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Comparative soil phosphorus requirements of four field crops

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Abstract

A range of soil phosphorus levels was established at one site on a euchrozem near Kingaroy in south-east Queensland, by dispersing rates of triple superphosphate (0–480 kg P/ha) through the 0–100 mm layer. Following two cover crops to allow equilibrium between fertiliser and soil, successive crops of barley, soybean, sorghum and peanut were grown.

For each plot and each crop, Mitscherlich equations were fitted to relative seed yield versus extractable soil phosphorus levels determined on soil samples taken prior to planting. Bicarbonate extractable P levels corresponding to 90% maximum seed yield for sorghum, barley, soybean and peanut were 34, 29, 18 and 10 mg/kg respectively.

Relative seed yields at the low bicarbonate extractable P levels (6–8 mg/kg) of the nil applied phosphorus plots decreased in the order: peanut $>>$ soybean $>$ sorghum $>$ barley.

In terms of increasing ability to utilise banded phosphorus fertiliser, the crops ranked: peanut $<$ soybean $<$ sorghum $<$ barley.

INTRODUCTION

Crops vary in their phosphorus fertiliser requirements because of differences in physiology; for example, rate of phosphorus uptake, and in morphology; for example, root surface area. This variation is important to the phosphorus fertiliser management of crop rotations as it dictates which crops will require fertiliser and which crops will produce maximum yields by utilising residual fertiliser phosphorus.

Crops vary in their ability to utilise band-applied phosphorus fertiliser. Kalra (1971) used radioactive tracer techniques to show that rapeseed (*Brassica napus*) obtained 38.8% of its phosphorus from a banded source in a low P soil, compared with only 13.1% for soybean (*Glycine max*). Strong and Soper (1973) studied the efficiency of a number of crops in absorbing phosphorus from a banded source. They concluded that an efficient plant must be able to extensively proliferate its root system around points of application of fertiliser pellets and/or have a root system which can very efficiently absorb phosphorus from high concentrations.

A fertiliser management strategy for a crop rotation must take into account the different ability of each crop to utilise diffuse sources of P, such as native soil P or residual fertiliser P which has been dispersed through the soil, and concentrated sources of P such as freshly applied banded fertiliser P. This study aimed to provide some of the basic information needed to derive a fertiliser management strategy for four crops by comparing yield responses to diffuse and concentrated sources of P.

MATERIALS AND METHODS

Experimental design and techniques

Field plots 5.4 m wide and 18 m long were established on a site on the J. Bjelke-Petersen Research Station near Kingaroy in south-east Queensland. The soil is a euchrozem of principal profile form Uf 6.31 (Northcote 1979). Some chemical characteristics of the 0–100 mm sample are: pH (1:5, soil:water), 6.2; exchangeable Ca, Mg, Na and K, 4.9, 5.9, 0.09 and 0.36 m equiv./100 g respectively; effective CEC, 12 m equiv./100 g; organic carbon content, 1%; and clay content, 55%.

On 8 September, 1983, phosphorus rates of 0, 30, 60, 120, 240 and 480 kg P/ha as triple superphosphate (19.2% P) were broadcast onto plots replicated three times in a completely randomised design. The site was then rotary hoed to ensure even mixing of the fertiliser to a depth of 100 mm.

At the time of planting each test crop, three previously unfertilised plots received 30 kg P/ha in a band 50 mm to the side of the seed.

After incorporation of the broadcast fertiliser, maize and navy bean cover crops were grown on the site during spring and summer (1983–84). The maize crop was forage harvested to avoid crop residue transfer between plots. The navy bean crop was harvested and plant residues were removed from the site.

The four test crops grown consecutively were barley (*Hordeum sativum*), soybean (*Glycine max)*, grain sorghum (*Sorghum bicolor*) and peanut (*Arachis hypogaea*). These crops were grown using conventional dryland techniques. However, supplementary spray irrigation was available to any crop experiencing prolonged moisture stress. Water (30 mm) was applied to ensure the emergence of the barley crop, and the soybean and peanut crops received one 60 mm application each at pod fill and at pegging stage, respectively.

Fertilisers were applied according to the requirements of each crop for particular nutrients and are shown in Table 1 together with some other management details.

Table 1. Some crop management details for the four crops

Crop	Cultivar	Planting rate kg/ha	Row spacing mm	Fertiliser applied kg/ha	Date planted	Date harvested
Barley	Grimmett	60	175	185 urea	18 June 84	20 Nov 84
Soybean	Bragg	65	900	Nil	3 Jan 85	16 May 85
Sorghum	CS 285	5	900	150 urea	12 Dec 85	14 May 86
Peanut	Virginia Bunch	90	900	100 muriate of potash	12 Nov 86	9 April 87

Soil sampling

Prior to the planting of each crop, ten 0–100 mm cores were taken at random from each plot, bulked to give one composite per plot, air dried, ground and sieved (< 2 mm).

Soil analysis

Bicarbonate extractable phosphorus (P_B) (Colwell 1963) and equilibrium phosphorus concentration (EPC) (Moody *et al.* 1983) were determined on all soil samples.

Mycorrhizal infection

Peanut root samples were taken at flowering from several plants in plots to which no P had been applied. Microscopic examination after staining revealed vesicles and hyphae of vesicular arbuscular mycorrhizae. Because the experimental area was not subjected to any fallow period greater than 7 months from the start of the experiment in 1983 to the final peanut crop in 1987, it is assumed that sufficient mycorrhizal inoculum was present at all times to infect all crops.

Statistical analysis

For each crop, Mitscherlich equations were fitted to absolute seed yield versus soil P test data and the maximum crop yield calculated. Relative seed yield (plot yield/maximum yield) × 100] for each plot was then calculated and a Mitscherlich equation fitted to the relative yield versus soil P test data. The mean relative yield of the 30 kg P/ha banded treatment was substituted into the appropriate (relative seed yield versus P_B) equation for each crop, to derive the P_B value providing the corresponding yield benefit.

The relationships between P_B sampled prior to each crop and the rate of initial P application (0, 30, 60, 120 and 240 kg P/ha) on 8 September 1983 were established. These quadratic regression equations of best fit, where x is the rate of applied P in kg/ha and y is the bicarbonate extractable phosphorus in mg/kg, are:

pre-navy bean (26 January 1984)

$$y = 5.19 + 0.2848\,x - 0.6918 \times 10^{-4}x^2 \qquad R^2 = 0.99$$

pre-barley (18 June 1984)

$$y = 4.14 + 0.1277\,x - 0.5766 \times 10^{-4}x^2 \qquad R^2 = 0.99$$

pre-soybean (3 January 1985)

$$y = 7.51 + 0.0821x - 0.2737 \times 10^{-4}x^2 \qquad R^2 = 0.99$$

pre-sorghum (12 December 1985)

$$y = 5.82 + 0.0766x - 0.2657 \times 10^{-4}x^2 \qquad R^2 = 0.99$$

pre-peanut (12 November 1986)

$$y = 7.82 + 0.0854x - 0.2697 \times 10^{-4}x^2 \qquad R^2 = 0.98$$

The initial broadcast P rate to produce the level of P_B providing the equivalent yield benefit to 30 kg/ha banded was then calculated from each of the equations. The ratio between the broadcast P rate so derived and 30 kg/ha is a measure of the relative effectiveness of the banded fertiliser applications.

RESULTS AND DISCUSSION

Seed yield

Maximum seed yields calculated for the four crops were 5051, 2629 and7561 kg/ha at 12% moisture content for barley, soybean and sorghum respectively, and 2387 kg nut-in-shell/ha at 9% moisture content for peanut.

Effect of time on extractable phosphorus

The reaction of phosphate with soil is characterised by two processes; fast fixation and slow fixation (Munns and Fox 1976). The former involves the adsorption of phosphate ions onto soil surfaces, and is characterised by a rapid decline in extractable phosphorus. The latter process is characterised by a much slower decline and comprises the balance between phosphorus removal, by further adsorption on soil surfaces and nett removal of phosphorus from the soil in harvested plant materials, and phosphorus addition, by mineralisation of organic matter. The effect of time on P_B is shown in Figure 1, which illustrates the rapid decline (fast fixation) which occurred in P_B between the pre-navy bean (26 January 1984) and pre-barley (18 June 1984) samplings. There is a tendency for P_B to continue to decline at later sampling times (slow fixation) although this decline is not always consistent. This suggests that the removal of phosphorus in harvested plant materials is not of sufficient magnitude to cause successive reductions in P_B following each crop. The equations shown above were calculated without correction for this removal.

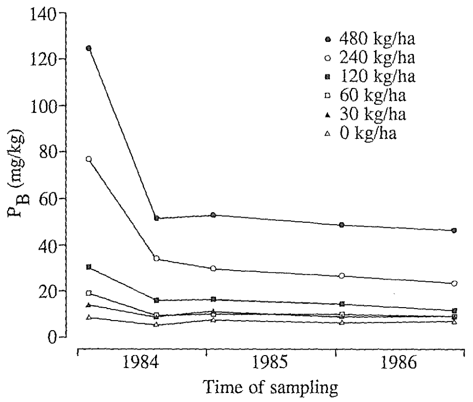

Figure 1. The effect of time on bicarbonate extractable phosphorus (P_B) after an initial application (8 Sep 83) of several rates of phosphorus.

Soil phosphorus requirements

The relationships between relative seed yields of the four crops and P_B are plotted in Figure 2, and the parameters and coefficients of determination obtained from the Mitscherlich equations of best fit are presented in Table 2. For all crops, the coefficients of determination for the relationships between soil P tests and relative yields were lower for EPC than for P_B. This was caused by the poor correlation between EPC and the lowest four P additions (0, 30, 60 and 120 kg P/ha). Coefficients of determination (R^2) ranged from 0.11 to 0.76 for the five pre-crop soil samplings. Thus, although the crop yields responded to these increasing P rates, EPC levels in general did not change.

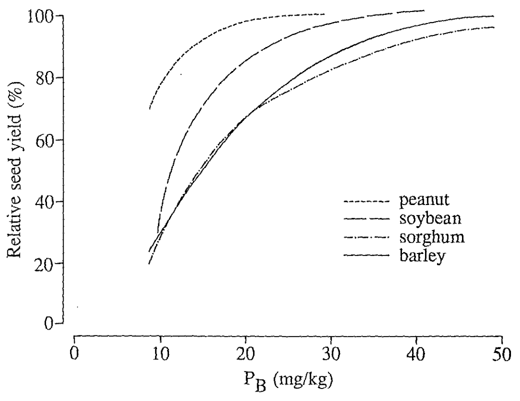

Figure 2. Relationship between relative seed yield of four crops and bicarbonate extractable phosphorus (P_B).

Table 2. Mitscherlich parameters and coefficients of determination (R^2) for the relationships between soil P tests and relative seed yields of four field crops

Crop	Soil test	Mitscherlich parameter*			R^2
		b_0	b_1	b_2	
Barley	P_B	105.00	125.69	0.0749	0.94
	EPC	110.72	174.96	0.2360	0.65
Soybean	P_B	99.32	197.35	0.1680	0.81
	EPC	100.36	251.39	0.6964	0.55
Sorghum	P_B	100.01	106.94	0.0698	0.93
	EPC	147.21	154.04	0.1173	0.74
Peanut	Pb	99.94	88.96	0.2196	0.41
	EPC	109.59	47.22	0.2691	0.25

* Mitscherlich equation of the form: $y = b_0 - b_1 e^{-b_2 x}$ where y = relative seed yield and x = soil test value.

At 90% of maximum seed yield P_B values were 29, 18, 34 and 10 mg/kg for barley, soybean, sorghum and peanut respectively, and corresponding EPC values were 9.1, 4.6 and 3.3 µg/L for barley, soybean and peanut respectively. The EPC value for sorghum was not calculated. The P_B value at 90% maximum yield for peanut compares favourably with approximately 12 mg/kg found by M. J. Whitehouse and S. Langford (unpub. data 1980), but the EPC of 4.6 µg/L for 90% maximum yield of soybean is much lower than the 14 µg/L reported by Moody *et al.* (1983). This difference is attributed to the poor correlation obtained between relative seed yield and EPC in the present study (Table 2). In order of increasing soil phosphorus requirements, the crops rank: peanut < soybean < barley < sorghum.

The relative yields of the crops in unfertilised soil (Table 3) decrease in the order: peanut >> soybean > sorghum > barley. These results indicate that although the relative yield of soybean is only slightly greater than that of sorghum where no P has been applied (on a soil with low P test level), it is much more responsive to increasing soil P levels or to the application of only moderate rates of P fertiliser (for example 30 kg P/ha). Peanut is very efficient at utilising soil phosphorus even at low soil test levels.

These results are similar to those obtained by M. J. Whitehouse and S. Langford (unpub. data 1980). They ranked peanut > navy bean > sorghum in ability to obtain their phosphorus requirements from unfertilised soil.

In order of increasing ability to utilise banded fertiliser, the crops rank: peanut < soybean < sorghum < barley (Table 3). As residual fertiliser phosphorus in a crop rotation will be dispersed by cultivation, peanut and to a lesser extent, soybean will be able to utilise this phosphorus source effectively. However, to obtain maximum fertiliser utilisation by sorghum and barley, banding at planting is required.

Table 3. Relative seed yields of four field crops at 0 and 30 kg P/ha band applied, and the relative effectiveness of 30 kg P/ha band applied, at specified background bicarbonate extractable phosphorus (P_B) levels

Crop	P_B mg/kg	Relative seed yield (%)		Relative effectiveness
		0 kg P/ha	30 kg P/ha	
Barley	6	15.0	76.4	4.4
Soybean	8	39.9	74.7	2.0
Sorghum	7	33.5	52.9	2.7
Peanut	7	85.5	92.6	1.4

The most efficient fertiliser management strategy for rotations involving these crops would therefore be to band apply sufficient P fertiliser to meet the requirements of barley and sorghum, and to grow soybeans and peanuts on the dispersed residual fertiliser.

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