The performance of residual and cumulative P applications on soils in the Mid-North of SA

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Key findings

- Residual phosphorus (P) (from a one-off application of a high rate in year one) provided a grain yield response in the second and third year at two of the three sites.
- The method for applying a high rate (90 kg P/ha) of P fertiliser was not important in these trials. High rates of P applied by either deep banding, spreading MAP or chicken litter spread in front of the seeder, all produced the same yield response at each site and year.
- At Hart and Crystal Brook repeated applications of P fertiliser rates showed the crop P requirements were not satisfied by lower rates in the second and third season. The highest repeated P rates (50 and 90 kg P/ha) were still increasing yields in year three at these sites.
- Partial gross margin (PGM) analysis showed within the range of MAP prices of $500-$1500/t the district practice strategy was never the highest PGM on these P responsive sites.
- When MAP reached $1500/t the chicken litter treatment became the highest PGM at Crystal Brook and one of the highest at Hart, despite freight and spreading costs.

Background

High fertiliser prices have increased grower interest in phosphorus (P) responses on variable soil types and improving returns from P fertiliser inputs. Recently, two SAGIT funded projects (TC219 and TC221) have examined P fertiliser response on a range of soil types with varying soil P availability. The trial locations were determined using soil pH maps and satellite NDVI imagery. To date 49 phosphorus response trials have been established across the Mid and Upper North and Northern Yorke Peninsula (NYP) to validate the P sufficiency index (pHnNDVI) methodology (refer to method section) of predicting P response based on these data layers.

Included in the 49 P response trials were three long term (3 year) trials established in 2021 at Spalding, Crystal Brook and Hart. These three sites are highly P responsive alkaline soil types. The project aims to address the following questions.

- What is the residual value of high rates of P from year 1 in following years?
- What is the effect of repeated high-rate P application vs district practice?
- What alternative application strategies can be implemented at high response sites in lieu of variable rate P application through the seeder?

Methods

In SAGIT project TC219, a methodology for estimating crop P responsiveness, the P sufficiency index, was developed. The P sufficiency index combines soil pH maps and historical satellite NDVI to estimate how responsive a given site will be to applied P fertiliser. The P sufficiency index has been given the acronym pHnNDVI as it is the pH value divided by NDVI normalised to the paddock average using the formula below:

pHnNDVI = soil pH / (NDVI/paddock NDVI average)

Areas of a paddock with high soil pH (> 7) and low relative NDVI (< 0.9) result in a high pHnNDVI value and are likely to be highly responsive to applied P. Areas with low pH (< 6.5) and high relative NDVI (> 1.1) result in a low pHnNDVI value and are likely to be unresponsive to applied P in the paddocks tested. This methodology has proven useful in determining the optimal site-specific P rate in paddocks tested across the Mid and Upper North and Northern Yorke Peninsula.

At the beginning of 2021 three highly P responsive sites were identified using the P sufficiency index methodology (Table 1). These sites were soil sampled (0-10 cm) pre-seeding in 2021. Soil pH levels ranged from 7.7 – 7.9 pH $CaCl_2$ which is categorised as moderately alkaline. The DGT-P values were low ranging from 18-23 µg/L (critical limit 60 µg/L). Full comprehensive soil test analysis was conducted for each site and no other nutritional constraints were identified (data not presented).

The crop sown at each location/year were chosen based on the hosting growers' rotation (Table 1).

Table 1. Average (Av) growing season rainfall (GSR = April – October), soil properties and crop sown for long-term P response sites.

Location	Soil pH ($CaCl_2$)	DGT-P µg/L	Colwell P mg/kg	PBI	pHnNDVI	2021 crop	2022 crop	2023 crop
Crystal Brook Av GSR 289 mm	7.8	23	29	88	11.9	Compass barley	PBA Highland XT lentil	Calibre wheat
Spalding Av GSR 268 mm	7.7	18	20	77	11.7	Scepter wheat	Spartacus CL barley	Commodus CL barley
Hart Av GSR 291 mm	7.9	17	40	110	10.0	Scepter wheat	PBA Jumbo 2 lentil	Calibre wheat

The long-term P fertiliser trials sown at all three sites can be divided into four main management strategies (Table 2) which were used to answer specific questions throughout the project. Phosphorus fertiliser was applied as MAP and nitrogen was balanced at seeding with urea to match the amount of nitrogen (N) in the 90 kg P/ha treatment. In the main treatments, the fertiliser was applied below the seed using a knife point press wheel system on 250 mm row spacing.

The chicken litter sourced for these trials had a total P concentration of 1.48%, total nitrogen concentration of 4.14% and moisture content of 15.4%. This treatment had a target of 75 kg P/ha broadcast as chicken litter (equivalent to 6250 kg/ha chicken litter) prior to seeding plus 15 kg P/ha as MAP applied below the seed, resulting in a total of 90 kg P/ha. The actual total P applied in the chicken litter treatment was 93 kg P/ha in the first year (Table 2). As the nitrogen in all other treatments was balanced to the 90 kg P/ha treatment it is important to note that the chicken litter treatment received an additional 178 kg N/ha compared to all other treatments.

Table 2. Treatment list showing units of P (kg P/ha) applied, the equivalent rate applied as MAP fertiliser (kg/ha) and cumulative P rate for the long-term P response trials in the Mid-North, SA.

Treat	**Management strategy**	**2021 P rate (kg P/ha)**	***Equivalent MAP (kg/ha)***	**2022 P rate (kg P/ha)**	***Equivalent MAP (kg/ha)***	**2023 P rate (kg P/ha)**	***Equivalent MAP (kg/ha)***	**Cumulative P rate (kg P/ha)**
1	Residual value of high P rates applied in year one	0	*0*	15	*68*	15	*68*	30
2		7.5	*34*	15	*68*	15	*68*	37.5
3		15	*68*	15	*68*	15	*68*	45
4		22.5	*102*	15	*68*	15	*68*	52.5
5		30	*136*	15	*68*	15	*68*	60
6		50	*227*	15	*68*	15	*68*	80
7		90	*409*	15	*68*	15	*68*	120
8	Alternative P management strategies	Spread MAP (90)*	*341 fb 68*	15	*68*	15	*68*	120
9		Chicken litter (93)**	*CL fb 68*	15	*68*	15	*68*	123
10	Value of repeated P rates over three years	0	*0*	0	*0*	0	*0*	0
11		7.5	*34*	7.5	*34*	7.5	*34*	22.5
12		22.5	*102*	22.5	*102*	22.5	*102*	67.5
13		30	*136*	30	*136*	30	*136*	90
14		50	*227*	50	*227*	50	*227*	150
15		90	*409*	90	*409*	90	*409*	270
16	Compare strategies above to high P rates in year three only	15	*68*	15	*68*	0	*0*	30
17		15	*68*	15	*68*	7.5	*34*	37.5
18		15	*68*	15	*68*	22.5	*102*	52.5
19		15	*68*	15	*68*	30	*136*	60
20		15	*68*	15	*68*	50	*227*	80
21		15	*68*	15	*68*	90	*409*	120

** 75 kg P/ha spread prior to sowing as MAP + 15 kg P/ha banded as MAP*
***78 kg P/ha spread as chicken litter prior to sowing + 15 kg P/ha banded as MAP*

Grain yield data was analysed using ASREML in R. Partial gross margin was calculated as cumulative income minus cumulative fertiliser cost.

Results and discussion

The long-term trials aimed to address three key research areas and the discussion has been structured around responding to these topics.

What is the residual value of high rates of P from year 1 in following years?

Banded MAP

The residual effect of P fertiliser rates (ranging from 0 – 90 kg P/ha) were assessed in year two and three in treatments where district practice applications (15 kg P/ha) followed the range of rates in the first season. The results from year three show at two of the sites, Hart and Crystal Brook, there was still evidence of residual P from high application rates in the first season (Figure 1 and 2). In contrast, at the Spalding site in the third season there was no grain yield response to the range of P rates (0-90 kg P/ha) applied in year one (Figure 3).

At Hart in year one, grain yields reached 137% of the untreated where rates of 50 kg P/ha or more were applied. High rates of P continued to produce higher grain yields in year two and three (Figure 1). These results show at Hart residual effects of high P rates in year one, were still being observed in year three.

Crystal Brook was the most responsive site in year one, where grain yields reached 170% of the untreated at a rate of 90 kg P/ha. In the second year the grain yield response to increasing P remained significant with maximum grain yields coming from the year one 90 kg P/ha application. In the third season the response to high rates of P in year one was not consistent (Figure 2). The 50 kg P/ha applied in the first year remained higher yielding compared to 0 kg P/ha however, the 90 kg P/ha was not different to the untreated.

Similarly, the Spalding site was highly responsive to P rates in year one, reaching 149% of the untreated with 90 kg P/ha. The chicken litter treatment produced higher grain yields than the comparable 90 kg P/ha MAP in all three years indicating other yield limitations (Figure 3). Protein data (not presented) showed nitrogen was limiting in year two which may have masked the P response in that season. Higher rates of nitrogen and foliar trace elements were applied in the third season to address any possible nutrient limitations. However, no response to high P rates applied in year one was recorded in year three (Figure 3). This indicates there was no legacy effect of the higher P rates carrying into the third year.

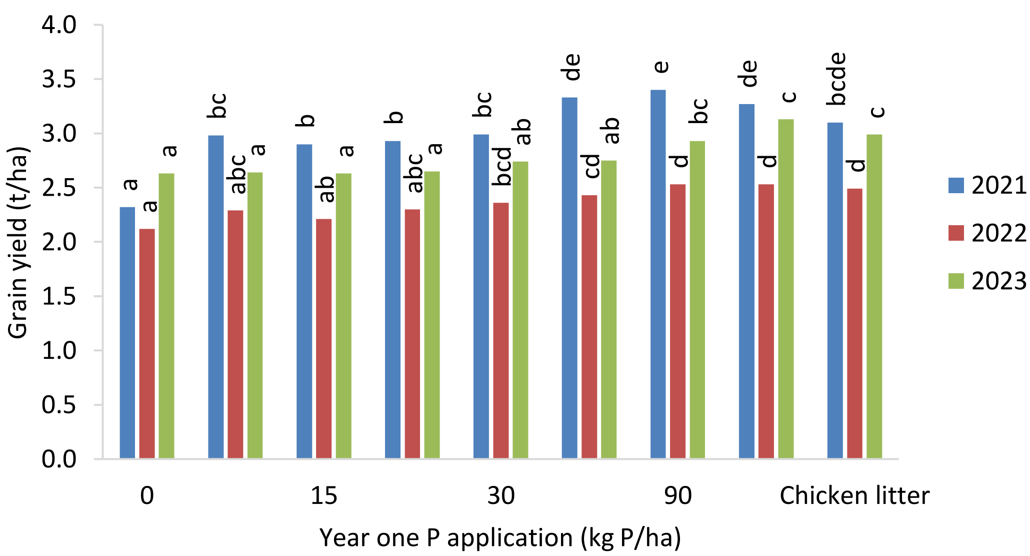

Figure 1. Grain yield (t/ha) over three seasons for P rates applied in year one at Hart, SA from 2021-2023. (P value for all 21 treatments; 2021 <0.001, 2022 <0.001 and 2023 <0.001). Bars within a year level that share a common letter are statistically similar.

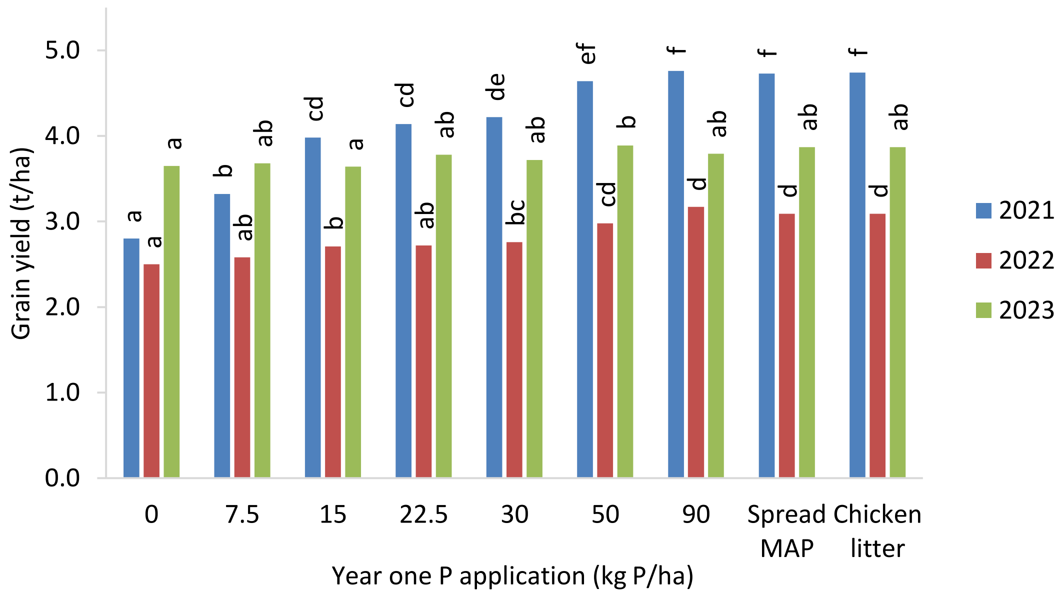

Figure 2. Grain yield (t/ha) over three seasons for P rates applied in year at Crystal Brook, SA from 2021-2023 (P value for all 21 treatments; 2021 <0.001, 2022 <0.001 and 2023 <0.001Bars within a year level that share a common letter are statistically similar.

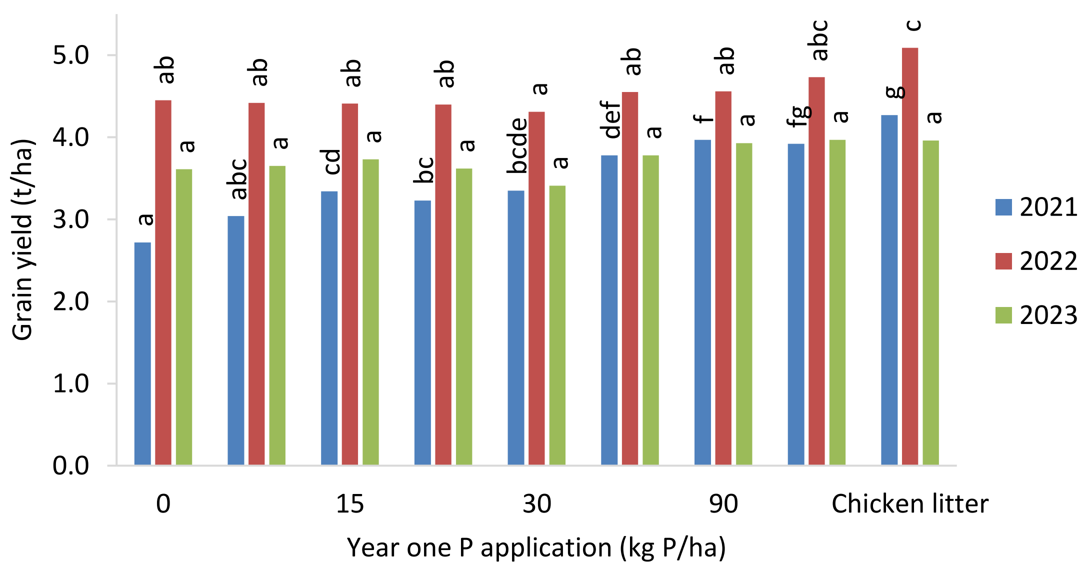

Figure 3. Grain yield (t/ha) over three seasons for P rates applied in year one at Spalding, SA from 2021-2023. (P value for all 21 treatments; 2021 <0.001, 2022 <0.001 and 2023 <0.001). Bars within a year level that share a common letter are statistically similar.

What alternative strategies can be implemented at high response sites in lieu of variable rate P application through the seeder?

Spread MAP and chicken litter application

At all three sites and in all seasons, the spread MAP treatment (75 kg P/ha spread in front of the seeder plus 15 kg P/ha MAP deep banded in year one) produced similar grain yields to the equivalent treatment of 90 kg P/ha MAP deep banded (Figures 1-3). The chicken litter treatment (78 kg P/ha of chicken litter spread in front of the seeder plus 15 kg P/ha MAP deep banded in year one) also produced similar grain yields to the equivalent treatment of 90 kg P/ha MAP deep banded at Hart and Crystal Brook in all three seasons. At these highly P responsive sites this result indicates the P fertiliser efficiency was similar regardless of application method.

At Spalding, grain yields from the chicken litter treatment were higher compared to the 90 kg P/ha deep banded in the first and second season. The chicken litter treatment received an additional 173 kg N/ha compared to other treatments. Grain protein data (not presented) indicated that the additional N likely contributed to the grain yield response in the first two seasons. In the third season there was no difference between the chicken litter treatments and the equivalent deep banded MAP treatment.

What is the effect of repeated high-rate P application vs district practice?

The district practice treatment refers to the repeated application of 15 kg P/ha (Table 2). This treatment is representative of the P management strategy used by all three trial cooperators in previous years.

The Crystal Brook and Hart sites showed similar responses with highest grain yields coming from repeated P rates of 50 and 90 kg P/ha in the trials in years two and three (Figure 4 and 5). At Hart, repeated applications of 30 kg P/ha were enough to outyield the district practice in years two and three (Figure 4). The same treatment increased yields above district practice in year two at Crystal Brook but no yield advantage was seen in year three. Repeated applications of 22.5 kg P/ha yielded the same as district practice for the three years at both Crystal Brook and Hart.

It was anticipated that with repeated applications of high rates, the crop P requirements would be satisfied by smaller applications in the second and third season. This was not observed with the highest repeated P rates still increasing yield into the third year at these sites. Further investigation is required to understand if higher yields continue from the highest P rates or if a point of P saturation occurs allowing lower P rates to satisfy crop requirements.

At Spalding, the application of P rates of 50 and 90 kg P/ha resulted in increased yields compared to the district practice in year one (Figure 6). Individual year analysis indicates a small grain yield response above 15 kg P/ha in year two and three. However, the cumulative grain yield analysis shows significant grain yield increases above district practice P rates with repeated applications of 50 and 90 kg P/ha. As discussed above, it is likely that nitrogen was a limiting factor at this site and confounds the grain yield results. The chicken litter treatment was the highest yielding at this site in year two.

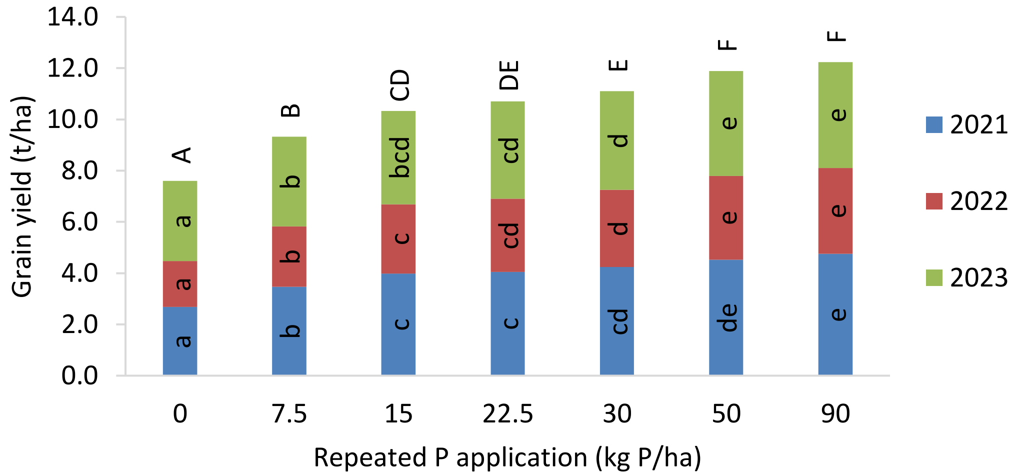

Figure 4. Hart cumulative grain yield for repeated applications of P fertiliser, P values = 2021 <0.001, 2022 <0.001, 2023 <0.001 and cumulative <0.001. Bars within a year level that share a common letter are statistically similar, capital letters refer cumulative yield analysis.

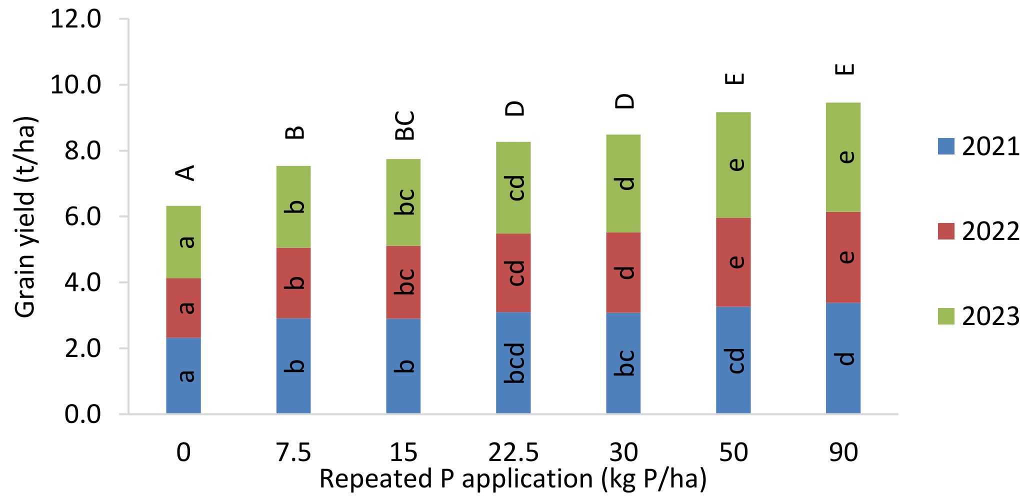

Figure 5. Crystal Brook cumulative grain yield for repeated applications of P fertiliser, P values = 2021 <0.001, 2022 <0.001, 2023 <0.001 and cumulative <0.001. Bars within a year level that share a common letter are statistically similar, capital letters refer cumulative yield analysis.

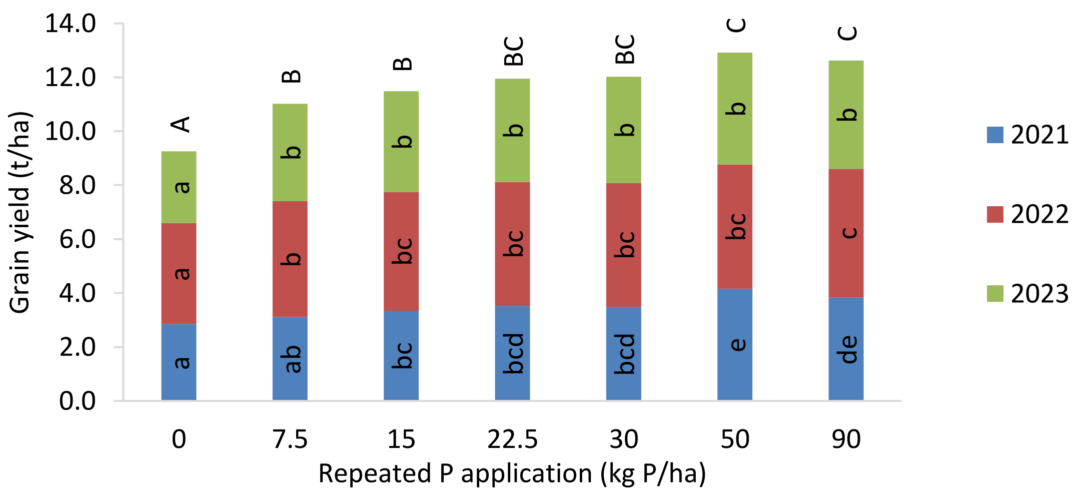

Figure 6. Spalding cumulative grain yield for repeated applications of P fertiliser, P values = 2021 <0.001, 2022 <0.001, 2023 <0.001 and cumulative <0.001. Bars within a year level that share a common letter are statistically similar, capital letters refer cumulative yield analysis.

Economic analysis of the different P management strategies

Whilst the repeated application of high P fertiliser rates has resulted in the largest cumulative grain yields, the cost of fertiliser also needs to be considered. The partial gross margin (PGM) has been calculated on the cumulative grain yield for all sites and presented with variable MAP pricing scenarios (Table 3 – next page).

The Spalding PGM values have been impacted by the variability of the site and due to the N limitation in year one and two, which affected grain yields in all treatments except for chicken litter (Appendix 1).

The Hart and Crystal Brook sites behaved similarly in terms of grain yields over the three years and therefore the PGMs are similar (Appendix 1). Firstly, within the range of MAP prices of $500-$1500/t the district practice treatment is never the highest PGM on these responsive sites. Therefore, the alternative P management strategies tested have potential to improve profitability. Secondly, when fertiliser prices are low (MAP $500/t) there is an economic advantage of achieving consistently higher yields with repeated P rates of 50 kg P/ha, which produces the highest PGM for these sites. As fertiliser prices increase, the optimum P rate for repeat applications declines, ultimately resulting in a lower PGM. This is where the value of residual P becomes important. Under high fertiliser prices (MAP $1500/t) the one-off high P rates in year one of 50 - 90 kg P/ha has a greater PGM than the repeat high applications. However, we would expect that the repeated applications of higher rates will have higher reserves to support ongoing productivity in the near future compared with the one-off high application rates. Soil testing planned for these trials will explore this.

Treatment 5-7 show the value of addressing P deficiency immediately, rather than putting it off for two seasons as in treatment 19-21. On average, at Hart and Crystal Brook there is a $272/ha advantage for addressing deficiency in year one with 30-90 kg P/ha, compared with year three (Appendix 1).

Under high MAP fertiliser prices ($1500/t) the chicken litter treatment provided the greatest PGM at Crystal Brook and one of the highest at Hart (Appendix 1). This alternative source of P becomes important under high MAP prices assuming the price does not increase from demand because of high synthetic P fertiliser prices. Not only is the chicken litter supplying P to the crop, but it is also supplying other nutrients which can potentially reduce the total synthetic fertiliser inputs, such as urea, to further decrease input costs whilst maintaining grain yields which ultimately increase PGM further.

Acknowledgements

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We also thank the participating growers involved in hosting the long-term field trials.

Appendix 1. Predicted cumulative yield and partial gross margin (PGM) for the three seasons at differing MAP fertiliser prices.

Treatment	2021 P rate (kg/ha)	2022 P rate (kg/ha)	2023 P rate (kg/ha)	Predicted cumulative yield (t/ha)			MAP $500/t			MAP $1000/t			MAP $1500/t		
				Crystal Brook	Hart	Spalding	Crystal Brook	Hart	Spalding	Crystal Brook	Hart	Spalding	Crystal Brook	Hart	Spalding
1	0	15	15	8.95	7.07	10.78	$3,477	$2,901	$2,763	$3,409	$2,833	$2,695	$3,340	$2,764	$2,626
2	7.5	15	15	9.58	7.91	11.11	$3,655	$3,204	$2,844	$3,570	$3,119	$2,759	$3,484	$3,033	$2,674
3	15	15	15	10.33	7.74	11.48	$3,882	$3,104	$2,935	$3,779	$3,001	$2,832	$3,677	$2,899	$2,730
4	22.5	15	15	10.64	7.88	11.25	$3,954	$3,165	$2,855	$3,834	$3,045	$2,735	$3,715	$2,926	$2,616
5	30	15	15	10.70	8.09	11.07	$3,967	$3,235	$2,799	$3,830	$3,098	$2,662	$3,694	$2,962	$2,526
6	50	15	15	11.51	8.51	12.11	$4,231	$3,343	$3,035	$4,049	$3,161	$2,853	$3,868	$2,980	$2,671
7	90	15	15	11.72	8.86	12.46	$4,273	$3,397	$3,041	$4,001	$3,125	$2,768	$3,728	$2,852	$2,495
8	Spread MAP	15	15	11.68	8.93	12.62	$4,215	$3,418	$3,078	$3,942	$3,146	$2,806	$3,669	$2,873	$2,533
9	Chicken litter	15	15	11.70	8.58	13.32	$4,065	$3,126	$3,099	$3,963	$3,024	$2,997	$3,860	$2,921	$2,895
10	0	0	0	7.60	6.32	9.26	$2,862	$2,620	$2,458	$2,862	$2,620	$2,458	$2,862	$2,620	$2,458
11	7.5	7.5	7.5	9.32	7.53	11.02	$3,511	$3,064	$2,859	$3,460	$3,013	$2,808	$3,409	$2,962	$2,757
12	22.5	22.5	22.5	10.70	8.27	11.95	$3,994	$3,280	$3,011	$3,841	$3,126	$2,857	$3,687	$2,973	$2,704
13	30	30	30	11.10	8.49	12.02	$4,117	$3,318	$2,975	$3,913	$3,114	$2,770	$3,708	$2,909	$2,566
14	50	50	50	11.89	9.17	12.62	$4,312	$3,490	$3,006	$3,971	$3,149	$2,665	$3,630	$2,808	$2,324
15	90	90	90	12.23	9.46	12.92	$4,158	$3,328	$2,824	$3,544	$2,715	$2,211	$2,931	$2,101	$1,597
16	15	15	0	10.08	7.57	10.48	$3,854	$3,087	$2,708	$3,786	$3,019	$2,640	$3,718	$2,950	$2,571
17	15	15	7.5	10.04	7.69	11.12	$3,800	$3,106	$2,856	$3,715	$3,021	$2,771	$3,629	$2,935	$2,685
18	15	15	22.5	10.30	7.90	11.78	$3,857	$3,147	$2,991	$3,737	$3,027	$2,871	$3,618	$2,908	$2,752
19	15	15	30	10.21	7.98	11.84	$3,807	$3,162	$2,994	$3,671	$3,025	$2,857	$3,534	$2,889	$2,721
20	15	15	50	10.46	8.09	11.91	$3,797	$3,149	$2,959	$3,615	$2,967	$2,777	$3,433	$2,786	$2,595
21	15	15	90	10.51	8.40	12.37	$3,750	$3,147	$2,991	$3,477	$2,875	$2,719	$3,204	$2,602	$2,446

Assumed grain pricing wheat $300/t, barley $250/t, lentil $700/t.
Chicken litter $54.70/t which includes cost of product, spreading and transport (averaged across the three sites).
White cells = grain yields at Spalding which were not nitrogen limited.