Expanding the use of Diffusive Gradients in Thin-Films (DGT) for assessing phosphorus requirements of different crop types

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Abstract

The DGT soil test for assessing plant-available phosphorus (P) in soil has now been calibrated over three growing seasons using field-based P response trials across a range of crops (wheat, barley, canola and peas). Regression analysis of relative early dry matter production and grain yield responses demonstrated that the DGT method predicted wheat responsiveness to applied P more accurately than Colwell P and resin P. Using regression the DGT method explained 75 % of the variation in response for early dry matter and 74 % for grain. No other significant regression relationships were obtained for the other soil tests, apart from resin P which explained 40 % of the variation in response for grain. The performance of the Colwell-P test was assessed after modification using the phosphorus buffering index (PBI) and correctly predicted the crop response to P for 17 of the 30 experiments, compared to 20/30 for resin P and 26/31 for DGT. These observations suggest that the DGT technique can assess plant available P in soils with significantly greater accuracy than traditional soil P testing methods. Phosphorus response trials with other crop types including barley, canola, field peas and chickpeas have shown that different crop types have varying abilities to utilise residual P in the soil. Importantly DGT has consistently been the most accurate method for predicting P response for each of these crop types.

Key Words

Nutrient availability, phosphorus deficiency, soil testing, soil fertility

Introduction

Phosphorus is one of the most expensive nutrient inputs used in broadacre cropping in Australia (FIFA 2008) and globally (van Raij et al. 2002). Therefore, there is major economic benefit in developing a soil test capable of accurately predicting the P status of a soil, which can facilitate efficient fertiliser strategies and reduce the risks of environmental pollution due to over fertilisation. The imperative for optimising fertiliser use has recently been emphasised in grain producing regions of southern Australia where there has been three consecutive seasons of drought, coupled with fluctuating fertiliser and grain prices, resulting in small economic returns. Documented failure of established soil testing methods, such as Colwell and Olsen, to reliably predict plant P requirements over a range of different soil types (e.g. Holford et al. 1985, Reuter et al. 1995) has generated interest in new test procedures. The proposed correction to the Colwell P method (Colwell 1963) using the phosphorus buffering index (PBI) as suggested by Moody (2007), has not yet been validated as a predictive tool for field trials. Substantial variations in soil types and soil pH provide challenges for any soil P test. Diffusive Gradients in Thin Films (DGT) is a new technique for measuring P that has recently been used for predicting wheat response to liquid and granular sources of P on acidic to neutral soils under glasshouse conditions (McBeath et al. 2007). The resin method is increasing in popularity and has been used widely in Brazil (van Raij et al. 1986). As with the resin method, the DGT method attempts to mimic the physico-chemical uptake of solutes by plant roots by providing a sink for the free phosphate ion. Possible advantages the DGT method may have over the resin method are: Firstly, the ferrihydrite binding layer used in DGT is highly specific for P and is thus less subject to anionic interferences compared to ion exchange (resin) methods (Mason et al. 2008); secondly, the presence of a diffusive layer in DGT limits the maximum flux of P onto the binding layer, facilitates precise flux calculations, and prevents contamination of the binding layer with particulate material; and lastly, the DGT device is placed directly onto the soil and hence preserves the diffusive limitation to P extraction which extraction methods fail to do. The amount of P accumulated onto the binding layer depends on the concentration of P in the soil pore water, as well as the rate at which P is supplied from the soil solid phase into the pore water, i.e. the rate of re-supply. In contrast, the resin method involves placing a resin strip into a soil solution and, as shown previously (Mason et al. 2008), the measurement of P that is obtained is influenced by a complex interaction between soil P buffer capacity and the ratio of soil to water employed.

The aim of this work was to compare the relationships between ‘available P’ as measured by three soil-testing methods and actual dry matter or grain yield response to P fertiliser under field conditions. The three methods used were DGT, resin, and the traditional bicarbonate extraction method of Colwell (Colwell 1963) with and without PBI interpretation (Moody 2007).

Methods

Soil Preparation

Soil samples (0-10 cm) were collected from the control plots (0P) from 31 wheat phosphorus response trials in southern Australia conducted between 2006 and 2009. Samples were also collected from other crop P response trials (barley 8 trials, peas 7, and canola 6). Soil sampling was performed at the time of sowing each trial and where possible each control plot was treated as a separate sample, otherwise a bulk sample of the control plots was obtained. Locations were representative of land used for grain production and the distribution was as follows, Western Australia (2 trials), South Australia (16), Victoria (13) and New South Wales (15). Soils were dried at 40^{o}C for at least 2 days until constant weight was obtained and then sieved (< 2 mm) prior to any soil testing.

Soil tests with crop response

Three soil P tests (DGT, Colwell and resin) were evaluated for their ability to predict early dry matter and grain response of the different crop types to an application of P by assessing the available P pool from the control plots (Mason et al. 2008, Colwell 1963, Saggar et al. 1999). Crop response was assessed by comparing the yield of the control (0P) with the maximum yield obtained with P application and was expressed as relative yield (%)

Relative yield (%) = Yield (control)/ Yield (Maximum) x 100

Determination of the maximum yield at each site was performed by fitting a Mitscherlich curve between yield obtained and the rate of P fertiliser applied in the form

$$y = y_o + a(1-e^{-bx}) \quad (1)$$

where y_o = calculated yield of control (0 P) and $y_o + a$ = maximum yield reached with the highest P application (x). This Mitscherlich curve was also used to determine the relationship between soil test measurements and crop response.

Results and Discussion

Soil test correlations with wheat response

There was no significant relationship at $p \leq 0.05$ observed between Colwell P values and wheat response to applied P at either early growth or maturity (Figures 1a and b). This result highlights the ineffectiveness of using the Colwell P method alone to assess available P in soil across widely differing soil types and therefore limits its use to predict plant growth responses to additions of P. The inability of the Colwell P method to predict crop response meant that no deficiency threshold values could be obtained. The PBI method was used to modify Colwell P values for each site (Moody 2007), and the performance of the test was assessed by determining whether crop response to applied P was correctly predicted at each site using the critical deficiency values of Moody (2007). If the PBI-modified Colwell P value was lower than the critical Colwell P (from Moody 2007), then a significant crop response was expected. From the 31 field sites, the PBI-modified Colwell method correctly predicted the grain response of only 17 sites (55 %).

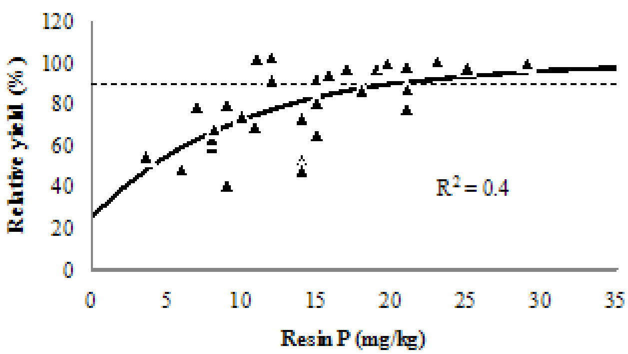
There was also no significant relationship between concentrations of resin-extractable P in soils and early dry matter response of wheat to applied P, but a significant relationship (R^2 = 0.4) with final grain yield was obtained (Figures 2a and b). The resin P deficiency threshold was 20 mg kg^{-1} obtained by calculating the intercept of the Mitscherlich curve and 90 % relative yield. Resin P correctly predicted crop responses to applied P at 20 out of the 30 sites (67 %).

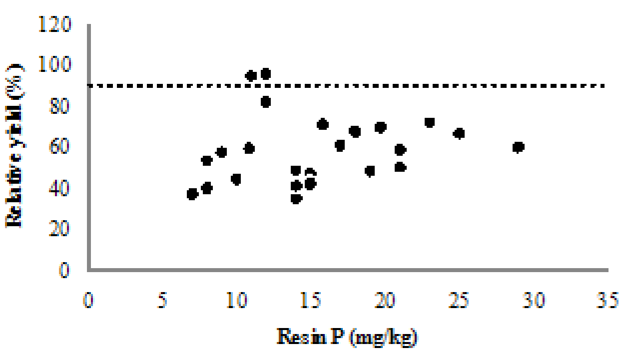
Concentrations of DGT-extractable P in soils were highly correlated with both early dry matter production (R^2 = 0.75) and grain yield (R^2 = 0.74) (Figures 3a and b). Phosphorus deficiency thresholds (90% relative yield) for wheat were 261 µg/L (C_{DGT}) for early dry matter production and 60 µg/L (C_{DGT}) for grain yield. Large deficiency thresholds between the two growth stages suggests early dry matter production with P application will not necessarily translate to an increase in grain yield if climatic conditions cannot support the extra crop potential produced earlier on. Wheat response assessed at GS30 is performed by taking all of the above ground plant material. The response at this growth period should reflect grain response only if all the tillers produced earlier contribute to grain yield in the same proportion. The DGT soil test correctly predicted the crop responses to P fertiliser at 26 of the 31 field sites (84%).

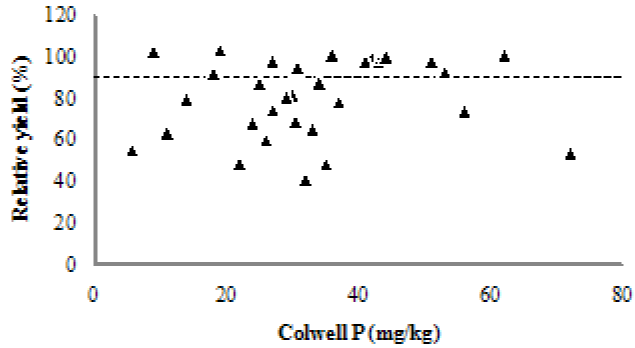
1b

1a

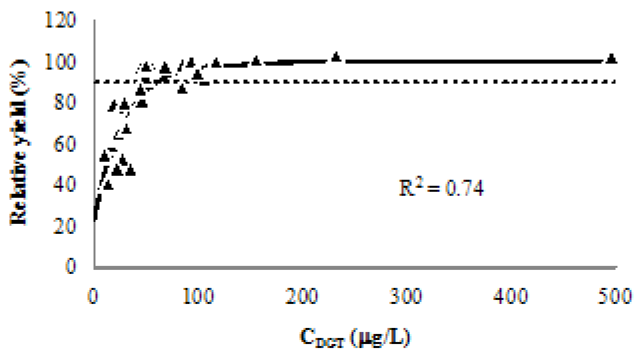
2b





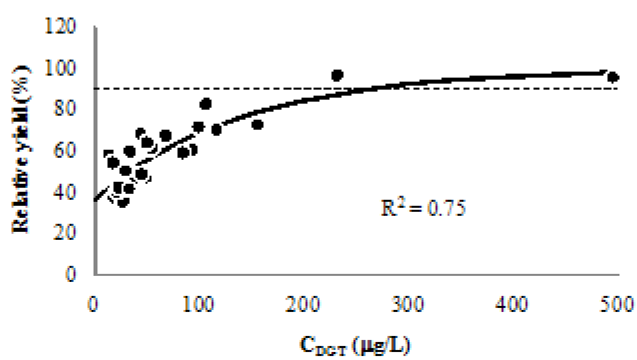

120
100
80
60
40
20
0
Relative yield (%)
0
20
40
60
80
Colwell P (mg/kg)

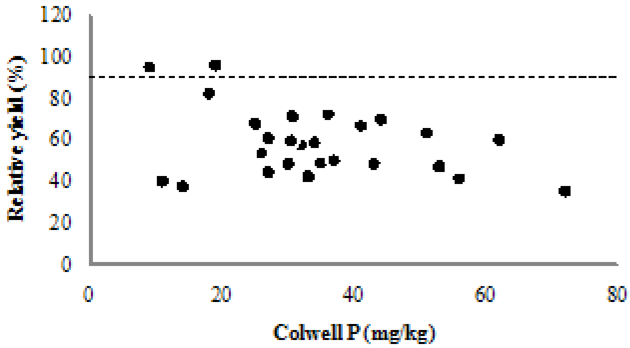
2a


120
100
80
60
40
20
0
Relative yield (%)
$R^2 = 0.74$
0
100
200
300
400
500
C_{DGT} (µg/L)

3b

3a


120
100
80
60
40
20
0
Relative yield (%)
$R^2 = 0.75$
0
100
200
300
400
500
C_{DGT} (µg/L)



c1)

Figure 1.

Relationship of soil test measurements 1) Colwell P, 2) resin P and 3) C_{DGT} (DGT) with wheat response (% relative yield) to P applications at two growth stages a) Early dry matter (GS30) and b) Grain.

Soil test correlations with other crop types

The Colwell P and resin P methods had varying success with regard to accurately predicting the response of other crop types. Colwell P was effective at explaining the variation in grain response of barley and performed moderately for peas and canola (Table 1). The resin P method accurately predicted the response of barley and peas to applied P, and was moderately correlated to canola responses. Overall the DGT method was effective in predicting the response of all crop types to applied P (Table 1). The trends in critical threshold values for each crop type was consistent for the three different soil tests apart from Colwell P and wheat where a relationship could not be obtained. From the small database tested it appears that the order of P efficiency is canola > peas > wheat > barley. These observations will need to be consolidated with further field trials in the future.

Conclusions

While the Colwell method is the most popular method to predict crop responses to applied P in Australia, its performance in this regard is often not strong (Colwell 1963, Holford et al. 1985, Reuter 1995), even when modified to account for soil P sorption behaviour (Moody 2007), often accounting for less than 65% of the variation in crop response to applied P. Our data support these findings, although we found Colwell P to perform particularly poorly on this set of soils. The resin P method improved the prediction of wheat grain response to applied P compared to the Colwell P method, but still only resulted in low to moderate accuracy (R^2<0.5). In comparison, the DGT method produced good relationships and correctly predicted wheat responses to applied P. It should also be noted that these results were obtained across a range of growing seasons and management variables including time of sowing and wheat varieties which appear not to have substantially affected relationships with DGT. The DGT method was able to accurately determine critical thresholds for a range of crops, and different critical concentrations of DGT-extractable P in soils suggested different crop P uptake efficiencies. The DGT results presented in this study provide optimism that a robust technique is available that correctly measures plant available P regardless of soil type, and without a requirement for additional corrections or interpretation. The use of DGT for accurate soil P testing could potentially improve P fertiliser efficiency for all types of agriculture.

Table 1. Summary of soil test relationships with crop response to an application of P and the critical thresholds produced by each test

	Crop type	Colwell P mg/kg	Resin P mg/kg	C_{DGT} □g/L
Correlation (R^2)	Wheat	n/a	0.4	***0.74***
	Barley	0.87	0.9	***0.96***
	Peas	0.59	***0.98***	0.81
	Canola	0.46	0.62	***0.87***
Critical threshold	Wheat	n/a	20	60
	Barley	44	26	79
	Peas	28	13	28
	Canola	20	6	11

n/a - No significant relationship obtainable ($p < 0.5$)

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