GRAINS RESEARCH UPDATE

STRATEGIC STEPS – ENDURING PROFIT

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Corowa

Thursday 15 February, 2018

9.00am to 1.00pm

Corowa RSL Club,

30 Betterment Parade, Corowa

#GRDCUpdates

Corowa GRDC Grains Research Update
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Program

9:00 am	**Riverine Plains Inc. welcome**	***Riverine Plains Inc.***
9:05 am	**GRDC welcome**	***GRDC***
9.15 am	**Canola — well executed agronomy still makes a difference in a tough 2017**	***Rohan Brill,*** *NSW DPI*
9.50 am	**Nitrogen dynamics in modern cropping systems**	***Jeff Baldock,*** *CSIRO*
10.25 am	**Riverine Plains Inc. research update**	***Cassandra Schefe,*** *Riverine Plains Inc.*
10.45 am	***Morning tea***	
11.15 am	**The National Paddock Survey - what causes the yield gap across Australian paddocks?**	***Roger Lawes,*** *CSIRO*
11.50 pm	**Pulse rhizobia performance on acid soils**	***Ross Ballard,*** *SARDI*
12.25 pm	**Simplifying methods to determine plant available water capacity (PAWC) of variable soils in Australian dryland grain production**	***John Stevenson,*** *Nuffield Scholar and Warrikiri Pty Ltd*
1.00 pm	***Close and evaluation***	***ORM***
1.05 pm	***Lunch***	

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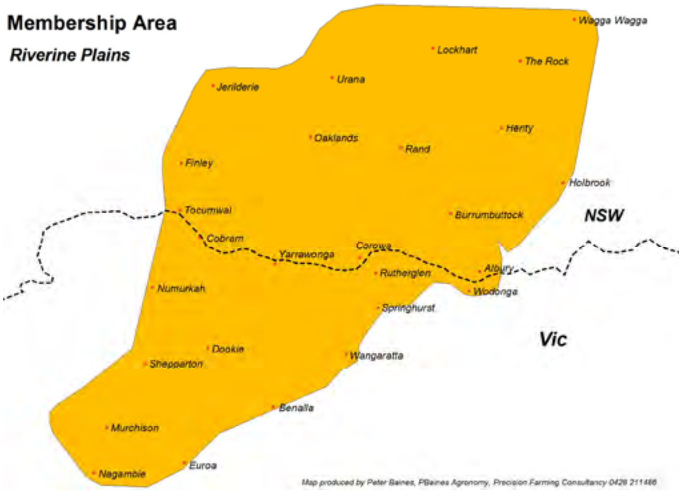

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Canola - well executed agronomy still makes a difference in a tough 2017

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GRDC project codes: CSP00187, DAN00213

Keywords

- canola, phenology, sowing date, flowering date, frost, nitrogen.

Take home messages

- In 2017, low yielding, unprofitable canola crops grew near profitable crops where strict attention to the system and timely agronomic management occurred.
- Matching the phenology of a variety with sowing date was paramount for grain yield, largely avoiding major frost damage. At all sites, yield was reduced when flowering started before August.
- Canola responded well to high rates of nitrogen (N) at moderate yield levels (2.0t/ha), even in a dry and frosty year.
- Hybrid canola generally outperformed open-pollinated (OP) canola especially in 2017, but sound agronomic management must accompany hybrids to maximise return on investment.
- In high yielding environments, highest yield (above 3t/ha) resulted from planting fast (e.g. Nuseed Diamond) and mid varieties (e.g. Pioneer® 45Y25 (RR) and Pioneer® 44Y90 (CL) but the very slow winter varieties still had profitable yields when planted in late March or mid-April as grain only crops.

Introduction

In the western cropping region of southern NSW (west of Wagga Wagga), extreme weather conditions experienced in 2017 made it difficult to grow profitable canola, yet there were crops that were profitable with grain yield of 1.0 to 2.0t/ha even in the same landscape where many crops yielded less than 0.5t/ha. In the eastern half of southern NSW, although much drier than average in 2017, canola yielded close to average with some exceptional results on the upper slopes.

There were consistent messages coming from the crops that were profitable in 2017, including:

1. Strict fallow weed control that conserved soil moisture from the very wet spring in 2016.
2. Even straw spread at 2016 harvest and prudent stubble grazing management to reduce seedbed moisture loss in autumn, and cover maintained at least until sowing.
3. Selection of paddocks with relatively high starting soil water and N.

4. Matching phenology and sowing date to minimise environmental stresses and optimise growth.
5. Sowing hybrid canola varieties (although this alone did not guarantee success).
6. Application of sufficient N to match grain yield potential.
7. Some element of luck e.g. timely rainfall for establishment and high elevation that reduced frost damage.

This paper will cover research that particularly focused on points 4 to 6 above, the agronomic management of the crop. The research reported here comes from two projects:

1. Optimised Canola Profitability (OCP) – a collaboration between NSW DPI, CSIRO, SARDI and GRDC, extending from southern Queensland to the Eyre Peninsula in SA.
2. High Yielding Canola (HYC) – a project funded under the new Grains and Pathology Partnership between NSW DPI and GRDC. This project is based in southern NSW with sites in the South West Slopes and in the Murrumbidgee Irrigation Area.

2017 research

The site details of the three experimental sites in southern NSW are summarised in Table 1.

Condobolin

The experiment at Condobolin was designed to determine the optimum sowing date, plant type, phenology and N management to optimise biomass accumulation, harvest index and ultimately grain yield under two contrasting scenarios, irrigated versus dryland. Four varieties were sown in a full factorial combination of sowing date, N rate and irrigation (Table 2). The extreme frost events of 2017 did have a large impact on the outcome (major frosts on 1 July (-6.8°C), 2 July (-5.5°C), 12 July (-4.0°C), 22 July (-5.1°C), 29 July (-4.1°C), 20 August (-4.5°C), 29 August (-5.3°C) and 1 September (-3.9°C)), but success under these circumstances was still influenced by manageable factors.

From the early (6 April) sowing, the fast varieties Nuseed Diamond and ATR Stingray⦶ started flowering in late June/early July (Table 3), whereas the slower varieties Archer and ATR Wahoo⦶ flowered over a month later, starting in August. From the 20 April sowing, Nuseed Diamond and ATR Stingray⦶ flowered about two weeks earlier than Archer and ATR Wahoo⦶ sown on 6 April. Irrigation and the high N rate both delayed the start of flowering by 3 to 4 days.

Table 1. Location, fallow rainfall (1 Nov to 31 March), in-crop rainfall (1 April to 31 October) and soil nitrogen (N) at sowing at three canola experimental sites in 2017.

Location	Region	Nov 16-Mar 17 Rainfall	Apr 17-Oct 17 Rainfall	Available N (sowing)
Condobolin	CW Plains	313mm	122mm*	77kg/ha
Ganmain	Riverina	180mm	190mm	123kg/ha
Wallendbeen	SW Slopes	228mm	279mm	187kg/ha

** 25mm of irrigation applied across whole site at Condobolin on 8-March to stimulate weeds and 15 mm applied on 13-April to ensure even establishment. CW=Central West, SW=South West.*

Table 2. Varieties (four), sowing dates (two), nitrogen rates (two), and irrigation treatments (two) applied in a factorial combination in an agronomy experiment at Condobolin, 2017.

Variety	Sowing date	Nitrogen Rate[1]	Irrigation[2]
Archer (slow hybrid Clearfield® (CL))	6-Apr	50 kg/ha	Nil (dryland)
Diamond (fast hybrid Conventional)	20-Apr	150 kg/ha	150 mm (irrigated)
ATR Wahoo⦶ (mid-slow Open Pollenated (OP) triazine			
ATR Stingray⦶ (fast OP TT)			

[1] All plots had 50kg/ha N broadcast as urea before sowing. An extra 100kg/ha of N was applied as urea for the 150kg/ha treatment at 6-8 leaf stage.

[2] Two irrigations of 30mm were applied to the irrigated treatment in March prior to sowing, one irrigation of 30mm applied 20 June and four irrigations of 15mm applied on 15 August, 1 September, 5 September and 20 September.

Table 3. Start of flowering (50% of plants with one open flower) of four canola varieties sown at two sowing dates at Condobolin, 2017.

Variety	6 April	20 April
Diamond	28 June	18 July
ATR Stingray⁽ᵈ⁾	5 July	23 July
ATR Wahoo⁽ᵈ⁾	6 August	16 August
Archer	9 August	18 August

The mid-slow variety ATR Wahoo⁽ᵈ⁾ and the slow variety Archer both yielded around 1t/ha in the dryland early sown treatment as their delayed flowering meant they were not too far advanced through podding when the severe frost occurred (although some frost damage would have been incurred) (Figure 1). The yield of both Archer and ATR Wahoo⁽ᵈ⁾ was reduced by sowing later as flowering was delayed and pod development was limited by elevated spring temperatures. The faster varieties Nuseed Diamond and ATR StingrayA were heavily penalised by frost at both sowing dates as flowering started (from both sowing dates) by mid-winter and were heavily penalised by the frost events in 2017. For these fast varieties it would be recommended not to sow before 25 April in most environments of southern NSW.

Irrigation (150mm total) doubled the average experimental yield from 0.64t/ha to 1.28t/ha (Figure 1). The increase in grain yield of the fast varieties from irrigation highlights the level of recovery that can be achieved by canola despite frost damage where sufficient soil water is available. While the main message of this experiment is that varietal phenology and sowing date need to be matched to avoid very early flowering of canola (before August at this site), extra water can help frosted canola recover. The main ways that growers can reliably provide extra water to their crops is through strict fallow management and crop sequence decisions such as utilising pulses and long fallow in lower rainfall environments that may leave behind some deeper soil water.

Despite the relatively low starting soil N level (77kg/ha) at the Condobolin site, there was no response to increasing N rate from 50 to 150kg/ha in either the irrigated or dryland treatment.

Ganmain

Similar to Condobolin, there were many severe frost events at Ganmain in 2017 (Figure 2) including 1 July (-5.5°C), 2-July (-4.1°C), 22 July (-3.5°C), 20 August (-3.4°C), 26 August (-3.1°C), 28 August (-4.4°C), 29 August (-5.7°C), 30 August (-3.5°C) and 17 September (-4.6°C). Rainfall was also well below average and there was a heat event of 36.3°C on 23 September (giving a temperature range of 40.9°C in less than one week!). Despite the extreme climatic conditions in 2017, average grain yield of the trial (2.1t/ha) was still close to average for the region (1.8t/ha to 2t/ha) due to deep stored water from spring rainfall in 2016.

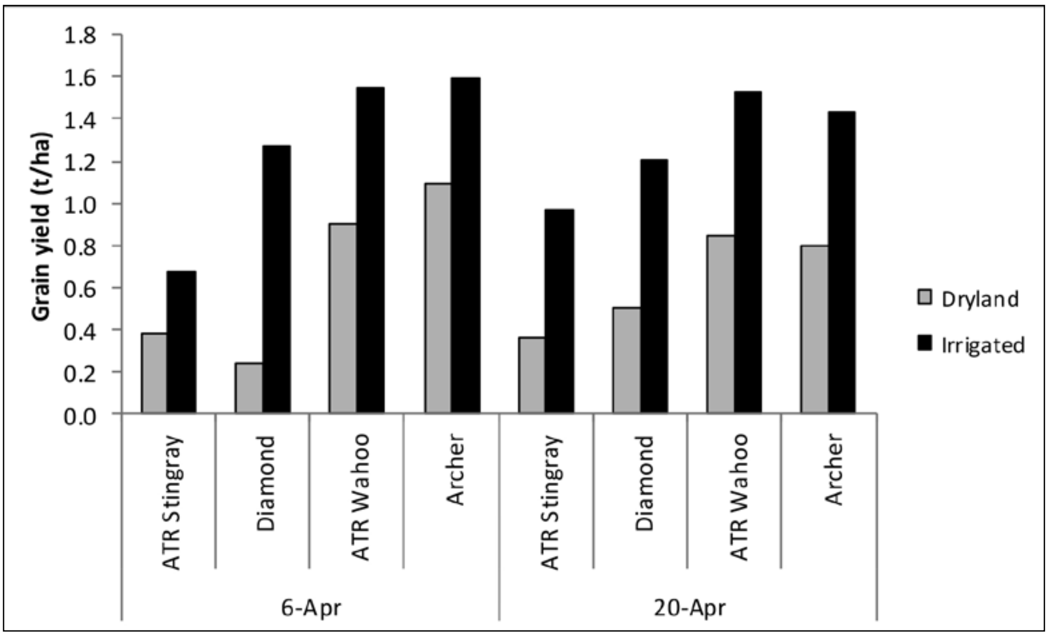

Figure 1. Grain yield of four canola varieties sown at two sowing dates, with (irrigated) or without (dryland) irrigation, at Condobolin in 2017 (l.s.d. P<0.05 = 0.26t/ha).

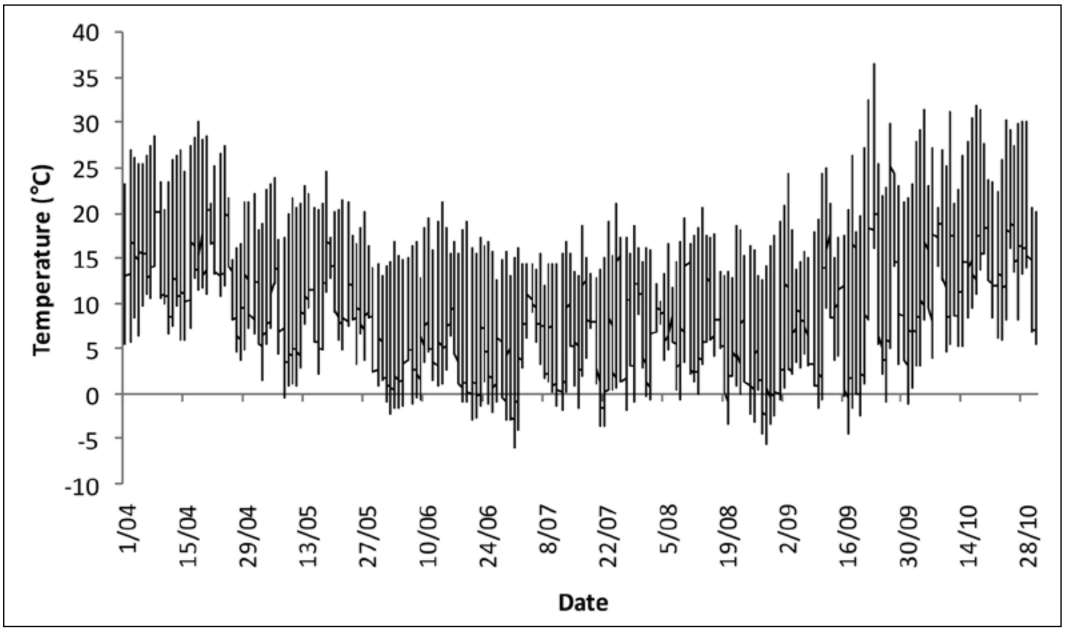

Figure 2. Temperature (°C) from 1 April to 31 October at the Ganmain experimental site, 10km north of Ganmain, NSW.

In this experiment (Figure 3), increased yield came from sowing varieties in their optimum window to achieve the optimum flowering date (early August) and where they were well fertilised with N. The fast varieties (Nuseed Diamond and ATR Stingray⁽ᵠ⁾) were heavily penalised by frost from early sowing (early flowering, see flowering dates in Figure 4) and the slower varieties (e.g. Archer and ATR Wahoo⁽ᵠ⁾) had reduced yield from later sowing as flowering occurred later (late August) than optimal and pod development was limited by rising spring temperatures. Importantly the N response increased for varieties sown in their correct window; for example there was a strong response to N with Archer, Pioneer® 45Y25 RR and ATR Wahoo⁽ᵠ⁾ sown early (flowering in early August) but minimal response when sown later (flowering in later August). Conversely there was a strong

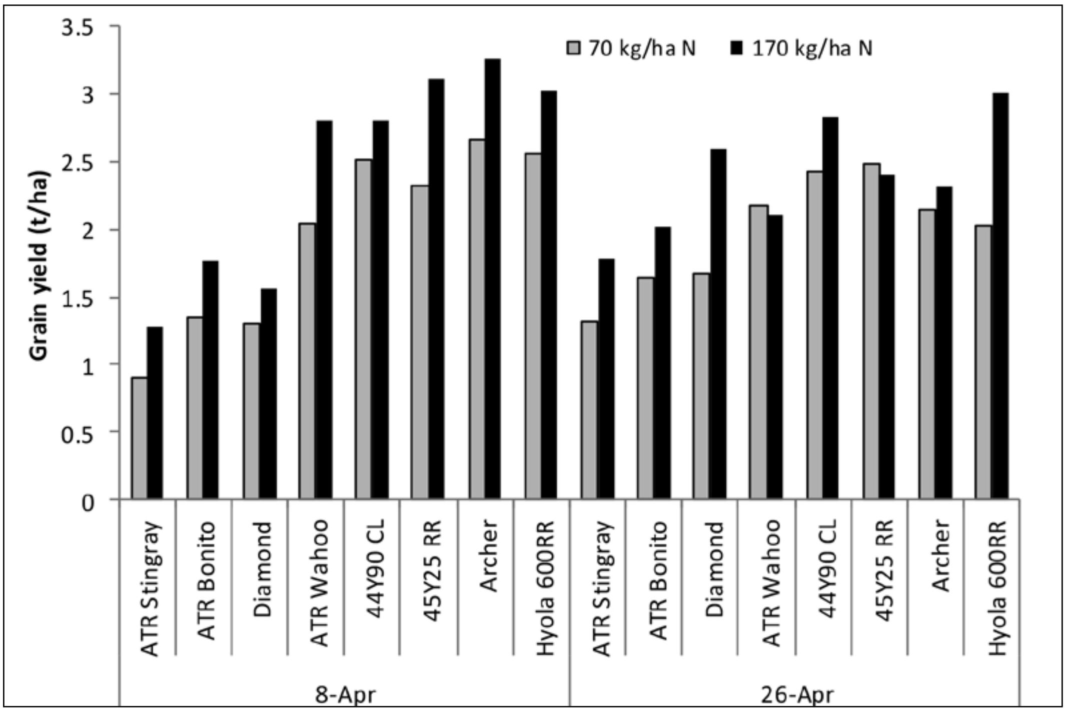

Figure 3. Grain yield of eight canola varieties sown at two sowing dates and fertilised at two nitrogen rates at Ganmain, 2017 (l.s.d. P<0.05 = 0.38t/ha).

response to N for Nuseed Diamond when sown later (flowering in early August) but not where it was sown early (flowering in early July). Both Pioneer® 44Y90 CL and Hyola 600RR responded well to N at both sowing dates (Figure 3).

There was an overall benefit of planting hybrid varieties; however varietal choice was less important than ensuring sowing date, phenology and N management were optimised. For example, the OP TT variety ATR Wahoo⁽ᵈ⁾ (2.8t/ha) sown early with a high rate of N yielded 0.7t/ha above the trial mean yield of 2.1t/ha, whereas there were several treatments where hybrids with inappropriate management yielded less than the trial mean.

A frost scoring system was developed for Ganmain where the number of viable seeds was counted in 20 pods on the main stem in each plot. There was a strong relationship between flowering date and the number of viable seeds per pod (Figure 4). Early sown Nuseed Diamond and ATR Stingray⁽ᵈ⁾ flowered in early July and both averaged less than six seeds per pod. From the same sowing date, Archer and ATR Wahoo⁽ᵈ⁾ delayed their flowering until early-mid August and both had more than ten viable seeds per pod. This scoring gave an insight into the level of frost damage in each variety but did not completely relate to grain yield as there were differences in the ability to compensate (with new pods) from frost damage.

There were differences in the severity of frost damage amongst varieties that flowered at a similar time, e.g. Pioneer® 44Y90 (CL) appeared to suffer less frost damage than ATR Bonito⁽ᵈ⁾ despite both flowering in early August. This might be partly explained by Pioneer® 44Y90 (CL) having more pods on the main stem (data not shown) so some of the pods on the upper parts of the main stem could have developed later and potentially avoided frost damage. In addition the higher N rate increased the number of viable seeds per pod; however this may have been partly a result of higher rates of N generally delaying phenology of canola.

Wallendbeen

An experiment was sown at Wallendbeen to determine the ideal canola plant type for high yielding environments, aiming to compare long season varieties sown early with fast varieties sown later. Growing season rainfall was approximately 100mm below average but grain yields were still high due to the long cool spring and high elevation (530m). Soil N at sowing was 187kg/ha and combined with the application of 150kg/ha N during the growing season (114kg/ha at sowing plus 46kg/

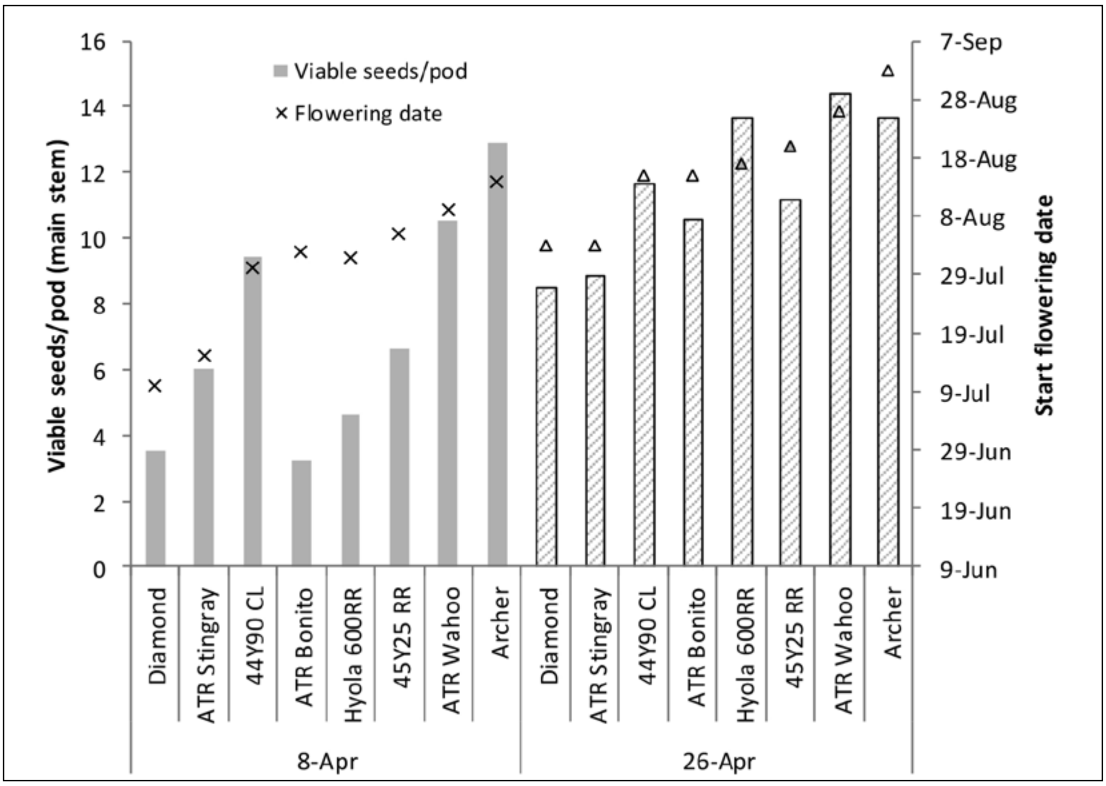

Figure 4. Viable seeds per pod (columns) and flowering date (× and Δ) of eight canola varieties sown at two sowing dates (averaged across N rates) at Ganmain, 2017 (Viable seeds/pod l.s.d. P<0.05 = 2.1)

ha on 4 July) and potential mineralisation of 60kg/ha, total available N was 397kg/ha. Early sown Nuseed Diamond (28 March) started flowering 22 June (Figure 5) and had only 30% viable seeds on the main stem while most other treatments were largely unaffected by frost. The slow spring varieties Victory 7001CL and ATR Wahoo[⊕] delayed their flowering until mid-August from a late March sowing while the winter varieties Hyola® 970CL and Edimax CL both flowered in a narrow window in late September to early October.

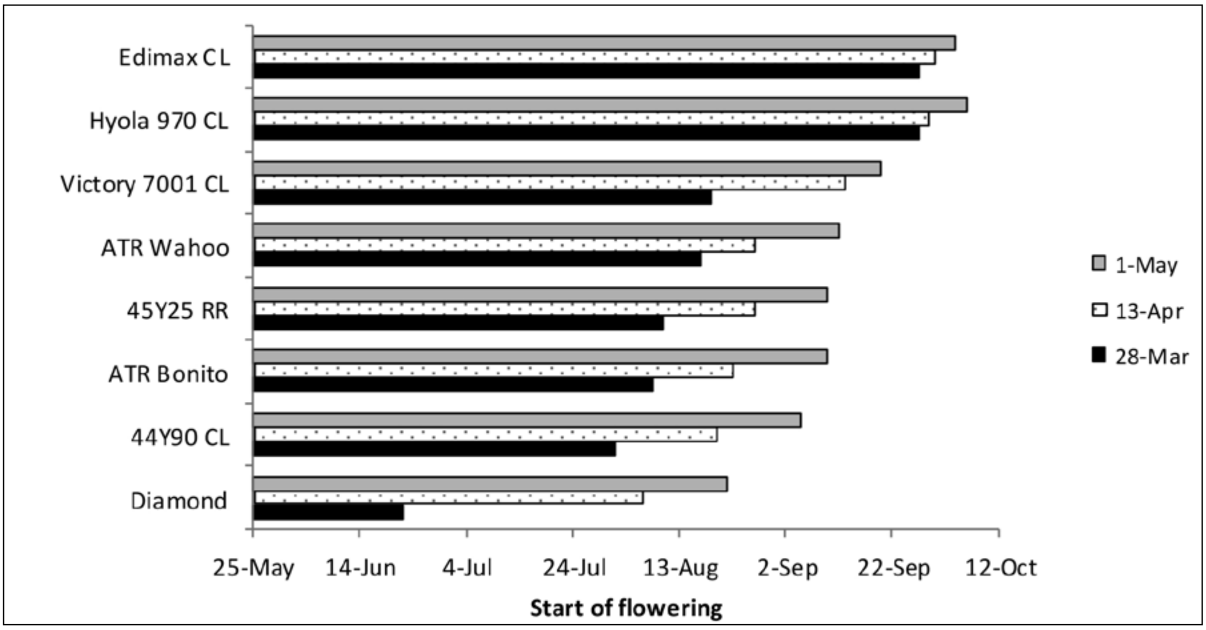

Figure 5. Start of flowering date (50% of plants with one open flower) of eight canola varieties sown at three sowing dates, Wallendbeen 2017.

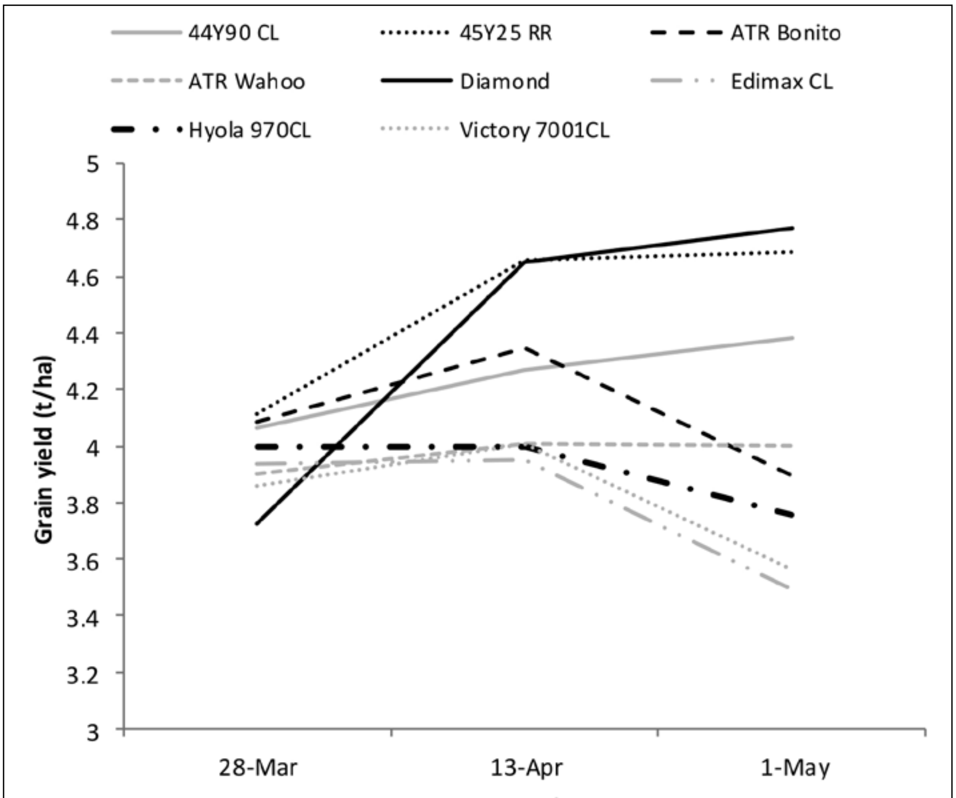

Figure 6. Grain yield of eight canola varieties sown at three sowing dates at Wallendbeen, 2017 (l.s.d. P<0.05 = 0.39t/ha).

The early sown Nuseed Diamond treatment that flowered on 22 June was penalised by frost and yielded 3.7t/ha but when sown on 1 May was the highest yielding treatment in the experiment at 4.8t/ha (Figure 6). Pioneer 45Y25 (RR) was the most consistently high yielding variety across the experiment but it also yielded more at the two later sowing dates than at the early sowing date. The winter varieties Hyola® 970CL and Edimax CL (both ungrazed) as well as the slow spring varieties Victory 7001CL and ATR Wahoo⁽ᴾ⁾ were the four lowest yielding varieties in the experiment, but yielded consistently across all sowing dates.

Conclusion

Although in many regions 2017 was a tough year for growing canola, there were still profitable crops grown in most environments through effective management and in some cases a little luck (from timely rainfall) and elevation. The correct matching of sowing date with phenology is the main message from 2017, reaffirming a consistent message from recent years of canola research.

Secondly, to achieve high yield, managing the crop with optimum N fertility and finally with the former two manageable factors in place, hybrid varieties can take grain yield to the next level — but won't be a silver bullet in isolation.

Although frost had a major impact on grain yield in 2017, especially in western areas, there were management decisions that significantly affected how the crops recovered after frost. Matching sowing date and phenology so that crops flowered in the optimum window ensured that crops were not too far advanced through pod set when the frosts hit but also not so late that yield was limited by rising spring temperatures. Hybrids tended to recover better from frost damage (which requires further investigation) but it was still possible to achieve profitable yields with OP varieties.

As well as the in-crop agronomic management factors, pre-crop management had a major bearing on outcomes for canola in 2017. Management of points 1 to 3 from the introduction including strict fallow and stubble management plus selecting the most suitable paddock for canola were critical for canola success in 2017 and need to be done well to get the best out of the agronomic management of canola.

Acknowledgements

The projects supporting this research are co-investment from GRDC, NSW DPI, CSIRO and SARDI. The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC — the authors would like to thank them for their continued support.

Particularly, the authors would like to thank the grower trial co-operators for the 2017 trials; Cameron Hazlett (Wallendbeen) and Dennis and Dianne Brill (Ganmain). Thanks also to technical staff for assistance including John Bromfield, Warren Bartlett, Sharni Hands and Sophie Prentice.

Further reading

https://grdc.com.au/10TipsEarlySownCanola

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Notes

Nitrogen dynamics in modern cropping systems

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GRDC project codes: CSP00207, CSP00203

Keywords

- nitrogen, soil organic matter, soil fertility, profitability.

Take home messages

- Matching the supply of nitrogen (N) with crop demand is critical to optimising nutrient use and profitability of grain production. Defining the ability of a soil to deliver available N both prior to and within the grain growing season is required to help optimise N fertiliser application rates.
- The amount of N delivered to crops from soil will be location specific due to variations in the environmental conditions, soil types and their properties and the manner in which agricultural management practices are implemented.
- N stocks in Australian soils are declining. On average, the production of cereal and oilseed crops is associated with a negative N balance. Performing N balance calculations is important to define the potential impacts of current management practices on long term soil productivity and N supply capacity.
- A short period of negative N balance is acceptable provided it is followed by a rebuilding phase through implementing practices capable of increasing soil organic N stock.
- As soil N supply capacity is reduced, a greater reliance on fertiliser N will result. Due to potential losses that N derived from fertilisers is exposed to, the greater reliance on fertiliser N may result in lower yields being associated with the optimisation of profits.

Background

Grain production in Australia occurred on 21Mha in 2015-16 (Australian Bureau of Statistics 2017b). Cereal production accounted for 17Mha with wheat accounting for the largest area (11Mha) and barley the second largest (4Mha). Contributions from oilseed and pulse crops were each approximately 2Mha. Combined, the gross value of Australian grain crops was $12.6 billion across 29,000 businesses, with wheat, barley and canola production providing a total of $9.9 billion (Australian Bureau of Statistics 2017a; Australian Bureau of Statistics 2017c). For individual businesses, setting and maintaining an ability to achieve appropriate yield targets is a critical step to defining the profitability of grain production.

The majority of grain produced in Australia is rainfed and grown under conditions where the availability of water defines potential productivity. Provision of an appropriate supply of nitrogen (N) and other nutrients, matched to the temporal demand of grain crops over the growing season is required to optimise profitability. If N supply is insufficient, water limited grain yields will not be attained. If too much N is present, the potential exists for vigorous early vegetative growth to lead to crops ‘haying-off’ under water limited conditions later in the growing season (van Herwaarden et al 1998).

Synchronising the rate of N supply with the demand of a growing crop is a challenge faced by grain growers. It requires an understanding of temporal crop demand and how best to satisfy that demand through the application of appropriate quantities of fertiliser. A key component associated with deciding how much fertiliser N to apply is estimating the quantity and temporal provision of N from soil. Given the contribution that purchasing and applying fertilisers makes to the variable cost of grain production in Australia (20-25% of variable costs (IPNI 2013), 12-30% for cereals and oilseeds and 6-16% for pulses depending on crop and rainfall zone (Rural Solutions SA 2017)), developing an ability to accurately predict and maintain the provision of N from soil will lead to more profitable grain production. This paper will consider the importance of soil derived available N to productivity, implications of running soil N supply capacity down and practices with a potential to alter soil N supply capacity.

Nitrogen supply in the context of potential productivity

Variations in the availability of water to grain crops across years and from location to location will mean that different amounts of N are required to optimise productivity and profitability. Defining potential grain yield on the basis of water availability (stored soil water at sowing + growing season rainfall) has been used to guide the definition of yield targets (Figure 1a). In Figure 1b, point B on the solid black line defines potential yield for a particular availability of water. Combining this potential with a protein target allows grain growers to estimate crop N requirement. However, defining an appropriate fertiliser application rate that matches N supply with crop demand requires a knowledge of the quantity of N that will be delivered from the soil. Without an understanding of soil N delivery, the use of inappropriate application rates of fertiliser N may occur and result in suboptimal yields (point A) and reduced profitability. Where management practices can be applied that shift the intercept term to lower values (move from point C to D) in response to a reduction in soil evaporation, run-off or deep drainage, yield potential will be enhanced and follow the dotted line. Under such conditions potential yield will move from point B to E, but attaining that yield will again require a knowledge of the amount of N that can be provided by a soil in order to define appropriate fertiliser application strategies.

The water use and water use efficiency concept can be extended to the efficiency frontier approach described by Keating *et al* (2013) (Figure 2). To introduce this approach, the change in grain yield or profit as a function of N fertiliser application rate is presented (Figure 2a). The economic optimum (point A on the dashed profit line) is likely to occur at an N fertiliser rate less than that required to maximise yield (point B on the solid yield line). The contribution to yield or profit due to the ability of a soil to provide N to a crop is defined by point C. As the soil contribution increases, the response curves for yield and profit will shift to the left and the fertiliser N application rate required to optimise profit will be reduced. Conversely, as the N supply capacity of a soil declines, a greater reliance on fertiliser N will result.

In Figure 2b, the efficiency frontier for profit as a function of investment is presented along with the

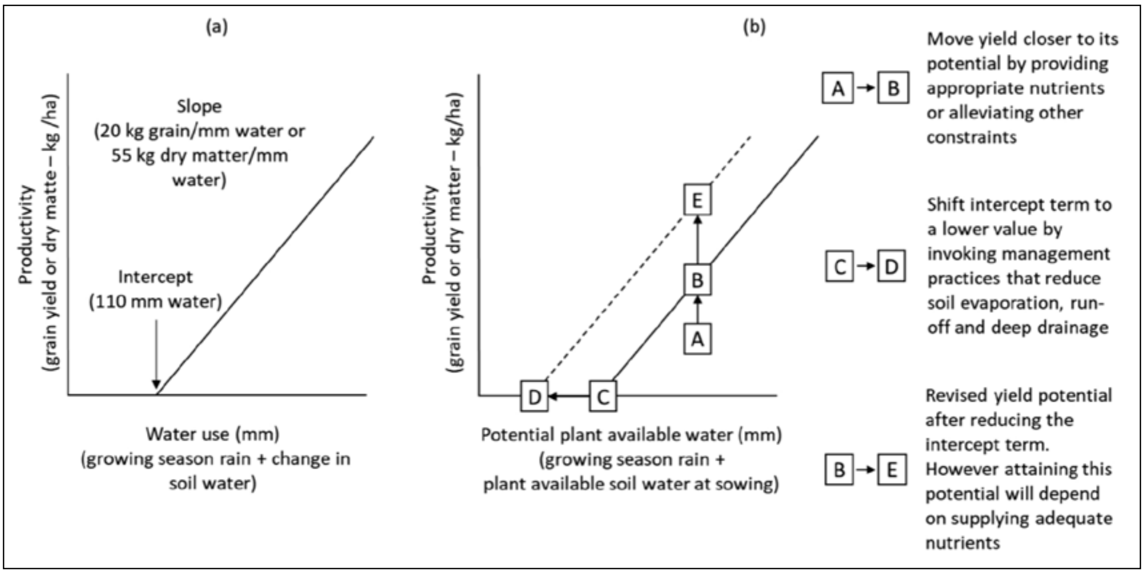

Figure 1. Concept of water limited potential **(a)** as defined originally by French and Schultz (1984) and **(b)** as subsequently modified.

changes that can occur if management actions are taken that can improve the efficiency frontier (e.g. enhanced infiltration of rainfall or water holding capacity). For this example, the investment will be taken to represent the costs associated with fertiliser N application and assuming that other costs are fixed. The current efficiency frontier is represented by the dotted line and the optimum fertiliser N application where profits are maximised corresponds to point D. If fertiliser N application is too low (point E), profit will be reduced due to the opportunity cost associated with forgone grain yield. If too much fertiliser N is applied (point F), profits will be reduced due to the decreased return on the investment made in buying and applying additional fertiliser. Under the conditions of a new efficiency frontier (solid line), if the fertiliser N addition associated with point D is maintained, profit may increase (point G) but it will not be optimised. To reach the new economic optimum (new profit maximisation), fertiliser N addition would have to be increased to that associated with point H.

Since the availability of N to grain crops results from a the combination of N supplied by the soil and any applied fertiliser N, maximising profits requires a knowledge of the amount of N that can be supplied by the soil (point C) to ensure that optimum fertiliser application rates can be defined. Only in the case where soils are not able to supply any N to grain crops will not knowing the ability of a soil to supply N have no impact on yield and profit outcomes.

However, under such conditions, it is likely that the soil will exist in a degraded state and optimisation of production even with the application of additional fertiliser will likely not be possible due to the existence of other factors constraining productivity.

The soil nitrogen cycle

The soil nitrogen cycle, showing the various pools and nitrogen transformations and movements, is presented in Figure 3. The majority (>95%) of nitrogen in a soil exists as insoluble organic matter (soil organic matter, soil microorganisms and plant residues). Nitrogen available to crops includes inorganic nitrogen (ammonium and nitrate) and soluble organic nitrogen. The biological processes of decomposition and mineralisation convert insoluble organic N into plant available forms. Although microorganisms mediate the production of available N, they also require N themselves. Under conditions where the organic matter being decomposed does not contain sufficient N to satisfy the requirements of the microorganisms, they will scavenge available N from the soil. This process is referred to as immobilisation and occurs when crop residues with high C/N ratios decompose in soil. Immobilised N is not lost from the soil system, but is converted into an organic form that can be mineralised back into an available form through decomposition.

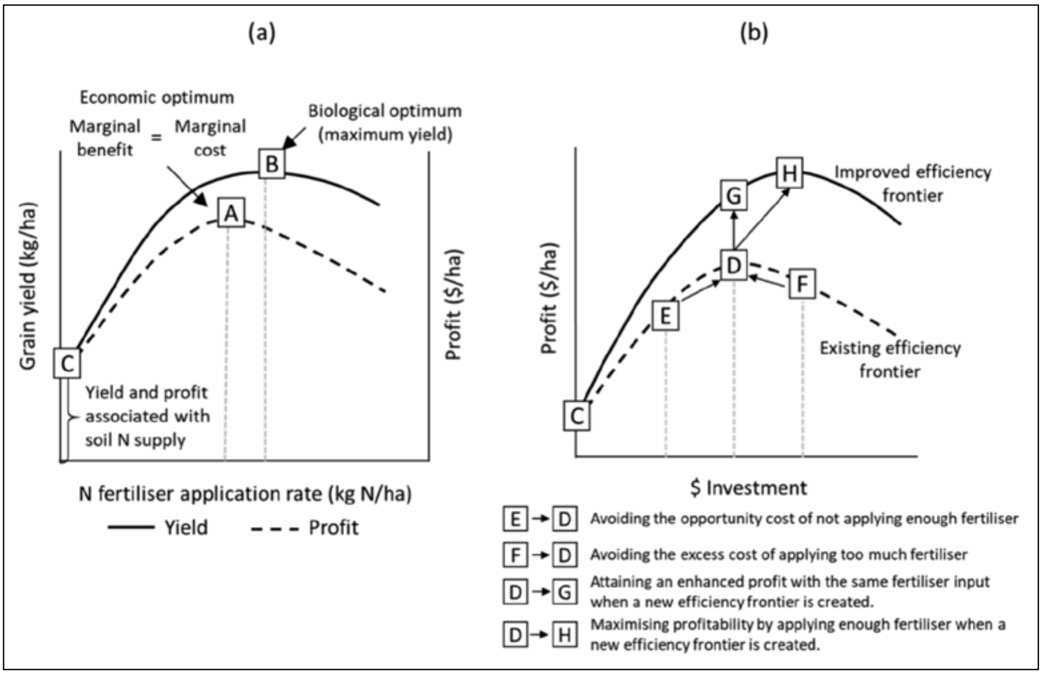

Figure 2. (a) Application of the efficiency frontier concept as described by Keating et al (2013) and **(b)** how modifying fertiliser addition rates on the basis of knowing soil nutrient supply will move profitability along existing and improved efficiency frontiers.

Nitrogen can be added to a soil in the form of inorganic (e.g. urea, di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP), etc.) or organic (e.g. manure, compost, etc.) fertilisers or through biological nitrogen fixation associated with free-living N_2 fixing organisms or the production of pasture or grain legumes. Several processes exist that can reduce the amount of N present in a soil including: removal in harvested products (grain, hay or meat), leaching of available N (large rainfall events), denitrification of nitrate (prolonged periods of wet soil) and volatilisation of ammonia (high pH soils or poor conditions after surface granular urea application). Increases in the potential for N loss through leaching, nitrification and volatilisation can occur when available N accumulates. Matching the supply of available N to crop N demand will reduce potential accumulations of available N and potential N losses.

Maintaining soil N status — is it important?

Implementing agricultural production on Australian soils has resulted in a decline of soil organic matter stocks to values representative of 30-80% of those in comparable soils under native vegetation (Luo et al 2010). As soil organic matter stocks decline, N bound with carbon (C) in the organic matter is mineralised to an available form. Based on a C:N ratio of 11.7, derived from data presented by Kirkby *et al* (2011), a loss of 10g C/kg soil within a 0-10 cm soil layer with a bulk density of 1.20Mg/m^3 would result in the mineralisation of 1028kg N/ha. Possible fates of the mineralised N include extraction in harvested products or loss from the soil.

Fertiliser N application rates have been guided by results obtained from fertiliser application rate trials. Although such trials are useful, they have tended to be used to define the minimum amount of fertiliser N required to optimise annual (short term) profitability. In essence such trials have taught grain growers how to most effectively mine nutrients from the soil. While in the short term this would appear to be a practice that optimises annual profits, with continuing declines in stocks of soil organic matter and associated N, the ability of soil to continue to supply the N required to meet crop demand will diminish. The result of such a progressive mining of nutrient stocks will be an increasing gap between the amount of N required by grain crops and the quantity that can be supplied by the soil. If not addressed, this will lead to an increasing dependence on fertilisers to achieve desired grain yield outcomes.

Assuming a yield target for wheat of 3t/ha with an 11% protein target, the amount of N required by the crop would be 159kg N/ha as calculated using Equation[1]. Values of 5.7 for the conversion of protein to N, 0.81 for N-harvest index, and 0.45 for N use efficiency were used.

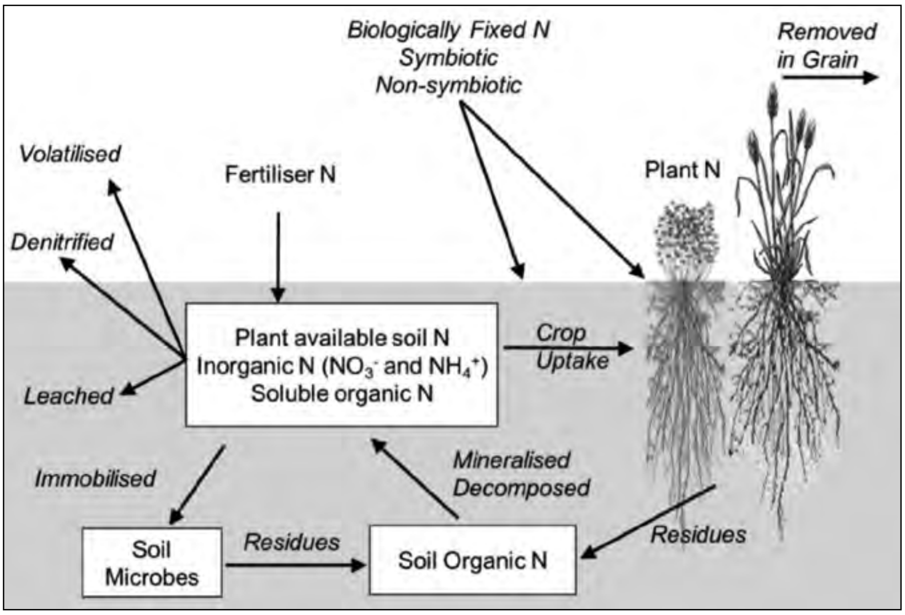

Figure 3. Forms, fluxes and transformations of nitrogen in soil.

$$N_{Required}\ (kg/ha) = \frac{\text{Potential crop yield (t/ha)} \times \text{Grain protein content (\%)}}{\text{Protein to N conversion} \times \text{N harvest index} \times \text{N use efficiency}} \times 10$$

Equation[1]

$$N_{Soil\ Supply}\ (kg/ha) = \begin{matrix}\text{Soil}\\\text{organic}\\\text{carbon}\\\text{(\%)}\end{matrix} \times \begin{matrix}\text{Bulk}\\\text{density}\\(Mg/m^3)\end{matrix} \times \begin{matrix}\text{Soil}\\\text{layer}\\\text{thickness}\\\text{(cm)}\end{matrix} \times \frac{1}{\text{C:N ratio}} \times \begin{matrix}\text{Percentage}\\\text{of total soil N}\\\text{that mineralises}\\\text{(\%)}\end{matrix} \times 100$$

Equation[2]

Assuming an N mineralisation rate of 3% of soil N per year, that all mineralised N is derived from the 0-10 cm soil layer with a bulk density of 1.3 Mg/m^3, an organic carbon content of 2.0% and a C:N ratio of 11.7, in the first year the soil would be able to supply 67kg N/ha (Equation [2]) and 92kg fertiliser N/ha would be required to achieve the target wheat yield and protein.

If this wheat crop is grown continuously every year and only enough fertiliser N is added to satisfy the N required by the crop above which is supplied by the soil, the changes in soil N supply and required fertiliser N over time are shown in Figure 4. After 10 years, the soil N supply capacity and the fertiliser N requirement would change to 49 and 110kg N/ha respectively.

Another factor that needs to be considered is the decrease in efficiency of fertiliser N use with increasing application rate (Figure 5a). Each incremental increase in yield will have a higher cost, particularly in progressing towards the biological optimum yield. A main contributor to this relationship resides in the mechanisms by which available N (i.e. fertiliser N) can be lost from the soil/crop system (e.g. volatilisation, denitrification and leaching), and the potential increase in the magnitude of these losses as the concentration of available N in soil increases in response to increasing fertiliser additions. As a result, where fertiliser N application rates have to increase in response to a decreased ability of the soil to supply N, the cost of achieving additional yield increments will likely increase and

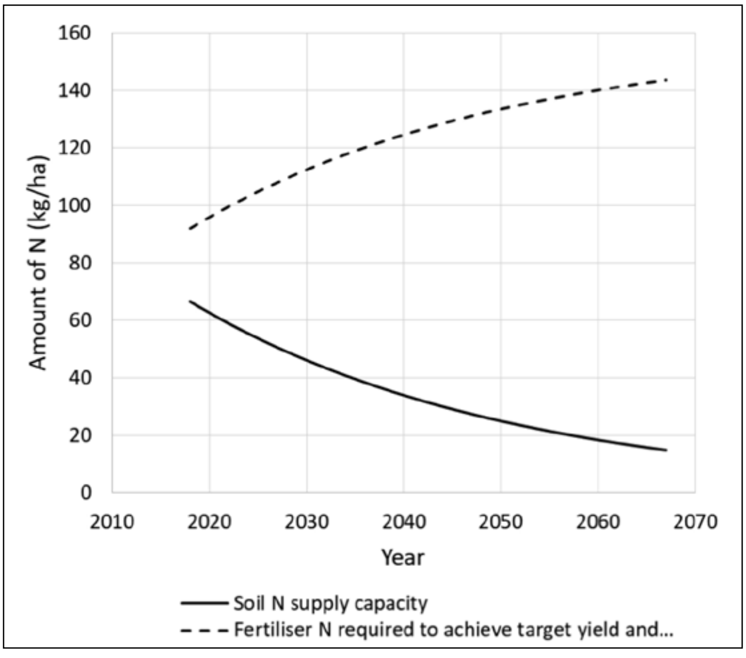

Figure 4. Change in soil N supply capacity (solid line) and fertiliser N requirement (dashed line) over time in the absence of any additions of N addition beyond that required for a 3t/ha wheat grain yield with 11% protein.

the profitability of applying additional fertiliser N will decrease. Under such circumstances, and assuming all other variable costs remain fixed, the economic optimum yield (where marginal benefit = marginal cost, Figure 5a) will decline as the ability of a soil to supply N decreases (point A versus point B in Figure 5b) as will profits (Figure 5c).

Part of the benefit provided by soil N supply, relative to fertiliser N application, resides in the fact that N derived from organic matter decomposition is metered out over the growing season and responds positively to the same environmental variations controlling crop growth and N demand (e.g. soil temperature and availability of water). With an increasing reliance on soil derived N, the supply and crop demand for N are likely to be better synchronised, leading to lower accumulations of available N in the soil. It is important to note that the different responses presented for the soils with a low and high N supply capacity in Figure 5 are conceptual and have been accentuated to demonstrate the points made above. A more complete economic assessment is required to quantify the magnitude of the proposed profitability differences and to fully assess the implications.

A range of performance indicators exist to quantify the effectiveness of fertiliser N management (Table 1). Each of the indicators provide useful, but different information. Partial factor productivity (PFP) provides an overall assessment of yield response per unit of fertiliser N applied, but fails to compensate for the amount of N supplied by the soil. Thus, where similar amounts of fertiliser N are applied to soils with different soil N supply capacities, different values for PFP will be obtained. On soils with a greater N supply capacity, PFP values would be inflated giving the impression of a greater fertiliser N use efficiency. The best use of PFP appears to be as a monitoring tool over a defined land area (e.g. paddock, farm or region). In this situation, increasing PFP likely indicates an improving soil N supply capacity and conversely a falling PFP likely indicates a reduction soil fertility and possible mining of soil N stocks.

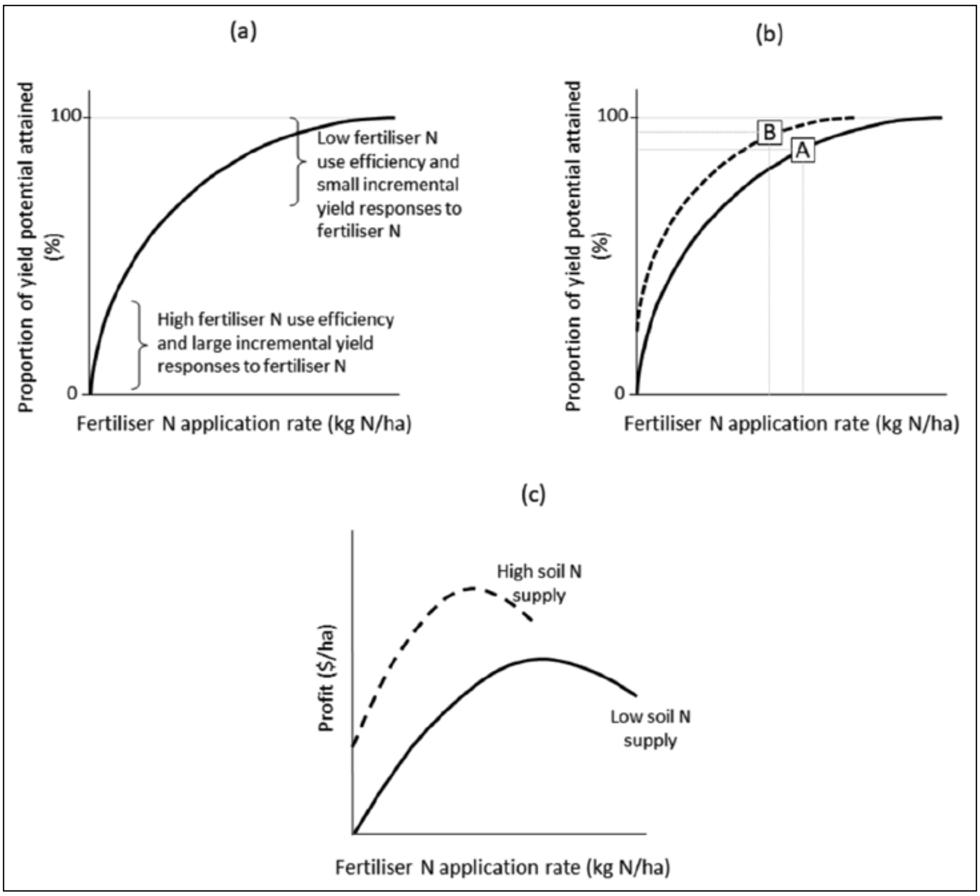

Figure 5. Changes in **(a)** fertiliser N use efficiency **(b)** grain yield and the profit optima and **(c)** profitability of grain production with increasing fertiliser N application rates for soil with a low (solid line) or high (dashed line) N supply capacity. Note that these diagrams are conceptual and differences between low and high N supply capacity have been accentuated for the purpose of demonstrating potential differences.

Table 1. Common performance indicators used to assess the effectiveness of nutrient management (based on Dobermann, 2005; Norton, 2016).

Performance indicator	Calculation	Units	Interpretation
Partial factor productivity (PFP)	PFP = YF/F	kg grain/kg fertiliser nutrient applied	Defines the return achieved per unit of fertiliser nutrient applied. PFP does not compensate for nutrient provided by the soil. High values could be due to efficiently managed systems or to a high soil nutrient supply capacity. Values typically range for 40 -70kg grain/kg applied nutrient.
Agronomic efficiency of applied nutrients (AE)	AE = (YF-Y0)/F	kg yield increase/kg fertiliser nutrient applied nutrients.	AE measures the additional yield achieved by applying fertiliser It provides a better assessment of the impact of fertiliser nutrients on yield than PFP through the inclusion of yields measured on unfertilised control plots. Values range from 10-30kg grain/kg N.
Partial nutrient balance (PNB)	PNB = G/F	kg nutrient in grain/kg fertiliser nutrient applied	PNB is the ratio of nutrient removed to nutrient applied. Values >0.5 suggest background supply is high and/or fertiliser nutrient losses are low. Values >1 imply an extraction and removal of nutrients that is greater than the amount of nutrient applied. Because it is a ratio, PNB does not provide a direct measure of the magnitude of nutrient depletion.
Nutrient balance intensity (NBI)	NBI = G-F	kg nutrient removed in products/ha - kg fertiliser nutrient applied/ha	Defines the difference between nutrient removed in products and fertiliser nutrient added. Positive values indicate nutrient mining and a depletion of soil nutrient supply capacity. The magnitude of NBI provides a direct measure of the extent of nutrient depletion in kg nutrient/ha.

F=the amount of fertiliser nutrient applied (kg ha^{-1})
Y_F=crop yield (kg/ha) obtained with the application of fertiliser nutrient.
Y_0=crop yield (kg/ha) in a control treatment with no fertiliser addition.
G=the amount of nutrient present in harvested grain (kg/ha).

In the calculation of agronomic efficiency (AE), the difference in yield between unfertilised and fertilised crops is expressed as a function of the amount of fertiliser applied. This provides a more robust assessment of the magnitude of grain yield increase per unit of fertiliser N applied. It is less confounded by variations in the N supply capacity of the soil than PFP. However, if large variations in soil N supply capacity exist, significant variations in AE could be observed. As noted for PFP, monitoring variations in AE through time over a defined land area would provide a means of defining the direction of changes in soil N stocks.

Partial nutrient balance (PNB) and nutrient balance intensity (NBI) both provide direct measures of the potential direction of change in soil N stocks by quantifying the difference between N supply and removal in harvested products. PNB values >1 imply a mining of the soil N stocks, while values <1 imply an enhancement. Where significant quantities of applied N are lost (e.g. through volatilisation of ammonia in response to an application of urea to a wet soil surface), a value of PNB <1 could be calculated, but would not provide a true indication of the net effect on soil N stocks. Additionally, because PNB is calculated as a ratio, it does not provide an indication of magnitude of potential changes (removals or additions). Calculating the value of NBI will quantify the magnitude of the change in soil N stocks. However, as for PNB, the ability of NBI to reflect actual changes in soil N stocks depends on the ability of the soil/crop system to retain supplied N.

When comparing indicator values across different studies it is important to consider the consistency in how the calculations were performed (what terms were included), whether they were applied to single crops or rotations and the area over which values have been integrated. All calculations in Table 1 are generally performed annually on the basis of fertiliser N being the source of nutrient addition and applied to single paddocks. Excluding N inputs from biological fixation, and manure applications, Norton et al (2015) obtained a PNB value of 1.10 for wheat. This suggests that when cereal crops are considered on their own, outside of crop rotations including legumes, a net removal of N has occurred. It is also likely that this net removal is a conservative estimate of the actual reduction in soil N stocks given that N removals due to leaching, volatilisation, denitrification and erosion were not included.

To provide guidance to Australian grain producing growers, values of PNB and NBI at farm or paddock scale should be performed and integrated over multiple years to account for crop rotations and variations in environmental conditions and yield. Norton (2016) examined data from 514 paddocks from 125 farms across four grain growing regions in south-eastern Australia and calculated PNB and NBI values for N over a period of 4-5 years. For this assessment, inputs from biological N fixation were estimated and included with fertiliser nutrient applications (Table 2). Although the magnitude of regional averages of PNB and NBI varied, the indices indicated an average net removal of N (PNB >1 and NBI<0). These results likely represent a conservative estimate of the real change in soil N stocks because losses due to leaching, ammonia volatilisation, denitrification and erosion were not included. The variability in NBI across paddocks and years was large and as yields increased there was a greater probability of obtaining a negative NBI.

Table 2. Values of PNB and NBI for N derived by Norton (2016) over a 4-5 year time frame for paddocks from the grain growing regions of south-eastern Australia. Values are provided as the mean±standard error of the mean.

Grain growing region	Nitrogen PNB	NBI
High rainfall zone	1.55±0.10	-13.1±2.0
Mallee	2.09±0.17	-9.5±1.2
Southern NSW	1.20±0.07	-4.1±2.9
Wimmera	1.21±0.11	-2.3±3.1

Each farm, and indeed each paddock, will experience different annual inputs, extractions and losses of N as a function of variations in applied management practices, soil properties and environmental conditions. It is important for grain growers to complete net N balance calculations (Equation[3]) for their own production systems to define how soil N stocks are changing. Although a trend to increasing N stocks is encouraged, it should be acknowledged that temporary periods of mining N stocks are acceptable, provided the extent of N mining is quantified and followed by a rebuilding phase in which N stocks are replenished. It is recommended that annual N balance calculations be performed; however, the values should be integrated and accumulated over time to define the full effect of applied management practices and temporal trends. Such information will allow grain growers to implement appropriate actions to maintain their production base into the future and continue to maximise profitable grain yield outcomes.

Factors that influence soil N supply capacity

A range of factors (environmental, soil and applied management) all interact to influence the ability of a soil to mineralise organic N and make it available to crops. Although many studies have attempted to quantify the impacts of particular factors, this is difficult given the strong interactions that exist. For example, it is difficult to define the impact of crop residue composition on N mineralisation without considering the impact of temperature and soil water content. However, it is possible to make broad comments in some instances. Across a range of soil textures it has been demonstrated that the production and retention of available N increases, goes through a maximum and then declines with increasing soil water content. It has also been shown that mineralisation and the production of available N will increase with increasing temperature. However it is also known that these two factors will

$$\text{N balance} = (N_F + N_{OA} + N_{dfa} + N_{dep}) - (N_R + N_L + N_V + N_{Den} + N_E)$$

Equation[3]

N_F= N added to the soil in the form of chemical fertilisers.

N_{OA}= N added to the soil in the form of organic amendments (e.g. manure, composts, etc.).

N_{dfa}= N derived from atmospheric N2 by symbiotic and non-symbiotic fixation.

N_{dep}= N deposition from the atmosphere.

N_R= N removed in harvested products.

N_L= leached from the root zone.

N_V= volatilised as ammonia from fertilisers and soils.

N_{Den}= N lost as N_2 and N_2O by denitrification.

N_E= N lost by erosion.

be interactive in their impact in field situations. It is proposed that variables inclusive of both terms (e.g. microbially active degree days) may provide a better integrator of environmental impacts on the delivery of available N from soil.

For soil properties, the content and composition of organic matter, soil texture, soil depth and soil biology have all been identified as factors that can alter the amount of nutrient mineralised. Organic matter is a diverse mixture of different components with varying C:N ratios and biochemical composition. Recent developments in the fractionation of soil organic matter into particulate, humus and resistant forms have found that these materials vary in C:N ratio and their contents of labile carbon. As a result, it is likely that at least a portion of the differences in delivery of available N to crops can be ascribed to compositional differences in soil organic matter (i.e. variations in the allocation of soil carbon to the particulate, humus and resistant fractions). Soil texture influences mineralisation directly and indirectly. With increasing clay content a greater surface area is available to adsorb and protect organic matter from decomposition resulting in a decline in the proportion of organic N that mineralises over time. The indirect impact of texture manifests through its impact on soil water — soils with higher clay contents retain more water than those with low clay contents and thus alter decomposition rates. Most nutrient mineralisation has been found to occur in the surface soil layers where concentrations of organic matter are greatest. However, nutrient mineralisation can occur at depth particularly where significant quantities of carbon exist (e.g. Vertosols or even in the rhizosphere component of low organic carbon soil). For mineralisation to occur it is also essential that a viable and active decomposer community exists including both microorganisms and soil fauna.

Agricultural management practices influence nutrient mineralisation principally through their impact on the quantity, composition and handling of crop and pasture residues. The quantities of residue returned to or onto the soil will vary substantially across the Australian grain growing region in response to species selection, soil type and environmental conditions. Species selection (e.g. legumes versus cereals) will also have a strong impact on the composition of the residues. Where large inputs of cereal residues with low nutrient content are returned, initial net immobilisations of nutrients are likely. Such removal is not permanent, but rather represents a conversion to a form that will be made available later as decomposition continues. Where legume residues are returned, mineralisation of nitrogen will likely be enhanced; however, as the N harvest index of grain legumes increases the amount of N returned in the residue and potentially made available will decline. An additional factor that has perhaps received less attention than required is the implication of the degree to which the residue is incorporated into the soil. With the movement towards less tillage, a greater proportion of crop and pasture residues are being retained on the soil surface. The impact of this on the relative amount of residue derived and soil derived organic carbon respired to CO_2 and the fate of residual nutrients requires further assessment. All root residue residues are returned to the soil, but significant uncertainty remains in how much organic matter is added below ground in the form of root structures and exudates and what the nutrient content of this material is.

The amount of nutrient mineralisation, particularly for N, that occurs over the non-crop period has typically been assessed through the collection and analysis of soil cores prior to sowing a crop. Significant stocks of available N can be found in soils at this time (>200kg N/ha) with the stocks generally being higher after canola, grain legumes and pastures than after cereals. When collecting samples for this assessment, it is important to ensure that the depth of sampling coincides with the effective rooting depth of the crop being sown.

Conclusion

Soil derived N is a limited resource. It can make significant contributions to the amount of N seen by a crop. As the capacity of a soil to deliver available N to crops declines, a greater reliance on fertiliser N will occur. As fertiliser N rates increase, the potential for N loss increases and typically leads to reduced fertiliser N use efficiency. As a result, with decreasing soil N supply capacity, optimised productivity (where marginal benefit=marginal cost) may move to lower yields.

Completing N balance calculations is essential for grain growers to gain an understanding of how their management practices are altering the stock of N present in their soils. N balance calculations should be completed annually, but integrated over time. Where negative N balances are obtained, the soil N resource is being mined. Under such circumstances, it is important to consider whether future long term (decadal) productivity and potential profit is being eroded to maximise short term (annual) values.

It is acknowledged that short term negative N balances are acceptable if a subsequent rebuilding phase is implemented. A range of management practices including stubble retention, grain and pasture legume production, green manuring, application of appropriate quantities of fertiliser N and application of organic amendments have the potential to rebuild soil organic N stocks.

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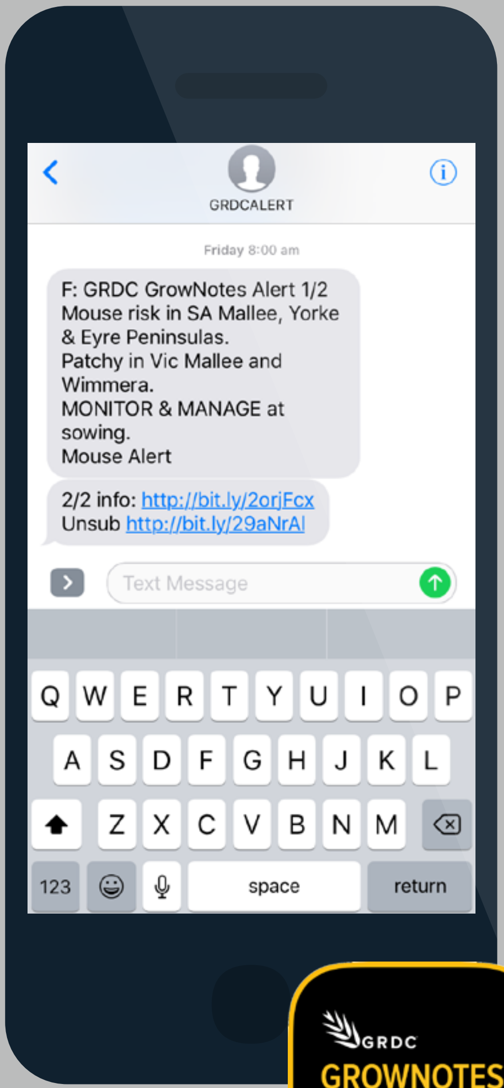

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GRDC GROWNOTES ALERT

Riverine Plains Inc research update

Cassandra Schefe.

Riverine Plains Inc.

GRDC project code: RPI0009

Keywords

- nitrogen, stubble, incorporation, frost.

Take home messages

- Riverine Plains Inc conducts a range of research activities, with investment from GRDC and other partners to provide local information to members.
- Large farm scale trials provide grower-relevant information.
- Decisions about stubble management require consideration of the whole system across a range of seasonal conditions.
- Stubble management can manipulate crop development.

Background

Riverine Plains Inc is a progressive grower group dedicated to improving the productivity of broadacre farming systems in north-east Victoria (VIC) and southern New South Wales (NSW). The group provides relevant and unbiased research and information to its members and acts as a conduit for information flow from credible research sources to its membership.

During 2017, Riverine Plains Inc contributed to a range of research projects, however this report will focus on the 'Maintaining profitable farming systems with retained stubble in the Riverine Plains region' project and a subset of work within this project focused on frost risk in stubble retained systems.

Results and discussion

The GRDC Stubble Project

The Stubble Project, 'Maintaining profitable farming systems with retained stubble in the Riverine Plains region' is funded by GRDC as part of a National Initiative (RPI0009) and conducted in partnership with the Foundation for Arable Research (FAR) Australia. It is looking at ways to improve and maintain profit and sustainability in stubble retention cropping systems across the region. Four large, commercial scale field trials ('Focus Farms') have been established across the region, which are comparing different stubble management practices and plant establishment, growth and yield (Table 1). Smaller trials are also evaluating the importance of timing of nitrogen (N) application, plant growth regulators, row spacing and variety selection in optimising production in stubble retained systems.

Comparative yields across seasons

The large plot field trials are always placed into a cereal stubble. Therefore, the sites do not continue in the same location every year, but are placed in different paddocks every year to maintain the same rotation position, with the trial crop being sown into wheat stubble. While the trial results cannot be directly compared across seasons (2014 to 2017), the effect of different stubble management techniques can be reviewed across years to determine if any single approach appears to consistently yield better (Tables 2 to 5).

Table 1. Different stubble management strategies for focus farms as part of the 'Maintaining profitable farming systems with retained stubble in the Riverine Plains region' project.

Henty (2014 to 2016)	Dookie (2014 to 2017)
- No till stubble retained (NTSR)	- Long stubble (NTSR)
- NTSR + 40kg N /ha at sowing	- Short stubble (NTSR)
- Mulched	- Cultivate (1 pass)
- Mulched + 40kg N/ha at sowing	- Remove straw
- Cultivate	- Burn
- Cultivate + 40kg N/ha at sowing	
Yarrawonga (2014 to 2017)	**Coreen/Corowa (2014 to 2017)**
- Long stubble (NTSR)	- NTSR
- Long stubble (NTSR) + 40kg N /ha at sowing	- Cultivate (1 pass)
- Short stubble (NTSR)	- Cultivate (1 pass) + 40kg N/ha
- Remove straw	- Burn
- Cultivate (1 pass)	- Faba bean (forage)
- Cultivate (1 pass) + 40kg N/ha	- Faba bean (grain)
- Burn	

Table 2. Comparative yields and protein contents for large plot field trials located at Coreen/Corowa over the 2014 to 2017 seasons.

Treatment	2014 Wheat Yield (t/ha)	2015 Wheat yield (t/ha)	2016 Barley yield (t/ha)	2017 to 2017 Wheat yield (t/ha)	2017 to 2017 Protein (%)
NTSR	3.17 a	4.33 a	5.24 a	4.00 a	9.5 b
Cultivated	3.18 a	4.18 a	5.10 a	3.57 b	10.7 a
Cultivated + 40kg N/ha	3.31 a	4.69 a	5.54 a	3.55 b	10.7 a
Burnt	3.10 a	3.95 a	4.81 a	3.75 ab	10.6 a
Grand Mean	**3.19**	**4.286**	**5.17**	**3.72**	**10.35**
LSD	0.53	0.808	1.01	0.286	0.86

Table 3. Comparative yields and protein contents for large plot field trials located at Yarrawonga over the 2014 to 2017 seasons.

Treatment	2014 Wheat Yield (t/ha)	2015 Wheat yield (t/ha)	2016 Wheat yield (t/ha)	2017 Wheat yield (t/ha)	2017 Protein (%)
Long stubble	4.43 a	3.13 a	5.86 bc	3.39 b	11.9 a
Long stubble + 40kg N/ha	4.18 a	3.20 a	6.19 ab	3.52 b	11.6 a
Short stubble		3.35 a	5.81 bc	3.38 b	11.5 a
Straw removed	4.53 a	3.03 a	5.60 c	3.65 ab	11.3 ab
Cultivated	4.54 a	3.10 a	5.90 bc	3.14 b	11.3 ab
Cultivate + 40kg N/ha	4.30 a	3.05 a	6.69 a	3.56 ab	11.4 a
Burnt	4.43 a	2.93 a	6.12 abc	4.08 a	10.7 b
Grand Mean	**4.36**	**3.11**	**6.03**	**3.53**	**11.38**
LSD	0.46	0.3	0.58	0.56	0.74

Table 4. Comparative yields and protein contents for large plot field trials located at Dookie over the 2014 to 2017 seasons.

Treatment	2014 Wheat yield (t/ha)	2015 Wheat yield (t/ha)	2016 Wheat yield (t/ha)	2017 Canola yield (t/ha)
Long stubble	4.98 b	2.41 a	5.80 a	3.70 a
Short stubble	5.66 a	2.52 a	5.37 a	3.75 a
Cultivated	5.56 a	2.39 a	5.60 a	3.85 a
Straw removed	5.66 a	2.32 a	6.00 a	3.74 a
Burnt	5.85 a	2.49 a	6.23 a	3.74 a
Grand Mean	**5.54**	**2.42**	**5.80**	**3.76**
LSD	0.45	0.22	1.02	0.16

Table 5. Comparative yields and protein contents for large plot field trials located at Henty over the 2014 to 2016 seasons (discontinued in 2017).

Treatment	2014		2015		2016
	Canola yield (t/ha)	Oil (%)	Canola yield (t/ha)	Oil (%)	Canola yield (t/ha)
NTSR	1.96 c	43.2 a	1.24 a	44.5 a	2.40 a
NTSR + 40kg N/ha	2.35 ab	42.7 a	1.32 a	41 b	2.26 a
Mulched	2.23 abc	43.8 a	1.44 a	43.6 a	2.48 a
Mulched + 40kg N/ha	2.14 bc	42.7 a	1.39 a	43.6 a	2.53 a
Cultivate	2.41 ab	43.7 a	1.43 a	44.3 a	2.80 a
Cultivate + 40kg N/ha	2.54 a	44.2 a	1.35 a	43.7 a	2.72 a
Grand Mean	**2.27**	**43.4**	**1.36**	**43.4**	**2.53**
LSD	0.35	0.45	0.62	1.59	0.72

Summary of yields under different stubble management techniques from 2014 to 2017

Coreen/Corowa: There were no differences in cereal yields due to stubble management techniques in 2014 to 2016. In 2017, the retained stubble treatment resulted in a yield increase compared to all other treatments.

Yarrawonga: In 2016, the addition of 40kg N/ha at sowing resulted in yield increases in both the stubble retained and cultivated treatments, while the burnt treatment increased yield in 2017.

Dookie: The only difference in yield was seen in 2014 when the long stubble incurred a yield penalty compared to all other treatments.

Henty: The mulched treatment with the addition of N at sowing had a higher canola yield in 2014.

Generally, across the past four seasons (2014 to 2017) stubble management has not been a key driver of yield, except for stubble height at Dookie, and addition of N at sowing at Yarrawonga and Henty in 2014. This general lack of effect may be largely due to extreme weather through some of the growing seasons (heat stress in October 2015, waterlogging and high cloud cover in winter and spring 2016), which would have overridden any effects of stubble management on yields.

Key reason for yield differences in 2017

The two key factors driving yields in 2017 were:

1. Lack of rain in spring 2017.
2. Frost damage.

The timing of flowering had a strong impact on the degree to which these two factors influenced final crop yields. Wheat varieties that flowered and filled grain earlier may have done better in the drier spring, which also means they may have been harvested before the harvest rains (e.g. Yarrawonga site, burnt treatment). The frost damage was also dependent upon the flowering date, although the odds were not great this year, due to the high number of frosts.

Therefore, the flowering date is obviously important. We know we can select different varieties with different flowering dates. Can we also use stubble management to manipulate flowering date?

Background — biomass lag with retained stubble

Over the 2014 to 2015 seasons, it was observed that the stubble retained treatments had lower dry matter contents during the earlier growth stages, however by flowering, there was little difference between plants grown in NTSR systems or where the stubble had been burnt or cultivated. The impact of this delay in biomass on the physiological development of the plant was unknown.

Were the plants growing in NTSR systems at the same growth stage, with less biomass, or was there a difference in growth stage? If there was a difference in physiological development of plants in NTSR and burnt or cultivated systems, this could relate to differences in how the crops handle frost and heat stress, based on a shift in the flowering window.

In order to understand if this **biomass lag** was simply a difference in the rate of dry matter accumulation or if it related to differences in growth stage, a series of growth stage assessments were done at the Coreen, Yarrawonga and Dookie sites in the 2016 season to understand what was happening.

At the Yarrawonga site, stubble management did not influence plant growth and development until stem elongation (11 July 2016) at which point all treatments except the tall stubble treatment began stem elongation. The tall stubble treatment took an extra three weeks to move into stem elongation.

The Dookie site showed differences in growth stage from seedling stage, with treatments separating from 27 June 2016. Plants in the burnt treatment were slightly more developed than the other treatment, with this increase largely maintained over the next four weeks. In comparison, while plants in the tall stubble treatment lagged in development from 27 June 2016, and showed minimal development at the next reading on 4 July 2016, by 18 July they had caught up to the short stubble and disced treatments, while the burnt treatment was still slightly ahead.

In comparison, there were no significant differences in growth stage development at the Coreen site, with plants in the stubble standing, disced and burnt treatments all developing at the same rate.

This work demonstrated that stubble management could have an impact on physiological maturity, which means that stubble could change the flowering date. But, what exactly caused this change? Was it the actual physical presence of the stubble, or was it something that changed in the environment in the presence or absence of stubble?

The three factors most likely to influence wheat growth in the presence or absence of stubble were considered to be:

- In-canopy temperature.
- In-crop N supply.
- Light availability to the crop.

These three factors will be discussed in detail in the presentation.

The impact of stubble on canopy temperature

From the start of the Stubble Project, there was a lot of interest from growers about the interaction between retaining stubble and frost risk – were crops more likely to suffer frost damage under retained stubble?

As the large field trial plots used within the Stubble Project are ideal for measuring temperature due to minimal 'edge effects', extra investment from the GRDC enabled three of the field sites to be instrumented for temperature monitoring (in-crop temperature loggers and a weather station next to the field site).

In-crop monitoring of canopy temperatures began in 2015, with field sites again instrumented in 2016 and 2017.

The three sites which were instrumented in 2015, 2016 and 2017 were:

Yarrawonga:

- o Treatments monitored: Long stubble, short stubble, cultivate, burn.
- o In-canopy data loggers at 300mm height, moved to 600mm height in September.
- o In-canopy data loggers at 50mm height above the soil.

Dookie:

- o Treatments monitored: Long stubble, short stubble, cultivate, burn.
- o In-canopy data loggers at 300mm height, moved to 600mm height in September.
- o In-canopy data loggers at 50mm height above the soil.
- o Data loggers buried 50mm under the soil surface.

Coreen:

- o Treatments monitored: NTSR, cultivate, burn.
- o In-canopy data loggers at 300mm height, moved to 600mm height in September.
- o In-canopy data loggers at 50mm height above the soil.

Frost damage was detected at the Yarrawonga and Coreen sites (Figures 1 and 3). While some variation can be seen at each temperature threshold, there were no significant differences in duration and intensity of cold experienced by each of the treatments.

The 2017 Dookie site (Figure 2) was located on the side of a hill, with treatments overlain in a randomised block design up the hill. This meant that each replicate of the stubble treatments experienced variation in altitude, which confounded any effects of treatment on in-canopy temperature. This explains the larger variation measured at the Dookie site. Generally, the Dookie site experienced very little time below zero (< 100 hours over the season), compared to the other sites.

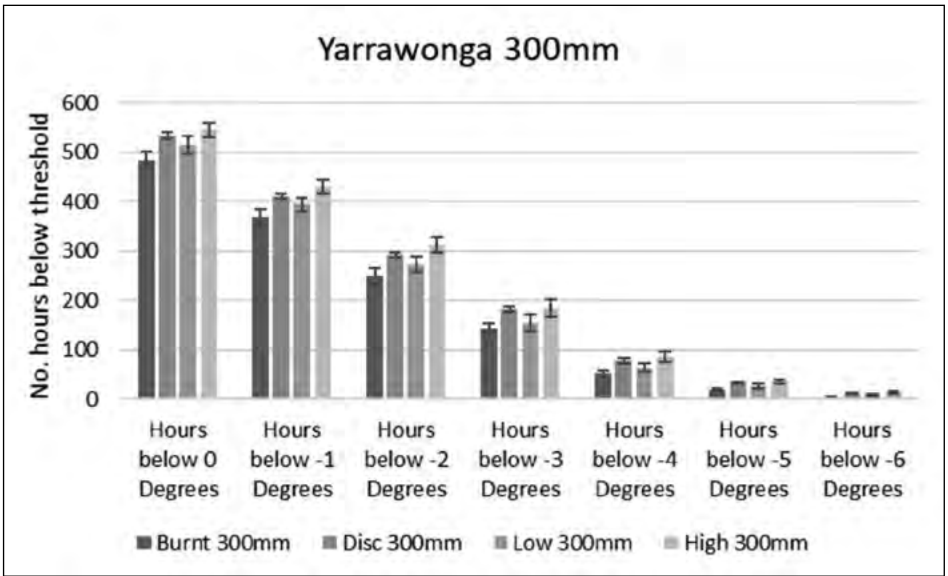

Figure 1. The number of hours that each stubble treatment spent below each temperature threshold at the Yarrawonga site, as monitored at the loggers placed 300mm above the soil surface, which were moved to 600mm height in September 2017. Bars are measures of standard error.

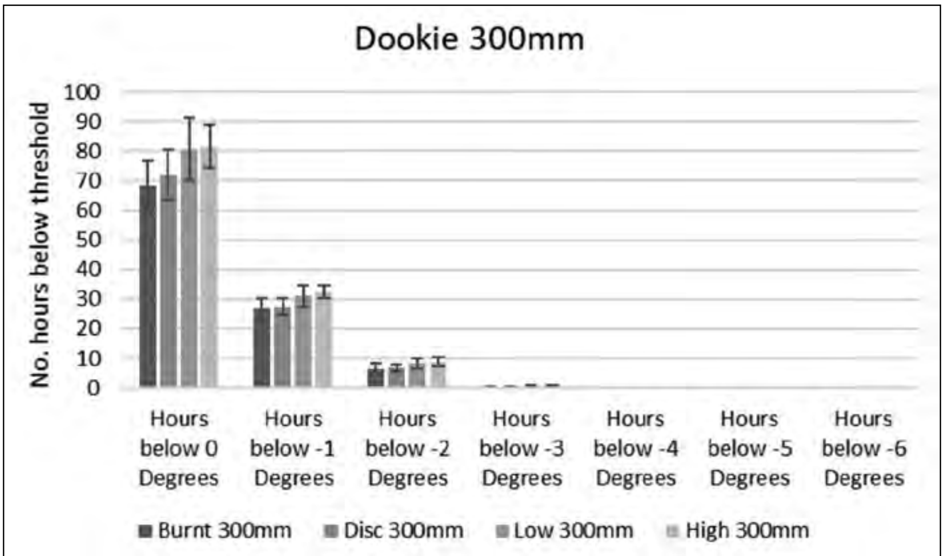

Figure 2. The number of hours that each stubble treatment spent below each temperature threshold at the Dookie site, as monitored at the loggers placed 300mm above the soil surface, which were moved to 600mm height in September 2017 (high canola crop). Note, this site was on a hill and experienced very little frost. Bars are measures of standard error.

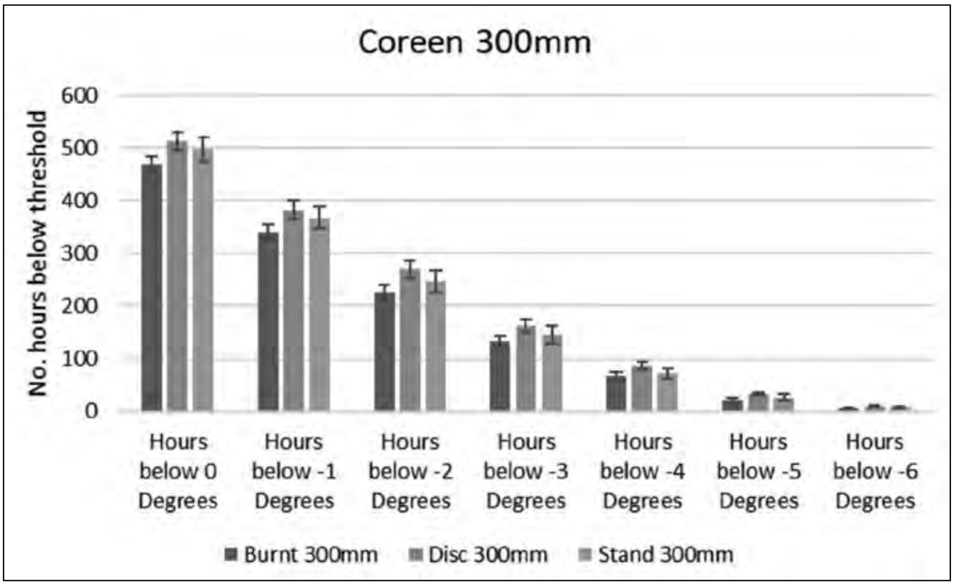

Figure 3. The number of hours that each stubble treatment spent below each temperature threshold at the Coreen site, as monitored at the loggers placed 300mm above the soil surface, which were moved to 600mm height in September 2017. Bars are measures of standard error.

A key point to remember with the data logger readings is that the temperatures recorded within the crop canopy may be up to **5°C** less than that recorded at a weather station. Therefore, when these loggers record temperatures less than zero, the adjacent weather station may still read above zero.

As frost damage tends to occur when the weather station reports temperatures less than zero, it is possible that the crop can withstand slightly negative temperatures (as measured in the crop canopy) without damage.

Considering there were about 500 hours below zero measured at the Yarrawonga and Coreen sites during the 2017 season (2016 had 160 to 270 hrs; 2015 had 230 to 270 hrs), there was only a small amount of variability measured within each treatment (as evident by the small error bars). If the stubble treatments were a large driver for in-canopy temperatures, this should have been clearly seen in the 2017 season. It was not. Therefore, it appears that in very cold winters, stubble management has very little effect on in-canopy temperature. So, changes in in-canopy temperature during the flowering period per se did not drive the difference in frost damage between burnt and stubble retained crops in the 2017 season.

But, we know that stubble management can alter the flowering window. Therefore, it is highly likely that this shift in flowering window is the reason why frost damage differed between stubble retained and burnt paddocks.

Some more detail on how the stubble may alter the flowering window will be discussed in the presentation.

Conclusion

The impact of stubble management has differed according to site and season over the past four years. It is important to view these results within the context of the seasonal conditions. Therefore, the most productive and profitable approach to stubble management may change according to the season (wet start to dry finish, dry start to wet finish, etc.).

While the GRDC Stubble Project will finish in June 2018, Riverine Plains Inc continues to conduct research on behalf of its members into 2018. To broaden the delivery of research to members, Riverine Plains Inc also collaborates with other organisations on a range of research projects, from weed seed management to soil constraints. This supports the ongoing establishment of on-farm trials within the region, ensuring that the results obtained are immediately relevant to local growers.

Acknowledgments

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC — the author would like to thank them for their continued support.

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The National Paddock Survey — what causes the yield gap across Australian paddocks?

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GRDC project code: BWD00025

Keywords

- paddock survey, yield gap.

Take home messages

- The yield gap, or the difference between actual and potential yield in wheat, was 1.1, 1.2 and 1.3t/ha across the Northern, Southern and Western GRDC regions of the Australian grain belt, respectively in 2015 and 2016.
- The cause of this yield gap is variable. No one factor (nitrogen (N), disease, weeds or rainfall) is a cause of the yield gap — it is a combination of factors.
- Growing season rainfall, the previous crop or crop sequence, N application, levels of disease and weeds were all important factors that were associated with the yield gap.

Background

The yield gap is the difference between the actual yield achieved by the grower and the water limited yield potential. The water limited potential is defined as the maximum possible yield able to be grown with the optimal sowing date, current varieties and nutrients, pests, diseases and weeds not limiting yield. It is usually calculated using a crop growth model. Previous studies have shown that well managed commercial crops can reach their potential (van Rees et al. 2014), showing it is not an unattainable or unrealistic yield. A previous study using shire-level data showed that the yield gaps average about 55% across Australia, meaning that the current yields growers are achieving are about half of that which is potentially possible (Hochman et al. 2016). A small yield gap indicates that management is near optimum. A large yield gap implies that crop productivity is constrained by abiotic and/or biotic factors, such as nutrient deficiencies, weeds, diseases and insects.

The potential exists to help growers increase on-farm yields by targeting the key factors that contribute to the yield gap. The yield gap is likely a result of multiple causal factors and due to a number of sub-optimal management activities. Identification of the most important factors will allow growers to prioritise their efforts in improving yield and profit. However, while we have a much clearer idea of the size of the yield gap across the grains industry, there is little quantitative understanding of the abiotic and/or biotic constraints on the yield gap at the individual paddock level.

In this national study, the aim was to determine the size and variation of yield gaps in rainfed wheat and seek to explain the agronomic reason behind the gap. Yield maps and hand-cuts were used to summarise actual crop yield. Crop simulation models such as the Agricultural Production Systems sIMulator (APSIM) (Holzworth, 2014) have been widely used in yield gap analysis (Calviño and

Sadras, 2002; Oliver and Robertson, 2013). The APSIM model was used in this project, combined with surveys of soil properties and agronomic practices, to estimate water limited potential yield.

Method

On-farm data collection

In the Western, Northern and Southern GRDC regions across the Australian grain belt, 250 paddocks were monitored for the growing seasons of 2015 and 2016 (Figure 1). These farms were selected on the basis that they were owned by leading growers and represent the range of prevailing rainfall and soil conditions across the grain belt.

Paddock monitoring protocol

Commercial wheat crops were monitored by collaborating consultants from pre-sowing to harvest at two transects (zones) selected within each paddock.

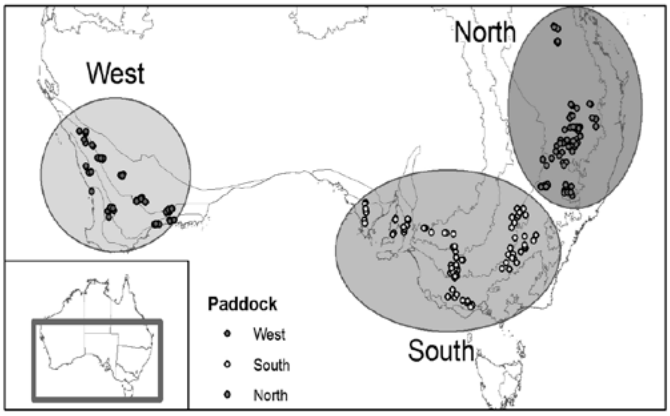

Figure 1. Location of the paddocks surveyed across Australia.

The variation in soil conditions and constraints within a paddock may affect crop performance. To consider such an effect, soil types were identified and soil water and mineral N before sowing were measured in the two selected zones. Cores were subdivided into depth increments to estimate the water and N availability down to a depth of 1m. Agronomic management details included the management of previous crop residues and tillage, variety, sowing date, plant density, and fertiliser management (type, application rate and date). The type and number of weeds, plants damaged by diseases and/or insects and root diseases were monitored at Zadok's growth stage 31 and Zadok's growth stage 65. The disease root health score was assessed as a 0–5 score where 0 = not observed and 5 = severe disease level. At the end of each season, crop yields were measured using a yield monitor attached to a grain harvester. The data collected for each season was reviewed at annual project meetings to allow consultants and researchers to discuss insights and information regarding individual paddock performance.

Simulation of potential yield and yield gap analysis

The difference between the simulated yield and actual yield, as measured by the yield monitor, was defined as the yield gap (Hochman et al. 2016). At the end of each season, water limited potential yields were simulated on both transects within each paddock using the APSIM model (Holzworth, 2014). Agronomic practices on each paddock were recorded (crop type, sowing date, plant density, residue and fertiliser) and used to initialise the model. Soil parameter values for the identified soil types in the surveyed paddocks were sourced from APSoil. Measured soil water and N at sowing were used at the start of the simulation to initialise the model. If initial data were missing, the model was initialised from expert opinion. Weather data were sourced from the nearest Scientific Information of Land Owners (SILO) meteorological stations to each farm. Simulations were run assuming that yield was not limited by N supply, weeds, pests, diseases, frost or heat damage.

Classification and Regression Tree (CART) was used to determine the relative importance of the factors that could influence the size of the yield gap including in-crop agronomic factors (weed densities of identified weed species, levels of disease severity, N fertiliser application) and other factors (region, soil type, previous crop). This analytical approach was chosen because it allows the variables to interact with each other and can identify complex relationships between multiple variables.

Results and discussion

Assessing survey data

When wheat was grown, the dominant previous crop was usually wheat in the Western and Southern regions. Conventional break crops, such as canola, chickpea, sorghum, oats or pasture, were less common. This was not the case in the North (Table 1). Growing season rainfall was highly variable across paddocks within and between regions, and between the 2015 and 2016 seasons (Figure 2a). The growing season rainfall was lowest in the Western region (192mm) and highest in the Southern region (296mm) (Table 1).

The average amount of N fertiliser applied to wheat was 32, 43, 26kg N/ha in the Western, Southern and Northern regions, respectively (Table 1), while it varied greatly among paddocks within each region. The average weed density at Zadok's stage 31 was 10 plants/m2 in both the Western and Southern regions with few paddocks with weeds detected in the Northern region. The incidences of diseases and insects were generally minor in most paddocks across regions and seasons with a trend for the incidences of diseases and insects being higher in the Western region compared to the Southern and Northern regions (Table 1). On average, the root health score was low across all three regions (Table 1), although there were occasional root health problems detected in some surveyed paddocks.

Average dry wheat yields, measured by growers with commercial grain harvesters, were lower in the Western region (2.5t/ha) than the Southern (3.7t/ha) and Northern regions (4.1t/ha).

The magnitude of yield gaps

There was considerable variability in the gap between water limited potential yield and actual farm yield (Figure 2b). For the 2015 and 2016 seasons, the yield gap of wheat ranged from 0 to 4.3t/ha in the Western region, with a mean value of 1.2t/ha (Figure 2a). It varied between 0 to 3.7t/ha in the Southern region and 0 to 5.3t/ha in the Northern region, with average values of 1.3 and 1.1t/ha, respectively. Extremes were statistical outliers (Figure 2a), and could point to problems with data collection or simulation modelling. In general, the size of yield gap was correlated with the size of potential yield and growers are unable to capture the extra yield on offer in the high rainfall zones (Figure 2b). In the Western Region, 46% of wheat paddocks achieved between 80% and 100% of yield potential. In the Southern region, 38% of wheat paddocks fell within this range. In the Northern region, 43% of paddocks fell with 80% to 100% of yield potential. Achieving yield potential is not

Table 1. The average of survey data across the Western, Southern and Northern regions for the growing seasons of 2015 and 2016.

	Western Region	Southern Region	Northern Region
No. of paddocks	78	53	38
Previous crop (%cereal/% break crop)	80/20	62/38	36/64
In-crop rainfall (mm)	192	296	230
Nitrogen supply (kg N/ha)	32	43	26
Weeds (plants/m^2)	10	10	0
Root health score	1.8	1.7	2.2
Disease (% affected plants)	12	4	8
Insect (% affected plants)	11	7	1
Yield (t/ha)	2.5	3.7	4.1

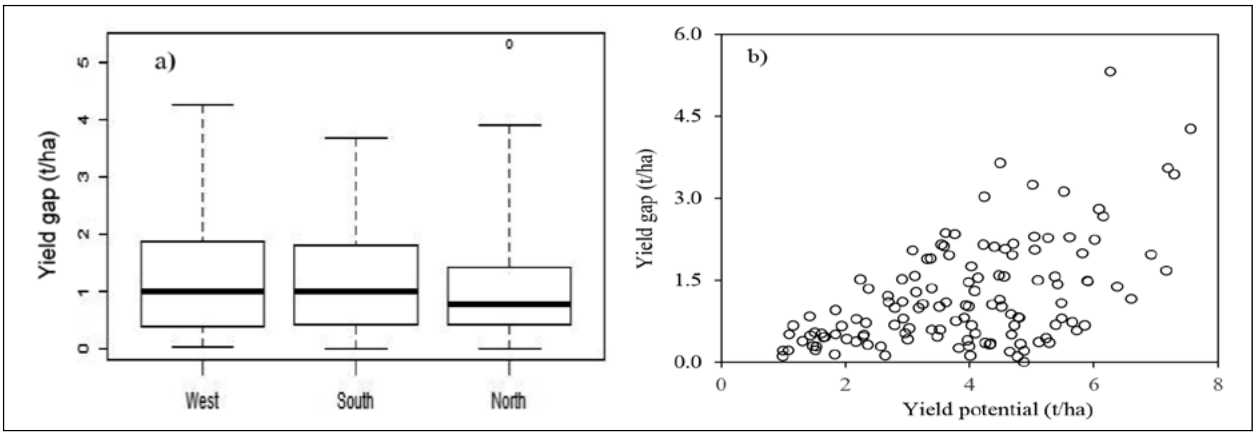

Figure 2. a) Yield gap of dryland wheat at Western, Southern and Northern regions for the seasons of 2015 and 2016. **b)** The relationship between yield gap and yield potential at the three regions for the two growing seasons.

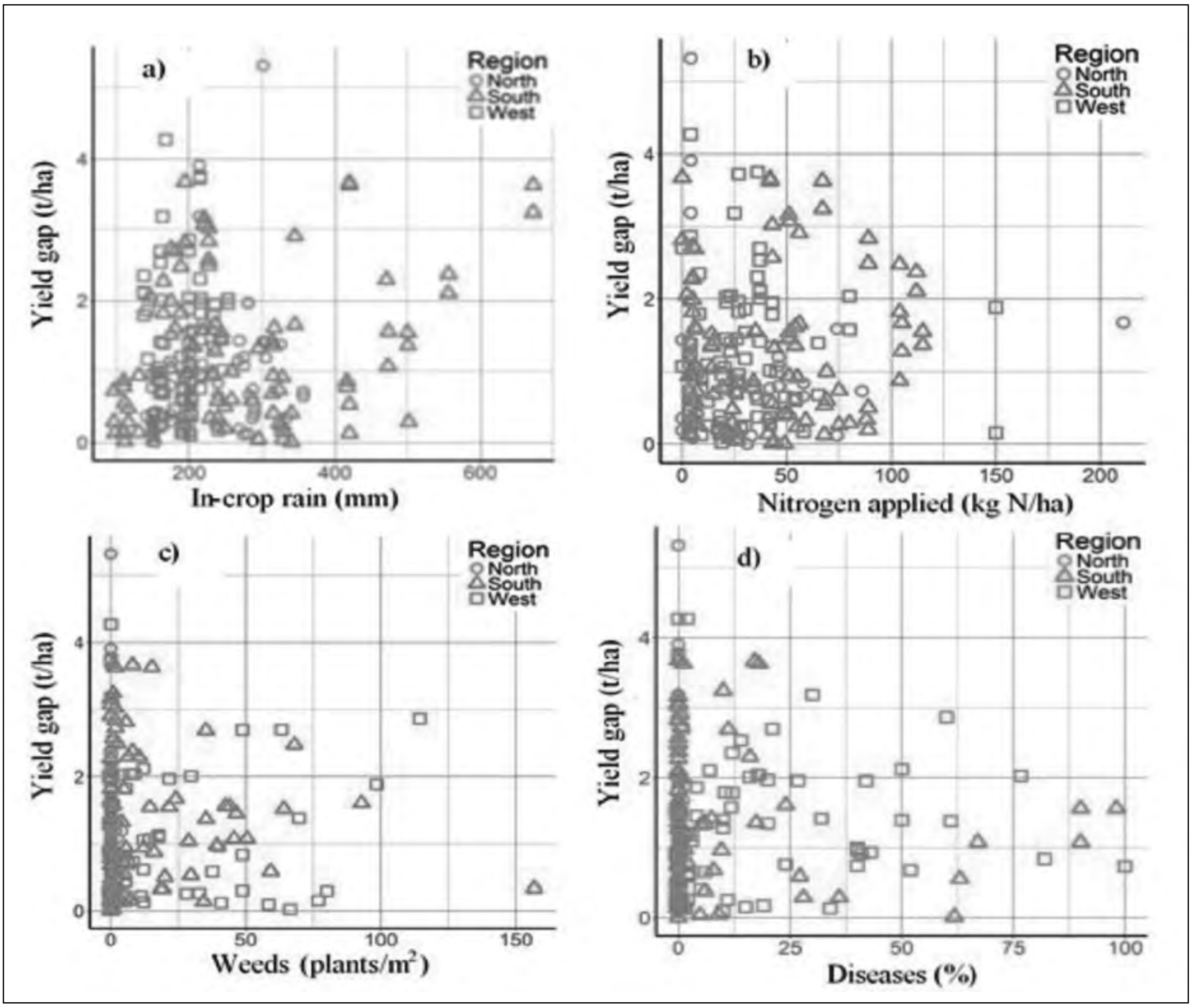

Figure 3. The relationship between wheat yield gap and in-crop rainfall (a), nitrogen applied (b), weeds (c) and disease (% affected plants), (d).

uncommon and demonstrates that yield potential is achievable for a broad range of growers, with paddocks on all soil types and rainfalls.

Factors associated with the yield gap

No significant relationship was observed between yield gap and any single factor (in-crop rainfall, N fertiliser application, weeds, diseases, insects and previous crop) (Figure 3). This suggests that the yield gap was caused by a combination of these effects, or the yield gap was driven by the first limiting constraint (Liebig's law), and a lack of a linear relationship is therefore not surprising. The CART analysis, which copes with such complex data, revealed that growing season rainfall, rate of applied N, the previous crop, disease levels and weed levels all contributed to the size of the yield gap (Table 2).

Table 2. The ranking (importance)* of the variables that contribute to the size of the yield gap across the three regions.

	In-crop rainfall	Nitrogen applied	Previous crop	Weeds	Root score
West	1 (109.8)	2 (17.7)	3 (6.1)	4 (0.8)	
South	4 (8.5)	1 (25.3)	2 (16.4)	5 (4.2)	3 (8.8)
North	1 (87.6)	2 (18.5)	4 (5.3)		3 (5.4)

**The number in brackets refers to an estimate of variable importance, as an absolute measure. It is used to assess the relative power of one variable over another.*

In the Western region, growing season rainfall was the most important variable to explain the yield gap. This was followed by the amount of N and the previous crop, with weeds having a minor influence. It suggests that larger yield gaps occur in the high rainfall zone, possibly because these yields are harder and more risky to achieve. Nitrogen does appear to be limiting the ability of growers to capture these higher yield potentials, while crop rotation is playing a role. Wheat on wheat is still common in the Western region. In the Southern region, the amount of applied N, the previous crop and root health score were the three most important variables. Weeds and growing season rainfall were of minor importance. In the Northern region, growing season rainfall, applied N and root score were the three most important variables. The implication is that N dynamics, growing season rainfall and crop rotation tend to play an important role in explaining the size of the yield gap. The potential to grow a high yielding crop is complicated because of the high N demands. These analyses suggest that in high yielding situations, the N demand of the crop is not being met and growers are under-fertilising in the high rainfall zones of Australia. This decision by growers may be sensible and rational, given the risks associated with targeting high yields.

Conclusion

The GRDC National Paddock Survey is helping to understand the critical drivers of the yield gap across Australia. There is potential to reduce the size of the yield gap with more targeted N management and crop rotation. Importantly though, multiple, interacting factors contribute to the yield gap.

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Pulse rhizobia performance on acid soils

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[Φ]Extra technical comment by Protech Consulting Pty Ltd

GRDC project codes: DAS00128, UA00138

Keywords

- soil acidity, rhizobia, inoculation, nodulation, faba bean, lentil, N_2-fixation.

Take home messages

- Inoculation of faba bean, lentil and field pea with rhizobia (*Rhizobium leguminosarum* bv. *viciae*) is critical on acid soils. Nodulation is improved by increased application rate of inoculation products.
- The lower limit of $pH_{(Ca)}$ for reliable nodulation with the commercial strains of faba bean and field pea rhizobia is 5.0.
- Liming to increase soil pH and increased rates of inoculation should be considered where soil $pH_{(Ca)}$ is below 5.0.
- Several strains of rhizobia with improved acidity tolerance have shown promise in the field on faba bean and broad bean. They are being more widely tested to develop a case for commercial release.
- Contact between rhizobia and incompatible pesticides should be avoided when sowing pulses on acid soils.

Background

Recent expansion of the pulse industry is seeing crops increasingly grown on soils below $pH_{(Ca)}$ 5.5. Faba beans are the pulse of choice in high rainfall acidic soil environments of south eastern Australia, while the high value of lentils is similarly seeing it sown on acidic soils in lower rainfall areas. The impact of acid soils on pulse production is also likely to increase as soils continue to acidify (Helyar et al. 1990), particularly where the sub-surface soil is acidic and difficult to ameliorate with lime.

Faba bean and lentil are recognised as being sensitive to soil acidity. A substantial part of this sensitivity is due to impacts on the symbiosis with reduced levels of nodulation and N_2-fixation reported on acidic soils (Burns et al. 2017). Another signpost of the sensitivity is that the rhizobia (*Rhizobium leguminosarum* bv. *viciae*) that nodulate these pulses (and also field pea and vetch) persist at lower numbers or are often absent in acid soils ($pH_{(Ca)}<6$). Inoculation is therefore recommended with a moderate to high chance of inoculation response on these soils (Drew et al. 2012a, 2012b, Denton et al. 2013).

Two inoculant strains are produced commercially. WSM-1455 (Group F) is produced mainly for faba bean and lentil, but is often also used on field pea. Sulfonylurea (SU)-303 (Group E) is produced for field pea and vetch. In our experience, these two inoculant strains are competent and reliably form nodules when used to inoculate pulses sown into soils above $pH_{(Ca)}$ 5.0, but are constrained below this level.

The performance of strains of rhizobia with improved acidity tolerance and other practices that can be used to improve pulse nodulation and N_2-fixation on acid soils are described in this paper.

Acid tolerant strains of rhizobia

Strains identified that improved nodulation in low pH hydroponic experiments

Hydroponic experiments have been used to determine if strains of rhizobia isolated from acid soils provided any advantage over the commercial inoculant strains at low pH. Plant growth solutions were maintained at pH 4.2, the point where the nodulation of field pea by inoculant strains SU-303 and WSM-1455 had previously been shown to be severely reduced in the test system.

Eleven rhizobia strains, comprising five from the South Australian Research and Development Institute (SARDI) (SRDI strains) and six from Murdoch University (WSM strains selected for field pea, supplied by Dr Ron Yates), were tested for their ability to nodulate Kaspa⁽ᵇ⁾ field peas at low pH.

The strains of rhizobia varied in their ability to form nodules. Inoculant strain WSM-1455 performed better than SU-303. Of the new strains, SRDI-954, SRDI-969, WSM-4643, WSM-4644 and WSM-4645 all nodulated more than 70% of plants. SRDI-969 stood out because it also increased nodule numbers more than six-fold, compared with both commercial inoculant strains (Figure 1).

Performance of rhizobia strains in the field

Rhizobia strains with putative acid tolerance were tested in the field between 2015 and 2017. Strains SRDI-954, SRDI-969, SRDI-970 and WSM-4643 performed best and provided substantial levels of improvement over the commercial inoculants at some sites, as described below.

2015 field trials

Strains SRDI-954 and SRDI-970 were initially provided as peat cultures to Maarten Ryder for testing in a GRDC Regional Cropping Solutions Network (RCSN) project examining a range of treatments to improve broad bean production on Kangaroo Island, SA.

In a small plot trial, both strains of rhizobia significantly increased the nodulation of broad bean compared to the current commercial strain — nodulation ratings were higher and more uniform. In addition, shoot nitrogen (N) and fixed N were almost doubled. In a complementary grower run trial (replicated four times), SRDI-954 again produced more nodules than WSM-1455, increased grain yield by 8% and the amount of N fixed by more than 40kg/ha. In these short term trials, the new rhizobia strains were more effective at improving nodulation than other agronomic treatments that included the addition of prilled lime (data not shown).

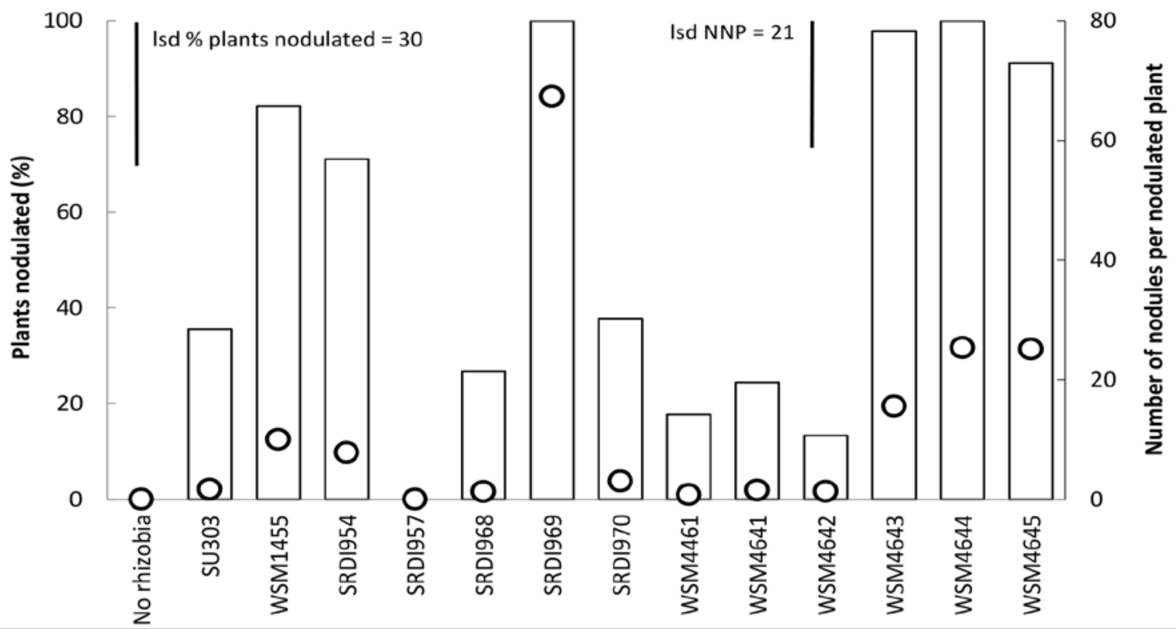

Figure 1. Effect of inoculation treatment on the percentage of Kaspa⁽ᵇ⁾ field pea seedlings forming nodules (left axis, columns) and the number of nodules per nodulated plant (NNP) (right axis, circles) at 20 days after inoculation.

2016 field trials

Following the promising results in 2015, the cohort of rhizobia strains was expanded and tested at another three locations in 2016 (Kangaroo Island, SA, Wanilla, SA, and Ballyrogan, VIC). Strains were applied at approximately four times the recommended rate, a strategy that we now believe probably moderated the extent of differences between the commercial inoculant and new strains of rhizobia (discussed later in section on inoculation rate).

The field sites were below pH$_{(Ca)}$ 5.0 (4.8, 4.9 and 4.6) and responsive to inoculation, due to the absence of naturalised rhizobia. Mean nodulation across the three sites was increased five-fold by the commercial inoculant strain (Table 1). Again, strain SRDI-954 significantly increased faba bean nodulation (+64%) on Kangaroo Island and averaged 124% across the three sites. Some strains did less well (e.g. WSM-4645).

N_2-fixation was significantly improved by inoculation, but was not further improved by the new strains of rhizobia (strain SRDI-969 ranked highest at 107%). On these acid soils, the best nodulated beans fixed approx. 150kg N/ha (not including roots).

Mean (three sites) grain yield with the commercial inoculant was 3.74t/ha and 3.93t/ha (105%) for strains SRDI-969 and WSM-4643, but the values were not significantly different (5% LSD). The grain yield result for WSM-4643 was largely driven by its good performance at one site.

Over the three measures (nodulation, grain yield and N_2-fixation), strains SRDI-954 and SRDI-969 were calculated to be 108% compared to the E/F inoculant. Strain SRDI-969 delivered the most consistent benefit (113%, 107% and 105%). Strain WSM-4645 was 69% of the E/F inoculant.

Two plant bioassays assessed the persistence of rhizobial strains in the soil. Soils were collected in the summer (2017) following the trials and used to inoculate plants growing in rhizobia-free media in the greenhouse. None of the rhizobial strains had persisted in the soil at a level substantially above the control treatments, meaning re-inoculation will be necessary even if the acid tolerant strains are used. The result also indicates there is still an opportunity for improvement beyond what is offered by the strains currently being evaluated.

Further evaluation of the strains was undertaken in 2017 and included a comparison of strain performance at a standard inoculation rate.

2017 field trials

Three trials were sown in 2017, comprising two faba beans and one lentil trial.

With faba bean at Wanilla (Eyre Peninsula, SA), rhizobia strains SRDI-954 and SRDI-969 outperformed WSM-1455 for both nodulation and grain yield, when applied to seed as a peat slurry at the standard rate of inoculation (Fig. 2). This site remained dry for four weeks after sowing, adding an additional stress on the rhizobia.

Nodulation results from a second faba bean trial sown at Chatsworth in VIC and a lentil trial near Griffith in southern NSW are shown in Table 2. It is the first time the new strains have been examined on lentil and demonstrates they competently nodulate that species. Growing conditions (waterlogging at Chatsworth, severe frost and below average rainfall at Griffith) were more limiting to grain yield than N2-fixation at both sites. There were no significant differences in grain yield.

Table 1. Mean data for nodulation, N^2-fixation and grain yield across three sites expressed a percentage of the commercial E or F inoculant strain.

	Nodulation % commercial inoculant	N_2-fixation % commercial inoculant	Grain yield % commercial inoculant
No rhizobia	20	47	50
Control (E or F inoculant)	100	100	100
SRDI-954	124	100	102
SRDI-969	113	107	105
SRDI-970	111	102	103
WSM-4643	99	93	105
WSM-4644	83	74	91

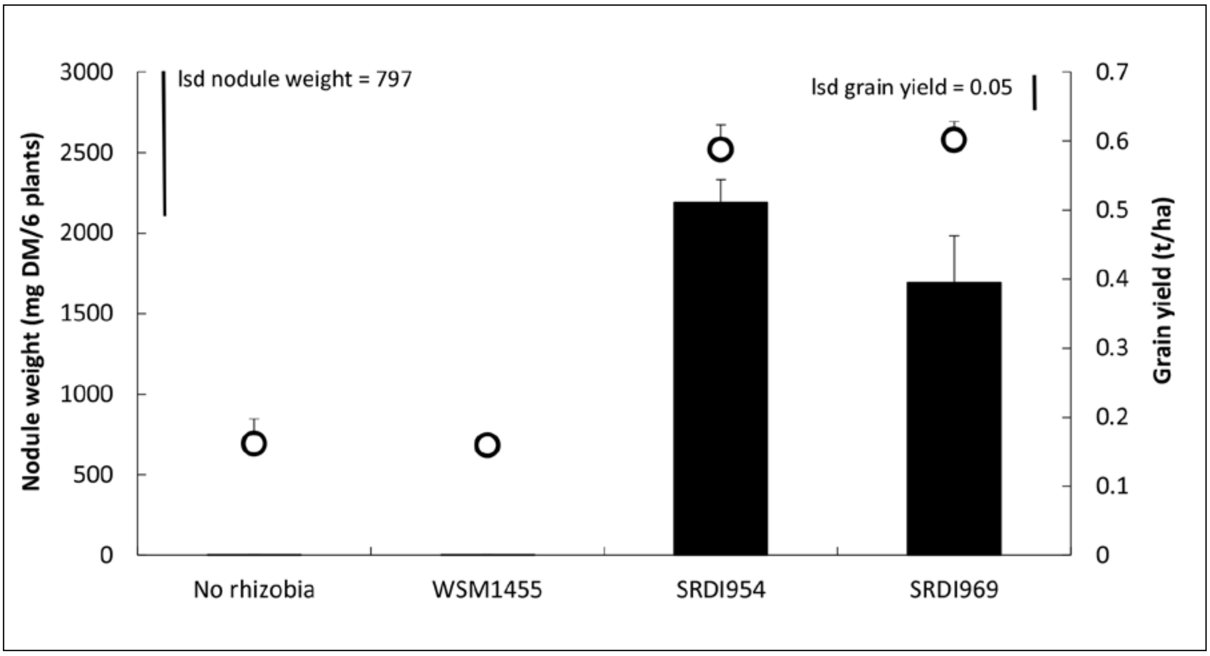

Figure 2. Effect of rhizobia strain on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᶦ⁾ faba bean at Wanilla, Eyre Peninsula, SA in 2017. Site pH($_{Ca}$) = 4.3, sown into dry soil 28 April. Standard rate of inoculation. Standard error of means shown as bars above columns and circles.

Overall field performance

The field results highlight the importance of good nodulation to establishing viable faba bean, lentil and field pea crops on very acid soils. Strain SRDI-954 improved nodulation over WSM-1455 at five sites and was equal at three sites where it has been tested. Strains SRDI-969, SRDI-970 and WSM-4643 improved nodulation at about a third of the sites where they have been tested. Further evaluation of the strains is planned for 2018, with increased emphasis on lentil.

\The WSM strains are primarily being developed for field pea on acid soils (Ron Yates, DAFWA). Based on our assessment of those strains, WSM-4643 is preferred for the pea inoculant because it was by far the most effective of the WSM strains on faba bean.

A new strain for faba bean (and possibly lentil) could be commercially available in 2022, subject to further work being completed to satisfy the criteria required for the replacement of a major inoculant strain.

Inoculation rate

Increasing the rate of inoculation has been shown to improve the nodulation and grain yield of faba bean in an acidic soil. Doubling the rate of inoculant applied as a peat slurry increased nodulation by 52% and grain yield by 41%, despite it being limited by seasonal conditions (Fig. 3). WSM-1455 only

Table 2. Effect of strain of rhizobia on the nodulation of faba bean and lentil.

	Chatsworth, VIC PBA Zahra⁽ᶦ⁾ faba bean pH($_{Ca}$) 4.7	Griffith, NSW PBA Ace⁽ᶦ⁾ lentils pH($_{Ca}$) 4.9
	Nodulation Score (0 to 5)	Nodulation nodules/plant
No rhizobia	0.50	1
WSM-1455 Gp F @ std rate	0.83	21
WSM-1455 Gp F @ double rate	1.15	32
SRDI-954	1.48	40*
SRDI-969	1.42	39*
SRDI-970	2.28*	Not tested
WSM-4643	2.15*	44*
Least significant difference (5%)	0.84	15

** Significantly different from WSM-1455 applied at standard rate*

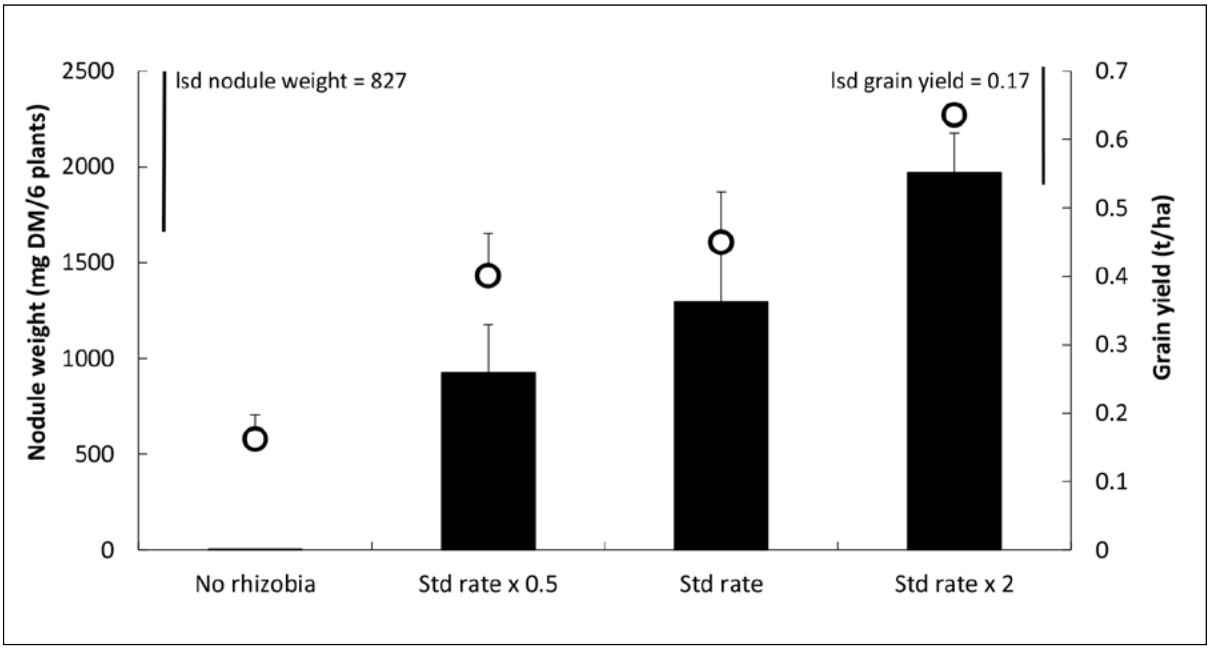

Figure 3. Effect of inoculation rate on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᴰ faba beans at Wanilla, Eyre Peninsula, SA, in 2017. Site pH$_{(Ca)}$ = 4.3, sown into dry soil 28 April. Values are the mean of three rhizobia strains (WSM-1455, SRDI-954 and SRDI-969). No-rhizobia treatment excluded from statistical analysis. Standard error of means shown as bars above columns and circles.

produced an acceptable level of nodulation at double the standard rate (data not shown).

Better nodulation in response to increased inoculation rate is commonly reported (Denton et al. 2013, Roughley et al. 1993) and provides a practical way of improving nodulation where pulses are sown for the first time, especially on hostile soils. However, a note of caution; growers have provided feedback that seeder blockages have resulted when they have increased the inoculation rate, so testing a small test batch of seed first to avoid such problems is suggested.

Pesticides

Particular care needs to be taken where rhizobia are applied with pesticides on seed, especially where it is to be sown into acidic soils. Rhizobia are best applied last and as close as possible to sowing. Within six hours is commonly recommended by inoculant manufacturers. The impacts of seed applied pesticides on rhizobia is often masked where there are naturalised rhizobia present in the soil, but are more likely to be seen on acid soils where there are no rhizobia. An example of such an impact is shown in Figure 4. The treatment of faba bean seed with Apron® Φ (metalaxyl) or P-Pickle T (PPT) (thiram and thiabendazole) fungicide prior to the application of rhizobia (as a peat slurry to the seed) caused significant reductions in both the amount of N fixed and grain yield. These reductions were the result of fewer rhizobia surviving on the seed and reduced nodulation (data not shown).

ΦApron® is not currently registered on faba bean. This product on faba bean is used for research purposes only. Commercial application of this product must adhere to label requirements.

Where pesticide application is necessary, granular rhizobial inoculant may provide a better option, reducing direct exposure of the rhizobia to the pesticide.

Inoculant formulation

Peat inoculant applied as a slurry to seed is the most common method used by growers and is reported to provide consistent and high levels of nodulation across a broad range of environments (Denton et al. 2009, 2017). This method provided satisfactory nodulation in our studies when used to deliver the acid tolerant strains of rhizobia, although granules on occasion have provided additional benefit. Specifically, nodulation by WSM-1455 was improved on two occasions where Novozymes 'TagTeam®' granules were used (Table 3).

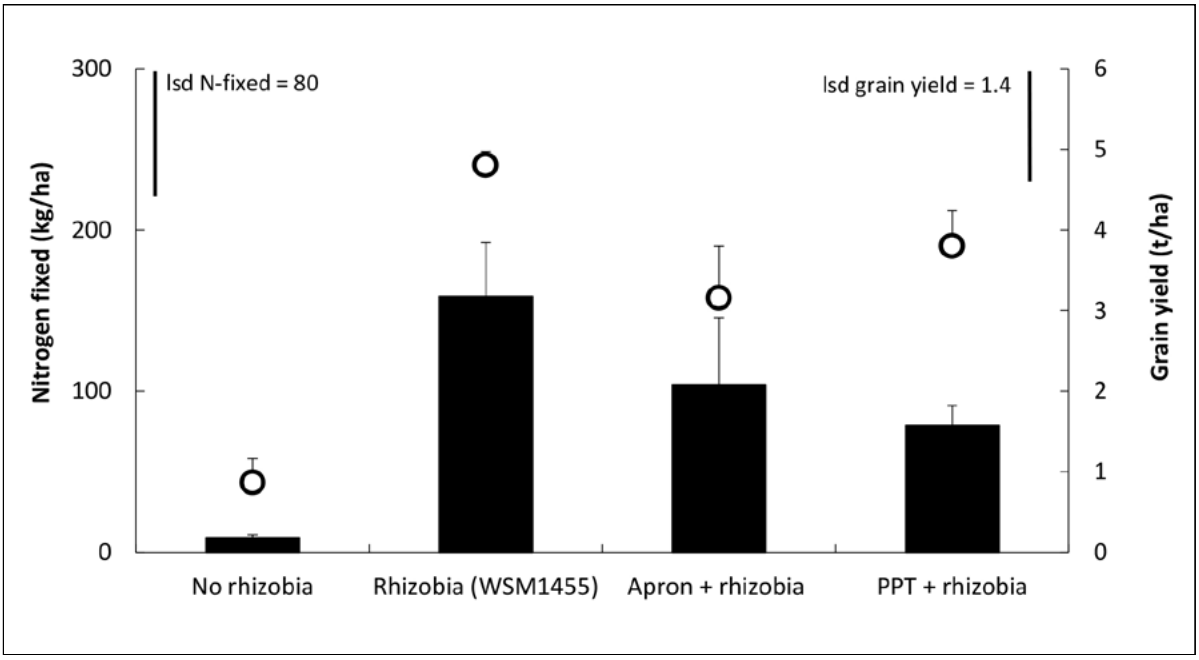

Figure 4. Effect of pesticide application to seed on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⊕ faba beans inoculated with Group F rhizobia (WSM-1455) at Ballyrogan VIC, 2016. Site pH $(_{Ca})$ = 4.6. Standard error of means shown as bars above columns and circles.

Table 3. Effect of inoculant formulation and inoculant strain on the nodulation of PBA KareemaA broad bean on Kangaroo Island, SA (sown after break) and PBA SamiraA faba beans at Wanilla, SA (sown dry). Within a site, values followed by the same letter are not significantly different.

Site	Peat slurry on seed with strain WSM-1455	TagTeam® Granule with strain WSM-1455	Peat slurry on seed with strain SRDI-954
Kangaroo Island, SA (nodule score, 0 to 5)	1.5 a	2.7 ab	3.3 bc
Wanilla, SA (mg nodule dry weight/6 plants)	273 a	1758 b	2190 b

At the dry sown Wanilla site (2017), where the performance of various inoculant formulations containing WSM-1455 was assessed, nodulation was positively correlated with the number of cells delivered by the product (the combination of the rhizobia number in the product and application rate) (Fig. 5).

The result demonstrates that granules can work in an acidic soil, but in step with the efficacy of inoculants more generally, their performance is likely to be dependent upon the number of rhizobia they deliver. Granules provide the possibility of being able to separate the rhizobia from seed applied pesticides and fertilisers which is desirable, and so the delivery of the improved rhizobia strains in a 'high count' granule may provide opportunity for further improvement.

Liming

The development of new rhizobia strains should not be seen as a replacement for liming. Even with good inoculation practice on acid soils, nodulation can remain below potential and rhizobial colonisation of the soil is limited, so the addition of lime is still needed. Liming to raise soil pH above pH$(_{Ca})$ 5.0 also corrects nutritional deficiencies and toxicities that more broadly limit crop performance.

Further, since nitrate leaching after pulse growth is a significant contributor to soil acidification, liming is important to counter this and prevent further acidification.

Improved rhizobia will still be of benefit where soils are limed, especially where there are acidic sub-surface soil layers that are difficult to remediate due to the slow movement of lime down the profile.

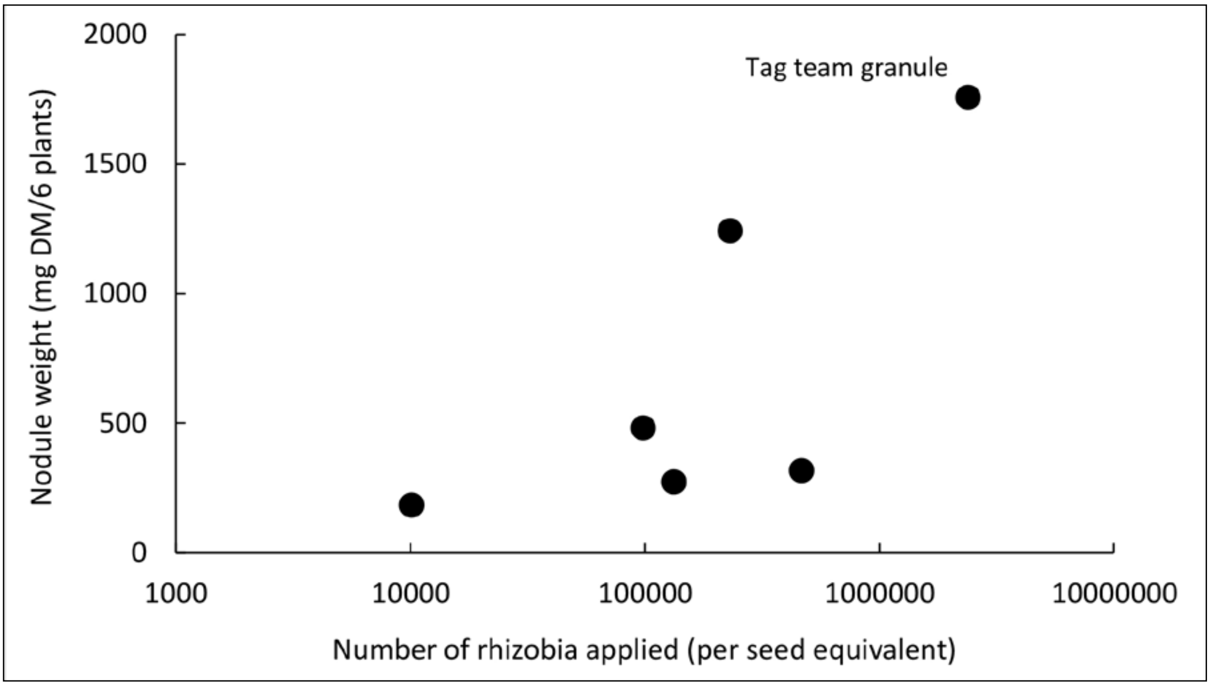

Figure 5. Relationship between number of rhizobia delivered at sowing by different inoculant formulations of rhizobia and the nodulation of PBA Samira⊕ faba beans sown at Wanilla, Eyre Peninsula, SA in 2017.

Discussion

There are reasonable prospects that a strain of rhizobia with improved acid tolerance can be selected for faba beans which are being grown on some very acid soils. An improved strain would also have the potential to be used on lentils which are in the same inoculation group. Improved acid tolerance of the rhizobia strains for faba beans and lentils may provide the potential to expand these crops into new environments and improve their performance in existing acid soil areas.

Where a rhizobia strain with improved acidity tolerance is combined with good inoculation practice, it should be possible to remove symbiotic constraints to faba bean production between $pH_{(Ca)}$ 4.5 and 5.0. The lower pH limit for lentils needs to be clarified, but they are generally regarded as more sensitive than faba beans. None of the rhizobia strains tested thus far appear to be able to persist in soil below $pH_{(Ca)}$ 5.0, therefore re-inoculation will be essential each time the crop is grown.

Until a new strain is available, growers should consider increasing their inoculation rate and avoid exposing the rhizobia to pesticides, where it is practical to do so.

Improved rhizobia should be seen as an accompaniment, not a replacement for liming. Liming remains important to prevent further acidification and is therefore critical to the longer term sustainability of the farming system. Surface soil (0-10cm) should be limed to at least $pH_{(Ca)}$ 5.0, noting that a higher target may be needed to achieve adequate amelioration where acidity is prevalent below the soil surface.

Further testing is needed and planned to satisfy the criteria for a rhizobia strain replacement, with a view to replacing WSM-1455 in 2022.

Useful resources

Inoculating Legumes: A Practical Guide:

https://grdc.com.au/resources-and-publications/all-publications/bookshop/2015/07/inoculating-legumes

Soil Acidity:

http://www.agbureau.com.au/projects/soil_acidity/

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WSM strains were provided by Dr Ron Yates, Department of Primary Industries and Regional Development.

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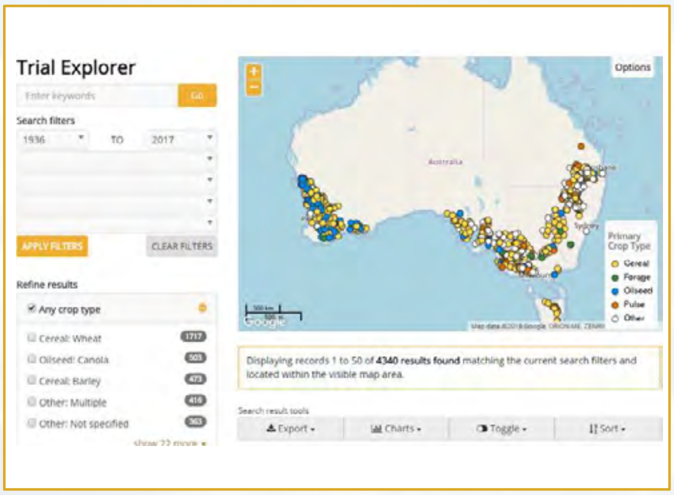

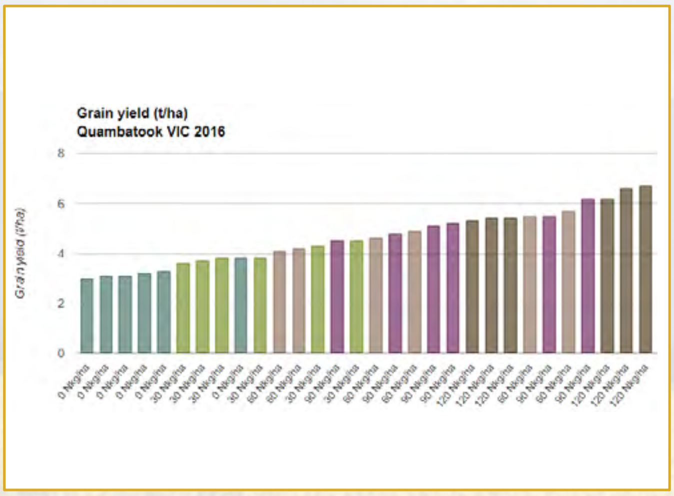

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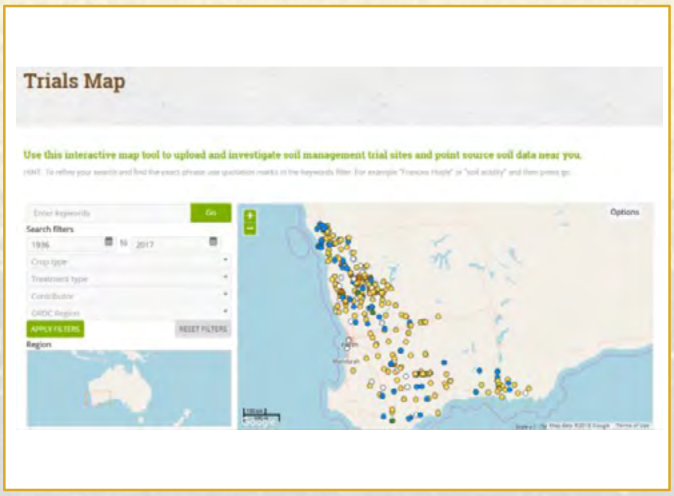

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Simplifying methods to determine plant available water capacity of variable soils in Australian dryland grain production

John Stevenson.

Warakirri Cropping.

Keywords

- plant available water capacity (PAWC), soils, remote sensing.

Take home messages

- Australian grain growers lead the world in their ability to produce crops in climatically restrictive environments.
- An efficient method to quantify plant available water will add value to current precision agriculture (PA) techniques by allowing growers to match production inputs and expectations with reality.
- The Internet Of Things (IOT) in agriculture has the potential to revolutionise a grower's ability to manage within their environment at an efficient cost.

Background

I manage a dryland grain growing property for the Warakirri Cropping business around the Lockhart Shire in the New South Wales (NSW) Riverina region. Warakirri Cropping operates a portfolio of 10 properties, owned by the Australian REST Superannuation business, throughout the Australian wheatbelt from Dalby in Queensland (QLD) to Merredin in Western Australia (WA).

The 8700 hectare 'Orange Park' aggregation is 93% arable and the crops grown include canola, wheat, barley, pulses and oaten hay. Soils range from iron rich, quartz red loams through to sodic red clays to heavy black self-mulching Vertosols. There are three full time staff on property and a mixture of owned equipment and contract support is used to ensure timeliness of operations. We are progressively adapting our systems to a controlled traffic farming (CTF) platform which will be on a 12/18/36m system for harvest/seeding/spraying and spreading using 3m wheel centres.

Nuffield Scholarship

Personally, and also as a business, we had a desire to better understand the plant available water capacity (PAWC) of our variable soils. Existing methods for soil characterisation were slow, expensive and site and crop specific. I wanted to find a better way.

The opportunity arose to apply for a Nuffield Farming Scholarship in 2015 and with the support of the GRDC Northern Region, Nuffield Australia and Warakirri Cropping, I started a scholarship in 2016. My topic was to investigate ways to close the gap between potential grain yield and soil PAWC, with a focus on boosting productivity from sustainable dryland cropping systems.

The first leg of my overseas journey was to embark on a Global Focus Program, where a group of scholars travel the world for six weeks to provide a snap shot of world agriculture. The trip saw our group travel to Singapore, Philippines, Hong Kong, China, Canada, USA and the UK. The highlight of the trip was China and the incredible pace of development over such a huge area. Food quality and food safety were also major focuses for Chinese agriculture with consumer access to food processing now the key to rebuilding public trust.

On my personal study tours, I travelled to Israel, Brazil, Texas, UK and New Zealand. The world of agriculture is incredibly diverse and following sixteen weeks of overseas travel through annual rainfall zones from 100mm to 3000mm, I cannot recommend strongly enough the benefit of exposure to the challenges faced by growers in differing environments.

Australian growers lead the world, by necessity, in their understanding of the value of stored soil moisture. I was shocked to find in many high rainfall environments, such as Brazil, Southern Texas and Northern England, that a minor interruption in rainfall occurrence of perhaps 14 days was a yield reducing drought event even though water was still flowing from deep field drains. It demonstrated subsoil constraints and with ever increasing land values, the benefit: cost of amelioration seemed clear to me. Israel, on the other hand, was highly efficient at its use of very scarce water resources. In the 38 years from 1975 to 2013, Israel has reduced its irrigated water requirement (ML/ha) by one third, whilst incredibly achieving a 12-fold increase in production from the same volume of water. The technology now in use in Israel has exciting potential for Australian farms in the near future as costs reduce. Whole of farm wireless connectivity and plant growth tracking were important systems now helping Israeli growers to maximise production.

Another exciting prospective technique was the use of an in-field penetrometer to measure near infra-red (NIR) reflectance/adsorption developed by Texas A&M University in collaboration with Sydney University. This process allowed growers a 3-dimensional view of their soil without the disruption of excavation. A NIR penetrometer has now been commercialised by Veris as the P4000.

EM38 mapping was well regarded although not widely adopted around the globe as a means of differentiating soil zones based on their electrical conductivity (EC). EM38 systems are evolving and products such as the Austrian 'Soil Mapper' are able to be installed to machinery as it passes over a field. This opens up the possibility of building relative soil water maps (as water is a strong driver of EC) in real time by measuring soil water at intervals throughout the season. This data could potentially apply nitrogenous fertilisers at variable rates in real time to match soil water to productive capacity.

Microwaves are also being used in experimental work to measure deep soil moisture and prototype sensors are now available to install on overhead irrigation systems (centre pivot/lateral) which can allow variable rate irrigation based on real time data.

Observation and recording of rainfall were found to be areas for improvement regardless of the annual rainfall. Recording systems were often remote from fields with questionable accuracy for the crops. New technologies allowing long range Wi-Fi with very low power demands are set to revolutionise such monitoring at a very reasonable expense.

Conclusion

The yield gap between crop production and available soil moisture exists globally, with Australian dryland growers very efficient compared to our overseas counterparts.

We need to do more to visualise our soils in 3-dimensions to allow us to address limitations in the root zone of crops and optimise inputs to match our soil's productive capacity. The NIR penetrometer was the most exciting potential new technology observed for this purpose.

EM38 developments to allow low cost multiple field passes seemed the most likely of the observed technologies to allow 'on the go' measurement of soil moisture.

Long Range Wireless Area Networks (LoRaWAN) are an exciting development which will allow remote monitoring of thousands of in-field sensors at very low cost.

Acknowledgements

My Nuffield Farming Scholarship was made possible by the generosity of Nuffield Australia proudly supported by my investor GRDC Northern Region.

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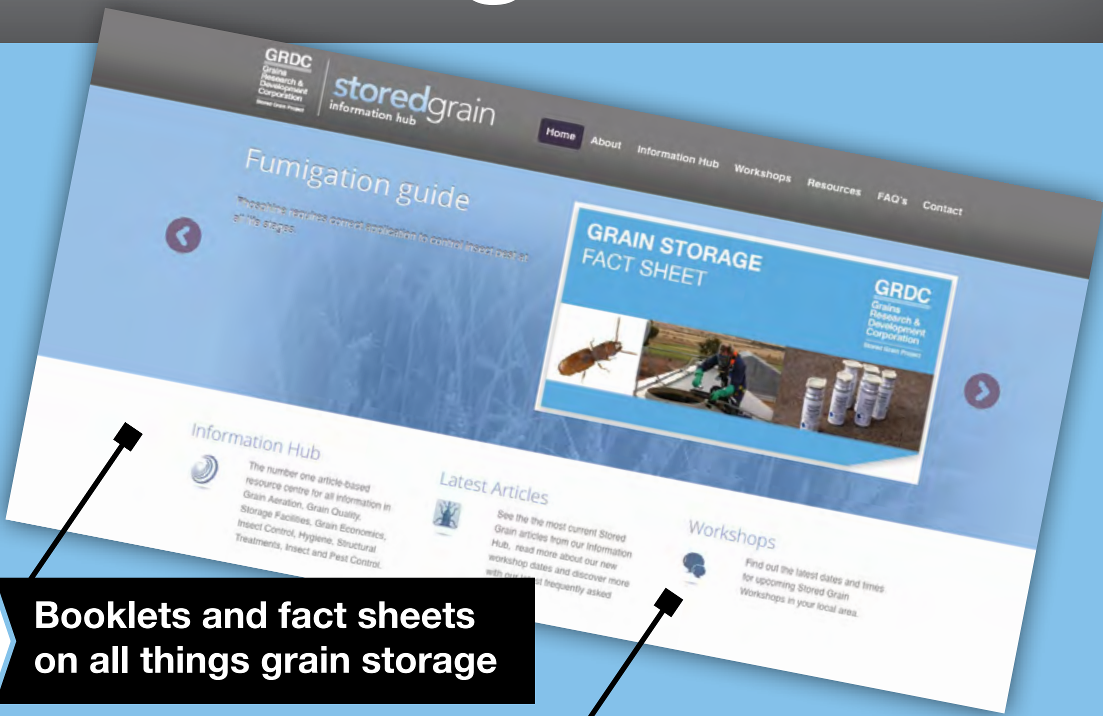

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The effects of stubble on nitrogen tie-up and supply

John Kirkegaard[1], Tony Swan[1], James Hunt[2], Gupta Vadakattu[1] and Kelly Jones[3].

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GRDC project codes: CSP186, CSP174

Keywords

- nitrogen, soil organic matter, immobilisation, crop residue, stubble retention.

Take home messages

- Cereal stubble should be thought of as a source of carbon (C) for microbes, not as a source of nitrogen (N) for crops. In no-till systems, only approximately 6% of the N requirement of crops is derived from the stubble.
- Nitrogen tie-up by cereal residue is not just a problem following incorporation — it occurs in surface-retained and standing-stubble systems and can reduce wheat yields by 0.3t/ha to 0.4t/ha.
- Management is reasonably straightforward — supply more N (5kg N for each t/ha of cereal residue) and supply it early to avoid impacts of N tie-up on crop yield and protein.
- Deep-banding N can improve the N uptake, yield and protein of crops, especially those in stubble-retained systems.

Background

Most dryland growers in Australia retain all, or most of their crop residues (wherever possible) to protect the soil, retain soil moisture and maintain soil fertility in the long term. However, a pro-active and flexible approach to stubble management that recognises and avoids situations in which stubble can reduce productivity or profitability makes sense, and has been promoted as part of the GRDC Stubble Initiative (Swan *et al.*, 2017a). One such situation is where large amounts of retained stubble, especially high C:N ratio cereal stubble, 'ties-up' soil N leading to N deficiency in the growing crop that may reduce yield. The timing, extent and consequences of N tie-up are all driven by variable weather events (rainfall and temperature) as well as soil and stubble type, so quite different outcomes may occur from season to season and in different paddocks. In this paper, the process of N tie-up or immobilisation as it is known is reviewed in simple terms, to understand the factors driving it. The results from a series of recent experiments in southern NSW (both long-term and short-term) that serve to illustrate the process are then provided, and the ways in which the negative consequences can be avoided while maintaining the benefits of stubble are discussed.

The process of 'N-tie up' (immobilisation) — put simply

Growers are always growing two crops – the above-ground crop (wheat, canola, lupin, etc.) is obvious, but the below-ground crop (the microbes) are always growing as well; and like the above-ground crop they need water, warm temperatures and nutrients to grow (there's as much total nutrient in the microbes/ha as in the mature crop, and two-thirds are in the top 10cm of soil!). There are two main differences between these two 'crops' — firstly the microbes can't get energy (carbon) from the sun like the above-ground plants, so they rely on crop residues as the source of energy (carbon). Secondly they don't live as long as crops — they can grow, die and decompose ('turnover') much more quickly than the plants — maybe two to three cycles in one growing season of the plant. The microbes are thus immobilising and then mineralising N as the energy sources available to them, come and go. In a growing season it is typical for the live microbial biomass to double by consuming C in residues and root exudates — but they need mineral nutrients as well. Over the longer-term the dead microbe bodies (containing C, N, phosphorus (P) and sulphur (S)) become the stable organic matter (humus) that slowly releases fertility to the soil. In the long-term, crop stubble provides a primary C-source to maintain that long-term fertility, but in the short-term the low N content in the cereal stubble means microbes initially need to use the existing soil mineral N (including fertiliser N) to grow, and compete with the plant for the soil N.

A worst-case scenario

That simplified background helps to understand the process of immobilisation, when and why it happens, and how it might be avoided or minimised. Imagine a paddock on the 5 April with 8t/ha of undecomposed standing wheat stubble from the previous crop after a dry summer. A 30mm storm wets the surface soil providing a sowing opportunity. Fearing the seeding equipment cannot handle the residue, but not wanting to lose the nutrients in the stubble by burning, the residue is mulched and incorporated into the soil. A canola crop is sown in mid-April with a small amount of N (to avoid seed burn) and further N application is delayed until bud visible due to the dry subsoil.

In this case, the cereal stubble (high C and low N – usually at a C:N ratio of approximately 90:1) is well mixed through a warm, moist soil giving the microbes maximum access to a big load of C (energy) — but not enough N (microbe bodies need a ratio of about 7:1). The microbes will need all of the available N in the stubble and the mineral N in the soil, and may even break-down some existing organic N (humus) to get more N if they need it. The microbes will grow rapidly, so when the crop is sown there will be little available mineral N - it's all 'tied-up' by the microbes as they grow their population on the new energy supply. Some of the microbes are always dying as well but for a time more are growing than dying, so there is 'net immobilisation'. As the soil cools down after sowing, the 'turnover' slows, and so is the time taken for more N to be released (mineralised) than consumed (immobilised) and net-mineralisation is delayed. Meanwhile — the relatively N-hungry canola crop is likely to become deficient in N as the rate of mineralisation in the winter is low. This temporary N-deficiency if not corrected or avoided, may or may not impact on yield depending on subsequent conditions.

Based on the simple principles above, it's relatively easy to think of ways to reduce the impact of immobilisation in this scenario:

- The stubble load could be reduced by baling, grazing or burning (less C to tie up the N).
- If the stubble was from a legume or a canola rather than a cereal (crop sequence planning) it would have lower C:N ratio and tie up less N.
- The stubble could be incorporated earlier (more time to move from immobilisation to mineralisation before the crop is sown).
- Nitrogen could be added during incorporation (to satisfy the microbes and speed up the 'turnover').
- More N could be added with the canola crop at sowing (to provide a new source of N to the crop and microbes), and this could be deep-banded (to keep the N away from the higher microbe population in the surface soil to give the crop an advantage).
- A different seeder could be used that can handle the higher residue without requiring incorporation (less N-poor residue in the soil).
- A legume could be sown rather than canola (the legume can supply its own N, can emerge through retained residue and often thrives in cereal residue).

In modern farming systems, where stubble is retained on the surface and often standing in no-till, control-traffic systems, less is known about the potential for immobilisation. In GRDC-funded experiments as part of the Stubble Initiative (CSP187, CSP00174), the dynamics of N in stubble-retained systems are being investigated. Examples from recent GRDC-funded experiments in southern NSW are provided in this paper and the evidence for the impact of immobilisation are discussed and some practical tips to avoid the risks of N tie-up are provided.

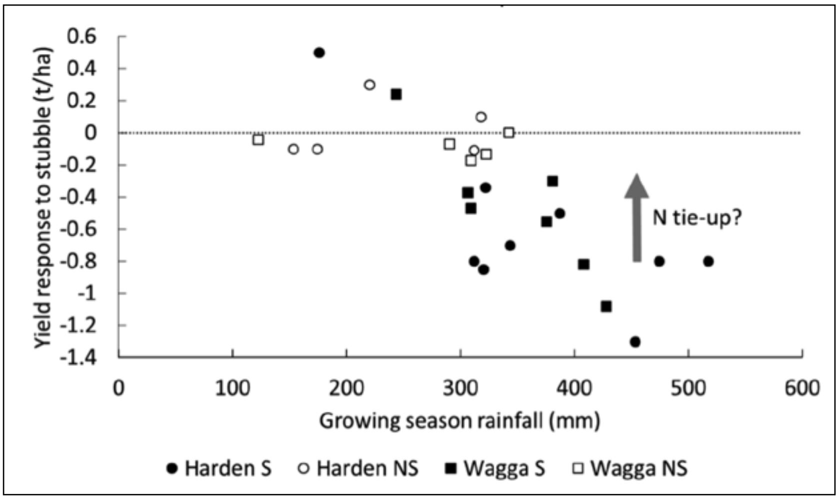

Figure 1. Effect of retained stubble on wheat yield is worse in wetter seasons at the Harden (circles) and Wagga (squares) long-term tillage sites. Open symbols indicated where difference between retained and burnt were not significant (NS), solid symbols indicated where difference between retained and burnt were significant (S).

Can stubble really reduce yield significantly in no-till systems — and is 'N-tie-up' a factor?

Harden long-term site

In a long-term study at Harden (28 years) the average wheat yield has been reduced by 0.3t/ha in stubble retained versus stubble burnt treatments, but the negative impacts of stubble were greater in wetter seasons (Figure 1). Nitrogen tie-up may be implicated in wetter years, due to higher crop demand for N and increased losses due to leaching or denitrification. But we rarely found significant differences in the starting soil mineral N pre-sowing. For many years, sufficient measurements were unavailable to determine whether N tie-up was an issue.

In 2017, two different experiments in sub-plots at Harden were implemented to investigate the potential role of N tie-up in the growth and yield penalties associated with stubble. A crop of wheat (cv. Scepter⁽ᵈ⁾) was sown on 5 May following a sequence of lupin-canola-wheat in the previous years. In both the stubble-retained and stubble-burnt treatments 50kg N/ha or 100kg N/ha broadcast as urea at sowing in one experiment were compared (Table 1), and in another experiment 100kg N/ha surface applied or 100kg/N deep-banded below the seed were compared (Table 2). The pre-sowing N to 1.6m was 166kg N/ha in retained and 191kg N/ha in burnt, but was not significantly different. Plant population, growth and N content at GS30 did not differ between treatments (data not shown) but by anthesis, the biomass and tiller density were significantly increased by the additional 50kg/ha of surface-applied N in the stubble-retained treatment, while there was no response in the stubble burnt treatment. At harvest, both stubble retention and increased N improved grain yield, but the increase due to N was higher under stubble retention (0.6t/ha) than stubble burnt presumably due to improved

Table 1. Effect of additional surface applied and deep-placed N on wheat response in stubble burnt and retained treatments at Harden in 2017.

Treatment		Anthesis		Harvest (@12.5%)	
Stubble	N	Biomass (t/ha)	Tillers (/m^2)	Yield (t/ha)	Protein (%)
Retain	50	7.1	324	4.3	8.8
	100	8.4	401	4.9	9.6
Burn	50	8.8	352	4.2	9.3
	100	8.7	372	4.5	10.5
LSD (P<0.05)	Stubble	0.9	ns	0.2	ns
	N	0.5	33	0.1	0.2
	Stubble x N	0.8	38	0.2	ns

water availability. The increase in yield with higher N, and the low protein overall (and with low N) suggests N may have been limiting at the site, but the water-saving benefits of the stubble may have outweighed the earlier effects of immobilisation.

Deep-banding the N fertiliser had no impact on crop biomass or N% at GS30, but increased both the biomass and N content of the tissue at anthesis more in the retained-stubble than in burnt stubble (Table 2). Retaining stubble decreased biomass overall but not tissue N. N uptake (kg/ha) at anthesis was significantly increased by deep-banding in both stubble treatments, however the increase was substantially higher in the stubble-retain treatment than in the burn treatment (38kg N/ha compared with15kg N/ha). The overall impact of deep-banding on yield persisted at harvest, but there was no effect, nor interaction with stubble retention, presumably due to other interactions with water availability. However the fact that deep-banding N has had a bigger impact in the stubble retained treatment provides evidence of an N-related growth limitation related to retained stubble. Its appearance at anthesis, and not earlier, presumably reflects the high starting soil N levels which were adequate to support early growth but the cold dry winter generated N deficiencies as the crop entered the rapid stem elongation phase. The increased protein content related to both burning and deep-banding and its independence from yield, suggest on-going N deficiencies generated by those treatments.

Temora site

At Temora, a nine-year experiment managed using no-till, controlled traffic, inter-row sowing (spear-point/press-wheels on 305mm spacing) in a canola-wheat-wheat system investigated the effects of stubble burning and stubble grazing on soil water, N and crop growth. In the stubble retained treatment, stubble was left standing through summer, and fallow weeds were strictly controlled. In the stubble grazed treatment weaner ewes were allowed to crash graze the stubble immediately after harvest for a period of seven to ten days and weeds were controlled thereafter. Stubble was burnt in mid-late March and the crop sown each year in mid-late April. Nitrogen was managed using annual pre-sowing soil tests whereby 5kg/ha N was applied at sowing and N was top-dressed at Z30 to attain 70% of maximum yield potential according to Yield Prophet® (Swan et al., 2017).

Burning

In un-grazed treatments, retaining stubble, rather than burning had no impact on the yield of canola or the first wheat crop over the nine years, but consistently reduced the yield of the second wheat crop by an average on 0.5t/ha (Table 3). This yield penalty was associated with an overall significant reduction in pre-sowing soil mineral-N of 13kg/ha, while there was no significant difference in pre-sowing N for the first wheat crop (Table 4).

Table 2. Effect of surface-applied and deep-banded N on wheat response in stubble-burnt and stubble-retained treatments at Harden in 2017.

Treatment		Anthesis			Harvest (@12.5%)	
Stubble	100 N	Biomass (t/ha)	Tissue N (%)	N Uptake (kg N/ha)	Yield (t/ha)	Protein (%)
Retain	Surface	8.1	1.1	91	4.5	9.3
	Deep	9.1	1.4	129	5.1	10.2
Burn	Surface	8.9	1.2	104	4.5	10.3
	Deep	9.5	1.3	119	5.0	10.8
LSD (P<0.05)	Stubble	0.6	ns	ns	ns	0.8
	N	0.2	0.1	8	0.2	0.4
	Stubble x N	0.6	0.2	12	ns	ns

Table 3. Effect of stubble burning on grain yields at Temora in Phase 1 and 2. Crops in italics are canola, and bold are the 2nd wheat crops.

Phase	Treatment	2009	2010	2011	2012	2013	2014	2015	2016	2017
Phase 1	Retain	1.7	*4.2*	4.6	**4.4**	*0.7*	3.8	**4.1**	*3.2*	3.7
	Burn	1.7	*4.0*	4.6	**5.0***	*1.0*	3.8	**4.6***	*3.2*	3.2
Phase 2	Retain	-	6.3	*3.4*	4.5	**2.0**	*2.0*	5.5	**5.2**	*2.1*
	Burn	-	6.2	*3.5*	4.8	**3.4***	*2.0*	5.3	**5.7***	*2.4*

** indicates where yields are significantly different*

Grazing

Grazing stubbles never reduced the yield of any crop at the site, but increased the yield of the second wheat crop by 1.2t/ha in 2013 (Phase 1) and by 1.0t/ha in 2015 (Phase 2) (Table 5). This was unrelated to pre-sowing soil N in 2013 (both had approximately 85kg N/ha at sowing) where suspected increased frost effects in the ungrazed stubble were expected. While in 2015, the yield benefit was related to pre-sowing N with an extra 61kg/ha N at sowing in the grazed plots. Overall, grazing increased the pre-sowing N by 13kg/ha in the first wheat crop and by 33kg/ha in the second wheat crop (Table 4).

Deep N placement

In an adjacent experiment at Temora in the wet year of 2016, deep N placement improved the growth, N uptake and yield of an N-deficient wheat crop but this occurred in both the stubble retained and the stubble removed treatments and there was no interaction suggesting N availability was not reduced under stubble retention (Table 6). However it was thought that the level of N loss due to waterlogging in the wet winter and the significant overall N deficiency may have masked these effects which were more obvious at Harden in 2017.

Post-sowing N tie-up by retained stubble

The evidence emerging from these studies suggests that even where cereal crop residues are retained on the soil surface (either standing or partially standing) and not incorporated, significant N immobilisation can be detected pre-sowing in some seasons. The extent to which differences emerge are related to seasonal conditions (wet, warm conditions) and to the time period between stubble treatment (burning or grazing) and soil sampling to allow differences to develop. However, even where soil N levels at sowing are similar between retained and burnt treatments (which may result from the fact that burning is done quite late) ongoing N immobilisation **post-sowing** by the microbes growing in-crop is likely to reduce the N available to crops in retained stubble as compared to those in burnt stubble. This was demonstrated in 2017 at Harden where the additional 50kg N/ha applied at sowing completely removed the early

Table 4. Mean effect of stubble burning or grazing across years and phases on soil mineral N (kg N/ha) to 1.6m depth prior to sowing either 1st or 2nd wheat crops at Temora. LSD for interaction of treatment and rotational position where P<0.05.

Rotation position	Stubble treatment		Grazing treatment	
	Retain	Burn	No graze	Graze
1st wheat	117	110	107	120
2nd wheat	102	115	92	125
LSD (P<0.05)	13	13		

Table 5. Effect of grazing stubble on grain yields at Temora in Phase 1 and 2. Crops in italics are canola, and bold are the 2nd wheat crops.

Phase	Treatment	2009	2010	2011	2012	2013	2014	2015	2016	2017
Phase 1	No graze	1.7	*4.2*	4.6	**4.4**	0.7	3.8	**4.1**	3.2	3.7
	Graze	1.7	*4.3*	4.5	**4.8**	0.9	3.7	**5.3***	3.3	3.3
Phase 2	No graze	-	6.3	*3.4*	4.5	**2.0**	*2.0*	5.5	**5.2**	*2.2*
	Graze	-	6.2	*3.3*	4.8	**3.0***	*2.2*	5.6	**5.6***	*x*

** shows where significantly different (P<0.05)*

Table 6. Effect of deep banding vs surface applied N (122kg N/ha as urea) at seeding, at Temora NSW in 2016 (starting soil N, 58kg/ha). The crop captured more N early in the season which increased biomass and yield in a very wet season. (Data mean of three stubble treatments).

Treatments	Z30			Anthesis			Grain Yield (t/ha)
	Biomass (t/ha)	N%	N-uptake (kg/ha)	Biomass (t/ha)	N%	N-uptake (kg/ha)	
Surface	1.4	3.8	51	7.8	1.3	103	4.0
Deep	1.4	4.4*	60	9.2*	1.5*	136*	5.2*

**indicates significant differences (P<0.01). (Data source: Kirkegaard et. al., CSIRO Stubble Initiative 2016 CSP00186).*

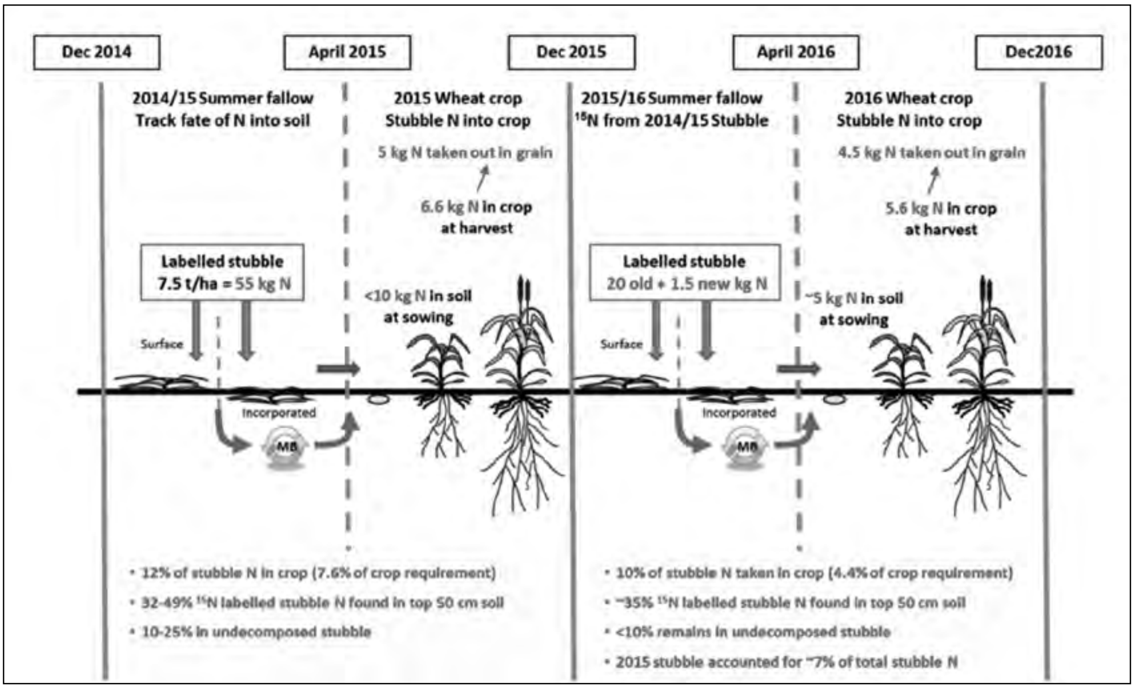

Figure 2. The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 7.5t/has of wheat stubble containing 55kg/ha N. The successive crops took up 12% (6.6kg N/ha) and 10% (5.6kg N/ha) of the N derived from the original stubble representing only 7.6% and 4.4% of the crops requirements. Most of the stubble N remained in the soil (35%) or was lost (33%).

growth reduction observed in the stubble-retained treatment, although due to the overall water limitation at the site, this did not translate into yield.

Cereal stubble isn't a good source of nitrogen for crops

Studies at three sites in southern Australia (Temora, Horsham and Karoonda) have tracked the fate of the N in stubble to determine how valuable it is for succeeding wheat crops under Australian systems. Stubble labelled with ^{15}N (a stable isotope that can be tracked in the soil) was used to track where the stubble N went. At Temora (Figure 2), of the 55kg/ha of N contained in 7.5t/ha of retained wheat residue retained in 2014, only 6.6kg/ha N (12 %) was taken up by the first crop (representing 12 % of crop requirement); and 5.6kg/ha N (10%) was taken up by the second wheat crop (4.4% of crop requirement). The majority of the N after two years remained in the soil organic matter pool (19.1kg N/ha or 35%) and some remained as undecomposed stubble (10% or 5.5kg N/ha). Thus we can account for around 67% of the original stubble N in crop (22%), soil (35%) and stubble (10%) with 33% unaccounted (lost below 50cm, denitrified). In similar work carried out in the UK which persisted for four years, crop uptake was 6.6%, 3.5%, 2.2% and 2.2% over the four years (total of 14.5%), 55% remained in the soil to 70cm, and 29% was lost from the system (Hart *et al.*, 1993). The main point is that the N in cereal stubble represented only 6% of crop requirements over two years (7.6% Year 1; 4.4% Year 2) and takes some time to be released through the organic pool into available forms during which losses can occur.

Conclusion

These studies have confirmed a risk of N-tie up by surface-retained and standing cereal residues which may occur in-season, rather than during the summer fallow, and so may not be picked up in pre-sowing soil mineral N measurements. Yield penalties for retained residues were significant, but confined to successive cereal crops, and could be reduced by reducing the stubble load or by applying more N (approximately 5kg N per t/ha of cereal residue) and applying it earlier to the following crop. Deep placement of the N improved N capture by crops irrespective of stubble management, but was especially effective in stubble-retained situations. In summary, N tie-up is an easily managed issue for growers with suitable attention to the management of stubble and N fertiliser.

Useful resources

http://www.farmlink.com.au/project/maintaining-profitable-farming-systems-with-retained-stubble

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Notes

THE 2017-2019 GRDC NORTHERN REGIONAL PANEL

FEBRUARY 2018

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John Minogue runs a mixed broadacre farming business and an agricultural consultancy, Agriculture and General Consulting, at Barmedman in south-west NSW. John is chair of the district council of the NSW Farmers' Association, sits on the grains committee of NSW Farmers' Assn and is a winner of the Central West Conservation Farmer of the Year award. His vast agricultural experience in central west NSW has given him a valuable insight into the long-term grains industry challenges.

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Arthur is a grain, cotton and beef producer near Chinchilla, Queensland. He has a business degree from the Queensland University of Technology in international business and management and has completed the Australian Institute of Company Directors course. He is a previous vice-president of AgForce Grains and has an extensive industry network throughout Queensland. Arthur believes technology and the ability to apply it across industry will be the key driver for economic growth in the grains industry.

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Roger Bolte is a fourth-generation farmer from the West Wyalong area in NSW, operating a 6500 ha winter cropping program with his wife and family focussing on cereals, legumes and hay. During his 35-years in the industry, Roger has been involved in R&D in various capacities and has had the opportunity to travel abroad and observe a variety of farming systems. He believes that R&D and education are the cornerstones of the industry and feels privileged to be afforded the opportunity to share his experiences.

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Roy Hamilton operates a 4400 ha mixed family farming enterprise near Rand in NSW's Riverina. He was an early adopter of minimum till practices and direct drill and press wheel technology and is currently migrating to CTF. The majority of the property is cropped while the remainder runs ewes and trade lambs. He has held roles on the south east NSW Regional Advisory Committee, the GRDC's southern region Regional Cropping Solutions Network and was a founding committee member of the Riverine Plains farming systems group.

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Graham has been Managing Director of a private agricultural consultancy at Emerald, Queensland, for the past 28 years, providing advice on the agronomy and management of summer and winter, dryland and irrigated crops in grain and mixed farming systems. He has extensive involvement in RD&E having participated in two decades of GRDC and DPI-funded farming systems research, particularly in weed management, soil fertility and adaption of agronomic practices in CQ farming systems. Graham was a member of the CQ Research Advisory Committee for over 10 years and Chairman for five years.

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Bruce and his family operate a 3400 ha family grain growing business near Parkes NSW, which produces a mixture of dryland winter cereals, pulses and oilseeds as well as summer dryland cereals, pulses and cotton grown on a 12m zero till CTF platform with full stubble retention. Bruce holds a Bachelor of Agricultural Economics from the University of Sydney and previously worked with PricewaterhouseCoopers in its Transfer Pricing practice. He is an active member of the grains industry and was awarded a Nuffield Scholarship in 2009.

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Dr Jo White is an experienced researcher with over 15 years' experience in agricultural research programs based at the Department of Agriculture and Fisheries in Queensland (DAFQ) and the University of Southern Queensland (USQ), including 10 years' experience in the field of plant pathology of broad acre summer crops. Jo has a keen interest in developing and delivering on-ground practical research solutions to growers which improve productivity and profitability of their farms and is now working as a private consultant based in Queensland.

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Lucy Broad is the General Manager of the Grains Research and Development Corporation's (GRDC) Grower Communication and Extension business group. Lucy holds a Bachelor of Science in Agriculture, majoring in agronomy, and prior to working at the GRDC spent the last 13 years as Director and then Managing Director of Cox Inall Communications and Cox Inall Change, Australia's largest and leading public relations agency working in the Agribusiness and Natural Resource Management arena. Her entire career has been in communications, first with the Australian Broadcasting Corporation and then overseeing communications and behaviour change strategies for clients across the agriculture, natural resource management, government and not-for-profit sectors.

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NORTHERN REGION GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK

FEBRUARY 2018

The Northern Region of the Grains Research and Development Corporation (GRDC) encompasses some of the most diverse cropping environments in Australia, ranging from temperate to tropical climates – it has the greatest diversity of crop and farming systems of the three GRDC regions.

Implemented, to provide structured grower engagement, the GRDC Grower Solutions Group projects and the RCSN project have become an important component of GRDC's investment process in the northern region. The Northern Region Grower Solutions Group and the RCSN have the function of identifying and, in the case of Grower Solutions Groups managing short-term projects that address ideas and opportunities raised at a local level which can be researched demonstrated and outcomes extended for immediate adoption by farmers in their own paddocks.

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Northern Grower Alliance (NGA) was established in 2005 to provide a regional capacity for industry-driven, applied agronomic grains research. NGA is currently working on a five year Grower Solutions project, fully funded by the GRDC, focussing on cropping areas from the Liverpool Plains to the Darling Downs and from Tamworth and Toowoomba in the east to Walgett, Mungindi and St George in the west. A network of six Local Research Groups, comprised of advisers and growers, raise and prioritise issues of local management concern to set the direction of research or extension activity. Areas of focus range from weed, disease and pest management through to nutrition and farming system issues.

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Grain Orana Alliance (GOA) is a not for profit organisation formed in 2009 to help meet growers research and extension needs in the Central West of NSW to support their enduring profitability. Currently operating under the GRDC Grower Solutions Group - Central NSW project, one of the key priorities is to identify and prioritise R,D and E needs within the region through engagement with local growers and advisers. This grower engagement helps direct both the GRDC investments in research projects and GOA's own successful research programs. GOA's research covers a wide range of relevant topics such as crop nutrition, disease management and weed control. The structure of the project allows for a rapid turnaround in research objectives to return solutions to growers in a timely and cost effective manner whilst applying scientific rigour in the trial work it undertakes. Trials are designed to seek readily adoptable solutions for growers which in turn are extended back through GOA's extensive grower and adviser network.

CENTRAL QUEENSLAND GROWER SOLUTIONS GROUP

ROD COLLINS

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The Central Queensland Grower Solutions project, is a GRDC and DAF Queensland investment in fast-tracking the adoption of relevant R,D & E outcomes to increase grower productivity and profitability across central Queensland. Covering approximately 550,000 ha and representing 450 grain producing businesses, the central Queensland region includes areas from Taroom and Theodore in the south to Mt McLaren and Kilcummin in the north, all of which are serviced by the project staff, located in Biloela and Emerald. Team leader Rod Collins is an experienced facilitator and extension officer with an extensive background in the central Queensland grains industry. He was part of the initial farming systems project team in the region throughout the late 90's and early 2000's which led the successful adoption of ley legumes to limit nutrient decline and wide row configurations in sorghum to improve yield reliability across central Queensland. He has more recently led the development and delivery of the Grains Best Management Practices program.

COASTAL HINTERLAND QUEENSLAND AND NORTH COAST NEW SOUTH WALES GROWER SOLUTIONS GROUP

The Coastal Hinterland Queensland and North Coast New South Wales Grower Solutions project was established to address the development and extension needs of grains in coastal and hinterland farming systems. This project has nodes in the Burdekin managed by Dr Steven Yeates from CSIRO; Grafton managed by Dr Natalie Moore from NSW DPI; Kingaroy managed by Nick Christodolou (QDAF) and Bundaberg managed by Neil Halpin.

BUNDABERG QUEENSLAND:

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Neil Halpin is a principal farming systems agronomist with the Queensland Department of Agriculture and Fisheries. He has over 30 year's field trail experience in conservation cropping systems, particularly in the sugar-based farming systems of the coastal Burnett. His passion is for the integration of grain legume break crops, reduced tillage, controlled traffic and organic matter retention in coastal farming systems. Maximising the productivity and profitability of grain legumes (peanuts, soybeans and mung beans) is a common theme throughout the various production areas and systems covered by this project.

KINGAROY QUEENSLAND:

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Nick Christodoulou is a principal agronomist with the Department of Agriculture & Fisheries (QDAF) on Qld's Darling Downs and brings over 25 years of field experience in grains, pastures & soil research, with skills in extension application specifically in supporting and implementing practice change. Nick has led the highly successful sustainable western farming systems project in Queensland. Nick was also project leader for Grain & Graze 1 Maranoa-Balonne and DAF leader for Grain & Graze 1 Border Rivers project, project leader for Grain and Graze 2 and was also Project leader for the Western QLD Grower Solutions project. Currently he is the coordinator for the Grower Solutions Southern Burnett program.

BURDEKIN QUEENSLAND:

STEPHEN YEATES

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The Burdekin & tropical regional node of the Coastal and Hinterland Growers Solution Project is led by CSIRO research agronomist Dr Stephen Yeates and technical officer Paul McLennan, who are based at the Australian Tropical Science and Innovation Precinct at James Cook University, Townsville. The Burdekin & tropical Grower Solutions node has a committed and expanding advisory group of farmers and agribusiness professionals. Due to the rapid increase in farmers producing mungbean in the region an open door policy has been adopted to advisory group membership to ensure a balance in priorities between experienced and new growers. The node is focused on integrating grain crops into sugar farming systems in the lower Burdekin irrigation area in NQ and more recently contributing to other regions in the semi-arid tropics that are expanding or diversifying into grain cropping. Information and training requests for information and training from the Ord River WA, Gilbert River NQ, Mackay and Ingham areas necessitated this expansion. Recent work has focussed on the introduction of mungbeans in the northern Queensland farming systems in collaboration with the GRDC supported entomologists Liz Williams and Hugh Brier, Col Douglas from the mungbean breeding team, the Australian Mungbean Association and Pulse Australia. Both Stephen and Paul have many decades of experience with crop research and development in tropical Australia.

GRAFTON NEW SOUTH WALES:

NATALIE MOORE

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The NSW North Coast regional node of the Coastal and Hinterland Grower Solutions Project is led by NSW DPI research agronomist Dr Natalie Moore and technical officer Mr Nathan Ensbey, who are based at the Grafton Primary Industries Institute. The NSW North Coast Grower Solutions node prioritises and addresses issues constraining grain production via an enthusiastic advisory group comprised of leading grain growers, commercial agronomists from across the region and NSW DPI technical staff. In this high rainfall production zone (800-1400mm pa), winter and summer grain production is an important component of farming systems that also includes sugar cane, beef and dairy grazing pastures, and rice. The region extends east of the Great Dividing Range from Taree in the south to the Tweed in the north. Both Natalie and Nathan have many years experience with research and development for coastal farming systems and are also currently involved with the Australian Soybean Breeding Program (GRDC/CSIRO/NSW DPI) and the Summer Pulse Agronomy Initiative (GRDC/NSW DPI).

REGIONAL CROPPING SYSTEMS NETWORK (RCSN) SOUTHERN NSW

CHRIS MINEHAN

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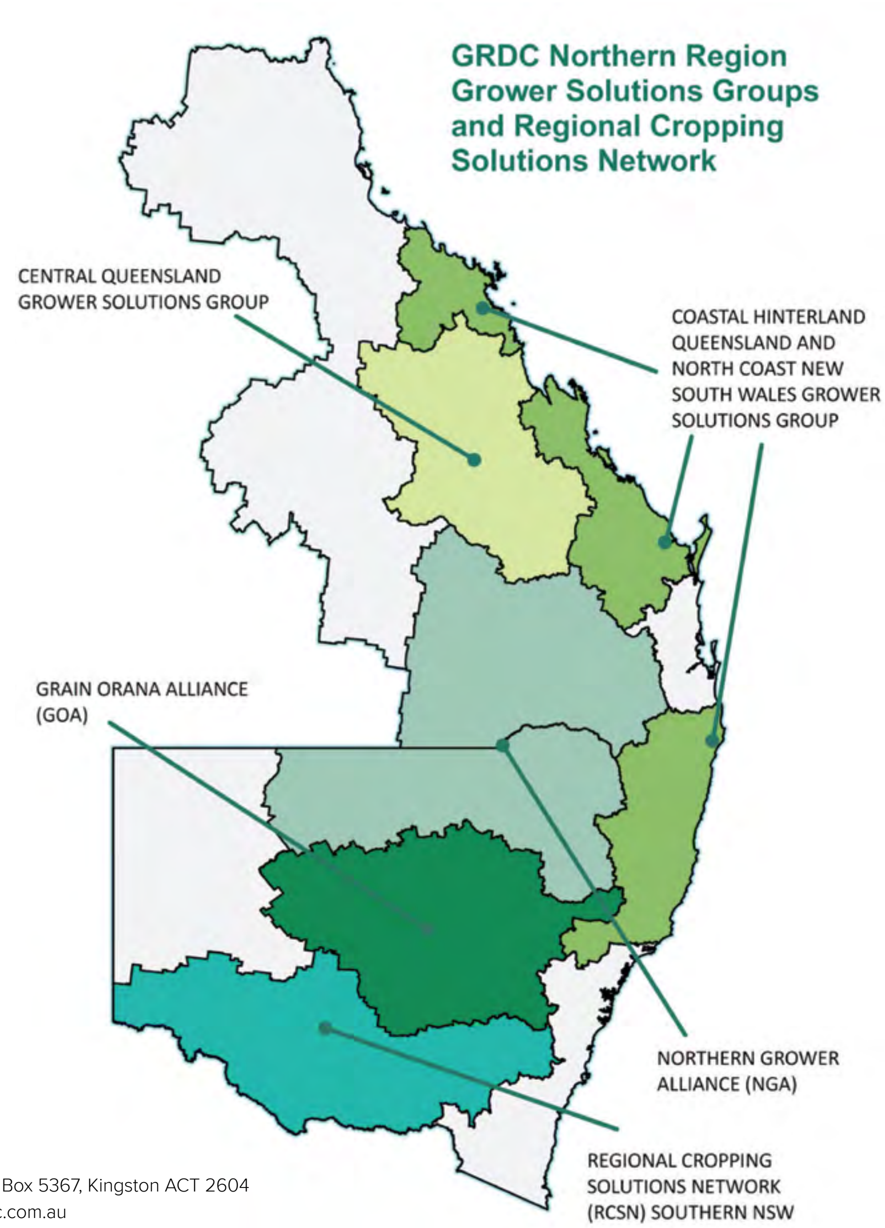
The Southern New South Wales Regional Cropping Solutions Network (RCSN) was established in 2017 to capture production ideas and opportunities identified by growers and advisers in the southern and western regions of New South Wales and ensure they translate into direct GRDC investments in local R, D & E priorities. The SNSW RCSN region covers a diverse area from the southern slopes and tablelands, through the Riverina and MIA, to the Mallee region of western NSW and the South Australian border. The region is diverse in terms of rainfall and climatic zones, encompassing rangelands, low, medium and high rainfall zones, plus irrigation. The SNSW RCSN is facilitated by Chris Minehan. Chris is an experienced farm business consultant and a director of Rural Management Strategies Pty Limited, based in Wagga Wagga, NSW. The process involves a series of Open Forum meetings which provide an opportunity for those involved in the grains industry to bring forward ideas, constraints and opportunities affecting grain grower profitability in their area. These ideas are reviewed by an RCSN committee comprises 12 members, including grain growers, advisers and researchers from across the region that meet twice per year to assist GRDC in understanding and prioritising issues relevant to southern NSW.



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- The local GRDC Grains Research Update steering committee that includes both government and private consultants and GRDC employees.
- Partnering organisation: Riverine Plains Inc.

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

You can now provide feedback electronically 'as you go'. An electronic evaluation form can be accessed by typing the URL address below into your internet browser.

To make the process as easy as possible, please follow these points:

- Complete the survey on one device (i.e. don't swap between your iPad and Smartphone devices. Information will be lost).
- One person per device (Once you start the survey, someone else cannot use your device to complete their survey).
- You can start and stop the survey whenever you choose, **just click 'Next' to save responses before exiting the survey**. For example, after a session you can complete the relevant questions and then re-access the survey following other sessions.

www.surveymonkey.com/r/Corowa-GRU

2018 Corowa GRDC Grains Research Update Evaluation

1. Name [ ]

ORM has permisssion to follow me up in regards to post event outcomes.

2. How would you describe your main role? *(choose one only)*

- ❑ Grower
- ❑ Agronomic adviser
- ❑ Farm business adviser
- ❑ Financial adviser
- ❑ Communications/extension
- ❑ Grain marketing
- ❑ Farm input/service provider
- ❑ Banking
- ❑ Accountant
- ❑ Researcher
- ❑ Student
- ❑ Other* (please specify)

Your feedback on the presentations

For each presentation you attended, please rate the content relevance and presentation quality on a scale of 0 to 10 by placing a number in the box (**10 = totally satisfactory, 0 = totally unsatisfactory**).

3. Canola - well executed agronomy still makes a difference in a tough 2017: *Rohan Brill*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

4. Nitrogen dynamics in modern cropping systems: *Jeff Baldock*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

5. Riverine Plains Inc. research update: *Cassandra Schefe*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

6. **The National Paddock Survey - what causes the yield gap across Australian paddocks?: *Roger Lawes***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

7. **Pulse rhizobia performance on acid soils: *Ross Ballard***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

8. **Simplifying methods to determine plant available water capacity (PAWC) of variable soils in Australian dryland grain production: *John Stevenson***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

Your next steps

9. **Please describe at least one new strategy you will undertake as a result of attending this Update event**

10. **What are the first steps you will take?**
    e.g. seek further information from a presenter, consider a new resource, talk to my network, start a trial in my business

Your feedback on the Update

11. Thinking about your Update experience, please consider how strongly you agree or disagree with the following statements

	Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
This Update has increased my awareness and knowledge of the latest in grains research	❑	❑	❑	❑	❑
Participating in this event has reinforced or enhanced my industry networks	❑	❑	❑	❑	❑
I know who to talk to, or where to go, to further explore the information that interested me	❑	❑	❑	❑	❑

Comments

12. Are there any subjects you would like covered in the next Update?

13. What is the likelihood you will attend an Update event like this in the future?

Very likely	Likely	May or may not	Unlikely	Will not attend
❑	❑	❑	❑	❑

Comments

14. Overall, how did the Update event meet your expectations?

Very much exceeded	Exceeded	Met	Partially met	Did not meet
❑	❑	❑	❑	❑

Comments

15. Finally, do you have any comments or suggestions to improve the GRDC Update events?

Thank you for your feedback.