Soil fertility and wheat crop response to phosphorus fertiliser on vertosols in low rainfall areas of the northern grain zone.

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ABSTRACT

Some soils of the western, lower rainfall areas of the northern NSW grain belt have been cropped for more than 40 years yet continue to be important sources of high protein wheat. The P fertiliser requirement of crops in these areas is difficult to predict due in part to large variation in rainfall. Results from field experiments between 1997 and 1999 in the Walgett and Moree areas of northern NSW show that the chemical and physical characteristics of vertosols are highly variable. Sampling the surface 0-10 or 0-15cm of soils can be inadequate for assessing soil P status. Available P below 10cm can make an important contribution to plant P uptake. Although grain yield was highly correlated with extractable P status of the soil profile to 80cm, factors other than soil P also influenced grain yield and response to P fertiliser at some sites. This paper discusses the relationships between soil characteristics, particularly those affecting crop water use, and grain response to P fertiliser in low rainfall areas.

KEY WORDS

Phosphorus, vertosols, fertiliser, low rainfall, guidelines.

INTRODUCTION

In the western, low rainfall areas of northern NSW, vertosols are the dominant soil order, and some have been cropped for more than four decades. Crop response to N fertiliser is common in northern wheat crops (12), and the probability of obtaining a response to other fertiliser nutrients, such as P, increases with the length of cropping history and cumulative nutrient removal. Most field research into the response of wheat to P fertiliser in northern NSW was conducted in areas with less variable and higher long-term mean annual rainfall than the cropping areas of the western plains (5, 6, 9, 10). Variation in rainfall and soil water content has been found to influence yield response to P fertiliser, the 'critical range' of extractable soil P, the relative effectiveness of fertiliser P, and the reliability of predicting P fertiliser requirement (2, 3, 11). Critical concentrations of extractable soil P were higher in years of high rainfall (8, 10), yet other work has shown that favourable soil water content can result in improved root growth and uptake of available soil P (14, 17), resulting in lower critical extractable P concentrations. We collaborated with growers and agronomists to study wheat response to P fertiliser in the lower rainfall cropping areas between Walgett and Moree in northern NSW. The main objective was to develop guidelines for P management.

Materials and methods

Field experiments were conducted from 1997-1999 in paddocks between Walgett (30.02^{o} S, 148.12^{o} E) and Moree (29.50^{o} S, 149.90^{o} E), that have mean annual rainfall of 478 mm and 579 mm, respectively. Experiments tested the response of wheat to P fertiliser at both paddock (strip) and plot scales, the former used commercial farm machinery and the latter used small-scale field plot research equipment. The soil at each field site was sampled to a minimum depth of 120 cm prior to sowing to measure chemical and physical characteristics and gravimetric water content.

Paddock strip-scale: The treatments were 0 and 10 kg ha^{-1} of P applied as triple superphosphate (18% P), and comprised strips of approximately 24 m x 700 m, allocated at random within 15 commercial wheat paddocks. Wheat (cv. chosen by the co-operating growers) was sown with the grower's planter at normal commercial rates. N fertiliser was applied at rates determined from pre-sowing soil analyses. Grain was harvested with a commercial header and experimental site yields were calculated with a mobile weighing bin fitted with load cells. Above ground biomass was measured at approximately mid-tillering, anthesis and maturity in 1997 and 1999. In 1998, extensive and prolonged flooding restricted sampling to maturity only, and most of the analyses presented here exclude the data due to the effects of prolonged waterlogging. Dried biomass and grain of all samples were ground to pass through a 0.5 mm mesh sieve and analysed for N and P content (1).

Plot-scale: The results of the plot-scale experiments reported here are from single sites sown each year at Moree (MorE and MorW in Figure 1). Treatments varied between years and details are presented in Table 1. Plot area varied also between years, but was a minimum of 2.4 m x 20 m. Sampling of above ground biomass was undertaken at similar developmental stages to the paddock-scale experiment. Grain was harvested with small-plot headers.

Table 1. Details of establishment and treatments for plot scale experiments sown at Moree, 1997 – 1999.

Year	Cultivar	Sowing date	Sowing rate ($kg\ ha^{-1}$)	Fertiliser N ($kg\ ha^{-1}$)	P fertiliser treatments ($kg\ ha^{-1}$)
1997	Sunstate	22/5	40	10	0, 10
1998	Sunstate	12/6	40	70	0, 5, 10, 20, 30
1999	Sunstate	18/6	50	40	0, 10, 20, 30

In 1997, 35 mm of water was applied to two sub-plots within each treatment plot at stem elongation. Whole plant above ground biomass was sampled from sub-plots and main plots 24 days later. In 1999, 38 mm of water was applied at mid-tillering to a single sub-plot within each plot. Whole plant above ground biomass was sampled immediately prior to watering, and 5 days later. The youngest fully emerged leaf blades (YFELB) from approximately100 plants were also sampled from each main plot and sub-plot, 5 days after the water application.

Environmental data were recorded at each experimental site. Plant available water at sowing was measured as the difference between soil water content and the lower limit (-1500 kPa.), summed to a profile depth of 120 cm. Crop water use efficiency was calculated (7) in such a way as to provide an apparent transpiration efficiency (yield per unit of transpiration).

RESULTS AND DISCUSSION

There were large differences in physico-chemical properties between soils. Notable characteristics were the presence of relatively large concentrations of bicarbonate-extractable P (4) below 0-10 cm depth (Figure 1) and high ESP in the subsoil (Figure 2) at many sites. The electrical conductivity of saturated extracts (EC_{se}) was very high (>7.7 $dS\ m^{-1}$) also in some subsoils (not presented).

There was no significant difference in grain yield ($p<0.05$) measured for the P treatments in the Walgett paddock-scale experiment, despite the concentration of bicarbonate-extractable P in the surface 0-10 cm of most paddocks being lower than published critical values (10). A weak and non-significant correlation occurred between grain yield and concentration of extractable P in the surface 0-10 cm measured using either bicarbonate extraction (4) or Ca lactate extraction (16) in results from 1997 and 1999. For these same years, a positive relationship occurred between grain yield and mean bicarbonate-extractable P concentration in the profile to 80 cm depth ($r^2 = 0.77$, $p<0.01$), suggesting that crops were taking up an important fraction of their P requirement from deeper in the profile. Assessment of the relationship between grain yield and potential transpiration indicated that all crops in 1997 and 1999 had transpiration efficiency (TE) greater than 10 kg ha^{-1} mm^{-1}; however, a negative relationship between TE and subsoil ESP ($r^2 = 0.58$, $p<0.01$) indicated that subsoil water use in some crops may have been restricted. Crop water status around anthesis has been identified as an important determinant of grain yield (15), and there was a positive correlation between rainfall received in September (approaching anthesis) and grain yield ($r^2 = 0.61$, $p<0.01$) and TE ($r^2 = 0.46$, $p<0.05$).

Adequate P supply from the very early stages of crop development is necessary for satisfactory plant growth, and yield. There was a significant positive correlation between early tissue P concentration (tillering stage) and grain yield ($r^2 = 0.42$, $p<0.05$) for the combined results of 1997 and 1999; however, there were no significant relationships between tissue P and bicarbonate-extractable soil P at any depth in the profile. Rainfall distribution in 1997 contrasted with that of 1999. In 1997, there was very little effective rainfall between sowing and anthesis, whereas 1999 was characterised by higher totals and more even distribution during this period. Simulation of soil water content in 1997 using the Perfect crop model (13) showed that water in the surface 0-10 cm was available to the crop only for brief periods at most sites during this period. Tissue P concentration during tillering in 1997 alone was most strongly correlated with bicarbonate-extractable P at the 10-20 cm depth ($r^2 = 0.57$, $p<0.05$), suggesting that uptake of soil P and possibly fertiliser P in the surface 0-10 cm was prevented by low soil water content.

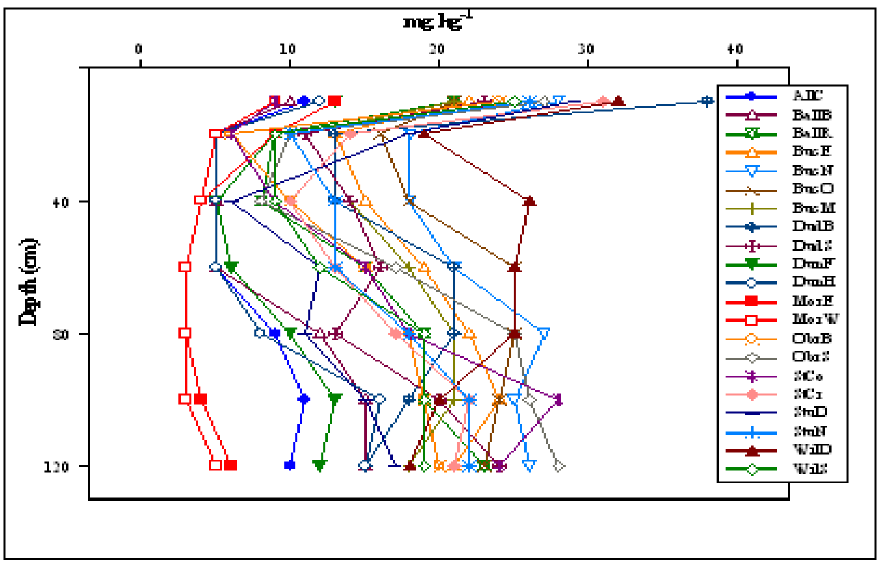

Figure 1. Concentration of bicarbonate-P (4) in the profile of Walgett and Moree vertosols, 1997-1999.

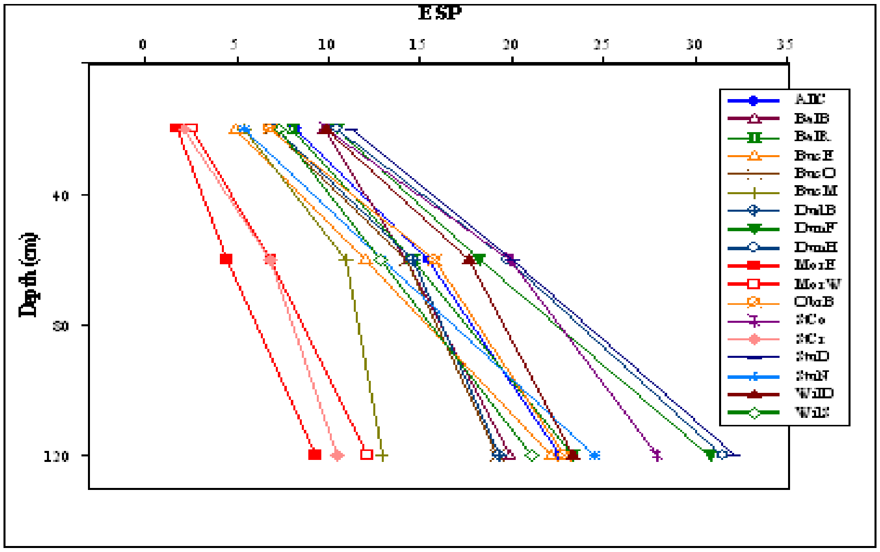

Figure 2. Exchangeable sodium percentage (ESP) in the profile of Walgett and Moree vertosols, 1997-1999.

The results from the plot-scale experiments showed significant responses to P fertiliser in each of the years. The soils had bicarbonate-extractable P concentrations of 13 mg kg^{-1} or less in the surface 0-10 cm and low concentrations below 20 cm (MorE and MorW in Figure 1) in comparison to most sites in the paddock-scale experiment. Although there were biomass DM and tissue P concentration responses to higher rates of P fertiliser at tillering and anthesis in 1998 and 1999, grain yield did not respond to P applications greater than 10 kg ha^{-1} in the seasonal conditions at these sites ($p<0.05$).

The application of 35 mm of water at stem elongation in 1997 increased uptake of soil P and possibly fertiliser P. Plants sampled 24 days after watering had significantly higher tissue P concentrations than the unwatered plants ($p<0.001$), but there was no significant difference in the tissue P concentration between P fertiliser treatments. At harvest, grain yields in the sub-plots were adjusted to account for the extra water supply (assuming an evapotranspiration efficiency of 10 kg grain ha^{-1} mm^{-1}). There were significant grain yield responses to both P fertiliser treatments ($p<0.05$) and surface water application ($p<0.001$) (Table 2). There was no significant interaction between water application and P fertiliser on grain yield.

In 1999, 25 mm of rainfall occurred two days after the water application at mid tillering, which probably resulted in no significant differences being measured in the P concentration of whole shoot and YFELB tissue between watered and unwatered plots. However, there was a significant increase in whole shoot P concentration after the rainfall for the unfertilised main plots ($p<0.05$).

Table 2. Grain yields (adjusted for irrigation effect) at MorW in 1997 for unwatered plots and sub-plots that received 38 mm of water at stem elongation. (SED: standard error of the difference between means).

	Unwatered (kg ha^{-1})	Watered (kg ha^{-1})
Nil P	1894	2612
P (10 kg ha^{-1})	2088	2962

SED P treatments: 45 SED water treatments: 71

Under dry seasonal conditions, it appears that uptake of available P in the surface soil is restricted, and the contribution of P from deeper in the profile may become more important for crop uptake. However, where the concentration of extractable P in the soil profile indicates possible crop response to P fertiliser, adverse subsoil conditions (such as sodicity or salinity; Figure 2) may restrict rooting depth and crop water use, thereby reducing the probability of response.

CONCLUSION

Grain yield response to P fertiliser was not measured on soils with a bicarbonate-extractable P concentration of more than 13 mg kg^{-1} in the surface 0-10 cm or with a mean concentration of 7-10 mg kg^{-1} between 10 cm and 80 cm. Current sampling strategies appear to be adequate for soils with more than 13-15 mg kg^{-1} of bicarbonate-extractable P in the surface 0-10 cm. However, for soils with less than 13-15 mg kg^{-1}, deeper sampling to 60-80 cm is recommended. The P status of the majority of wheat paddocks sampled in the Walgett region in this study was sufficient for crop requirements (Figure 1). A minority of paddocks with relatively low P in both the surface and sub-surface that did not respond to P fertiliser, require monitoring. The probability of P response will be reduced in vertosols with subsoil characteristics that impede root function.

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