AgGrow
AGRONOMY + RESEARCH

LIME RESPONSE ON ACID, LOW RAINFALL, SANDY SOILS OF SOUTHWESTERN NSW

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Charles Sturt University

GRDC INVESTMENT FROM NATIONAL GROWER NETWORK (AGG2206-001RTX)

This project is a collaboration with Jason Condon, CSU.

How to best manage acid soils in SW NSW

KEY POINTS

- **Lime has increased soil pH, soil P availability and shown interesting interactions with micronutrients.**
- **Incorporation of lime to the depth of the acidic layer is necessary. Cultivation alone, without the addition of lime, had no influence on soil pH. In treatments where lime was applied at 3 t/ha, cultivation increased the depth of pH change. In treatments where 6 t/ha lime was applied, soil pH increased to a depth of 20cm relative to the control.**
- **Increase in soil pH resulted in an increase in available phosphorus, with an increase of 7-8 mg/kg Colwell P observed in the surface layer of limed versus unlimed plots.**
- **Liming promoted the uptake of applied micronutrients, with yield gains up to 0.5 t/ha observed in this trial by applying a micronutrient (zinc, copper & molybdenum) foliar spray with lime, compared to where micronutrients were applied without lime.**
- **Whilst cultivation alone had no influence on grain yield in 2022, both lime application and cultivation provided some benefits in 2023.**
- **After 2 years no economic advantage of lime was observed, although it is expected that lime will continue to provide economic benefits in the rotation in the future.**

BACKGROUND:

Discussions in Grower Network forums in the GRDC sub-region of Southwest NSW highlighted the need to understand reports of poor lime responses on acid sandy soils that typically have low organic matter.

Some soils in the low rainfall cropping regions of Western NSW are acid (pH <4.8 $CaCl_2$) but do not have elevated aluminium (Al) levels in the soil. These soils are typically low in organic carbon and CEC and commercial rates of lime anecdotally have not provided crop responses that are measurable in increased grain yield.

Whilst possible explanations include secondary limitations, manganese (Mn) toxicity, lime quality, lime application method and a subsurface acid throttle, there is a need to validate the issue of acid soils that are anecdotally unresponsive to lime in western NSW so that crop yield gaps can be reduced. In addition, as acidity has increased the soil P bank has also risen well above critical values, even after very good seasons, indicating potential P tie ups as a direct result from acid soil conditions.

This project collaborates with Dr Jason Condon (CSU) and links with the work he is currently undertaking on acid soils to ensure any learnings from past or existing research can be considered in this localised investment. It will provide some useful guidelines into getting the best out of lime, and its impact on soil pH and access to soil P reserves.

This report, as part of this project, covers trial results from the 2022 and 2023 cropping seasons.

TRIAL DETAILS

A trial was established in May 2022 at the Ag Grow Agronomy research farm 'Ridge Top' near Beelbangera, 16km NE of Griffith in southern New South Wales. The site chosen was based on prior knowledge of historical soil tests, as well as the soil type being locally relevant in the region.

The trial was set up to measure:

1. The efficacy of applied lime on grain yield and profitability
2. Differences between incorporation methods
3. Differences between incorporation depths
4. Impact on phosphorous uptake efficiency

The trial was statistically designed and consisted of 4 replications with treatments including:

3 lime rates
- 0 t/ha lime
- 3 t/ha lime
- 6 t/ha lime

5 cultivation treatments
- nil cultivation
- 10 cm chisel + offset
- 20 cm chisel + offset
- 20 cm chisel + offset twice
- rotary hoe

4 Phosphorus (P) treatments
- Plus P
- Nil P
- Plus P + Micro
- Nil P + Micro

The full list of 12 treatments included in the trial is shown in table 1.

Table 1: Treatment list for lime and cultivation trial

TREATMENT #	LIME RATE	CULTIVATION	NUTRITION
Treatment 1	0 t/ha lime	nil cultivation	Plus Phosphorus
Treatment 2	0 t/ha lime	10 cm chisel + offset	Plus Phosphorus
Treatment 3	0 t/ha lime	20 cm chisel + offset	Plus Phosphorus
Treatment 4	0 t/ha lime	20 cm chisel + offset twice	Plus Phosphorus
Treatment 5	0 t/ha lime	rotary hoe	Plus Phosphorus
Treatment 6	3 t/ha lime	nil cultivation	Plus Phosphorus
Treatment 7	3 t/ha lime	10 cm chisel + offset	Plus Phosphorus
Treatment 8	6 t/ha lime	20 cm chisel + offset	Plus Phosphorus
Treatment 9	6 t/ha lime	20 cm chisel + offset twice	Plus Phosphorus
Treatment 10	6 t/ha lime	rotary hoe	Plus Phosphorus
Treatment 11a	0 t/ha lime	rotary hoe	Nil Phosphorus
Treatment 11b	0 t/ha lime	rotary hoe	Nil Phosphorus + Micro
Treatment 11c	0 t/ha lime	rotary hoe	Plus Phosphorus + Micro
Treatment 12a	6 t/ha lime	rotary hoe	Nil Phosphorus
Treatment 12b	6 t/ha lime	rotary hoe	Nil Phosphorus + Micro
Treatment 12c	6 t/ha lime	rotary hoe	Plus Phosphorus + Micro

Note: Treatments 11 and 12 were split plots, each consisting of 3 nutrient treatments

Comprehensive soil tests, including soil organic carbon, NO3, NH4, Colwell P, pH, EC, ESP, and trace elements, were undertaken at the trial site in April 2022, table 2. These tests helped to determine the treatments and rates of lime used in the trial.

Table 2: Soil test results, April 2022.

Soil Test Results: 2022	0-5cm	5-10cm	10-15cm	15-20cm
NO3-N (ppm)	9	6	6	10
NH4-N (ppm)	0	0	0	0
pH ($CaCl_2$)	5.4	4.4	4.5	5.2
Colwell P	55	48	29	34
Potassium [Am. Acet.] (meq/100g)	0.69	0.5	0.42	0.4
Magnesium [Am. Acet.] (meq/100g)	0.73	0.45	0.53	0.66
Calcium [Am. Acet.] (meq/100g)	2.25	1.61	2.02	2.59
Sulphur [MCP] (ppm)	2	4	4	2
Manganese [DTPA] (ppm)	7.3	10.4	9.6	4.9
Boron [CaCl2] (ppm)	0.3	0.2	0.2	0.2
Copper [DTPA] (ppm)	0.3	0.3	0.2	0.2
Iron [DTPA] (ppm)	10	17	14	6
Zinc [DTPA] (ppm)	0.5	0.2	0.1	-0.1
EC [1:5 H2O] (dS/m)	0.04	0.02	0.02	0.03
CEC (meq/100g)	3.7	2.74	3.1	3.71
Organic Matter (%)	1.2	0.9	0.9	0.9
Ca:Mg Ratio	3.1	3.58	3.83	3.92

2022 trial details:

Prior to sowing (5th May 2022), lime and cultivation treatments were applied. The trial was sown on the 6th May 2022 with Rockstar wheat at 40 kg/ha, with 80 kg/ha MAP applied to appropriate treatments. It was sown with a Morris Contour Drill plot seeder with 25cm row spacings x 7 rows. Plots were 36m x 1.75m ($63m_2$), except for treatments 11 and 12 which were split plots (consisting of 3 plots 12m x 1.75m – $21m^2$).

As per commercial practice, appropriate pest, disease and weed control was undertaken pre-emergence and again in crop. Trace element treatments were applied on 4th July and 21st July to the appropriate plots in treatments 11 and 12. The trial was harvested 1st December 2022.

2023 trial details:

Following wheat sown in 2022, the site was sown to Trident canola on 14th April 2023 at 2.5 kg/ha, with 70 kg/ha Superphosphate applied to appropriate plots. In addition, 100 kg/ha urea was spread 1st April, and the trials were topdressed with 100 kg/ha Gran-Am in July. Trials were baited for mice after sowing. Trace element treatments were applied on 22nd June to the appropriate plots in treatments 11 and 12.

Appropriate pest, disease and weed control was also undertaken on the trial post-emergent, with the trials sprayed early August with 450ml/ha Prosaro. The trial was harvested 24th October 2023.

Seasonal Conditions

2022: The 2022 season was wet all round. Coming into the 2022 cropping season moisture profiles were generally full, from a wet 2021 and with rain at harvest and above average January rain. The wet weather continued at sowing, with above average rainfall in April and May.

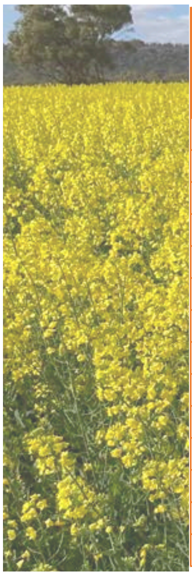
June and July were the only months that had below average rainfall, allowing things to dry out a bit, with some severe frosts mid-July. Wet conditions then persisted for the remainder of the 2022 season, table 3.

The conditions in 2022 were conducive for a high disease pressure year, with a run of previous good years, mild temperatures and good early crop vigour. As such 2022 was one of the worst disease pressure years, with very early disease development. Ensuring crops were protected from disease such as stripe rust was very important. The trials received 3 timely fungicide sprays for stripe rust to minimise infection.

2023: The 2022 season was generally wet, so coming into the 2023 season there was a full profile of moisture. Whilst this trial was sown into moisture, there was little rain the second half of April and most of May drying out the top profile, table 3. These drier conditions led to slower early crop growth.

There were good conditions in June and early July, which allowed crops to get away and tap into subsoil moisture reserves. Dry and frosty conditions persisted in August and early September. The season finished with hot dry conditions, with canola quickly ripening.

Table 3: Rainfall data for the site 2022 and 2023



MONTH	"Ridgetop" Beelbangera 2022	Griffith Airport 2022	"Ridgetop" Beelbangera 2023	Griffith Airport 2023	*Griffith Airport Long Term (1958 to 2023)*
January	83	172	31	39	36
February	12	2.2	0	0	28.1
March	31.5	53	61.5	12.2	35.8
April	67	72.2	33	34	29.2
May	82.5	80.4	9	10.6	35.1
June	10	18.8	41.5	38	35.4
July	21.5	19.4	18	24.4	32.6
August	40	82.4	10	18	35
September	96.5	49.6	0	2.4	32.9
October	233	203.6	25	12.4	40.4
November	63.5	87.8	78	90.6	35.5
December	4	9.2		53.2	32.9
TOTAL	***744.5***	***850.6***	***307***	***334.8***	***409.8***
GSR (April - Oct)	***550.5***	***526.4***	***136.5***	***139.8***	***240.6***

2023 Soil Test Results:

Repeat comprehensive soil tests, sampling at 5 depths (0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-30cm) in each plot, were undertaken 27th February 2023 before sowing, appendix 1. A summary of the effect of lime application on incorporation method and nutrient interactions is below.

Comparison of lime incorporation method:

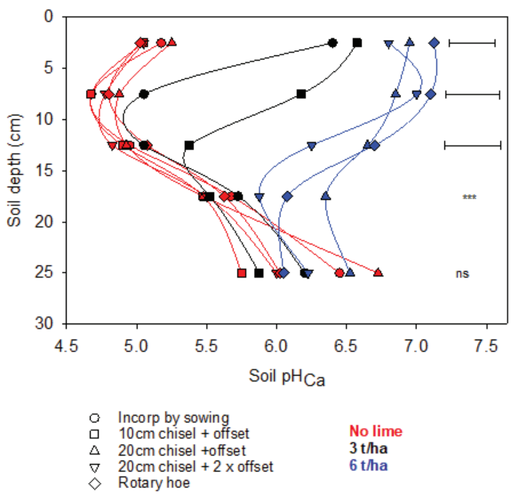
Treatment effect on soil pH ($CaCl_2$)

There were no significant differences in the soil pH of treatments that received no lime, figure 1, regardless of cultivation treatments (red lines and symbols).

The 6 t/ha lime treatments increased soil pH relative to the control to 20cm. Incorporation method had no significant effect on pH profile when lime was applied at 6 t/ha.

Cultivation increased the depth of pH change when lime was applied at 3 t/ha. The 10 cm chisel followed by offset disc significantly increased pH in the 5-10 cm layer relative to the control and lime at 3 t/ha that was incorporated by sowing.

Figure 1: Treatment effect on soil pH



*Horizontal bars indicate least significant difference (p=0.05), *** indicates significant main effect for lime addition where no individual treatment differences occurred, ns denotes no significant difference*

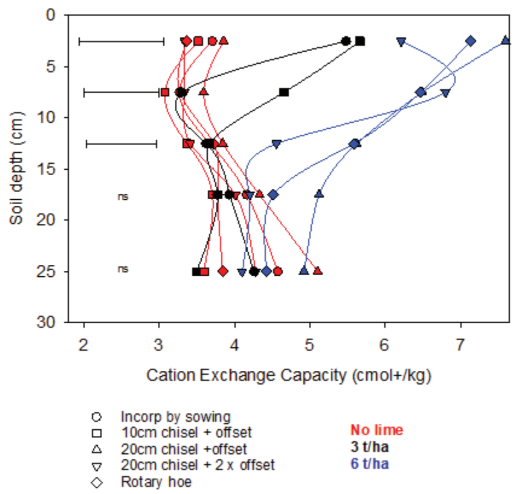
Main effect for lime addition on Cation Exchange Percentage (CEC)

There were no significant differences in the CEC of treatments that received no lime, figure 2, regardless of cultivation treatments (red lines and symbols).

The 6 t/ha lime treatments increased CEC to a depth of 15cm relative to the unlimed treatments receiving the same cultivation.

Cultivation increased the depth of CEC change when lime was applied at 3 t/ha. The 10 cm chisel followed by offset disc significantly increased CEC in the 5-10 cm layer relative to the control and lime at 3 t/ha that was incorporated by sowing. The increases in CEC match the increases in soil pH due to treatment.

Figure 2: Treatment effect of lime effect on CEC

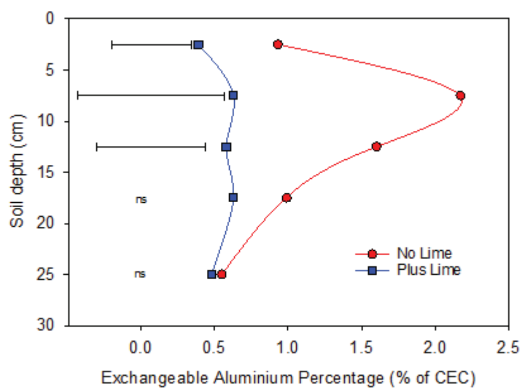


Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

Main effect for lime addition on exchangeable aluminium percentage

There was no significant difference between individual treatments or main effects of cultivation. The main effect of lime addition resulted in a significant decrease in Al% from the soil surface to a depth of 15 cm, figure 3. Maximum Al% was 2% in the 5-10 cm layer.

Figure 3: Lime effect on Al%



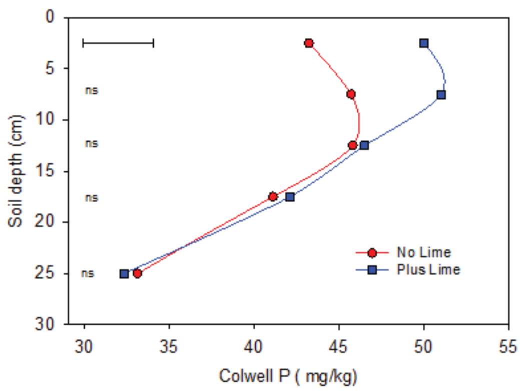
Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

Main effect for lime addition on Colwell P

There was no significant difference between individual treatments or main effects of cultivation.

The main effect of lime addition resulted in a significant increase in Colwell P in the surface layer only, figure 4. The difference being approximately 7 mg/kg more Colwell P in the limed plots.

Figure 4: Lime effect on Colwell P



Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

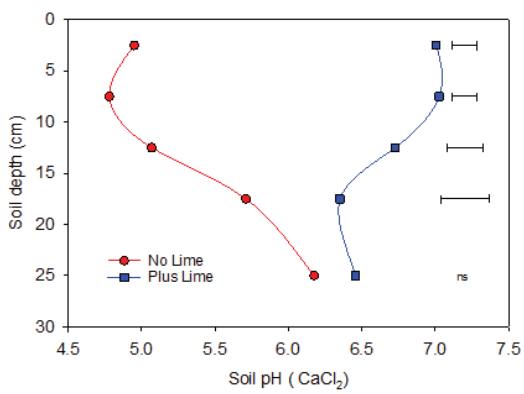
Comparison of lime incorporation x nutrient interactions:

There were no statistically significant interactions between lime and nutrient addition apparent in the soil data from soil sampled in 2023. However significant main effects of lime application did occur for soil pH, CEC, Aluminium and to a small extent, Colwell P.

Treatment effect on soil pH ($CaCl_2$)

As expected, the application of lime increased soil pH relative to nil lime to a depth of 20 cm which was the depth of incorporation by rotary hoe, figure 5.

Figure 5: Effect of lime on pH (CaCl2)

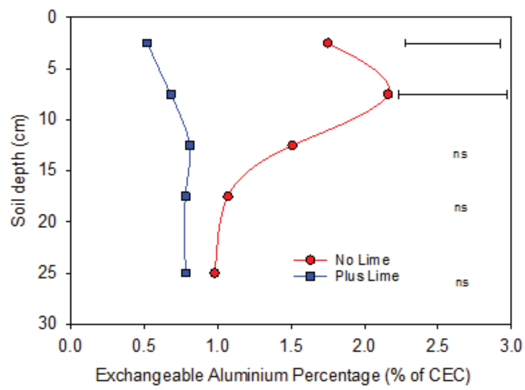


Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

Treatment effect on Al%

In response to the main effect of lime application on soil pH, the addition of lime also resulted in the significant decrease in exchangeable aluminium percentage. However, unlike pH, this effect was statistically significant in the surface 10 cm only, figure 6.

Figure 6: Lime effect on Al%

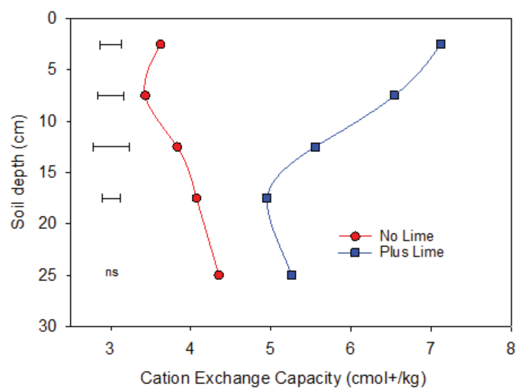


Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

Main effect for lime addition on Cation Exchange Percentage (CEC)

Also related to increased soil pH, there was a significant main effect for lime addition on the cation exchange capacity of the soil. Lime significantly increased the CEC relative to the unlimed treatments to a depth of 20 cm, the depth of incorporation by the rotary hoe, figure 7.

Figure 7: Lime effect on CEC

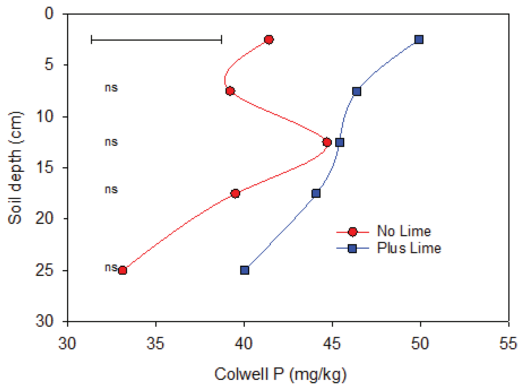


Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

Main effect for lime addition on Colwell P

There was a significant main effect for lime on the Colwell P of the soil, figure 8. Lime increased Colwell P by 8.5 mg/kg.

Figure 8: Lime effect on Colwell P



Horizontal bars indicate least significant difference (p=0.05), ns denotes no significant difference

RESULTS AND DISCUSSION

Establishment, NDVI, grain yield and grain quality, were all assessed and statistically analysed using Genstat.

The significant main effects or interactions for each season are reported below.

2022 SEASON - RESULTS

Interaction of lime and incorporation method

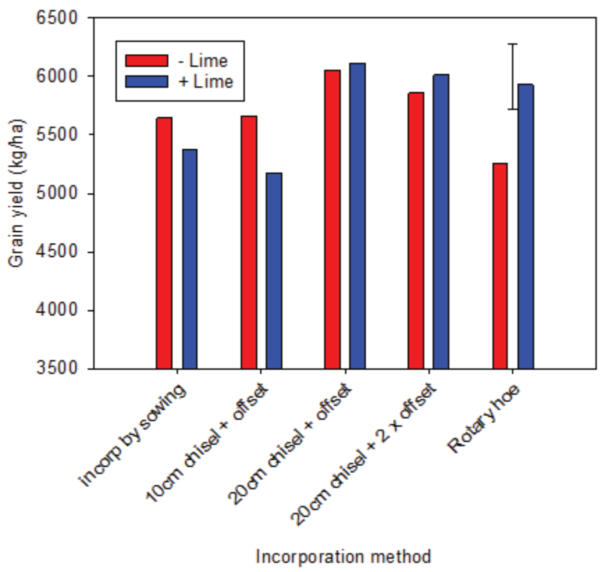
Grain Yield:

There was no statistical difference in the yields from unlimed plots of the various incorporation methods. That is, cultivation alone did not significantly influence yield, figure 9.

There was also no significant difference in yield of incorporated by sowing or the 10cm chisel + offset incorporation treatments. However, when 6 t lime/ha was incorporated to a depth of 20 cm the yield was significantly greater than when lime was incorporated by sowing.

Cultivation with the rotary hoe in the absence of lime resulted in a significant decrease in grain yield relative to the limed rotary hoe plots.

Figure 9: 2022 Grain Yield – lime by cultivation treatment



line bar indicates least significant difference (p=0.05)

Interaction of lime and nutrients

There were no significant effects of treatment on establishment counts. The application of Lime or P individually increased early vigour. The application of lime significantly increased vigour score from 6.4 to 6.8 (p=0.007) compared to unlimed plots. The application of P increased vigour from 5.9 to 7.2 (p<0.001) compared to zero P treatments.

Applying micronutrients without P significantly decreased flowering NDVI (0.465) compared to nil, P only or P and micronutrients treatments (0.53, 0.54, 0.58 respectively).

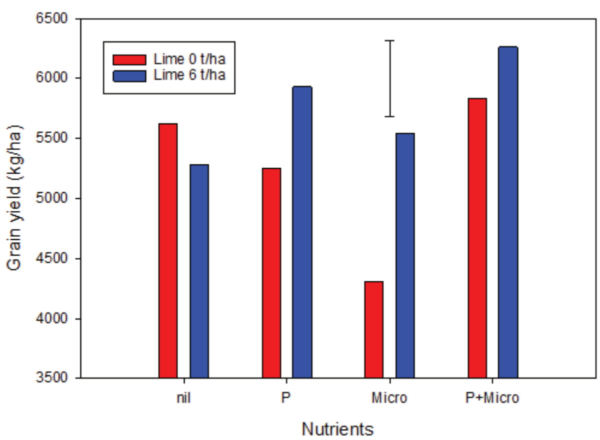
Grain Yield:

Adding micronutrients without adding lime significantly decreased yield, figure 10. Adding P after liming increased yield compared to adding P to an unlimed soil. However, this yield increase was not significantly different to the control.

Liming had no significant effect on grain yield in the absence of any other nutrient addition. Applying P only had no impact on yield relative to the control. However, when the soil was limed, the application of P significantly increased grain yield from 5.5 to 5.9 t/ha.

Adding micronutrients without P or lime caused a significant yield penalty compared to the control or had no significant effect on yield when applied with lime relative to the control. When micronutrients were added with P, the results were statistically the same as when only P was applied indicating that P was the driving response, with micronutrients having no impact.

Figure 10: 2022 Grain Yield – lime by P treatment



line bar indicates least significant difference (p=0.05)

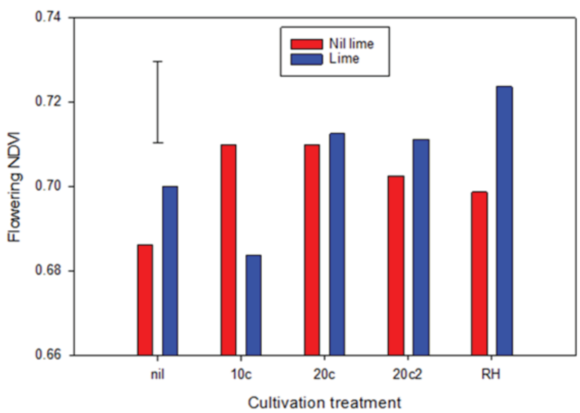
2023 RESULTS

Interaction of lime and incorporation method

NDVI: To provide an assessment of biomass, an NDVI reading was taken using a handheld GreenSeeker crop sensor.

The application of lime had a positive effect on NDVI at flowering on all treatments except 10cm chisel + offset, figure 11. Cultivation with the rotary hoe in the absence of lime resulted in a significant decrease in NDVI relative to the limed rotary hoe plots.

Figure 11: 2023 NDVI – Lime x cultivation treatment



line bar indicates least significant difference (p=0.05)

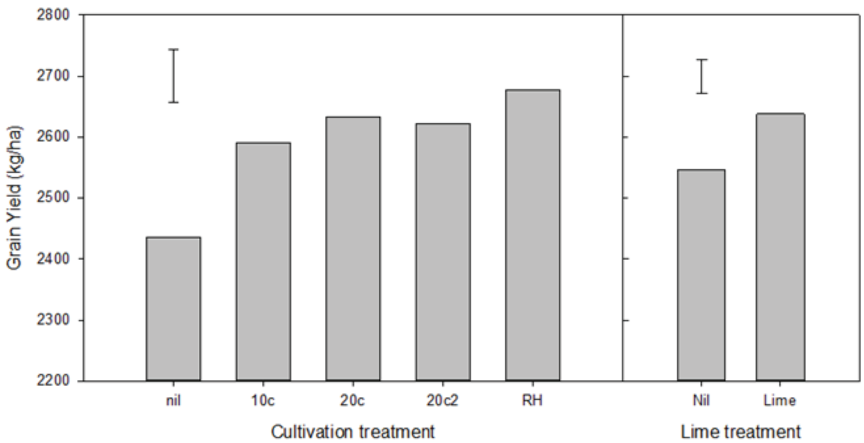
Grain Yield:

There was a significant difference in grain yield for lime application and cultivation treatment, figure 12.

Cultivation alone had a significant influence on grain yield, with nil cultivation plots (2436 kg/ha) yielding significantly lower than all other cultivation treatments.

The addition of lime, across cultivation and nutrient treatments, significantly increased grain yield, from 2547 kg/ha to 2638 kg/ha.

Figure 12: 2023 Grain Yield – Cultivation and lime treatment



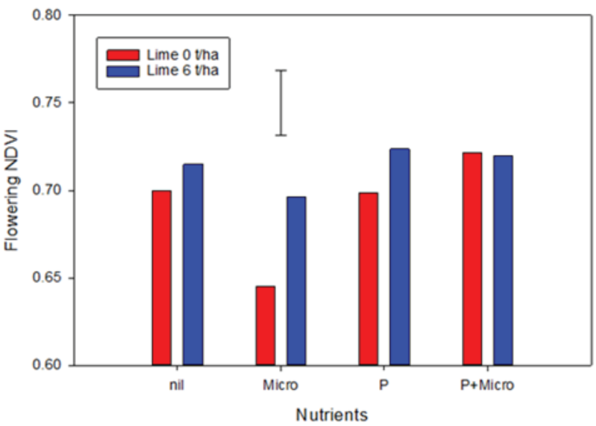
line bar indicates least significant difference (p=0.05)

Interaction of lime and nutrients

NDVI & Grain Yield:

For both NDVI and grain yield, figures 13 and 14, adding micronutrients without P or lime caused a significant decrease in NDVI value and a yield penalty compared to the control.

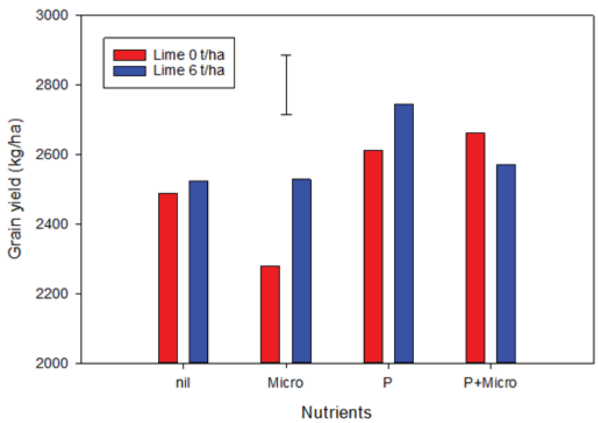
Figure 13: 2023 NDVI – Lime x P x micronutrients



line bar indicates least significant difference (p=0.05)

When micronutrients were added with P, the results were statistically the same as when only P was applied indicating that P was the driving response, with micronutrients having no impact.

Figure 14: 2023 Grain Yield – Lime x P x micronutrients



line bar indicates least significant difference (p=0.05)

Economics:

After 2 years of the project the treatment which had the greatest profit, above the control (treatment 1), was treatment 3 ($121), table 4. Treatment 3 had no lime applied and was deep cultivated and offset with phosphorus applied at sowing. Other treatments to return a positive profit over the control; which had no cultivation or lime applied, were treatments 11a ($91) which had no lime or P applied and was rotary hoed and treatment 11c ($7) which also had no lime applied and was rotary hoed but had P and micronutrients applied.

Treatments without lime and with phosphorous, regardless of cultivation treatment, returned higher profits after 2 years compared to treatments that received lime.

Treatments which had 6t lime and phosphorous applied, regardless of cultivation method, although increased grain yield and had the highest revenue after 2 years, returned negative profits compared to the control. The benefit of lime application was not recouped after the 2 years.

Adding micronutrients, without phosphorus and regardless of lime, also returned a negative profit with treatment 12b (6 t lime + rotary hoe with no P + micronutrients) having the lowest profit (-$674) after 2 years.

Table 4: Profit ($/ha) for each treatment, compared to control (treatment 1).

Trt No.	TREATMENT	*2022 Wheat Grain Yield (kg/ha)*	*2022 Revenue *based on wheat $330 on farm*	*2023 Canola Grain Yield (kg/ha)*	*2023 Revenue *based on canola $625 on farm*	Total Revenue ($)	Treatment Cost ** ($)	Revenue *minus* Treatment Costs ($)	Profit (compared to control)
1	0|nil|P	*5643*	*1862*	*2467*	*1542*	3,404	152	3,252	*0*
2	0|10 cm chisel + offset|P	*5660*	*1868*	*2538*	*1586*	3,454	222	3,232	-$ *20*
3	0|20cm chisel + offset|P	*6052*	*1997*	*2580*	*1612*	3,609	237	3,372	$ *121*
4	0|20 cm chisel + offest twice|P	*5860*	*1934*	*2537*	*1586*	3,520	277	3,243	-$ *9*
5	0|rotary hoe|P	*5251*	*1733*	*2612*	*1632*	3,365	222	3,143	-$ *109*
6	3|nil|P	*5377*	*1774*	*2405*	*1503*	3,278	489	2,789	-$ *463*
7	3|10 cm chisel + offset|P	*5172*	*1707*	*2645*	*1653*	3,360	559	2,801	-$ *451*
8	6|20cm chisel + offset|P	*6114*	*2018*	*2687*	*1680*	3,697	889	2,808	-$ *443*
9	6|20 cm chisel + offest twice|P	*6013*	*1984*	*2707*	*1692*	3,676	929	2,747	-$ *505*
10	6|rotary hoe|P	*5931*	*1957*	*2745*	*1716*	3,673	874	2,799	-$ *453*
11a	0|rotary hoe|Nil P	*5624*	*1856*	*2490*	*1556*	3,412	70	3,342	$ *91*
11b	0|rotary hoe|Nil P + micro	*4310*	*1422*	*2280*	*1425*	2,847	178	2,669	-$ *582*
11c	0|rotary hoe|P + micro	*5834*	*1925*	*2661*	*1663*	3,588	330	3,258	$ *7*
12a	6|rotary hoe|Nil P	*5285*	*1744*	*2525*	*1578*	3,322	722	2,600	-$ *652*
12b	6|rotary hoe|Nil P + micro	*5538*	*1827*	*2529*	*1581*	3,408	830	2,578	-$ *674*
12c	6|rotary hoe|P + micro	*6262*	*2067*	*2572*	*1607*	3,674	982	2,692	-$ *560*

**Costs are based on actual paddock costs; Treatment costs are those above the standard paddock costs of $767/ha in 2022 and $656/ha in 2023 and are the costs attributed to the actual treatment.

Cultivation costs

Offset	*$40/ha*
Shallow cultivation	*$30*
Deep cultivation	*$45*
Rotary hoe	*$70*

Other Input costs

Lime	*$105/t*	*plus $22/ha spread*
Superphosphate	*$400/t*	*plus $10/ha application*
MAP	*$1550/t*	*plus $10/ha application*
Micronutrients	*$28/ha*	*plus $8/ha application*

DISCUSSION

The 2 years of this project have shown the value of lime in increasing soil pH, soil Phosphorus (P) availability and has also shown interactions with lime, P and micronutrients, which may need more exploring.

The application of lime increased soil pH relative to the nil lime treatment to a depth of 20cm, which was the depth of incorporation by the rotary hoe. It also resulted in a significant increase in Colwell P in the surface layer. The addition of micronutrients alone, that is without Phosphorus or lime, resulted in significantly reduced grain yields in both 2022 and 2023.

No economic advantage of lime was observed as yet in the trial, although it is expected lime will provide economic benefits in the rotation in the future. In the two years of the experiment, wheat was grown in 2022 and canola in 2023. To gain a better representation of the impact of the liming and cultivation strategies on the full rotation, the project would benefit from another few years of data. To complete the rotation, the paddock will be sown to wheat in 2024, a pulse crop in 2025 and then wheat in 2026. Capturing this data would add further value to understanding why growers are investing in lime and not seeing the benefits.

The cultivation component of this trial is showing similar soil test results to other research, where cultivation has increased the depth of pH change when lime was applied relative to the control.

Furthermore, it would give us the opportunity to look more closely at the interaction of P. The trial is measuring the impact of lime on P and has the potential to include further work on potential savings on applied fertiliser P in limed paddocks.

APPENDIX 1:

2023 Soil test results – pH ($CaCl_2$) and Phosphorus results

Appendix 1: Soi Test Results - February 2023 pH and P

2023 Feb Soil Tests	pH [1:5 CaCl2]						Phosphorus [Colwell] (ppm)					
TREATMENT	0-5cm	5-10cm	10-15cm	15-20cm	20-30cm	*Average*	0-5cm	5-10cm	10-15cm	Column1	20-30cm	*Average*
0|nil|P	5.18	4.68	4.95	5.68	6.45	***5.39***	45.5	43.8	45.3	35.8	34.0	***40.9***
0|10 cm chisel + offset|P	5.05	4.68	4.90	5.48	5.75	***5.17***	48.0	43.8	50.5	41.0	30.8	***42.8***
0|20cm chisel + offset|P	5.25	4.88	4.93	5.48	6.73	***5.45***	45.0	52.8	50.5	40.0	35.8	***44.8***
0|20 cm chisel + offest twice|P	5.05	4.78	4.83	5.50	6.00	***5.23***	40.5	47.0	46.5	49.5	37.8	***44.3***
0|rotary hoe|P	5.03	4.80	5.08	5.63	6.03	***5.31***	37.0	41.0	36.3	39.5	27.5	***36.3***
3|nil|P	6.40	5.05	5.05	5.73	6.20	***5.69***	49.3	44.5	42.3	40.8	25.8	***40.5***
3|10 cm chisel + offset|P	6.58	6.18	5.38	5.53	5.88	***5.91***	48.0	46.3	47.3	34.8	28.8	***41.0***
6|20cm chisel + offset|P	6.95	6.85	6.65	6.35	6.53	***6.67***	47.5	51.0	42.0	35.3	36.0	***42.4***
6|20 cm chisel + offest twice|P	6.80	7.00	6.25	5.88	6.23	***6.43***	56.5	58.0	52.3	45.3	39.3	***50.3***
6|rotary hoe|P	7.13	7.10	6.70	6.08	6.05	***6.61***	48.5	55.3	48.8	54.3	31.8	***47.7***
0|rotary hoe|P + micro	5.05	4.88	5.15	5.93	6.63	***5.51***	36.3	35.5	35.5	39.0	31.0	***35.3***
0|rotary hoe|Nil P	4.88	4.70	5.00	5.93	6.28	***5.36***	45.5	47.5	58.0	36.5	36.3	***44.8***
0|rotary hoe|Nil P + micro	4.85	4.75	5.05	5.45	5.78	***5.18***	46.8	33.0	49.0	42.0	37.8	***41.7***
6|rotary hoe|P + micro	6.93	7.05	6.85	6.60	6.63	***6.81***	46.5	45.0	39.5	43.3	35.8	***42.0***
6|rotary hoe|Nil P	6.93	7.00	6.75	6.55	6.85	***6.82***	49.5	46.0	39.5	36.5	38.3	***42.0***
6|rotary hoe|Nil P + micro	7.05	7.10	6.60	6.10	6.23	***6.62***	55.0	45.3	51.5	42.8	50.8	***49.1***
Average	***5.94***	***5.72***	***5.63***	***5.87***	***6.26***	***5.88***	***46.6***	***46.0***	***45.9***	***41.0***	***34.8***	***42.9***

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