Diffusive Gradients in Thin-films (DGT) as a technique for accurately predicting Phosphorus fertiliser requirements

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Abstract

Drought and rising prices require growers to make difficult and strategic decisions regarding application of P fertilisers. Better decisions will be made if they are based on reliable information including accurate assessment of soil available P status. Previous work under glasshouse conditions showed DGT was an improved alternative to other soil P testing techniques for predicting P availability. However, before DGT can be considered as a replacement soil P test by growers or commercial parties, testing and validation of performance is required under field conditions. In 2007 experiments were undertaken to validate the accuracy of DGT in assessing P availability and crop response to applications of P fertiliser in the field. Samples were taken from more than 20 P response trials throughout southern Australia. Each soil test measurement was correlated with the response of the crop (% relative yield) to the application of P by taking dry matter cuts at mid-late tillering. No significant coefficient of determination for the regression fit (R^2) was obtained for Colwell P highlighting the ineffectiveness of this soil test across different soil types in predicting dry matter (DM) response. The regression of resin P measurements with relative DM yield using a Mitscherlich type equation had a coefficient of determination of $R^2 = 0.43$, (0.29 wheat only). The DGT technique definitively separated out responsive and non-responsive sites and the coefficient of determination value for the regression fit was $R^2 = 0.82$, (0.71 wheat only). This highlights the superior accuracy of DGT in predicting P response for a range of different soil types compared to the other soil tests.

Key Words

Phosphorus deficiency, Diffusive Gradients in Thin-Films (DGT), Phosphorus Nutrition

Introduction

Assessment of available P through soil testing methods is important for efficient fertiliser application. The ideal soil test should measure the form of P that is available to the plant, reflecting supply from the soil solution through diffusion and its replenishment from the soil solid phase. The soil test should also give reliable information on available P irrespective of soil type. Due to their simplicity extraction methods are still commonly used as soil tests for assessment of available P, but are becoming less popular due to a lack of confidence in the reliability of the results. A solution containing bicarbonate, such as that used for extraction in the Colwell P method, can also extract relatively stable forms of P (such as calcium phosphates) from the soil that are not plant available. In fact, it has been found that Colwell P values tend to be relatively high on calcareous soils despite the fact that crops grown on these soils are renowned for their poor P nutritional status.

Both the Colwell P method and the resin P test which has been proposed as a potential alternative to Colwell P use a relatively wide ratio of soil to extractant (Colwell) or water (resin). These ratios are not representative of the soil: water ratios found under field conditions. Soil responds to diluting solutions by replenishing the solution with P from the soil solid phase. Mason *et al.* (2007) have shown that an increase in resin P measurements is obtained when the soil solid-phase to water ratio decreases, although the magnitude of the increase is not consistent across different soil types. Therefore, the key question remains as to which soil to solution ratio best corresponds with plant P availability? DGT methodology offers a potential alternative for testing of extractable P without some of the problems associated with the other soil P tests. Firstly, measurements are performed on soils adjusted to 80 %

water holding capacity which is likely to be at a soil: water ratio more agronomically relevant than those used by other soil P tests. Secondly, DGT offers the advantage that the ferrihydrite binding agent used with DGT technology is very specific for P. Consequently, unlike non-specific anion resins, DGT P sorption is unaffected by anions such as sulphate, bicarbonate, nitrate and chloride present in solution at concentrations relevant to agricultural soils. Lastly, DGT is not based on an equilibrium process but integrates solution concentrations of P with the P resupply capacity of a soil, therefore mimicking plant uptake processes.

Methods

Field Sites

Samples were taken from over 20 field sites throughout southern Australia with a variety of P response trials.

Soil Sampling

Soil samples (0 – 10cm, 10 cores using 1.5cm corer) were taken from replicated (4 – 6) control plots at sowing of each trial. Samples were then dried at 40^{o}C in an oven and sieved (< 2mm). Available P measurements using Colwell P, resin and DGT were performed on each replicate soil sample. Detailed methodology for these soil tests can be found in Colwell 1964 (Colwell P), Saggar et al. 1999 (resin P) and Mason *et al*. 2005 (DGT). Each soil test measurement was related to the response of the crop to the application of P by taking dry matter cuts at mid-late tillering. P nutrition is very important in the early growth stages of a crop so that any P deficiency at this growth stage will influence dry matter production and may ultimately reduce grain yield potential.

Dry matter (DM) increases due to P fertiliser applications were expressed as a % relative DM yield calculated as:

% relative DM yield = (DM yield from control plots / highest DM yield obtained) x 100

Field sites were classified as responsive or non-responsive to an application of P using the Students T test ($p < 0.05$) as performed by Menzies *et al*. 2007. Soils were classified as responsive if the DM yield obtained at the highest P application was significantly different to the DM yield of the control.

Results

Response to P

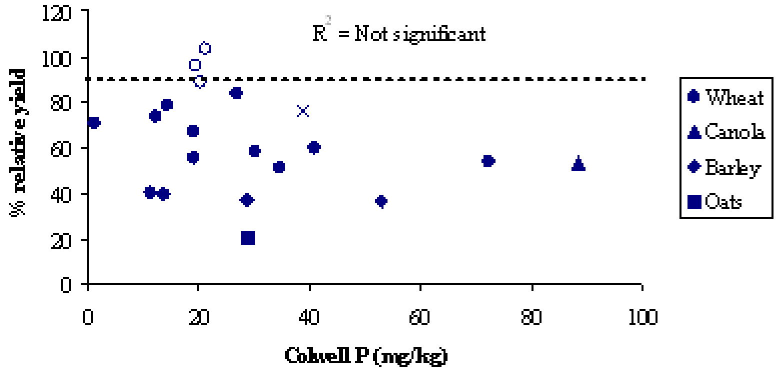
Statistical analysis of plant DM data from 21 field sites showed that 5 sites were non-responsive ($p < 0.05$, students T test) at the highest application rate of P (Table 1). Typically the critical soil test value was evaluated at 90 % relative DM yield (Moody 2007, Reuter *et al*. 1995). Two sites (Port Kenny and Horsham) have relative DM yields < 80 % and for the purpose of this article have been classified as responsive, although statistically they are non-responsive ($p < 0.05$) due to high variability in DM yield between control plots.

Table 1. Soil test values and dry matter (DM) yield responses from 20 field sites in southern Australia

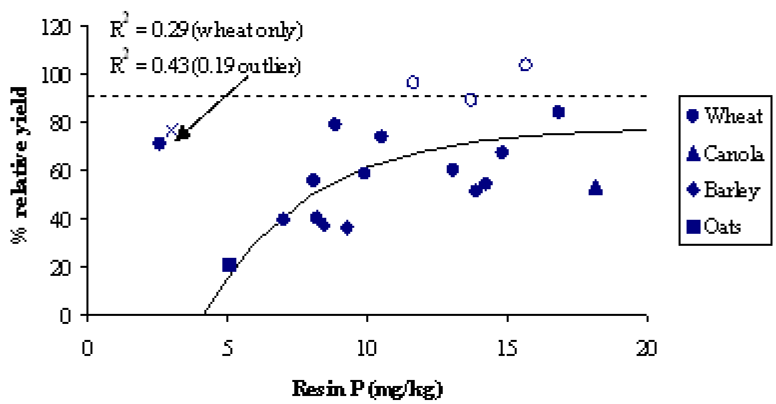
Site	Colwell mg/kg	Resin mg/kg	DGT (C_E) µg/L	% relative DM yield	P responsive ($p < 0.05$)	Crop type
Calca	11.3	8.2	568	40	Yes	Wheat
Port Kenny	38.9	3	248	77	No	Wheat
Stansbury	19.4	11.6	5718	96	No	Wheat
Hopetoun	21.1	15.7	2320	103	No	Wheat
Birchip	26.8	16.9	1187	84	Yes	Wheat
Kadina	40.8	13.1	940	59	Yes	Wheat
Horsham	14.3	8.9	648	79	No	Wheat
Illaboo	34.7	13.9	728	51	Yes	Wheat
Illaboo	30.2	10	599	58	Yes	Wheat
Riverway	19	14.8	841	67	Yes	Wheat
Blue Hills	12.2	10.5	538	73	Yes	Wheat
Byalla	20.2	13.7	1329	89	No	Wheat
Boyup brook	72.3	14.2	562	54	Yes	Wheat
Newdegate	19.1	8.1	397	55	Yes	Wheat
Moora	1.3	2.6	774	71	Yes	Wheat
Condobolin	13.8	7.1	329	39	Yes	Wheat
Morlup	88.4	18.1	587	53	Yes	Canola
Wooldridge	28.5	8.5	410	37	Yes	Barley
Balla Hills	53	9.3	224	36	Yes	Barley
Macleay	29	5.1	55	20	Yes	Oats

Soil tests with relative yield (%)

Relationships between relative DM yield (%) and soil test values for control soils are shown in Figure 1. No significant coefficient of determination for the regression fit (R^2) was obtained for Colwell P highlighting the ineffectiveness of this soil test across different soil types in predicting DM response. It can be seen that there is a wide range of Colwell soil test values where it is unclear whether a response to P will be obtained or not (Figure 1a). The coefficient of determination for the regression of resin P measurements with relative DM yield using a Mitscherlich type equation was $R^2 = 0.43$ (Figure 1b) and there was better separation of responsive and non responsive sites compared to the Colwell P method. However, there is still a region of resin P values ranging from 11.6 – 16.9 mg/kg (wheat only) between which it is unclear if there will be a response to P or not. Two regression fit values are shown in Figure 1b as a regression fit was performed on 1) all data and 2) for sites where just wheat was grown. There is also a significant outlier which reduces the R^2 value to 0.19. Overall, the DGT technique has definitively separated out responsive and non-responsive sites (Figure 1c) and the coefficient of determination for the regression fit was $R^2 = 0.82$, (0.71 wheat only). This highlights the superior accuracy of DGT in predicting P response for a range of different soil types compared to the other soil tests.



a)



b)

c)

c)

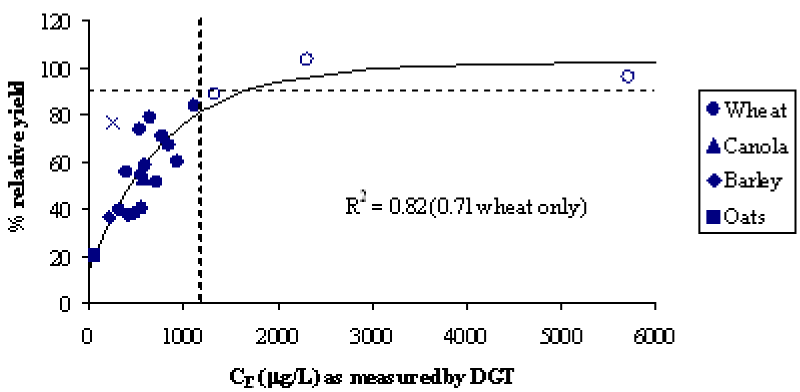


Figure 1. Relationship between crop dry matter yield taken at mid-late tillering (expressed as % relative DM yield) with soil available P test value measured using a) Colwell P, b) resin and c) DGT. Open circles represent non-responsive soils, outlier (X) discussed in the text above.

The critical deficiency threshold for P deficiency is 1652 µg/L C_E when determined using the intercept of the curve and 90 % relative DM yield. However, when using the separation of responsive and non-responsive sites the critical value was between 1187 and 1329 µg/L which is close to the critical threshold value of 1154 µg/L obtained using DGT in glasshouse trial work (Mason PhD Thesis UA, 2006). This is an encouraging result considering the greater number of variables across field trials than in pot studies e.g. fertiliser type and wheat varieties. One outlier, represented by a cross was not included in the assessment of soil P test performance. This site, Port Kenny, is highly calcareous (30 % $CaCO_3$) and it is highly likely the P application as granular form (TSP) has been ineffective. Both the resin and DGT soil tests suggest this site should be responsive. Port Kenny and Horsham have relative DM yields < 80 % and for the purpose of this article have been classified as responsive, although statistically they are non-responsive ($p < 0.05$) due to high variability in DM yield between control plots.

When using the relationship between soil test and relative DM yield it is important to establish if the maximum yield at each site has been reached. In some circumstances a selection of these sites may have not reached their full yield benefit due to relatively low P application rates (10 kg/ha). Repeat analysis using only the sites where the maximum yield had clearly been reached still confirmed DGT as a more reliable predictor of plant available P (data not shown). Resulting coefficients of determination for the regression fits (R^2) were Colwell – 0.5, resin – 0.53 and DGT – 0.92. Data analysis has been undertaken for grain yields although it appears the poor finish to the growing season in 2007 in most locations studied has compromised final yield benefit from P application compared to that seen in early growth stages. Thus, relationships of grain response with soil tests have decreased the relationships (R^2) significantly although DGT is still the best of the three tests.

Conclusion

DGT has been shown to be a more accurate predictor of plant P availability in the field than other established soil tests (Colwell and resin), as assessed by early dry matter response to P application. The DGT critical P deficiency threshold obtained from the field correlates well with that obtained in previous glasshouse trials.

Further field testing is required to assess the performance of DGT under contrasting climatic seasons and on other soil types. However, DGT is initially showing great promise as a reliable soil test.

Caution must be used when using Colwell P values on their own for fertiliser recommendations without other soil parameters being assessed.

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