Office Use Only

Project Code	AS219
Project Type	Research

FINAL REPORT 2022

Applicants must read the *SAGIT Project Funding Guidelines* prior to completing this form. These guidelines can be downloaded from www.sagit.com.au

Final reports must be submitted by email to admin@sagit.com.au as a Microsoft Word document in the format shown **within two months** after the completion of the Project Term.

PROJECT CODE	AS219
PROJECT TITLE (10 words maximum)	
Optimizing P Nutrition in Pulses to Maximize N fixation and Yield	

PROJECT DURATION *These dates **must** be the same as those stated in the Funding Agreement.*	
Project start date	**1/07/2019**
Project end date	**30/06/2022**

PROJECT SUPERVISOR CONTACT DETAILS *(responsible for the overall project)*		
Title:	**First Name:**	**Surname:**
Dr.	Sean	Mason
Organisation:	Agronomy Solutions Pty. Ltd.	

PROJECT REPORT: *Please provide a clear description for each of the following:*

Executive Summary (200 words maximum)

A few paragraphs covering what was discovered, written in a manner that is easily understood and relevant to SA growers. A number of key dot points should be included which can be used in SAGIT communication programs.

Phosphorus nutrition continues to be a challenge for SA broad acre farmers on calcareous soils with high P buffering capacities. Prior to this project there was limited knowledge of pulse P requirements on P responsive soil types and the potential flow on effects of extra N fixation via improved pulse production if pulse P requirements were comparable to cereals.

This project has outlined over very contrasting seasons that on highly P responsive soils that;

- Optimising Phosphorus nutrition is key for the cereal phase for maximising gross margins in a 2–3-year crop rotation.
- Phosphorus inputs can increase pulse nodulation and N fixation. Standard applications rates of MAP (40-50 kg/ha) were sufficient to meet Pulse P requirements.
- High fertiliser (applied with the seed) can be detrimental to pulse emergence and may be exacerbated on calcareous soils with high salt loads. Offset fertiliser applications from seed when possible.
- Residual P (after pulse crop) is important for maximising production in P deficient soils for subsequent non-legume phases.
- Pre-sowing soil sampling for mineral N may underestimate pools of nitrogen from pulse crop residues made available during the next growing seasons through mineralisation.

Project objectives

A concise statement of the aims of the project in outcome terms should be provided.

This project will provide South Australian pulse growers with clear guidelines for optimising P fertiliser form and rate for key pulse crops (lentil, chickpea, bean) on P responsive soils. The economic benefits of improved P nutrition through optimisation of biomass, N fixation and yield will be determined.

This will be done by:

i) Establishing field trials of lentil, chickpea and faba bean in SA on P responsive soils to assess optimal rate of MAP in year 1 of trials and potential N benefits to the following crops in years 2 and 3.

ii) Establishing field trials of lentil in SA on P responsive soils to determine optimal form and rate of P.

Trials will be assessed for nodulation, nitrogen fixation and yield to determine which options maximise crop productivity and are most economically effective.

This project complements existing GRDC projects and the new SARDI led GRDC investment, "*Increasing the effectiveness of nitrogen fixation in pulse crops through development of improved rhizobial strains, inoculation and crop management practices*".

Overall Performance

A concise statement indicating the extent to which the project objectives were achieved, a list of personnel who participated in the Research Project including co-operators, and any difficulties encountered and the reasons for these difficulties.

All project objectives were achieved which included a slight variation to initial trial plans. This variation was put forward and approved by SAGIT in late 2019 due to a crop initiation site at Condowie in 2019 being severely impacted by frost and very low rainfall. This resulted in very poor crop production and yields (< 0.5 t/ha) and therefore potential benefits of P nutrition could not be evaluated. The trial was moved to Port Broughton in 2020 to avoid the potential frost risk.

Urania Pulse P and P product site was implemented and managed by Sam Holmes and Central Ag Solutions from 2019 through to 2021.
The 2019 Condowie Pulse P site was implemented and managed by AgXtra and the 2020 Pulse P and P product trial was managed by SARDI.
Dr. Liz Farquharson (SARDI) contributed to the project through intellectual support in pulse nodulation and nitrogen fixation, statistical analysis, report writing, field sampling of pulses, nodulation and N fixation assessments through her laboratory.

KEY PERFORMANCE INDICATORS (KPI)

*Please indicate whether KPIs were achieved. The KPIs **must** be the same as those stated in the Application for Funding and a brief explanation provided as to how they were achieved or why they were not achieved.*

KPI	Achieved	If not achieved, please state reason.
Locate P responsive sites; soils collected from potential field sites and P levels assessed.	Yes ☒ No ☐	
Field trials established to evaluate multiple P rates with lentils, chickpeas, beans and wheat and P form with lentil.	Yes ☒ No ☐	
Field trials sampled and harvested to evaluate multiple P rates with lentils, chickpeas, beans and wheat and P form with lentil. Samples prepared for 15N analysis to measure N fixation from pulse crops (this analysis has associated time delays and therefore a brief updated report can be delivered to SAGIT on 31/03/2020).	Yes ☒ No ☐	
Progress report submitted to SAGIT	Yes ☒ No ☐	
Locate P responsive site (Trial 2). Soils collected from potential field sites and P levels assessed. Perform deep N measures associated with trial 1.	Yes ☒ No ☐	
Field trials established: Trial 1 - Sow 2019 P response trial (Urania only) with wheat or canola to assess N benefit to following crop. Trial 2 – Field trial established to evaluate multiple P rates with lentils, chickpeas, beans and wheat (replicated from 2019 – See variation). Trial 2 – Sow P product response trial with lentils	Yes ☒ No ☐	
Field trials sampled and harvested to evaluate multiple P rates with lentils, chickpeas, beans and wheat and P form with lentil. Samples prepared for 15N analysis to measure N fixation from pulse crops (this analysis has associated time delays and therefore a brief updated report can be delivered to SAGIT on 31/03/2021).	Yes ☒ No ☐	
Progress report submitted to SAGIT	Yes ☒ No ☐	

Field trials established: Trial 1 - Sow 2019 and 2020 P response trials with wheat or canola	Yes ☒ No ☐	
Harvest P response trials (wheat or canola)	Yes ☒ No ☐	
Progress report submitted to SAGIT	Yes ☒ No ☐	
Final report submitted to SAGIT	Yes ☒ No ☐	

Forms variation approved by SAGIT in 2019

TECHNICAL INFORMATION (Not to exceed **three** pages)

Provide sufficient data and short clear statements of outcomes.

1) Pulse crop (chickpea - CP, faba bean - FB, lentil - L) phosphorus requirements compared to wheat – W and potential N benefits to following crops

Three crop x P rate trials were set up for this project – Condowie 2019, Urania 2019 and Port Broughton 2020 (please refer to supplementary file for full details). As mentioned previously due to poor yields at Condowie the site was discontinued and the new site at Port Broughton was established. Following trial establishment at Urania, residual N benefits were assessed by sowing canola in 2020 and wheat in 2021. Wheat was sown in 2021 at Port Broughton following trial initiation in 2020. The results from Urania and Port Broughton will be the focus point for the following report.

Table 1: Trial details to fulfill project aim 1).

Site	2019 crops	2019 sowing date	2020 crop(s)	2020 sowing date	2021 crop	2021 sowing date	Trial Contractor
Condowie	Chickpea, faba bean, lentil wheat	29/05/2019	N/A	N/A	N/A	N/A	AgXtra
Urania	Chickpea, faba bean, lentil wheat	17/05/2019	Canola	03/05/2020	Wheat (Scepter)	15/05/2021	Central Ag Solutions
Port Broughton	N/A		Chickpea, faba bean, lentil wheat	12/05/2020	Wheat (Scepter)	12/05/2021	SARDI (2020) Ag Consulting and Research (2021)

Phosphorus requirements for different crop types:

Urania and Port Broughton sites were significantly responsive to applied P ($p < 0.05$), confirming pre-sowing soil test results indicating high P buffering capacity of soils. Although similar trends were observed at both sites and similar growing season rainfall (April- Oct), 176 mm at Urania to 263 mm at Pt Broughton, very dry conditions at Port Boughton in July/August resulted in vastly different biomass and grain yields. The greatest and most consistent response to applied P was observed for wheat with increases of 0.85 t/ha observed at Urania (max yield = 4.45 t/ha) and 0.7 t/ha at Pt Broughton (max yield = 1.3 t/ha). Optimal P rates for wheat grain production at both sites were approximately 30 kg P/ha which is consistent with recent P trials in the region on similar soil types and soil P levels (Table S1). The three pulse crops failed to deliver the same degree of yield response to applied P as wheat, potentially due to other interactions outlined in the conclusions. Faba bean yields at Urania responded positively, but not significantly, to P application (grain yield increase = 0.5 t/ha at 60 kg P/ha, yield max = 2.6 t/ha) (Figure 2). In comparison yields for chickpea (0.33 t/ha) and lentil (0.88 t/ha) were low and did not respond to increases P applications. Pulse crop yields at Port Broughton were below 0.4 t/ha which made responsive assessments to applied P difficult.

Pulse crop nodulation and N fixation with applied P:

In season assessment of pulse nodulation and N fixation highlighted potential benefits of improved crop performance by maximizing growth in overcoming P deficiency (Figure 1). Applied P significantly increased nodulation for faba bean but no significant increases were observed by increasing P rates above 10 kg P/ha. Positive trends were less pronounced for lentils (but also observed in lentil P-product trials outlined below) and nonexistent for chickpea. Importantly

applications of MAP at commonly applied levels in pulses (50-60 kg/ha) did not reduce crop nodulation.

Nitrogen fixation measurements with applied P were variable, with lentil and faba bean outperforming chickpea. Generally higher P levels improved N fixation above that of 0 P. Nitrogen fixation is a function of good nodulation and demand by the growing crop for N (Figures S3, & S4), where agronomic conditions are suited to the pulse variety, N fixation levels can be high, e.g., Faba bean at Urania fixed over 100 kg/ha in P-20 treatments, compared to just 27 kg/ha at Pt. Broughton, which was better suited to lentils. When considering Pulse P requirements on responsive soils it is essential to ensure the crop is well suited to the soil and climatic conditions to maximise production and N fixation.

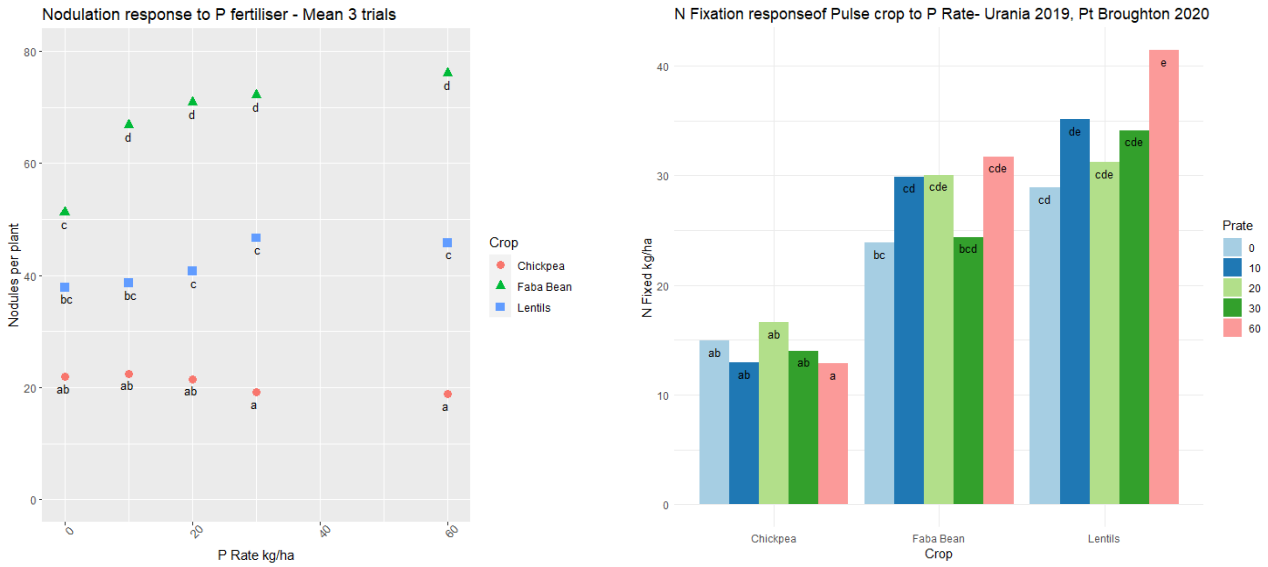

Figure 1: Impact of P application rate (applied as MAP) on three pulse crops; Left- nodulation per plant (mean of three replicated field trials), Right- Fixed nitrogen in shoots (mean of two replicated field trials). Multi-site spatial analysis performed using ASREML in RStudio, letters which differ indicate treatments are significantly different ($p<0.05$).

Residual benefits of pulse crops to following non-pulse crops in rotation:

The potential increases in pulse N contributions to the cropping system, in response to P applications, was explored by over sowing the initial crop x treatment trial with a non-pulse crop in years 2 and 3. For the residual crop phase there was no additional N applied and a blanket rate of P at 20 kg P/ha was applied as Pasture King to ensure treatment differences reflected N benefits from pulse crop N fixation or residual MAP- N. At Urania, canola was sown in 2020 with wheat in the following year (2021) while at Port Broughton, wheat was sown in 2021.

There were no significant effects of 2019 applied P on canola grain yield in 2020 or wheat grain yield in 2021 at Urania (Figure 2). Positive trends were obtained for canola after chickpea ($R^2 = 0.9$) and faba bean ($R^2 = 0.88$) with applied P which could be attributed to excess N and stored water from a poor 2019 chickpea crop and underestimated fixed N contribution from improved yields with applied P for 2019 faba bean (Figure 2). No trends or significant differences were obtained for the 2021 wheat phase for any yield measurement (NDVI or grain). Overall yields for the three crop seasons trended positively with applied P (Figure 2 and S9) with rotations CP-C-W and W-C-W providing the strongest correlations ($R^2 > 0.88$). Optimal P x residual N rate for each combination in order of CP, FB, L, W was 30, 20, 10, 30 kg P/ha. Overall yield returns were in the order of W > FB > L > CP which translated to overall partial gross margins (Figure S6) using decile 5 grain and fertilizer prices.

At Port Broughton there was a significant ($p < 0.05$) 2019 crop effect on resulting 2020 wheat grain yields (Figure 3). Wheat following either faba bean or lentil produced significantly higher grain yields compared to wheat or chickpea. As with Urania, there was no significant residual applied P effect on

2021 wheat yields but highly positively correlations (R^2 > 0.86) with 2019 applied P occurred for all pulse/wheat (2020) and wheat (2021) yield combinations (Figure S9). Optimal P x residual N rate for maximising grain yields for each combination in order of CP, FB, L, W was 20, 20, 20, 60 kg P/ha. Overall yield returns were in the order of W = FB = L > CP which translated to overall partial gross margins (Figure S8) using decile 5 grain and fertilizer prices.

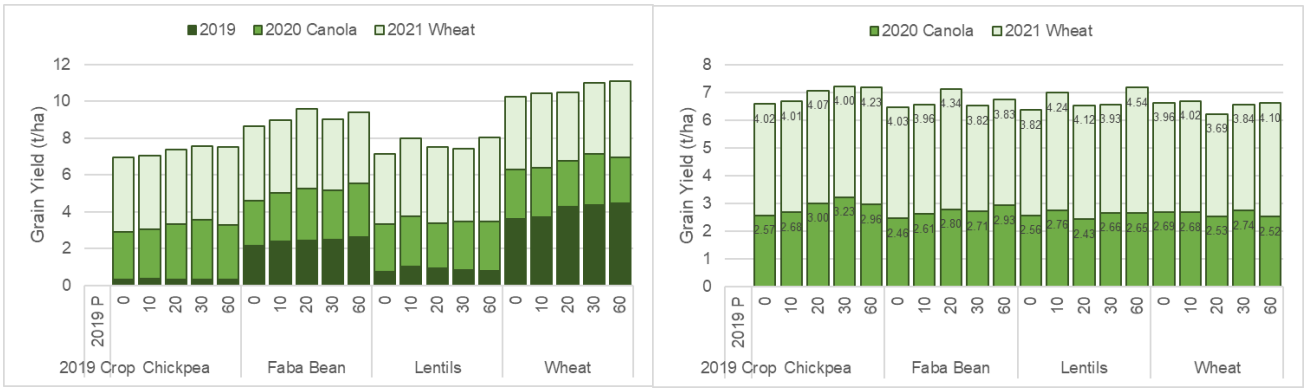

Figure 2: Grain yields for Urania, for each 2019 crop x applied P combination (left) pulse/wheat (2019), canola (2020) and wheat (2021) and right: Canola (2020) and Wheat (2021) only.

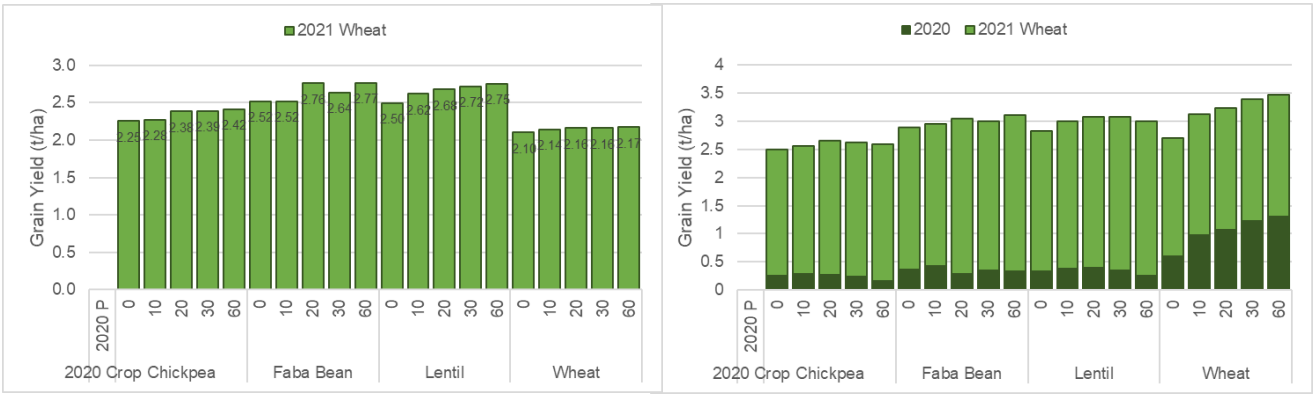

Figure 3: Mean grain yields of wheat (2021) for each 2020 crop x applied P combination (left) and mean grain yields for each crop x applied P combination including the initial crop grain yields (right) at Port Broughton.

2) Optimal form and rate of Phosphorus to maximize Lentil yields and N fixation

Two replicated trials were performed alongside the crop P requirement trials (described above) at Urania in 2019 and Port Broughton in 2020 to assess different form of P and their impact in improving lentil yields (biomass and grain) for maximizing N fixation for future crops in rotation. The four P x N treatment combinations were MAP (no N balance), MAP (with N balanced as urea), Pasture King and Phosphoric acid with increasing rates of each in order of 0, 5, 10, 20 and 40 kg P/ha.

At both sites there was no significant effect ($p > 0.05$) of applied P increasing lentil grain yields despite both sites being responsive to applied P for wheat. Grain yields were generally poor which likely resulted in poor conversion of early biomass to grain, < 1.3 t/ha at Urania and < 0.8 t/ha at Port Broughton. Multi-site analysis revealed that applied P significantly increased measured nodules per plant, with MAP and phosphoric acid both producing higher nodules numbers compared to MAP + urea (Figures S11 & S12).

Despite no increases in lentil grain yield to applied P at either site, applied P increased N fixation overall with > 10 kg P/ha applications increasing N fixation over the control but overall N fixation benefits were small (Figure 4). Combinations of fertilizer product x P rate were variable; MAP and

Pasture King were similar, where Urea rates were high (low P) nodulation and N fixation was reduced, Phos Acid at 60 units compromised early plant growth, thus reducing overall N fixation.

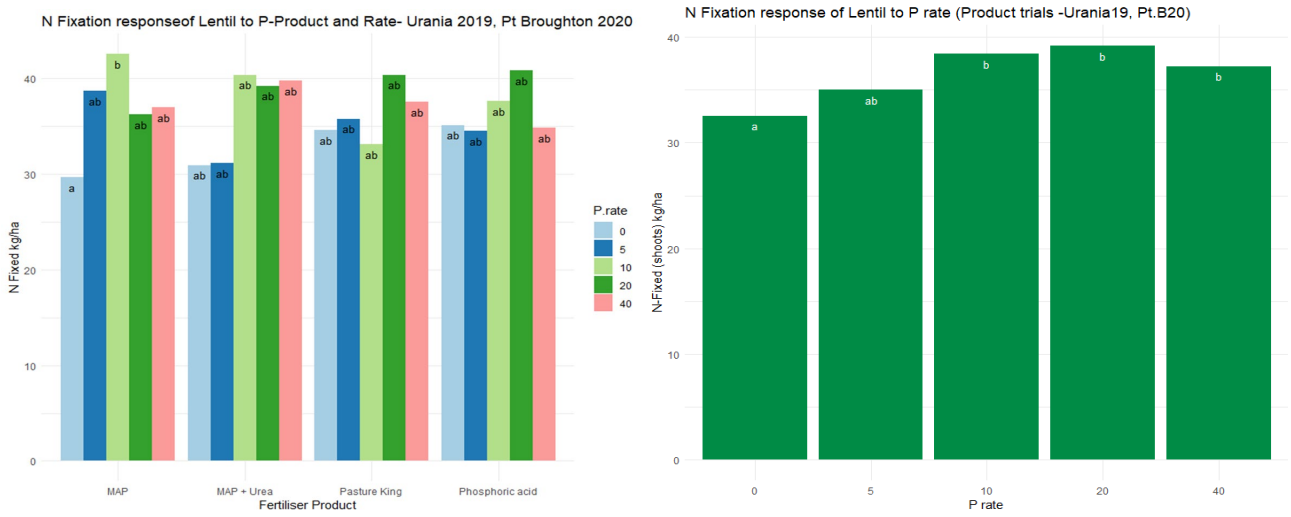

Figure 4: Lentil N fixation for each P treatment x P rate at both sites (left) and mean P product effect on lentil N fixation at both sites (right). Multi-site spatial analysis performed using ASREML in RStudio, letters which differ indicate treatments are significantly different ($p<0.05$).

CONCLUSIONS REACHED &/OR DISCOVERIES MADE (Not to exceed one page)

Please provide concise statement of any conclusions reached &/or discoveries made.

Phosphorus nutrition continues to be a challenge for SA broad acre farmers with soil types driving responses to the value of applying significant amounts of P fertiliser to maximize grain yields and gross margins. Prior to this project there was limited knowledge of pulse P requirements on P responsive soil types and the resulting flow on effects of extra N fixation via improved pulse production if pulse P requirements were comparable to cereals.

This project has outlined over very contrasting seasons the main benefit of identifying P responsive soil types and increasing P rates accordingly to maximize yields and gross margins will occur for the cereal phase of the rotation. For all three trial sites including the compromised Condowie site (2019) pulse yields were less than a third of the yield obtained for wheat apart from faba bean at Urania which yielded 56% of wheat. In season assessments of nodulation, NDVI, peak biomass revealed small positive trends with increasing applied P.

Results have outlined that maximizing pulse biomass through good management practices remains important for optimal N fixation but the benefits of optimizing P nutrition through high P rates required for cereals appear to be only a small part of the management package. This in part could be due to the ability of some pulse crops such as faba bean to solubilise P in calcareous soils through the production of root exudates (Rose et al. 2010).

For both sites the yield combination that provided the highest overall yield returns which translated to partial gross margins for Urania was wheat followed by either canola – wheat (Urania) or wheat (Port Broughton). Wheat following lentil at Port Broughton generated the greatest partial gross margins closely followed by wheat on wheat with adequate P nutrition. Chickpeas performed poorly with either faba bean or lentil providing the highest returns for a break crop pulse option.

Even though responses of pulses to higher than typical replacement P rates are small and benefits to extra N fixation were minimal this project has shown that residual applied P x N (through MAP or N fix) is important to an overall crop rotation with significant correlations obtained for each crop rotation with applied P. Optimal P rates for maximizing crop production ranged from 10-30 kg P/ha.

Throughout this project soil N (deep) and P (shallow) levels were monitored prior to each season and used as an indication of residual reserves from the prior season treatments x resulting yields. Deep soil N taken within two months of sowing times appeared to underestimate the available N pool through pulse N fixation and was highly sensitive to the N applied through the cereal phase in the first year. Nitrogen fixation benefits of pulses for the following crop relies on breakdown of the pulse root/shoot system which is dependent on seasonal conditions particularly in the lead up to sowing. It appears that measuring potential N banks following pulses through deep N tests should be used with caution. See Supplementary report for soil P and N levels post each trial season.

Soil types driving current responses to applied P are characterized by high P buffering mechanisms usually driven by the presence of calcium carbonate. Quite often these soils can offer other challenges to crop production which can include high surface salt, subsoil sodicity, subsoil boron. It appears through emergence counts performed at Port Broughton that the inability of pulses to maximize growth through high P rates could be attributed to the high background salt index that high fertilizer rates can provide. High P rates (e.g., 60kg P/ha) significantly decreased chickpea and lentil emergence with lentil appearing to be the most sensitive as emergence was significantly impacted as low as 20 kg P/ha. Seeding systems used in the project didn't have the ability to separate out the seed and fertilizer which meant the maximum potential impact of high fertilizer rates in the presence of the seed. This is an important consideration for growers looking at upfront fertilizer additions to lentils in low buffered soils or soils with already elevated salt levels. SAGIT is currently funding two projects in this area (see future work).

Reference:

Rose TJ, Damon P, Rengel Z, 2010. Phosphorus-efficient faba bean (*Vicia Faba* L.) genotypes enhance subsequent wheat crop growth in an acid and alkaline soil, *Crop and Pasture Science*, 61, 1009-1016.

INTELLECTUAL PROPERTY

Please provide concise statement of any intellectual property generated and potential for commercialisation.

None

APPLICATION / COMMUNICATION OF RESULTS

A concise statement describing activities undertaken to communicate the results of the project to the grains industry. This should include:

- *Main findings of the project in a dot point form suitable for use in communications to farmers;*
- *A statement of potential industry impact*
- *Publications and extension articles delivered as part of the project; and,*
- *Suggested path to market for the results including barriers to adoption.*

Note that SAGIT may directly extend information from Final reports to growers. If applicable, attach a list of published material.

Main findings of the project in a dot point form suitable for use in communications to farmers;

- Optimising Phosphorus nutrition is key for the cereal phase for maximising gross margins in a 2–3-year crop rotation.
- Phosphorus inputs can increase pulse nodulation and N fixation. Standard applications rates of MAP (40-50 kg/ha) were sufficient to meet Pulse P requirements.
- High fertiliser (applied with the seed) can be detrimental to pulse emergence and may be exacerbated on calcareous soils with high salt loads. Offset fertiliser applications from seed when possible.
- Residual P (after pulse crop) is important for maximising production in P deficient soils for subsequent non-legume phases.
- Pre-sowing soil sampling for mineral N may underestimate pools of nitrogen from pulse crop residues made available during the next growing seasons through mineralisation

A statement of potential industry impact

This project has delivered new knowledge for pulse P requirements and the potential flow on effects for maximising N fixation and available N for the next non-pulse crop phase. Maximising pulse biomass production is key to optimizing pulse nodulation and fixation with optimal P nutrition one of many drivers. The importance of outlining P deficient zones and addressing these zones with adequate P application rates for maximising crop yields which carries through common crop rotations has been outlined.
New information on pulse sensitivities to fertilizer applications and soil salinity thresholds has been gained which has led to further research that will assist growers with improved management directions of both sowing and fertilizer management to maximise pulse emergence, early growth and N fixation.

- *Publications and extension articles delivered as part of the project; and,*

Project results have been included in several communication events particularly recently around Phosphorus and Nitrogen budgeting and closely aligned with communication avenues for TC221.

- GRDC advisor updates livestream 23/2/2022
- GRDC regional updates – Bordertown 2022, Arthurton 2022 > 50 attendees.
- Nutrien Ag Solutions – SA Conference – 3/3/2022 - > 30 attendees
- Presentation to farm management group 2/3/2022 – 12 attendees
- NSS grower presentation day 15/2/2022 – 45 attendees
- Articles included in Hart, NSS and AIR EP annual results books

Posts on the Agronomy Solutions Twitter page together with information built into Agronomy Solutions website.

With the full assessment of results and conclusions the project team will endeavor to continually communicate the project results through similar avenues as outlined above. There is the opportunity to prepare at least one journal paper as this kind of work to the best of our knowledge is the first of its kind in Australian broad acre agriculture

- *Suggested path to market for the results including barriers to adoption.*

See last comment above for future path to market. In combination with UA221 and the Central Ag Solutions project there is significant opportunity to develop information packages for optimizing pulse production through relatively straight forward management options. Barriers to adoption would be linked to current on farm machinery including seeder setups of fertiliser delivery with respect to seed, guidance technology and reluctance to identify P responsive paddock zones.

POSSIBLE FUTURE WORK

Provide possible future directions for the research arising from the project including potential for further work and partnerships.

As mentioned in the conclusions, SAGIT is funding two projects which are semi-related to maximizing pulse production with upfront fertilizer additions.

UA221 Understanding and managing fertiliser toxicity in pulses in SA.

Project led by Central Ag Solutions is assessing the impact of on row vs off row sowing on YP which includes pulses and most recent findings has suggested on row benefits are driven by lower soil salt levels and increasing MAP rates amplify the off-row salt effects.

Currently there are very little guidelines to background constraints for pulse production in particular lentils and salt. We currently default back to cereal soil salinity thresholds which don't apply to the more sensitive pulse crops. This might be able to be explored relatively easy and cheaply.