

Integrating spatial data and long-term strategies for improved phosphorus fertiliser management

Sam Trengove¹, Stuart Sherriff¹, Sarah Noack¹, Jordan Bruce¹, Declan Anderson¹ and Sean Mason²

¹Trengove Consulting, ²Agronomy Solutions

Key findings

- A methodology called the phosphorus (P) sufficiency index (pHnNDVI) has been developed for combining soil pH and NDVI data layers and generating P fertiliser prescription maps for use in variable rate seeders and spreaders.
- Across 57 P fertiliser response trials conducted from 2019-2024 the optimal P rate to maximise partial gross margin ranged from 0 up to 50 kg P/ha.
- Among different long-term P management strategies trialed, increases in DGT-P levels pre-seeding in 2024 generally only occurred where high rates of P fertiliser (50 or 90 kg P/ha) had been applied repeatedly or the year prior to soil sampling.
- Residual P available in the year following fertiliser application continued to increase grain yields in four out of six trial years, however generally only at rates greater than 50 kg P/ha. This is highlighted in highly P responsive soils, where current district practice application rates of 10-20 kg P/ha are unlikely to provide any useful residual P from the season prior.

Background

Fertiliser inputs are the single largest variable cost for grain growers producing a crop. The variability in rainfall experienced by growers coupled with high fertiliser prices has resulted in conservative fertiliser management. As a consequence, phosphorus (P) deficiency still causes yield losses in many environments and soil types across SA. In contrast there are many areas where P response is minimal and optimum gross margin can be achieved with little or no application of P fertiliser.

The use of pH mapping has become common practice to identify areas within a paddock of low pH to improve lime application efficiency. While generating pH maps and comparing them with satellite NDVI imagery, it has been observed that high pH areas on the map correlate with low crop vigour and P deficiency in many instances (Trengove et al. 2019; Mason et al. 2022) (Figure 1). This finding resulted in the development of the P sufficiency index.

The P sufficiency index has been given the acronym pHnNDVI as it is the soil pH value divided by NDVI normalised to the paddock average using the formula below.

$\text{pHnNDVI} = \text{soil pH} / (\text{NDVI}/\text{paddock NDVI average}).$

Areas of a paddock with high soil pH (>7.5) and low relative normalised NDVI (<0.9) result in a high pHnNDVI value and are likely to be highly responsive to applied P (for example, site 23 and 25 in Figure 1). Areas with lower pH (<6.5) and high relative NDVI (>1.1) result in a low pHnNDVI value and are likely to be unresponsive to applied P (for example site 22 in Figure 1). This data layer can then be used to generate P application maps for variable rate seeding operations.

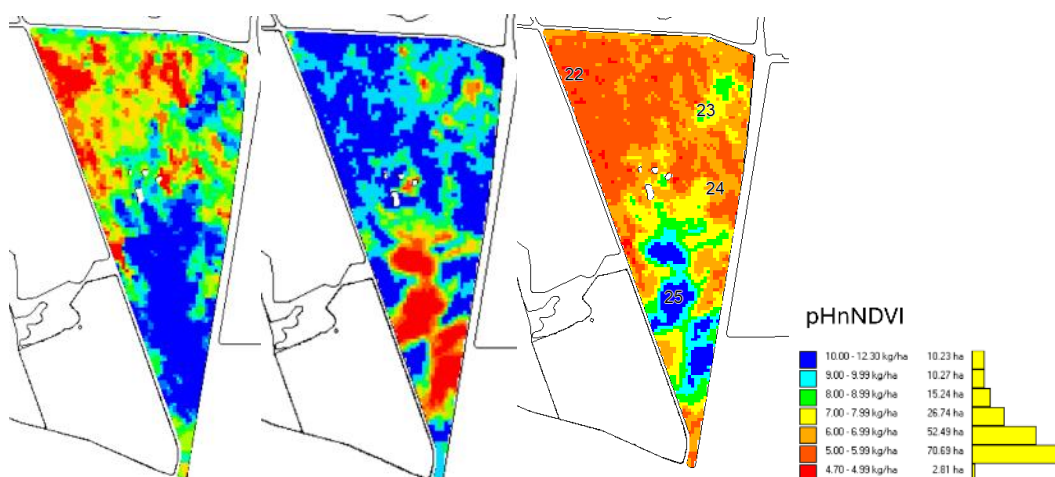


Figure 1. Soil pH (left), satellite NDVI (middle) and pHnNDVI (right) for a paddock at Crystal Brook

Methodology

From 2019 to 2024, 57 P fertiliser rate response trials have been established across 14 paddocks in the Mid North, Yorke Peninsula, Eyre Peninsula and Mallee. Within each paddock the pHnNDVI maps were used to locate four small plot trials with seven P rates ranging from 0-90 kg P/ha. The P fertiliser was applied as MAP and urea was used to match the nitrogen to the highest P rate at each trial. All fertiliser was applied below the seed using a knife point and press wheel system. The plots were monitored for Normalised Difference Vegetation Index (NDVI), leaf tissue P concentration, grain yield and quality. NDVI and grain yield will be discussed in this paper.

Three of the 57 trial sites (Hart, Spalding and Crystal Brook) had long-term trial sites established in 2021 where the range of P rates were applied. The P fertiliser management strategies evaluated single applications of high P rates (0-90 kg P/ha) followed by 15 kg P/ha in subsequent seasons or repeated applications of 0-90 kg P/ha applied each season. Alternative P management strategies were also included such as broadcasting MAP prior to seeding and the use of chicken litter. Full trial details and soil characterisations can be found in previous reports (Tregrove et al. 2023). Soil samples were collected from these plots prior to sowing in the fourth season (2024) to assess changes in soil P levels, Colwell P, and DGT-P.

Results and discussion

Field evaluation of the P sufficiency index

In paddocks with significant spatial variation the P sufficiency index has shown it can accurately predict areas of low, medium and high P response in the Mid North and Yorke Peninsula. More recently, this method has also been tested in areas of the Mallee and the Eyre Peninsula. This trial series has provided a robust database to assess the capabilities of the pHnNDVI methodology (Figure 2).

Across six years of investigation there was a strong in-season biomass response (measured by Greenseeker NDVI) to higher rates of P with increasing pHnNDVI (Figure 2). This strong relationship for crop biomass can be used by growers for hay crops and biomass production for grazing.

The P rate to achieve maximum biomass and pHnNDVI relationships have been stronger than the yield response. This can be attributed to the fact that biomass (NDVI) is assessed earlier in the season and is less likely to be influenced by as many factors as grain yield such as seasonal conditions, crop disease, herbicide residues, frost and weed competition.

For paddocks that contain soil types such as calcarosols, dermosols, chromosols and sodosols the model has been most accurate. For paddocks that contain vertosols (deep black cracking clays) the model has been less accurate. It is unclear why the vertosols do not produce similar grain yield responses when predicted to be highly P responsive. Both soil test values (DGT-P range 14-97 µg/L) and the pHnNDVI suggest they should be P responsive, and while they produce a biomass response this has not translated into grain yield. This lack of grain yield response on vertosols has been observed in other trials in the Southern region. For this reason, the vertosol sites have been removed from the dataset presented here (Figure 2).

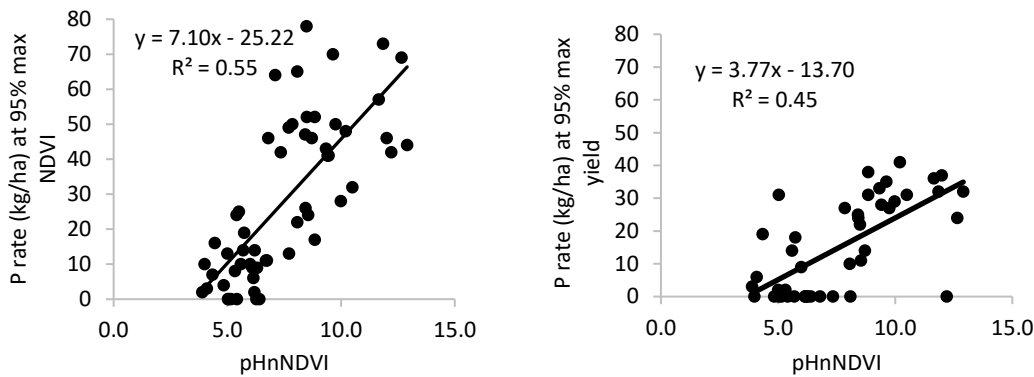


Figure 2. Relationship between pHnNDVI and P fertiliser rate (kg/ha) at 95% maximum NDVI for 57 sites (left) and 95% maximum grain yield for 45 sites across the Mid North, Yorke Peninsula and Eyre Peninsula (right).

The pHnNDVI has been able to predict where there will be a low P requirement to maximise partial gross margin (PGM), however, there has been some variability around the higher end of the pHnNDVI scale. Where grain yields were low, the grain yield response to P has been reduced, resulting in a lower P rate to maximise PGM than predicted by pHnNDVI alone. Where a grain yield potential (maximum yield) for the site is included in the prediction model, the accuracy is improved (Table 1).

The information presented in Table 1 can be used by growers and advisers to determine the optimum P rate for given paddock zones. The response modelling shows at low pHnNDVI (<5) there is a low predicted P rate requirement (0-5 kg P/ha). As pHnNDVI increases the P fertiliser rate required to maximise PGM also increases and it increases at a faster rate at higher yields. For example, at pHnNDVI 11 a crop with 3.0 t/ha yield potential is predicted to require 18 kg P/ha. However, as the yield potential for the same pHnNDVI increases to 6.0 t/ha, the P fertiliser required is now 40 kg P/ha.

Grain yield data from a reliable historical yield map could be included in the model with pHnNDVI to produce a P rate prescription, or a yield target could be chosen for a given paddock to calculate the optimum P rate to produce the prescription.

Table 1. Predicted P rate (kg P/ha) at maximum partial gross margin for pHnNDVI and site max yield.

$P \text{ rate at max PGM} = -4.72 - 3.66 * \text{site max yield} + 1.01 * (\text{site max yield} * \text{pHnNDVI})$, $R^2 = 0.56$
 Assumptions for gross margins – MAP = \$1100/t, lentil = \$800/t, wheat = \$330/t, barley = \$275/t.

Site max yield	1	2	3	4	5	6	7
pHnNDVI	Predicted P rate at Max PGM						
4	0	0	0	0	0	0	0
5	0	0	0	1	2	4	5
6	0	0	2	5	7	10	12
7	0	2	5	9	12	16	19
8	0	4	8	13	17	22	26
9	1	6	12	17	22	28	33
10	2	8	15	21	27	34	40
11	3	10	18	25	32	40	47
12	4	12	21	29	37	46	54
13	5	14	24	33	43	52	61

Long-term P management trials

Residual soil available P from repeated and once off applications of P fertiliser rates

The P use efficiency (PUE) of fertilisers is generally low in the year of application, ranging from 2-26% in this trial series, however, it continues to provide P to crops for several years. Pre-seeding 2024, the three long-term trials were soil sampled (following three trial seasons) to understand if the various P management strategies have built up or mined soil available P compared to year one.

At Hart all DGT-P values remained below the critical limit (60 µg/L). There was a greater range and higher number of treatments above the critical DGT-P at both Crystal Brook and Spalding (Figures 3 and 4). Among the three trial sites, Hart has the highest PBI (111) compared to Spalding (77) and Crystal Brook (88) which indicates a stronger ability to bind added fertiliser P. This has likely contributed to the lower P availability and lower variation in DGT-P values at this site.

Among all the strategies trialed, the only P rates to have an impact on starting DGT-P were generally where high rates of P fertiliser had been applied repeatedly each year (Figure 3) or in year three only, prior to testing in year 4 (Figure 4). This shows a portion of the fertiliser P applied in these high rates last season or cumulatively has carried over in the plant available form and will be available to the subsequent crop. However, it also highlights P fertiliser rates of <50 kg P/ha applied repeatedly or in a single season, are not sufficient to increase DGT-P to an impactful level the following season on P fixing soils.

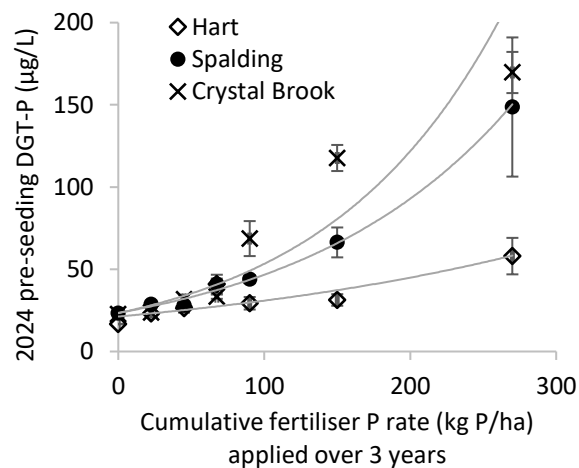


Figure 3. Pre-seeding 2024 DGT-P following three seasons (2021-2023) of repeated applications of P fertiliser rates ranging from 0-90 kg P/ha for Hart ($R^2 = 0.79$), Spalding ($R^2 = 0.997$) and Crystal Brook ($R^2 = 0.87$).

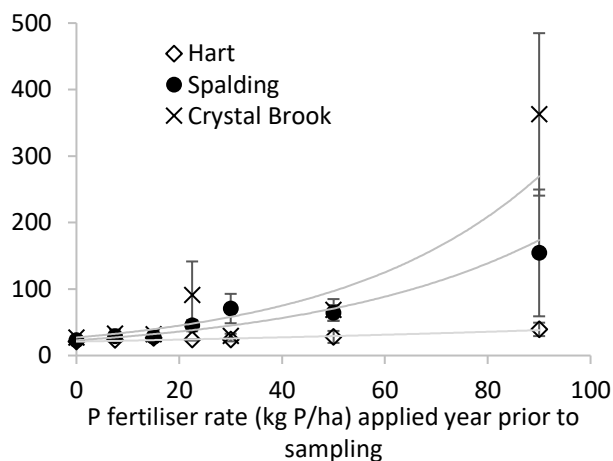


Figure 4. Pre-seeding DGT-P following once off applications of P fertiliser rates ranging from 0-90 kg P/ha the year prior (2023) to sampling at Hart ($R^2 = 0.92$), Spalding ($R^2 = 0.94$) and Crystal Brook ($R^2 = 0.94$).

In addition to soil testing, yield responses assessing the value of residual P were also measured (Figure 5). In general, yield responses were measured in year 2 in response to P application the year prior in four out of six site years, as demonstrated at Hart (Figure 5). Responses were also observed in year 3 in two out of three site years, though the level of response declines from year 2 to 3 (Figure 5). However, while there are meaningful responses to residual applied P, the Hart results also demonstrate that higher yields are attainable in subsequent years, by repeatedly applying higher rates, rather than relying on the residual benefit of the year prior.

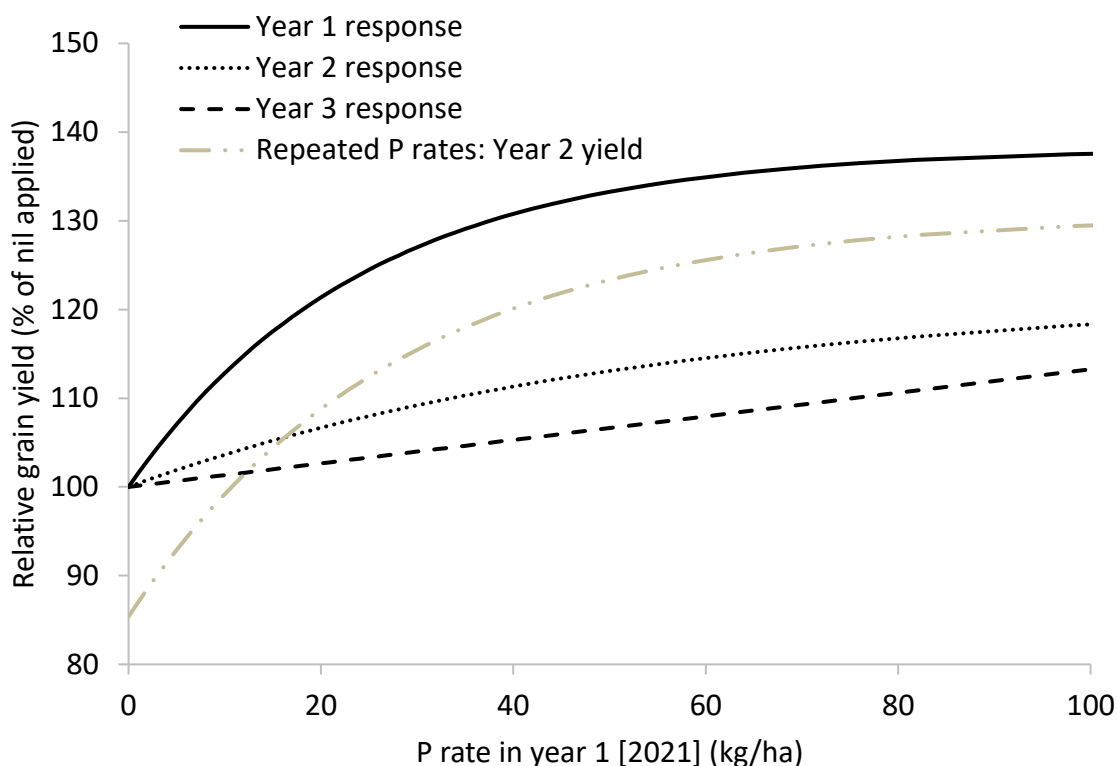


Figure 5. Grain yield response at Hart to P rate range applied in year 1 (2021) and residual response to year 1 application in year 2 (2022) and year 3 (2023) when 15 kg P/ha was applied in those years. This is compared with the response in year 2, when the P rate range are repeated in both years.

Crop response to P fertiliser strategies in a dry 2024

Wheat (Hart)

Grain yields at the Hart site in 2024 were low, averaging 0.83 t/ha (Figure 6). High rates of P fertiliser (50 kg P/ha and 90 kg P/ha) applied in 2024 led to increased grain yields. On average these two application rates increased grain yield by 40% (0.3 t/ha) compared to the district practice treatment (15 kg/ha/year). The slightly lower P rate of 30 kg P/ha also increased grain yield this season. This demonstrates that even in a low yielding year such as 2024, grain yield increases are still likely on these responsive soil types, although the rate that optimises gross margin will be lower, as per Table 1.

The alternative P management strategies had mixed outcomes on wheat grain yield this season. Broadcasting MAP did not improve grain yields compared to the district practice treatment. However, the application of chicken litter (2021 and 2024) increased grain yield by 23%. As previously reported the chicken litter treatment has generally performed as well as higher P rates and provided one of the highest PGM at both Hart and Crystal Brook (Tregrove et al. 2023).

Repeated applications of different P fertiliser rates (0-90 kg P/ha) did not result in a consistent increase in grain yield (Figure 6). Two out of the five P fertiliser rates resulted in improved grain yield (22.5 kg P/ha and 50 kg P/ha) while the remaining were no different to the district practice. It is likely crop water use in previous seasons (e.g. high yielding treatments = less carried over soil water) may have influenced the results in these treatments this season. This lack of response in the year following high applications of P fertiliser demonstrates that on these soil types relying on the previous year's fertiliser is likely to result in reduced grain yields.

As a result of the dry season and low grain yields it is not surprising that grain protein across the trial was high, averaging 13.6% (data not shown). In general, there was little variation among the P management strategies. The most consistent outcome was higher grain protein where 90 kg P/ha had been applied in 2024 (one off or repeated application strategies).

Lentils (Crystal Brook and Spalding)

Grain yields across both sites were low averaging 0.46 t/ha at Crystal Brook (Figure 6) and 0.86 t/ha at Spalding. At Crystal Brook there were minor differences in lentil grain yield among the P management strategies. Generally, the highest grain yield came from the application of 90 kg P/ha applied this season as either MAP spread prior to sowing or the repeated application.

At Spalding, there were even fewer differences in grain yield compared to the Crystal Brook site. All P management strategies had grain yield similar to the district practice. The only exception was the repeated 0 kg P/ha which reduced grain yield.

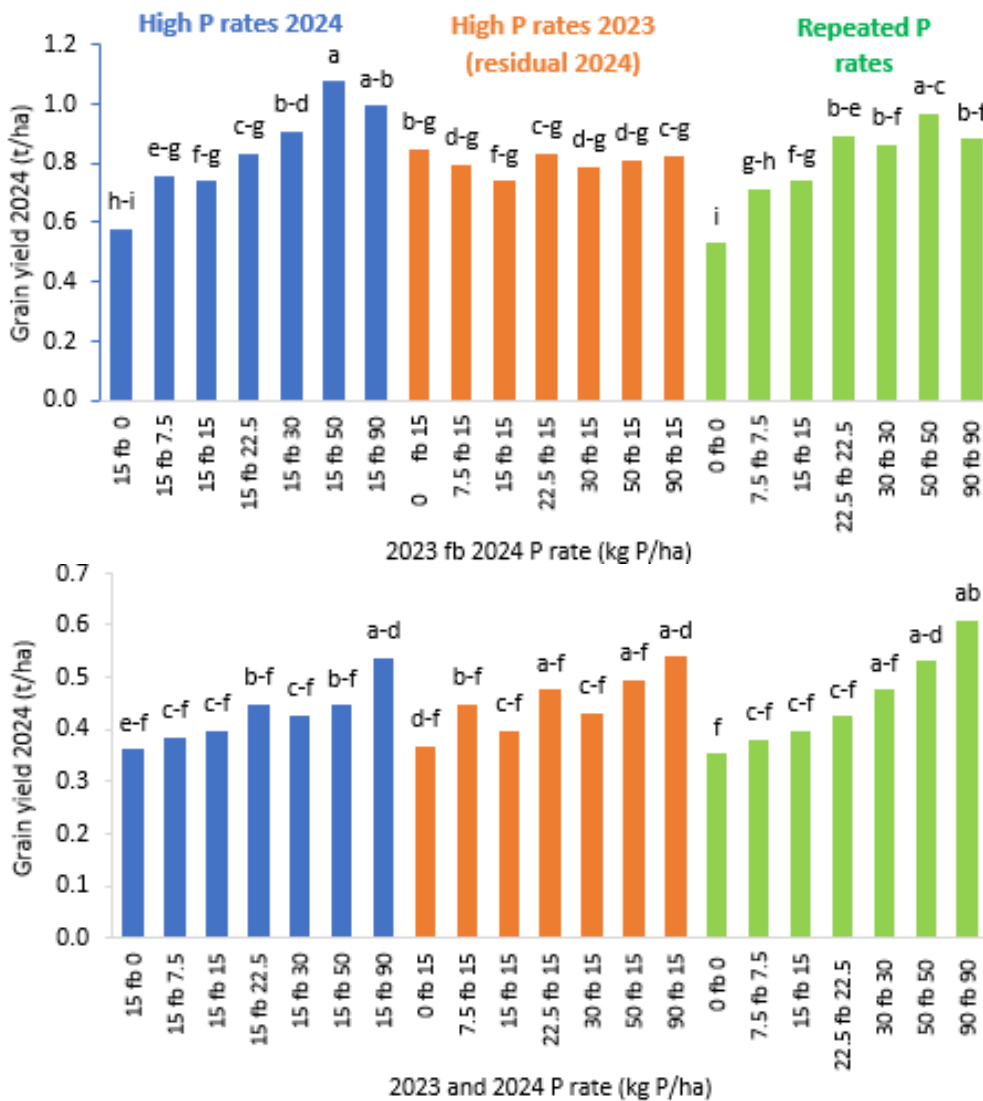


Figure 6. Grain yield (t/ha) for the Hart (top) and Crystal Brook (bottom) long-term P management site 2024.

Implications for P fertiliser management in 2025

It is common for growers in the southern region to use a P replacement strategy based on the amount of P removed in the grain (i.e. 3 kg P/t cereal grain) to determine fertiliser P application rates. Using this strategy, 'district practice' P fertiliser rates are generally in the range of 10-20 kg P/ha/annum. Given the below average grain yields last season, it would be fair to assume <5 kg P/ha has been exported in the grain in many areas. The P replacement strategy would therefore assume a reduction in P fertiliser rates going into this season. Using the field trials above we explore the question – can we cut back to 5 kg P/ha as replacement this season?

This research has shown at district practice P fertiliser application rates (<20 kg P/ha) a grower cannot rely on residual P from the season prior if the zone or paddock is P responsive with moderate PBI (range 77-110 at these sites). Repeated applications of >20 kg P/ha or more were required to shift pre-seeding DGT-P soil levels enough to have any implications on crop growth and grain yield.

The yield responses from Hart (Figure 5) have shown the response to residual P, when returning to district practice in year 2 and year 3. However, this graph also shows how much economic benefit is lost by not applying the optimum P rate or continuing with repeated fertiliser rates. It is in fact, a demonstration of what not to do on P responsive soils, unless the expectation is for low cereal yield potential of less than 2 t/ha. Reducing P fertiliser rates coming into 2025 will limit the yield potential of this season's crop (year 1 response), and the yield potential of the subsequent crop may also be limited (year 2 response), even when 'district practice' rates are reapplied in future years.

Conversely, P fertiliser management for non-responsive zones/paddocks requires a different approach. For these areas there is significant value in residual fertiliser P from previous applications. In some cases, they are not responsive to P at all, and it is rare that they respond to greater than replacement levels. The pHnNDVI methodology can help to identify where these areas are, and it can be used to make considerable savings on P fertiliser application on these soil types.

Acknowledgements

This research is made possible by the contributions of the Wundke, Stephenson and Sargent families through trial cooperation for long-term trials. Other growers involved in the projects include Bill Trengove, Leigh Fuller, James Venning, Joe & Jess Koch, Scott Weckert, Kenton Angel, Tristan Baldock, Andrew Thomas and David Cooper. This program is co-funded by SAGIT and GRDC (project code TCO 06024) and the authors would like to thank them for their investment in this research. We would also like to acknowledge the previous SAGIT investments (TC221 and TC219) to establish and monitor the single year and long-term field trials.

References

Mason S, Trengove S, Sherriff S, Bruce J (2022) An informed approach to phosphorus management in 2022. GRDC Update Adelaide

Trengove S, Sherriff S, Bruce J and Mason S (2023) [The performance of residual and cumulative P applications on soils in the Mid North of SA](#). Hart Trial Results Book 2023.