Final Report: Agronomic efficiency trial at *Gindurra*

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Summary

The use of inorganic N (nitrogen) fertiliser is the largest source of greenhouse gas (GHG) emissions for broadacre cropping farms. Finding ways to reduce the amount applied while still getting acceptable yields can potentially save money for farmers and improve environmental outcomes.

SoilCQuest conducted a trial in 2024 in collaboration with Viridis Ag, at their farm 'Gindurra' in Canowindra, NSW, to test and compare foliar urea-N, and humic-coated urea to uncoated granular urea fertilisation.

In this trial, 20% less total N was applied with the foliar application compared to the granular urea treatments, under the hypothesis that timely application of lower amounts of liquid urea will provide sufficient N when the plant needs it. For the humic-coated urea, the hypothesis was that humic coating could bind with some of the urea, reducing volatization of ammonia and increasing N use efficiency.

At season's end, results showed that there were no statistically significant differences in canola yield across treatments, with yields of 2.90, 2.94, and 2.96 t/ha recorded for humic-coated urea, foliar-applied liquid urea, and uncoated granular urea, respectively. This means that for the 2024 season, foliar-applied urea achieved the same yield as granular urea, but with 20% less nitrogen input. A 20% reduction in N input implies a 20% reduction in associated scope 3 GHG emissions compared to standard practice.

Although humic-coated urea showed indications in the lab incubation of losing 15% less ammonia compared to uncoated urea, this did not translate to yield increases under field conditions. The same quantity of N was applied to the field with the humic-coated urea treatment as in the uncoated urea treatment.

The use of liquid urea as a foliar fertiliser is still uncommon among Australian cropping farmers due to the additional cost, and not all farmers are equipped with the necessary equipment for foliar applications. However, with new mandatory GHG reporting requirements coming into effect as of January 2025, there may now be a greater interest among corporate farms in considering strategies such as foliar N fertilisation to reduce their Scope 3 emissions profile.

In this trial, marginal gross profits from the use of liquid urea and humic-coated urea were about 2% lower compared to uncoated granular urea. However, this difference was calculated from yield differences that were not statistically significant.

Based on positive reports from other Australian farmers who have mainstreamed foliar applications into their fertilisation strategy, we expect to obtain greater performance and yield benefits with continued use of this practice.

Our consultation with Joel Williams, a leading expert on foliar fertilisation (and SoilCQuest Research committee member), revealed the following recommendations for improvement:

- Ensure rainwater or reverse osmosis water is used with a target pH of 5 to 5.5,
- Add a carbon source to chelate nutrients and improve urea leaf contact.
- Add trace elements according to soil and plant needs for better N metabolism in the plant, particularly Mo, Mg, Fe, Zn, Ca, and small amounts of Ni can be effective

At the end of this report, we conducted additional analysis to investigate what was indeed responsible for the variation in canola yield (up to 1.7 t/ha) that we observed across the paddock. Our analysis revealed that the soil's physical and topographic features in the paddock accounted for up to 39% of the yield variation. Additionally, higher-yielding areas of the paddock exhibited higher levels of soil organic carbon (SOC) and calcium. We were able to provide soil quality zone maps which pinpoint where productivity was higher and lower and which variables were responsible for greater productivity. Expanding this work across the whole farm, and focussing amelioration budget on specific areas, has potential to lift average yield across the farm.

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Introduction

As part of Australia's commitment to the 2015 Paris Agreement, all sectors of the economy, including agriculture, will be increasingly expected to find ways to reduce their greenhouse gas emissions (GHGs). Synthetic nitrogen (N) fertiliser production and use contribute to around 10% of global agriculture GHGs and 2% of global anthropogenic GHGs (Menegat et al. 2022). In Australia, N-related emissions contribute 60-95% of the greenhouse gas (GHG) footprint for wheat production (Wang and Dalal, 2015). Urea, the most common N fertiliser used globally, spiked in price in the last few years due to geopolitical events, reducing farm profits. Thus, efforts to make more efficient use of N fertiliser can lead to economic and environmental benefits.

In addition, research shows that application of inorganic N to soil favours allocation of photosynthetic energy to shoot biomass over root biomass (Feng et al. 2023). Root biomass contributes more to soil C stocks both directly and via its fuelling of microbial populations, which contribute necromass to the soil C pool. Shoot biomass contributes less to the soil C pool, because it can be exported offsite, can be burnt on the surface, can be photodegraded by UV (Wang et al. 2021), and is physically disassociated from soil C storage sites in soil. This is especially the case in no- and low-till cropping systems such as those prevalent in Australia's dry land cropping areas. Excess NO3 in the soil at sowing time >50 kg/ha can suppress nodulation in N2-fixing legumes (GRDC, 2014). N fertiliser, in general, can also suppress the presence and functioning of free-living N2-fixing organisms (diazotrophs) (Fan et al. 2019). At the same time, N is essential for plants, microbes, other soil biota, and the formation of soil organic matter.

David et al. (2009) show that in farmer fields in former prairie soil Mollisols in the U.S.A., carbon and nitrogen levels have not declined over time when moderate amounts of inorganic N have been used. This concurs with recent results from Ordóñez et al. 2021 who showed that maise roots reached their maximum size at moderate N fertilisation (168 kg N ha-1) but were lower at both nil and excess (336 kg N ha-1). Therefore, moderate N fertilisation can support soil carbon building. Kirkby et al. 2013 showed that increasing soil carbon via the microbial pathway requires a stoichiometric balance of CNPS (carbon: nitrogen: phosphorus: sulfur). When the proper amounts of NPS are balanced to C inputs, clear increases in microbial biomass become apparent.

One thing that academics do agree upon is the need to reduce excessive use of inorganic N, which can hamper our efforts to store soil organic carbon (SOC), via several mechanisms, including:

- Inhibition of root growth at high N rates (Ordonez et al. 2021, Chen et al. 2020). Chen et al. 2020 explain that although the chlorophyll content in leaves increases with excess N, the balance of carbon and N metabolism can be disturbed by high N fertiliser application rates
- Acidification of the soil from ammoniacal fertilisers. The use of NH4 fertilisers involves the release of H+ into the soil, resulting in a lower pH. Acidic conditions are sub-optimal for the functioning of most microbes, and this will, in time, have adverse knock-on effects for microbially derived SOC
- A stimulation of shoot biomass vs root biomass from excess N fertilisation has been shown to increase the supply of particulate organic carbon compared to mineral-associated organic carbon into the soil. This has ramifications for the turnover time of carbon in soil, with POC being more liable to loss than MOAM (Tang et al. 2023)

Nitrogen is a reactive element that is prone to loss via NH3 volatilisation, denitrification (resulting in N2, NO2, and N2O), and NO3 leaching. Much of the N fertiliser applied to soils does not reach plants and can be a source of pollution to the environment and the climate. In Australia, urea is the predominant fertiliser of choice, and the main pathway of loss for urea is NH3 volatilisation. It is estimated that up to 30% of urea N can be lost via this pathway (DPI WA, 2021).

For the environmental, agronomic and economic reasons mentioned above, there is a growing motivation among farmers and their advisers to explore different ways to deliver N to their crops. Delivery of N via foliar application is one method that has been shown to improve N use efficiency, especially under drier conditions where there is insufficient moisture to dissolve fertiliser and for it to be adsorbed via the roots. Foliar N fertilisation has been mainly applied before flowering to boost protein levels in grain. However, yield increases can also be achieved if foliar N is applied during tillering.

Foliar N is more expensive than granular N, and there are limitations to how much can be applied via the leaf without scorching the leaves. There is a potential for farmers to save both money and decrease their total N input (and associated emissions) via foliar application of N. However, this potential requires knowledge of the best way to use the products to achieve the desired aim.

Another method for conserving nitrogen in fertiliser is applying a humic coating to urea granules. The humic coating can reduce alkalinity in the interface between the soil and the urea granule, thereby minimising ammonia loss. The humic coating gradually dissolves from the granule in contact with water and thus may also act to release the N more slowly into the soil water.

This farm trial aims to validate the use of liquid urea as a foliar spray and a humic-coated urea product to see if benefits can accrue in terms of yield and N use efficiency. A successful outcome would give evidence for reducing N fertilizer amounts while still achieving yield goals, with indirect benefits for reducing associated N2O emissions in cropping systems.

Methods

Field site

The trial was conducted on ‘P2’ Paddock at Viridis Ag’s ‘Gindurra’ farm in Canowindra (-33.521251, 148.688922) in 2024 (Fig. 1). Canola (variety 44y94cl) was sown on the 15th of April and harvested 16th of November. Baseline soil samples were taken in March of 2024, with a summary of soil properties shown in Table 1.

Fig. 1. P2. Field site for 2023 trial at ‘Gindurra’, Viridis Ag, in Canowindra

Table 1. Soil Properties of P2 Paddock, Gindurra Farm, Canowindra at 0-10 cm depth in March 2024 (n=40)

Soil Property	Unit	Value
Texture		Clay Loam
pH		6.36 ± 0.46
EC	dSm	0.07 ± 0.03
Total Org. C	%	1.43 ± 0.33
Total N	%	0.13
NO3-N	mg kg-1	21 ± 18
C:N		10.77 ±
Soil organic matter	(%)	2.5 ± 0.65
Total P	mg kg-1	46 ± 18
Colwell P	mg kg-1	49 ± 13
PBI		40 ± 11
Total Ca	mg kg-1	1769 ± 590
Soluble C	mg kg-1	
Ca:Mg		10 ± 3.42
Exchangeable Ca	cmol+ kg-1	6.32 ± 1.92 (81%)
ECEC	cmol+ kg-1	7.81 ± 2.26
Zn	mg kg-1	1.8 ± 1.31
Si	mg kg-1	60 ± 13
Cl	mg kg-1	50 ± 22
Boron	mg kg-1	0.44 ± 0.13

Experimental design

The treatments included in the trial included are listed below in Table 2.

Table 3. Methods and measurements taken throughout field trial

Treatment	Description of Fertiliser Treatment	Total applied N (kg/ha)
N control – No Urea topdressing (1 replicate) α	Zero top dressing fertiliser applied (only one strip required so we can calculate the additional crop effect from top dressing treatments). Still receives MAP	3.6 (in MAP)
Granular Urea (Control) (4 replicate strips)	Granular urea top dressing x 2 applications • 100 kg Green urea applied at 6-8 leaf stage (28th May) β • 150 kg Normal urea applied at stem elongation (dose season dependent)	3.6 (MAP) 46 (Gr. Urea-1) 69 (Gr. Urea-2) = 118.6
Granular Urea (coated with humic acid – FertiCoat by Omnia.com.au) (4 replicate strips)	• 100 kg Green urea applied at 6-8 leaf stage (29th May) • 150 kg Humic coated urea applied at stem elongation	118.6
Granular+Foliar Split (4 replicate strips)	Granular urea top dressing x 1, and 2 x applications of liquid urea • 100 kg Green urea applied at 6-8 leaf stage 1. 100 L liquid urea applied at stem elongation • 100 L liquid urea at 10-20% flowering	1. (MAP) 46 (Gr.Urea) 2 x 24= 48 (N Fol 24%) =97.6 (20% reduction in total N depending on season)

α Note: post-trial the farm manager informed that the Control strip was mistakenly not left unfertilised and indeed received 118.6 kg N ha-1. Therefore, this Control strip is deemed void for the further analysis in the report.

β Note: Post trial start – the farm manager informed that Green Urea was also applied instead of normal urea at 6-8 leaf stage (this was not part of the original plan).

The treatments were set out in the paddock in 32 m wide strips as shown in Fig. 2.

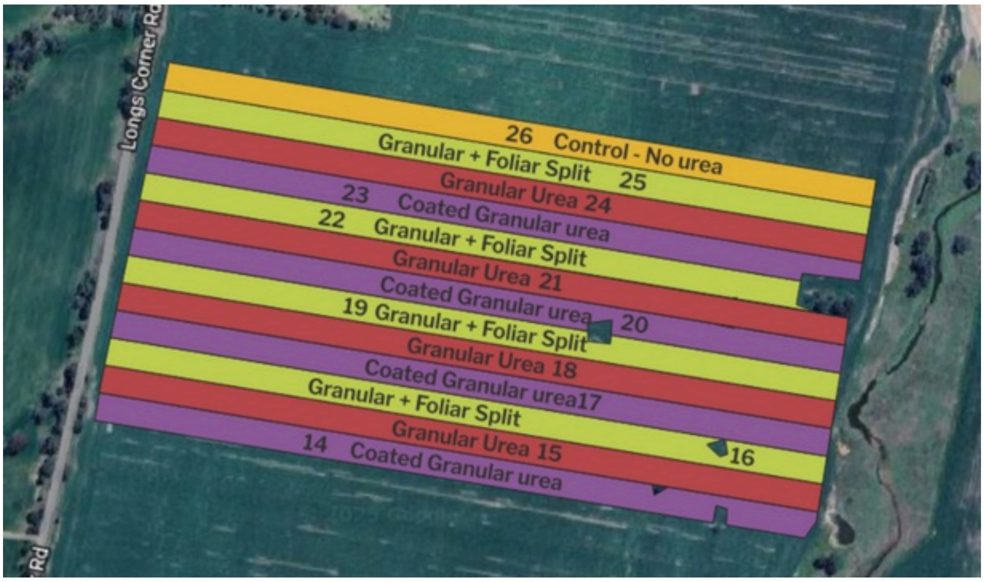

Fig. 2. Arrangement of the treatments in strips across the trial field at 'Gindurra', Canowindra in 2024. Each strip is 36 m wide.

Fertiliser products

The liquid urea product used in the trial was Easy N 24, produced by Easy Liquids (Incitec Pivot), which contains 24% w/v of N. The supplier partially subsidised the product in return for sharing trial results.

The humic-coated urea was made by applying 5 L Ferticoat per tonne of urea. The coating was achieved by adding the ferticoat to the area when it was being augured into a container. The supplier Omnia recommends that the coated urea be left to dry for a day and then augered one more time to break up any clumping of the granules. The product was supplied freely for the trial in return for sharing trial results.

Testing the effect of urea coating on ammonia volatilisation

A short lab study was conducted to test the efficacy of the humic coating in preserving or slowing down the release of NH3 into the atmosphere. An incubation test was conducted where increasing amounts (30-300 mg) of urea and humic-coated urea were surface applied to 30 cm3 of moist soil (9 ml of water applied to 30 cm3 of air-dried soil). The soil and fertiliser were incubated in an air-tight jar for 19 hours at 22-24 °C. A Solvita SLAN gel probe was inserted into the air space of the gas, which changes colour on contact with NH3 and can provide an estimate of the concentration increase of the NH3 based on a factory calibration relating the colour to NH3.

Results

Paddock yield

There was a large variation in yield across the paddock ranging from 2.06 t/ha in the lowest area (dark blue) to 3.77 t/ha in the highest area (yellow) (Fig. 3). The field trial was located in the middle of the paddock where the extremes of high and low were avoided to some extent.

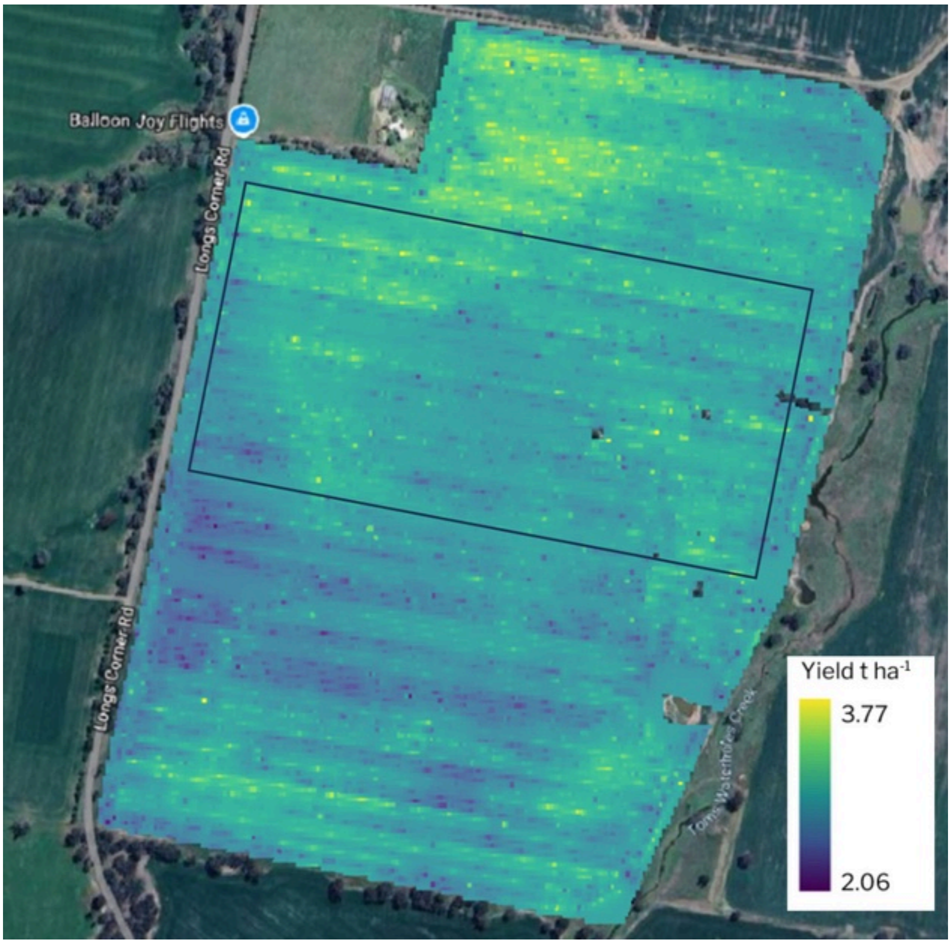

Fig. 3. Yield map across the whole paddock regardless of treatment. The box shows the location of the field trial. [-1] https://yieldgapaustralia.com.au/maps/

Effect of fertiliser treatment on yield

There was no significant difference in canola yield due to the different fertiliser treatments applied, with canola yields of 2.90, 2.94, and 2,96 t/ha recorded for humic-coated urea, foliar-applied urea, and uncoated urea, respectively (Table 3).

The Yield Gap online app calculates that for canola growing on a chromosol in the Cowra region, the average water-limited yield potential is 2.4 t ha-1. This means the average canola yield of 2.93 t ha-1 achieved in 2024 on P2 field outperformed the regional average yield Cowra district by nearly 500 kg per ha1. However, it should be noted the yield gap app uses data prior to 2014, and since then new higher yielding varieties of Canola have become available.

Table 3. Canola Yield (t/ha) per strip and treatment

Strip	Treatment	Mean	Min	Max	St. Dev.
26	Control - No Urea α	3.05	2.69	3.67	0.1
25	Granular Urea + Foliar	3.03	2.19	3.68	0.15
24	Granular Urea	3.02	2.53	3.47	0.1
23	Humic Coated Granular Urea	2.94	2.32	3.54	0.13
22	Granular Urea + Foliar	2.93	2.46	3.42	0.07
21	Granular Urea	2.98	2.48	3.62	0.12
20	Humic Coated Granular Urea	2.91	2.36	3.69	0.1
19	Granular Urea + Foliar	2.93	2.55	3.77	0.09
18	Granular Urea	2.9	2.4	3.43	0.11
17	Humic Coated Granular Urea	2.91	2.55	3.4	0.09
16	Granular Urea + Foliar	2.85	2.28	3.53	0.14
15	Granular Urea	2.92	2.49	3.52	0.11
14	Humic Coated Granular Urea	2.85	2.33	3.49	0.13

Table 3. Canola Yield (t/ha) per strip and treatment

Canola Grain Yield (t ha-1)	Mean*	Min	Max	St. Dev.
Granula Urea	2.96	2.48	3.51	0.11
Humic Coated Urea	2.9	2.39	3.53	0.11
Granular Urea + Foliar	2.94	2.37	3.6	0.12

*No significant differences between treatments
α We were informed by the farm manager that a mistake was made and that this zero urea strip did in fact receive the same amount of urea as the "Granular Urea treatment". Therefore, this control strip was not included further in the analysis.

Foliar applied liquid urea improves agronomic efficiency

Agronomic efficiency which is defined as the kg of grain produced from each kg of N fertiliser input was 20% higher ($p<0.001$) in foliar urea treatment compared to either granular urea and/or humic-coated urea (Fig. 4). What is inconclusive is whether there was a true gain in agronomic efficiency due to mode of application (foliar) or whether N application rates of 97.6 kg N /ha was located already at the top of the N response curve, with further N inputs giving diminishing returns. If this trial is repeated, inclusion of a control treatment where granular urea is applied at the same N dose as the foliar treatment would provide comparative evidence to answer this question.

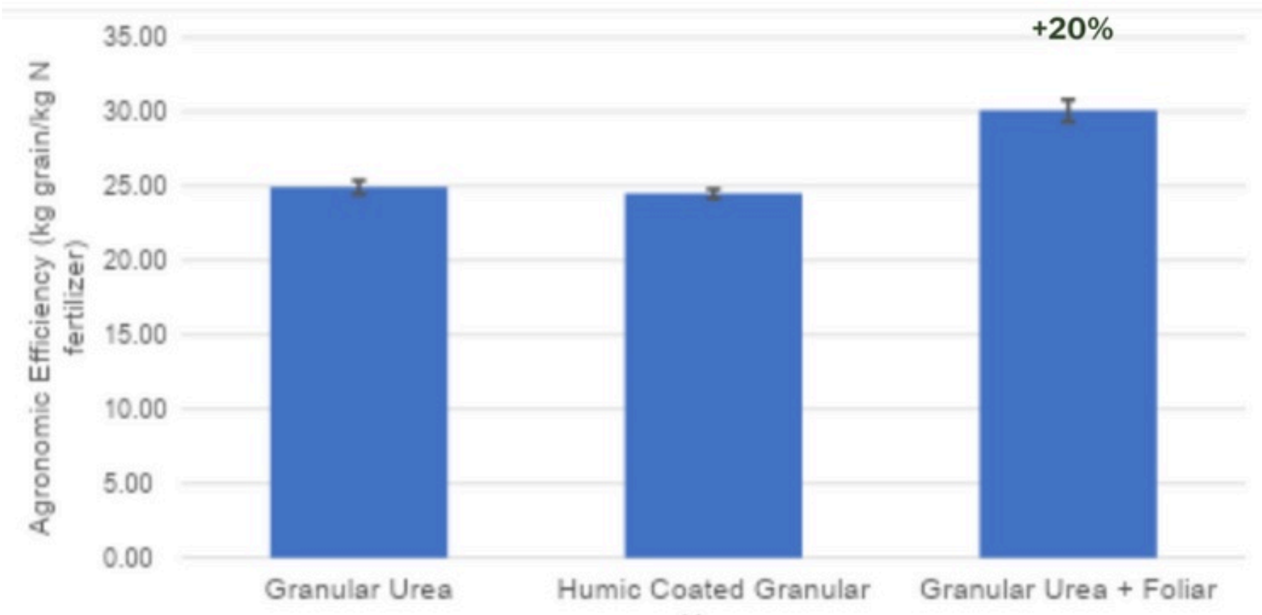

Fig. 4. Agronomic Efficiency (kg grain/ kg N fertiliser applied)

Humic coating reduces ammonia loss

The incubation test using the Solvita SLAN test (Fig. 5) showed that after 24 hours the humic coated urea released 15% less NH3 than the uncoated urea (Fig. 6).

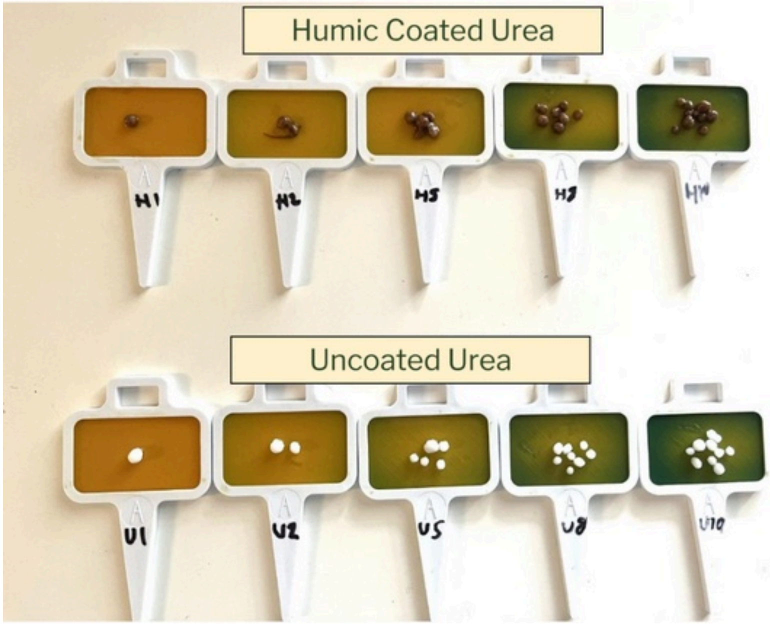

Fig. 5. Visualisation of the colourimetric response of the NH3 sensitive Solvita gel probes to increasing amounts of humic-coated and uncoated urea after 19 hours incubation in moist field soil. More green indicates a greater concentration of ammonia present in the incubation flask.

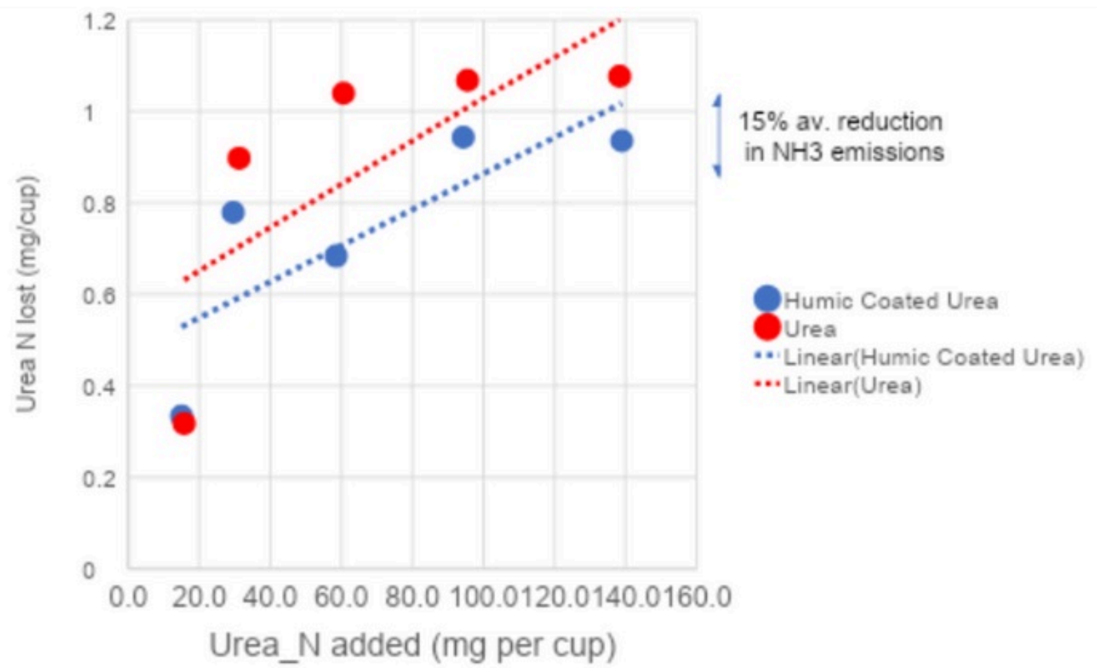

Fig. 6. NH3-N loss at different application rates of soil surface-applied urea or humic-coated urea.

Factors that influenced yield

In the absence of a N fertiliser treatment effect on yield, we were curious to understand the fundamental factors that influenced the observed yield variability of 1.7 t/ha across the paddock, as shown in Fig. 3.

To answer this question, we analysed possible causes using available datasets at our disposal, including baseline soil samples taken in March 2024, and modelled soil data available from CSIRO via Australia's Terrestrial Ecosystem Research Network (TERN). Specifically, we found that the data related to multiple geographic variables, including terrain relief (e.g., slope, aspect, and elevation) and parent material (e.g., soil mineralogy and clay content), were summarised in a Principal Component Analysis.

To relate yield data to underlying soil properties across the paddock we created a Voronoi diagram map (Fig. 7) using QGIS software, which creates a zone around each soil sample point with the borders of each zone determined by an algorithm which takes into consideration the distance between points.

Fig. 7. Voronoi soil zone map. The paddock is split into soil zone polygons which are centred around where soil samples were taken. These zones are then used to attach additional information such as yield, and topographical data.

We were then able to use this Voronoi map with the multiple paddock zones to intersect other soil maps available from TERN, such as modelled available water capacity, and build a multi-variate dataset consisting of soil chemical and physical data.

This multivariate dataset was used to run a linear mixed-effects model using the LME4 package in R software to gain insight into the influence of these multiple soil chemical and physical variables on canola yield across the paddock. The dependent variable used in the model was Canola yield, and the independent variables are listed with the results in Table 5. Random effects were assigned to the location of the zone on the paddock.

Table 5. Model results from linear mixed effects model

	F-value	P-value	Significance level
(Intercept)	87067.25	<.0001	
Combined PCA of soil relief and parent material	34.32	<.0001	***
Modelled Avail. Water Capacity (mm in 0-100cm depth)	9.14	0.004	***
SOC_pc	8.83	0.004	***
Total Ca	6.29	0.02	*
Exch. Ca	6.11	0.02	*
Mod_Clay_0.5c	5.15	0.03	*
Ca:Mg	4.14	0.05	*
Elevation (m)	3.37	0.07	ns
EC_dSm	1.84	0.18	ns
C:N	1.46	0.23	ns
Exchangeable K	1.32	0.25	ns
Zn	1.18	0.28	ns
pH	0.91	0.35	ns
Exchangeable K	0.56	0.46	ns
ECEC	0.45	0.51	ns
Total P	0.39	0.54	ns
Total C	0.31	0.58	ns
NO3-N	0.14	0.71	ns
P_Buffer.Index_Colwell.adj.	0.09	0.76	ns
Boron	0.05	0.82	ns

The underlying physical and topographic characteristics of the soil explained 39% of the variation across the paddock. Yield was also positively correlated with soil organic carbon and calcium levels. We categorised the paddock into three productivity zones, high, medium and low, shown in yellow, green, and purple areas (Fig 8). The High yellow zone yielded on 2.97 t/ha, the Medium green zone yielded 2.91 t/ha, and the Low purple zone yielded 2.81 t/ha (Table 6). The higher productivity areas also had higher soil organic carbon and calcium levels (Table 6).

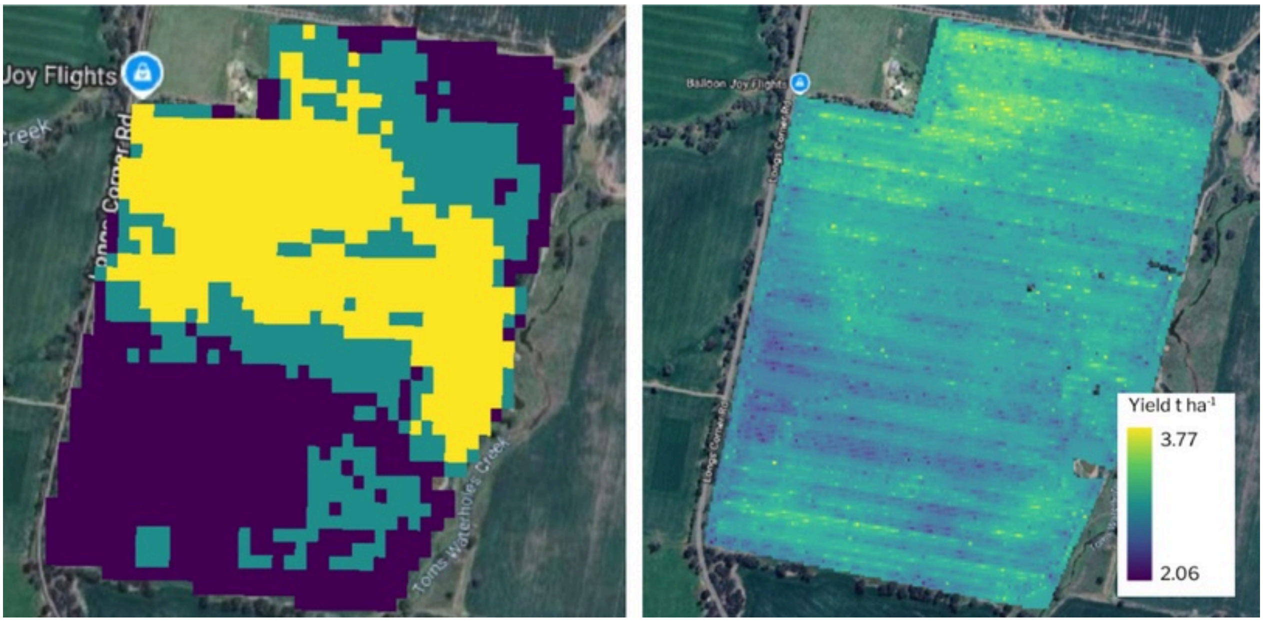

Fig. 8. (left) Soil quality map showing areas three areas of the paddock which shared similar topographic and physical characteristics and (right) the canola yield that was achieved on the field. The yellow area was the highest yielding and the purple area the lowest yielding.

Table 6. Yield and soil differences in three soil quality zones

Soil Quality Zone	High	Medium	Low	Soil Quality Zone
Average Yield (t/ha)	2.97 ±0.08	2.91 ±0.10	2.81 ± 0.1	Average Yield (t/ha)
SOC (%)	1.29 ±0.31	1.25 ±0.33	1.12 ±0.27	SOC (%)
Total Calcium (mg/kg)	1994 ±850	1706 ±470	1576 ±524	Total Calcium (mg/kg)

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