Replacement P- can it maintain soil fertility and crop production?

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Abstract
Soil P has been accumulating beyond the sufficiency range for crop production across some dryland cropping regions of Australia (Weaver and Wong, 2011). This was particularly the case in the dry seasons of the Millennium Drought where blanket fertiliser application rates were often in excess of P removal and resulted in an increase in soil P levels. In addition, the reduced incomes following drought coupled with increasing fertiliser costs made standard fertiliser inputs difficult to afford. A management strategy of replacing the amount of P removed in the previous season would enable reduced inputs following poor seasons. However, it is not certain that replacement P is adequate to maintain soil P levels, or that it is in fact the most economically favourable P management strategy. A trial was established at Minnipa Agricultural Centre in 2009, comparing conventional fertiliser rates with replacement P rates on two soil types. No response to applied P was recorded in 2009, the first year of the trial, indicating that adequate amounts of soil available P were initially present. In 2010, a decile 9 growing season, and 2011, a decile 5 growing season, there was a significant ($P < 0.05$) response to added P, but due to high yields the replacement P rate was similar to the district practice of 10 kg P/ha at 8-13 kg P/ha in 2010 and 2011 respectively. Over 3 years of crop production the replacement P strategy has been economically better than district practice in 2009 and 2010 but not in 2011. Shifting fertiliser inputs in response to seasonal effects on soil fertility could be of benefit to fertiliser use efficiency, but requires careful monitoring as measured soil test P levels declined in response to replacement P rates.

Key Words
Fertilisers, P removal, soil test P, Colwell, DGT

Introduction
Fertiliser is one of the highest on-farm variable costs (ABARE, 2010) and is expected to increase in the future (FAO, 2010). Given the high climatic and spatial variability, low nutrient use efficiency and market volatility faced by growers in the low rainfall region of the upper Eyre Peninsula, identifying the most profitable rate of phosphorus (P) fertiliser presents a challenge to dryland farmers. Historically, recommended P rates have exceeded plant requirements, taking into account P requirements for regular annual medic pasture phases in the rotation. This has resulted in high levels of P in the soil. However a recent intensification of cereal cropping, combined with a string of poor seasons and increasing fertiliser prices has resulted in farmers reassessing the amount of fertiliser they use. For more efficient P management, it is possible that lower fertiliser inputs would be offset by crops utilising soil P reserves accumulated in previous poor seasons. To test this concept of better matching the crop import and export of P, replacement P application rates were investigated on two soil types over four growing seasons at Minnipa, Eyre Peninsula.

Methods

Two replicated trials were established on alkaline soils with low P buffering capacity, in Paddock North 1 (N1) on Minnipa Agricultural Centre (MAC) in 2009; one on a deep red sandy loam and the second on a shallow, constrained loam. Prior to establishing the trials in 2009 Colwell P levels were 25 and 35 mg/kg on the sandy loam and constrained loam respectively (Table 1), at or above the estimated critical Colwell P value.
There were four P treatments of nil, district practice (10 kg P/ha), twice district practice (20 kg P/ha) and replacement P tested for three consecutive years on the same plot in a completely randomised block design with four replicates. Table 2 shows the P applied as diammonium phosphate (DAP) banded at sowing. The replacement P rate was based on the estimated P exported from the paddock calculated using an average grain P concentration of 3 kg P/t of cereal grain harvested the previous year (Lester et al 2009). The replacement P rate used in 2009 was calculated by using the zone average wheat grain yield from the two soil types obtained in 2008. Nitrogen was balanced with urea to give a total of 18 kg N/ha on all treatments. In 2009 and 2010 the trial was sown with Wyalkatchem wheat at 60 kg/ha on 7 May and 3 June respectively,

while in 2011 the trial was sown with Scope barley at 50 kg/ha on 3 May. Crop performance measurements included dry matter at late tillering, grain yield and quality. Annual soil measurements included soil P levels (Colwell P and DGT-P (since 2010)) taken before sowing.

Table 1: Soil characteristics of P Replacement trial site, paddock N1 MAC 2009

	Sandy Loam	Constrained Loam
$pH_{1:5}$ (0-10cm)	8.6	8.7
Colwell P (0-10 cm (mg/kg)	25	35
PBI (0-10 cm)	78	96
Critical Colwell P (mg/kg)*	25	28
Depth to soil $CaCO_3$ > 25% (m)	0.6	0.4
Depth to B > 15 mg/kg (m)	1.0	0.6
Depth to Cl > 1000 mg/kg (m)	0.8	0.6

*Equation published in Moody 2007

Table 2. Phosphorus applied (kg/ha) at Minnipa in 2009, 2010 and 2011 with replacement P derived from yield in the preceding season.

Treatment	Yield 2008 (t/ha)	P applied 2009 (kg/ha)	Yield 2009 (t/ha)	P applied 2010 (kg/ha)	Yield 2010 (t/ha)	P applied 2011 (kg/ha)	Yield 2011 (t/ha)
Sandy Loam							
0 P	n/a	0	3.9	0	3.9	0	2.4
10 P	n/a	10	4.4	10	4.0	10	2.9
20 P	n/a	20	4.6	20	4.4	20	2.9
Replacement P	0.65*	2	4.3	13.3	4.3	12.9	2.9
LSD (P < 0.05)	n/a		0.4		0.4		0.24
Constrained Loam							
P	n/a	0	2.9	0	3.5	0	1.8
10 P	n/a	10	2.8	10	3.7	10	2.1
20 P	n/a	20	3.1	20	3.9	20	2.0
Replacement P	0.39*	1.2	2.7	8.4	3.9	11.9	2.1
LSD (P < 0.05)	n/a		0.3		0.3		0.14

* calculated using the zone average wheat grain yield in 2008

Results

Soil tests taken before sowing in the 2011 season in the sandy loam showed that the Colwell P levels had fallen from the 2009 and 2010 levels in all treatments, with the exception of the 20 kg/ha P treatment which remained the same (Figure 1a). In the constrained loam, the Colwell P levels dropped in 2011 compared to 2010, except for the 20 kg/ha P treatment (Figure 1b), but were similar to the initial 2009 levels. However soil test values from both sites in 2010 were estimated to be above the critical Colwell P value suggesting little or no likely response to applied P in 2010 while 2011 Colwell P levels suggest a small response was expected on the sandy loam but little or no likely response on the constrained loam with 2011 P applications assuming PBI and critical Colwell P relationships for barley are similar to wheat. (Figure 1).

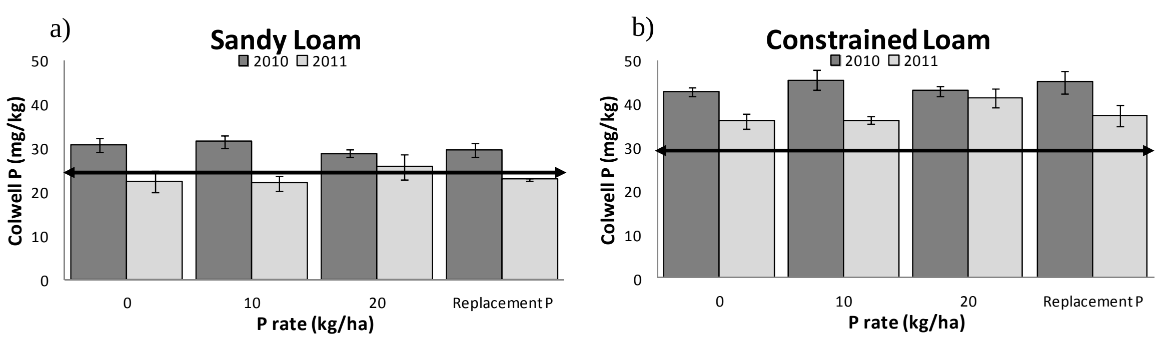

Figure 1. Colwell P values for P treatments prior to sowing in 2009, 2010 and 2011 on the a) sandy loam and b) constrained loam. Arrow represents the critical Colwell P value (for wheat) calculated from PBI values at each site using Moody et al. (2007) (Table 1). Standard error bars are given on each column.

Analysis of the same soil samples using DGT from 2010 revealed a similar pattern with respect to P treatments and the maintenance of P levels at the high P addition level (Figure 2). However, the DGT values were at or below the critical level suggesting that there would a yield response from applied P for plots with less than 20 kg applied P (Figure 2).

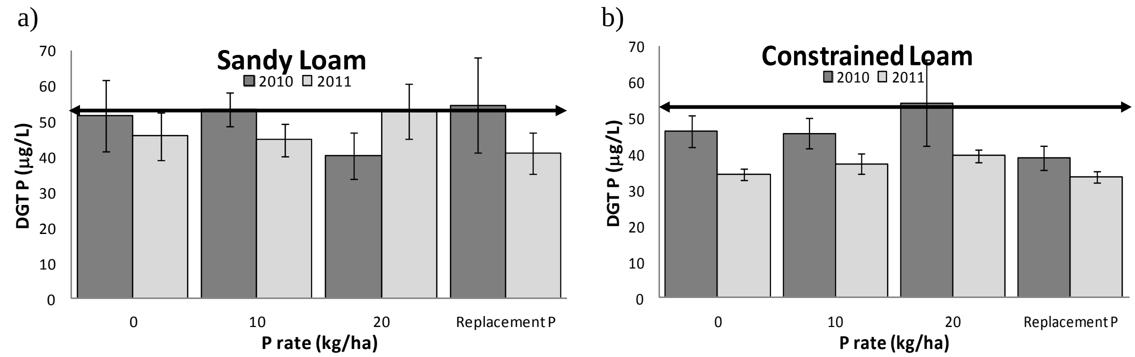

Figure 2. DGT- P values with P treatments prior to sowing in 2010 and 2011 in a) the sandy loam and b) the constrained loam. Arrow represents the critical DGT P value for wheat calculated from replicated field trials (2006-2010). Standard error bars are given on each column.

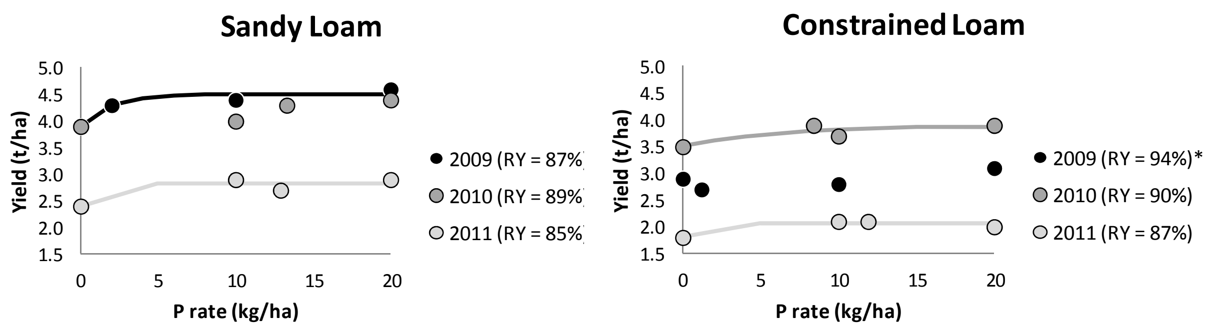

Figure 3. Crop response to P treatments and % relative yield (Yo/Y max*100) 2009-11 in a) Sandy Loam and b) Constrained Loam. *Ymax unable to be determined and therefore yield obtained @ 20 kg P/ha used as Ymax

In 2009 there was a yield response to all applied P treatments in the sandy loam (Figure 3), while in the constrained loam there was only a response to applied P at 20 kg P/ha. In 2010 there was a response to P at rates greater than 10 kg P/ha in the sandy loam compared to nil P, but the nil P treatment produced less grain yield than all other P treatments in the constrained loam. In 2011 there was higher grain yield with all levels of applied P compared to 0P in both soils, as predicted by the DGT P data in figure 2.

Table 3: Grain quality parameters of test weight (kg/hL), protein (%) and screenings in the sandy loam and constrained loam for 2009, 2010 and 2011

Treatment	2009			2010			2011		
	Test Weight (kg/hL)	Protein (%)	Screenings (%)	Test Weight (kg/hL)	Protein (%)	Screenings (%)	Test Weight (kg/hL)	Protein (%)	Screenings (%)
Sandy Loam									
0 P	85.3	10.5	1.0	79.7	9.8	2.3	58.0	12.0	32.4
10 P	85.1	10.5	0.8	79.8	10.0	2.4	59.0	11.8	27.3
20 P	85.5	10.9	0.7	79.5	10.1	2.5	59.4	11.9	23.8
Replacement P	84.4	10.5	0.7	79.8	10.1	2.4	59.0	12.2	28.5
LSD ($P < 0.05$)	*ns*	*0.2*	*0.2*	*ns*	*0.2*	*ns*	*0.60*	*ns*	*5.8*
Constrained Loam									
0 P	85.1	10.5	0.8	81.4	10.5	2.5	58.5	11.9	25.6
10 P	85.4	10.6	0.7	78.3	10.3	3.1	59.2	11.7	21.5
20 P	84.8	10.9	0.6	79.4	10.2	2.8	59.5	11.9	21.5
Replacement P	85.2	10.5	0.7	79.0	10.4	2.3	59.2	11.7	26.4

LSD (P < 0.05)	*0.59*	*0.3*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

There was no test weight response to applied P in 2009; but there was a protein response at 20 kg P/ha in both soils (Table 3). In 2010, test weights were greater than 78 g/hL and screenings were 3.1% or less for all treatments. At P rates of more than 10 kg/ha protein increased compared to the nil P treatment in the sandy loam, while in the constrained loam protein levels were similar across all treatments. In 2011 the addition of P in the sandy loam resulted in a lower screening percentage and higher test weight. However, the generally low test weights and high screenings percentage is likely to be a result of a late leaf rust infection and the 6 week dry period experienced by the crop in mid August to late September.

A basic gross income analysis on all treatments showed that applied P resulted in an increased gross income in the sandy loam in 2009 while in the constrained loam there was an increase in gross income in response to the 20 kg P/ha only (Table 4). In 2010 the replacement P and 20 kg P/ha treatments resulted in a higher gross income in both soils. In 2011 the highest total gross income in both soils was produced by the 10 kg P/ha treatment, followed by the replacement P strategy. Due to the slightly higher fertiliser cost for the replacement P strategy, there was a 2% decrease in gross income in the sandy loam and 4% decrease in the constrained loam for replacement P compared to the 10 kg/ha P treatment. After 3 years, the cumulative gross income analysis has shown a replacement P strategy has performed better than the district practice of 10 kg P/ha in both soil types.

Table 4: Gross income in response to P treatments in 2009, 2010, 2011 and the accumulated 2009-11 gross income from the 2 soils.

P Applied (kg/ha)	2009 Gross Income[1] ($/ha)	2010 Gross Income[1] ($/ha)	2011 Gross Income[1] ($/ha)	Accumulated Gross Income 2009-11 ($/ha)
		Sandy Loam		
0	848	1025	386	2259
10	906	1025	443	2374
20	941	1106	415	2462
Replacement P	966	1085	434	2485
		Constrained Loam		
0	573	873	226	1672
10	548	944	317	1809
20	606	972	279	1857
Replacement P	570	995	306	1871

[1]*Gross income calculated using yield x price less fertiliser costs delivered cash on 1 December each year*

Conclusion

In alkaline loamy soil types, representative of many low rainfall cropping soils, there was an economic benefit gained from using the replacement P strategy, especially in 2009 when the level of fertiliser required to replace the P exported in the previous 2008 harvest was low. However, soil available P reserves appear in decline at replacement P rates. The Colwell P test was inconsistent for correctly predicting a response to P fertiliser while the DGT-P test correctly predicted the grain yield response to additional P in 2010 and 2011, demonstrating the utility of this test for monitoring soil P reserves and P fertiliser requirement.

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