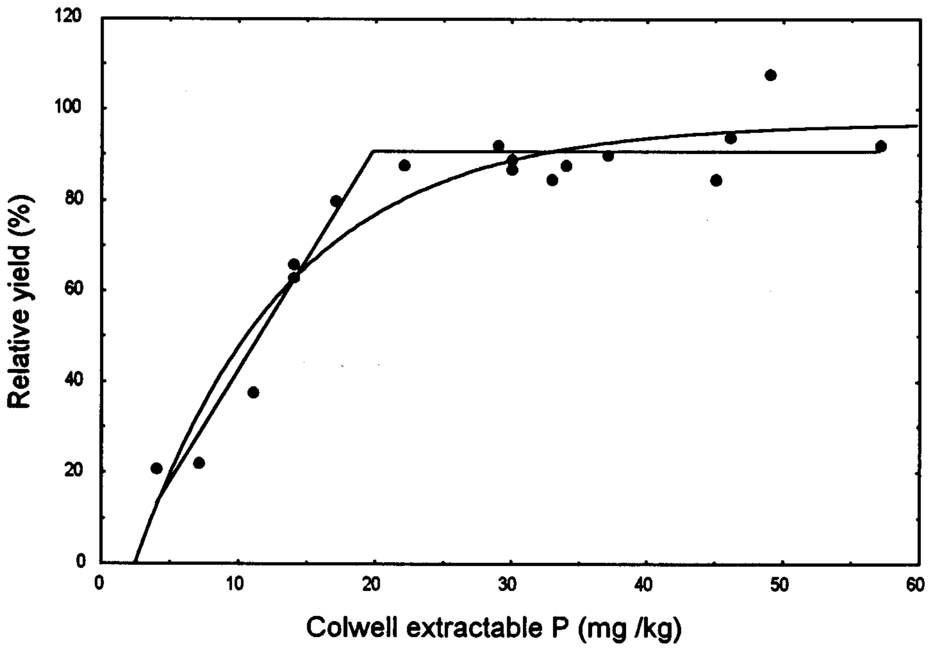

Fig. 1. Relationship between relative grain yield of maize and Colwell extractable phosphorus for 17 Ferrosols. Mitscherlich equation of best fit is $y = 97 - 120{\cdot}9e^{-0{\cdot}090x}$ ($R^2 = 0{\cdot}916$, $P < 0{\cdot}001$). For linear response and plateau equation of best fit, $R^2 = 0{\cdot}941$ ($P < 0{\cdot}001$).

Neither EPC nor P_C was as highly correlated with relative grain yield as was P_B. The best fit Mitscherlich equation explained 71% of the variance for EPC, and 40% of that for P_C. This result suggests that soil P supply to maize is dependent on the quantity factor, that is, the amount of P in solution plus an amount of P adsorbed onto soil surfaces. This contrasts with P supply from similar soils to soybean, which is dependent on the intensity factor (i.e. the P concentration in the soil solution) (Moody *et al.* 1983). The difference in the P supply factor determining P availability to these 2-row crops on Ferrosols is probably a reflection of the relative depletion of soil P reserves in the root-zone by the 2 crops. Phosphorus uptake is initially dependent on soil solution P concentration (intensity), but continued depletion of solution P causes the rate of P arrival at the root surface to be increasingly determined by the desorption buffer capacity of the soil and the quantity factor. The difference between the crops in P depletion of the root-zone may be caused by differences in (*a*) the contribution of mycorrhizae and root hairs to the overall P uptake of the 2 crops, (*b*) the physiological uptake characteristics of the roots, or (*c*) the patterns of plant P demand during the development of the crops.

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