GRAINS RESEARCH UPDATE

STRATEGIC STEPS – ENDURING PROFIT

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

The Rock

Thursday 15th March

9.00am to 1.00pm

The Rock Memorial Bowling Club,

86 Urana Street, The Rock

#GRDCUpdates

The Rock GRDC Grains Research Update convened by ORM Pty Ltd.

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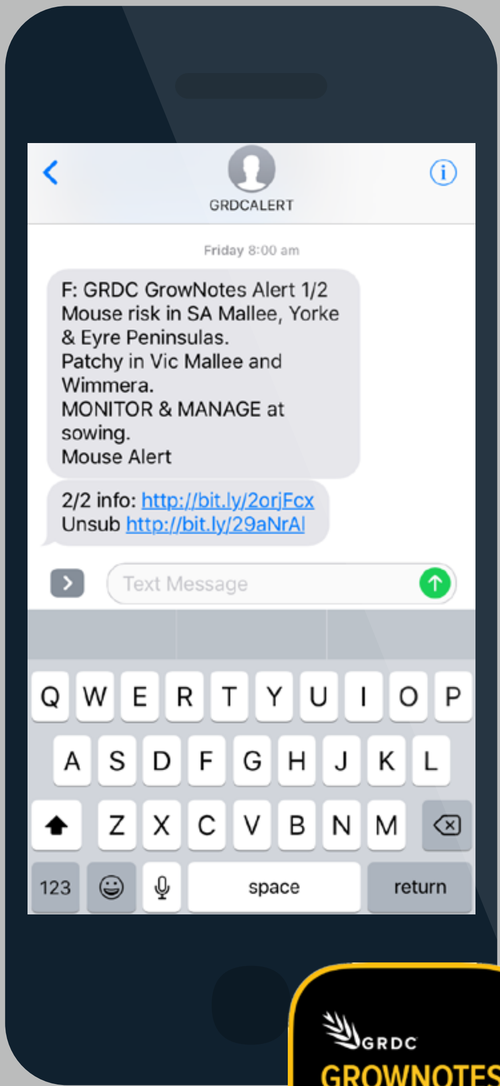

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GRDC GROWNOTES ALERT

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].

[1]CSIRO Agriculture and Food; [2]LaTrobe University; [3]Farmlink Research.

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 (crop roots and 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.

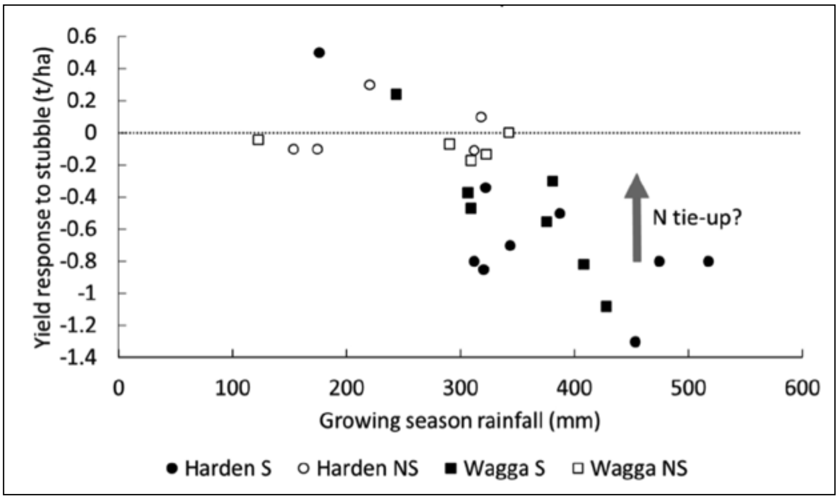

Figure 1. Effect of retained stubble on wheat yield is worse in wetter seasons at the Harden (circles) and Wagga (squares) long-term tillage sites. Open symbols indicated where difference between retained and burnt were not significant (NS), solid symbols indicated where difference between retained and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

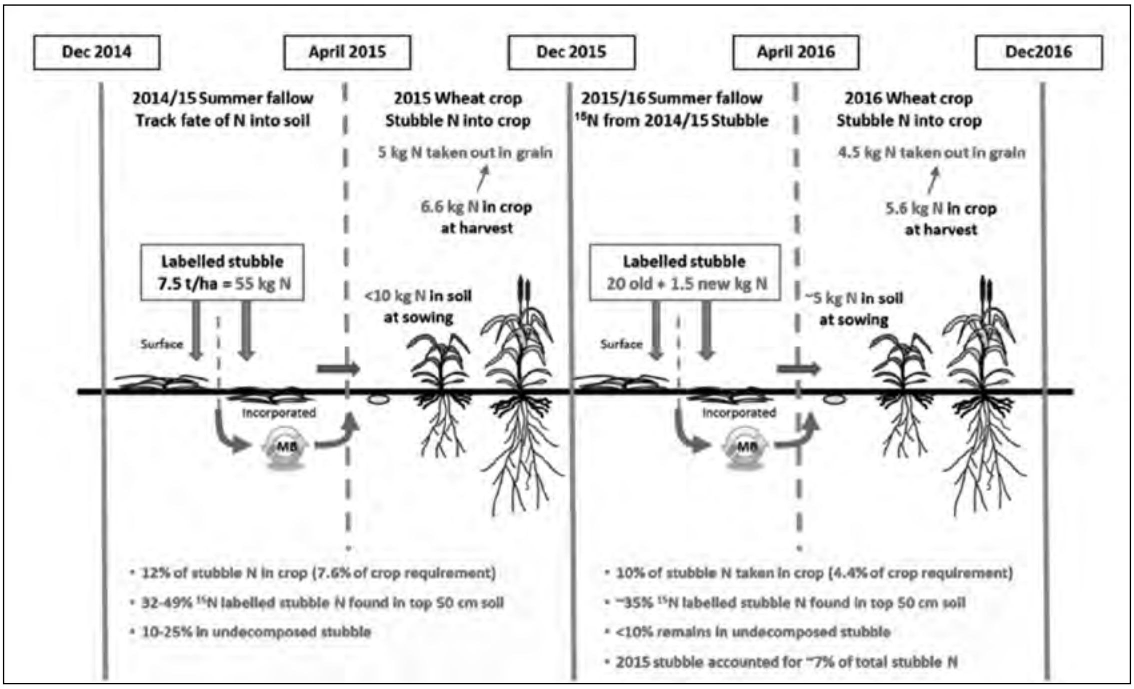

Figure 2. The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 7.5t/has of wheat stubble containing 55kg/ha N. The successive crops took up 12% (6.6kg N/ha) and 10% (5.6kg N/ha) of the N derived from the original stubble representing 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 crop 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

Better pastures, better crops - management of pastures in a mixed farming system

Tim Condon.

Delta Agribusiness, Harden NSW.

ΦExtra technical comment by Protech Consulting Pty Ltd

Keywords

- pasture, lucerne, perennial grasses, annual legumes, nutrition, weeds, transition, tillage, pH-acidity, persistence, winter cleaning.

Take home messages

- A pasture phase rebuilds organic carbon (C) and soil nitrogen (N) reserves.
- A pasture phase provides opportunities to reduce the weed seed bank prior to cropping.
- To achieve these benefits, the pasture must be dense, productive and persistent.
- Soil test - ensure that all nutrition issues are addressed at establishment and across the entire pasture phase, in particular phosphorus (P), sulphur (S) and molybdenum (Mo).
- pH stratification and subsoil acidity have the potential to severely compromise pasture production.
- Pasture legumes must have effective rhizobia nodules to fix N effectively.
- Winter cleaning within the pasture phase is a highly effective practice for weed control and lasting crop rotational benefits in terms of N and cereal root diseases.
- Match pasture type to desired outcome and utilisation potential.

Background

Across the southern NSW cropping belt, there has been a multitude of research projects conducted and papers written about the management of pastures in a mixed farming system. The biological processes and systemic effects are very well understood, however a large amount of this research was carried out in the 1990s and as this decade came to a close, one paper concluded that 'the relevance of pasture-crop rotations is decreasing as sheep numbers decline and cropping area increases' and in 2001 this same paper identified that 'there has been little attention paid to the long term consequences of continuous cropping around the issues of nitrogen, weeds, residues, tillage, lime and gypsum' (Angus, Kirkegaard and Peoples, 2001). So fifteen to twenty years on, what has changed in southern NSW?:

- The area of continuous cropping has increased.
- Crop rotations are longer on the arable zones of mixed farms.
- Canola is the dominant broadleaf break crop.
- There is not a stable, reliable pulse crop being widely grown in southern NSW.
- Organic N levels have declined under long term cropping.
- Weeds are an ongoing issue.
- Direct drilling using knife point press wheel seeders and retaining stubbles are common practice.

- pH stratification and acidic subsoils are a constraint.
- Phosphorus stratification is not well understood.
- Recently livestock enterprises have reached new profitability levels, often higher than cropping and with less risk. Mixed farmers are capitalising on the synergies of grazing crops, pastures and cash crop systems.
- Well managed pastures are one of the key drivers of the profitability, sustainability and resilience of these systems.

It is this last bullet point that is the focus of this paper and in particular, what is the ability of a well-managed pasture phase to deliver significant benefits to the subsequent cropping phase? The main areas of discussion are on:

- Pasture types on typical mixed farms.
- The positive impacts that pastures have on the soil resource.
- Long term weed seed bank management.
- Transitioning from pasture to crop and from crop to pasture.

A typical mixed farm

A 'typical mixed farm' is a very difficult thing to describe given the significant variation in farm size and enterprise mix across southern NSW. Table 1 attempts to standardise the typical differences from west to east.

Just as describing the typical farm is difficult, so too is describing a typical pasture. By far the dominant improved species are lucerne, sub clover and arrow leaf clover. Moving east as rainfall increases, perennial grasses are included in the majority of mixes and the pasture phase is longer.

Whatever the mix utilised from this diverse range of pasture species and varieties, the key to bringing the many positive benefits available from the pasture phase across to the subsequent cropping phase is to use the pasture that is best suited to each paddock and manage it to ensure that it is dense, persistent and productive for the entire time that it is there.

The impact of pastures on the soil resource

Pastures are recognised as providing a long term benefit to the soil resource both in terms of soil structure and soil fertility. There are two major nutritional benefits that flow from a pasture phase to the subsequent cropping phase — residual organic N from pasture legumes and an increase in soil C levels. A well-managed legume based pasture can fix between 100 and 200kg/ha of N annually. This number is highly correlated to the shoot dry matter produced. As a rough rule of thumb, research indicates that most legumes fix between 15 and 25kg of N/t of dry matter. This is, of course, dependent on effective nodulation. Pasture type also influences the subsequent supply of N mineralisation into the crop rotation as shown in Figure 1.

Table 1. Land use breakup of mixed farms across the southern NSW region.

	West < 450 mm		Middle 450 - 550 mm		East > 550 mm	
Ha	2,000		2,000		2,000	
Crop	1,800	90%	1,300	65%	1,000	50%
Grazing crop		nil	390	*(30% of crop)*	400	*(40% of crop)*
Pasture	200	10%	700	35%	1,000	50%
dse/ha	1,000	5.0	10,000	9.2	15,000	10.7

Table 2. Typical pasture species used across the southern NSW region.

	West < 450 mm	Middle 450 - 550 mm	East > 550 mm
Species used	Lucerne	Lucerne & Chicory	Lucerne & Chicory
	Sub & Medic	Sub & Medic	Perennial Grasses
	Annual clovers	Annual clovers	Sub & Medic
	Vetch	White clover	Annual clovers
		Prairie grass	White clover
			Prairie grass
Phase years	2 to 4	3 to 5	5 to 10

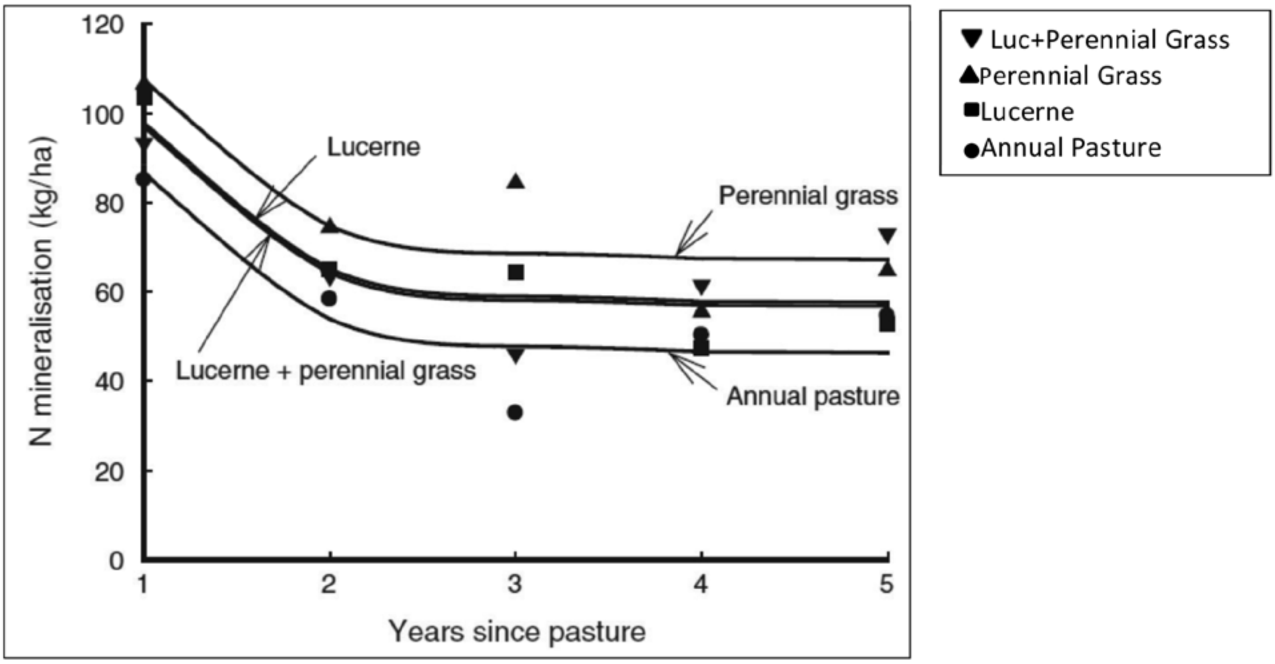

Figure 1. N mineralisation rates in relation to previous pasture type and the number of years since the pasture phase (Source: Angus, Bolger, Kirkegaard, Peoples, 2006).

Building up the soil organic matter pool improves soil structure and provides more regulated soil water holding capacity and nutrient cycling and is a very slow biological process. Long term research at Harden by John Kirkegaard and Clive Kirkby of CSIRO has shown that long term cropping (stubble retained — direct drill) depletes soil organic C by approximately 50kg/ha per year, while a pasture phase can increase soil organic C levels by 200 to 550kg/ha per year. The latter is by far, the fastest way to substantially rebuild organic C levels. However, to do this, the pasture must be productive. Recent research has shown that fertility is vital to drive this process (Chan et al. 2010). Without sufficient phosphorus (P) and sulphur (S), the available C and N in the pasture residues cannot be converted to stable humus, which would increase the organic N and C pools in the soil (Kirkby et al. 2014).

Another benefit of deep rooted perennial pasture species, such as lucerne and chicory, is that they have the ability to improve the macro porosity of the soil well into the subsoil layers. The initial benefit is higher infiltration capacity, as well as greater access to deeper water and nutrients for subsequent crops (McCallum et al. 2014). In southern NSW, chicory is particularly useful for penetrating acidic subsoils. The downside to this was very evident across the 'millennium drought', years (2002 – 2009) during which these deep rooted perennials de-watered the subsoil, with negative impacts on subsequent crops. However, this short term impact is outweighed by the long term residual benefits of greater macro porosity. Tap rooted crops could not achieve the same effect.

Table 3. Residual root channels increase infiltration rates into the subsoil.

Prior Pasture	Temora NSW		Birchip VIC
	Infiltration Rate mm/hr	Macropores > 2.0 mm	Infiltration Rate mm/hr
Annual Crops	2	68	3
Lucerne	10	225	6

(Source: McCallum et al. 2014)

Weed seed bank management

Pasture establishment provides an opportunity to reduce the weed seed bank because ideally the pasture density will be high enough to out compete weeds which can be easily achieved with a planned establishment program; an appropriate sowing rate and species mix.

During the pasture phase there are a number of opportunities for reducing the weed seed bank.

These include:

- Fodder conservation as hay and/or silage.
- Spray topping and/or fallowing.
- Winter cleaning of pastures with grazing and herbicides.

Towards the end of the pasture phase it is then important to implement a weed control strategy that achieves zero weed seed set for the three years prior to returning to the cropping phase. A typical strategy would aim to reduce the seed set by 70 to 80 % in year one by utilising strategic crash grazing (running large numbers of livestock in small areas for a very short period of time), fodder conservation or spray topping. This would then be followed by a winter clean in year two and an early fallow in year three.

Winter cleaning involves the use of grazing and herbicides to control a range of broadleaf and annual grass weeds, including capeweed, radish, fumitory, mustards, milk thistle, prickly lettuce, ryegrass, barley grass, brome grass, wild oats and vulpia.

The process aims to:

- Graze the paddock very hard so the pasture left is very short.
- Apply a low dose of Gramoxone® herbicide after grazing to reduce any residual bulky areas that stock cannot reach.
- A week later, apply a herbicide mix of Gramoxone® and Simazine[Φa] (plus broadleaf herbicide).
- An alternative herbicide option is propyzamide[Φb].

[Φa]Gesatop is not registered for use on capeweed, radish, fumitory, mustards, milk thistle or prickly lettuce. [Φb]Label states not registered for use on capeweed, radish, fumitory, mustards, milk thistle, prickly lettuce, ryegrass, barley grass, brome grass or wild oats.

It needs to be noted that this strategy has a significant impact on the desirable species in the pasture. It will take at least eight weeks for the pasture to rebuild dry matter levels back to levels to allow grazing. Consequently, winter stocking rates need to be managed accordingly and it's highly beneficial to have grazing crops available elsewhere on the farm.

The added proven benefit from winter cleaning is increased N supply to the subsequent crops, along with control of cereal root disease pathogens, if a cereal is to be the first crop in the rotation. Winter cleaning in the year prior to cropping has been shown to increase canola yields by 80% in canola and 40% in wheat with significant increases in the order of 10-15% for the subsequent three years (Harris et al. 2002).

Fallowing involves leaving the land unseeded for a growing season and is an important weed control opportunity. To maximise the level of weed control, apply robust herbicide rates of a glyphosate based application and fallow early. This is then followed by some grazing to reduce the bulk with the aim of maintaining ground cover over the summer period. If any weeds survive the initial glyphosate based application, then a double knock with Gramoxone® is advised.

Fallowing in early spring will also provide a greater opportunity for spring rainfall to be captured, particularly with perennial species e.g. lucerne and

Table 4. Expected levels of ryegrass control from different management strategies (Source: Roundup Ready® canola resistance management plan).

Tactic	Ryegrass control level (%) likely (range)
Mowing + Crash grazing	95 (90-98)
Hay, silage, green manure	90 (80-98)
Strategic grazing	75 (30-95)
Winter cleaning	90 (80-98)
Spray topping to reduce grasses	75 (50-90)
Spray fallowing — double knock	90 (80-98)

Table 5. The effect of timing of removal of lucerne prior to cropping on soil mineral N, wheat N uptake and grain yield at Junee Reefs, NSW.			
Timing of lucerne removal	Soil Mineral N 0.0 - 2.0 m	Wheat Shoot N Uptake	Grain Yield
months	Kg N/ha	Kg N/ha	t/ha
2	59	86	3.8
4	111	109	5.0
6	206	137	5.9

(Source: Angus et al., 2000)

phalaris, and nutrients conserved for the subsequent crop (Table 5). To maximise this opportunity, the fallow must be kept weed free and ground cover maintained over the summer period.

Transitioning from pasture to crop

The chosen time to transition from pasture to crop varies from farm to farm. The timing ranges from a set rotation to simply when the pasture declines to a point where it is no longer productive. Ideally, the transition should occur while the pasture is still fully productive, providing a significant grazing resource, weed control options and building soil resources. If the pasture phase is extended, lucerne and other perennials will thin out to the point where they become vulnerable to invasion by annual weeds. At this point it's important to return to crop.

Prior to pasture removal, soil testing will indicate the fertility status of the paddock. If pH levels have declined then lime should be applied to raise the pH of the top 10.0cm to at least 5.5 $CaCl_2$ and strategically cultivated to fully incorporate the lime (Conyers et al. 2017). This strategic cultivation can also have other benefits as described by Conyers et al. 2017.

Transitioning from crop to pasture

The optimal chosen time to transition from crop to pasture also varies from farm to farm. The time is often dictated by the financial return expected from the crop which is influenced by the fertility level of the soil and the weed burden and their corresponding effect on crop yield and input costs. It would be preferable to rotate the paddock back to pasture without a weed burden compromising pasture establishment.

Pasture establishment

Getting this transition right and establishing a dense, productive pasture are critical for achieving the benefits outlined previously. A number of factors influence the success of pasture establishment:

- Nutrition - especially phosphorus (P), sulphur (S) and molybdenum (Mo).
- Acidity.
- Weeds, insects and diseases.
- Establishment technique – under sowing or direct seeding of pasture only.

Nutrition

Often setting the paddock up for the pasture phase from a nutritional aspect is overlooked. It is assumed that things were right for the cropping phase so they will be right for the pasture. Two recent projects looking at legume performance have highlighted that things may not be as they seem.

Firstly, the GRDC supported, NSWDPI project (DAN00191) 'Boosting pulse crop performance on acid soils' (Burns, Norton and Tyndall, 2016) has identified that pH stratification is a significant issue for pulse crop nodulation and performance. They found it reasonable to conclude that the presence of undetected, but severely acidic layers is likely to be a major factor responsible for inconsistent 'performance' of acid-sensitive pulses on slightly acid (pH $CaCL_2$ >5.0) and moderately acid soils (pH $CaCL_2$ 4.6 to 5.0) of the medium and high rainfall zones. Pasture production would be expected to be compromised in the same way, significantly reducing immediate performance and the carryover benefits.

Secondly, 'The Trouble with Sub' project, funded by the Riverina Local Land Services (LLS) in conjunction with many collaborators, surveyed 81

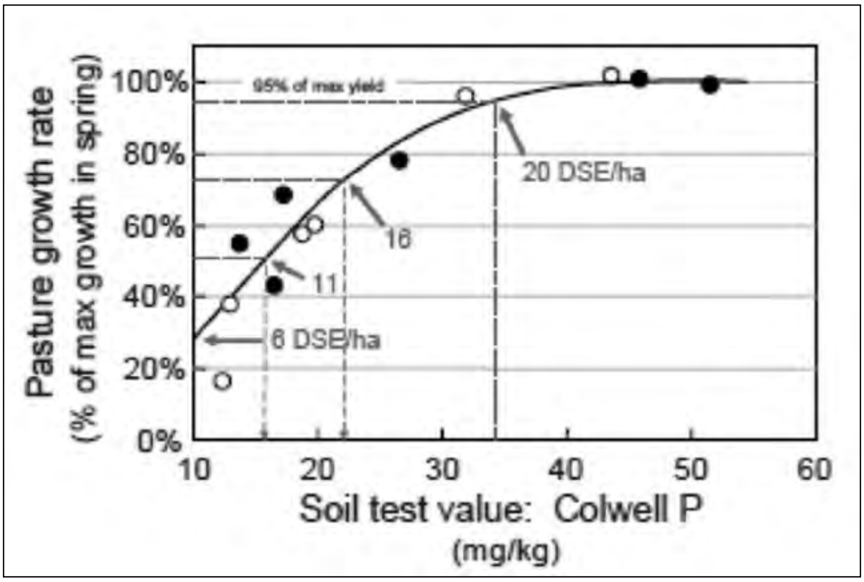

Figure 2. Critical soil phosphorus values relative to stocking rate. (Source: Five easy steps to ensure you are making money from superphosphate (Simpson et al. 2009)).

clover paddocks in the spring of 2015 across the Riverina and south west slopes region.

Some key findings from this project were:

- Legumes comprised 48% of the pasture base.
- Only 23% of paddocks had sub clover with good rhizobium nodulation.
- Nodulation in 45% of paddocks was poor.
- 22% of paddocks had damaging pH levels in the topsoil layer with Al% > 5.0 %.
- 40% of paddocks had a damaging subsoil pH levels with the pH CaCl2 of the 10 to 20cm layer being less than 4.5.
- Only 4% of paddocks had a history of Mo in the past 10 years.
- 61% of paddocks have a history of fertiliser applications.

Phosphorus (P) drives overall pasture production by boosting the legume content which fixes more N which helps drive pasture growth. The critical level of Colwell P to maximise pasture production depends on the desired stocking rate, soil type and environment as outlined in Figure 2. This issue is comprehensively covered in the publication, 'Five easy steps to ensure you are making money from superphosphate" (Simpson et al. 2009).

The current standard practice on most mixed farms is to build the P level of the paddock across the cropping phase with annual mono-ammonium phosphate (MAP) inputs, then let it run down through the pasture phase. As pasture phases become longer (greater than three years), regular soil testing to monitor P, S and pH is recommended. A typical program that aims to maintain an ideal level of pH, P, Mo and S for pasture and crop production is illustrated through a case study paddock in Table 6.

The key message here is to ensure that all nutritional issues are fully considered. Soil testing regularly will determine if a top up lime application and strategic incorporation may be required, along with an application of Mo to ensure conditions are suitable for legume pasture production. More regular P and S applications may be required as well.

Table 6. Soil testing, lime/pH, P, S and Mo management over a 20 year period.

PADDOCK Windmill	DATE	P	S	pH CaCl2	Al %	OC %	Lime Yr	Rate t/ha	Yr Gyp	Year Mo
Crop 97 - 01	09/11/1997	6		4.9	2.2	0.8	98	2.7	98	98
Past 02 - 03	20/03/2000	21	7.8	6.0	1.0	1.3				
Crop 04 - 07	19/01/2004	18	4.7	5.6		1.2			05	07
Past 08 - 13	15/01/2009	25	3.1	5.3	1.1	1.3				
Crop 14 - Current	30/01/2014	30	7.0	5.1	2.5	1.4	15	1.0	15	15

MAP applied @ 90kg/ha to all crops, with Single Super applied @ 120kg/ha in 2010.

Weeds, insects and diseases

Weeds, insects and disease all need to be managed as per current industry practice. Some new pests such as earwigs and slugs need to be considered as they can quickly bare out large areas of establishing pastures, the effects of which carry right through the pasture and well into the next cropping phase.

Careful attention also needs to be paid to the emerging weed problems of prickly lettuce and milk thistle, particularly in the year prior to pasture establishment, as these weeds can be hard to control in some pasture mixes. It is also advisable to be very cautious of the plant back periods that must be observed for herbicides such as Lontrel® for control of these weeds. In general, it is important to refer to the label of any herbicide used prior to sowing the pasture to ensure that there will be no risk of **residual herbicide** carry over effects. In particular, group B herbicides (e.g. Atlantis®) which are being increasingly used to manage wild oats in cereals as well as chemistry used on Clearfield™ crops. Some common herbicides and their plant backs are listed in Table 7.

Establishment technique

Regionally there are two methods of establishing pastures:

1. Under a cover crop
2. Direct seeding of pasture alone.

There is always debate about which method is best practice, without a clear outcome. There are many research papers that show that cover cropping increases the risk of pasture establishment failure, and reduces the pasture biomass production in the year after establishment as shown in Table 8.

However, the whole farm economic analysis from this same research project concluded that there was no difference in the probable farm cash balance at the end of a decade between pasture establishment techniques. Hence, across the region the dominant method (greater than 80%) of pasture establishment is under a cover crop. There are, however, some clear directions that come from this research:

- Use a low cover crop seeding rate, relative to environment.
- Lucerne and chicory based pastures are more likely to establish under a cover crop
- Perennial grasses, such as phalaris, fescue and cocksfoot are more likely to fail.

Table 7. Plant back periods for various herbicides prior to pasture establishment.

Product	Plant back in months	
	Lucerne	Sub Clover
Lontrel Adv	9	9
Intervix	10	10
Spinnaker	10	10
Atlantis OD	21	21
Sakura	21	9

Note: As there are often rainfall and soil type requirements that affect these periods, refer to the label.

Table 8. Difference in biomass production in the year after establishment.

Year & site	Species	No Cover Crop t/ha DM	Plus cover crop t/ha DM	% Reduction
2009 Yerong Creek	Lucerne	20.9	14.4	31
	Phalaris	8.3	2.6	69
	Chicory	13.8	7.0	49
2009 Ariah Park	Lucerne	7.5	4.3	43
	Phalaris	5.4	0.7	87

Source: Hayes et al., 2015.

- Short term straight annual legumes are best direct seeded.
- Short term, three year 'rebuilding pastures' are best established without a cover crop.

From my experience and observation, there are several rules of thumb that can be followed to reduce the risk of pasture establishment failure:

- **Cover crop choice** —Cover crops that finish early in the spring will give the pasture the chance to utilise spring rains for improved establishment. Short season barley and wheats are therefore popular choices. Canola is also being used more widely where weeds are not an issue. Within species there are options on what is the most competitive crop. For example, the wheat varieties Condo$^{(D}$ and Spitfire$^{(D}$ are quick, erect and low tillering.
- **Time of sowing** — Plan to seed undersown paddocks right at the front of the cover crop sowing window to improve establishment opportunities and avoid heat stress in spring. This is where the wheat variety Lancer$^{(D}$, which is very slow and poorly competitive through the winter may have a place, as opposed to a high tillering tall variety like Gregory$^{(D}$ which should be avoided.
- **Direction of sowing** — It is now recognised that sowing in an east -west direction significantly reduces weed competition in the inter-row. **To improve the growth and establishment of the undersown pasture, sow in a north-south direction.**
- **Pasture type, seasonal conditions and outlook** — If sowing perennial grass based pastures in a dry autumn with the forecast of a dry spring, do not use a cover crop, or consider not sowing the pasture at all.
- **Environment** — in low rainfall environments (< 400mm), use cover crops with caution.

Case study

This short case study is a real example of how the introduction of a pasture phase can rebuild fertility and get on top of a significant weed burden on a mixed farm in the mid rainfall belt on the southwest slopes of NSW.

A 1,000 hectare block was purchased in 2005. The block had been continuously cropped for the previous 15 years. The new rotation changed from 100% crop to 70% crop with 30% pasture because of ryegrass and poor fertility.

Paddocks are now cropped for seven years and out to pasture for four or five years. Pastures are lucerne/clover based and are winter cleaned* in year 2 or 3, have hay made in year 4 (the year prior to being spring fallowed) and spring fallowed in year 5.The cropping phase began with triazine tolerant (TT) canola, followed by wheat with Sakura®.

*** Winter cleaning was predominantly Gramoxone/simazine/ Tigrex®, herbicide mix but now also includes propyzimide.**

The canola area now varies between 33% and 45% of crop area depending on the grain market outlook. Winter cleaning and narrow windrow burning have been critical in getting the ryegrass back in control. In the past, without pasture on this farm, achieving protein levels in wheat over 9.5 to 10.0 % rarely happened. For the 2016 harvest, the wheat yields ranged from 4.0t/ha of APW1 on the last of the long term crop paddocks, up to 5.8t/ha of AH2 on paddocks with the second crop after a pasture phase.

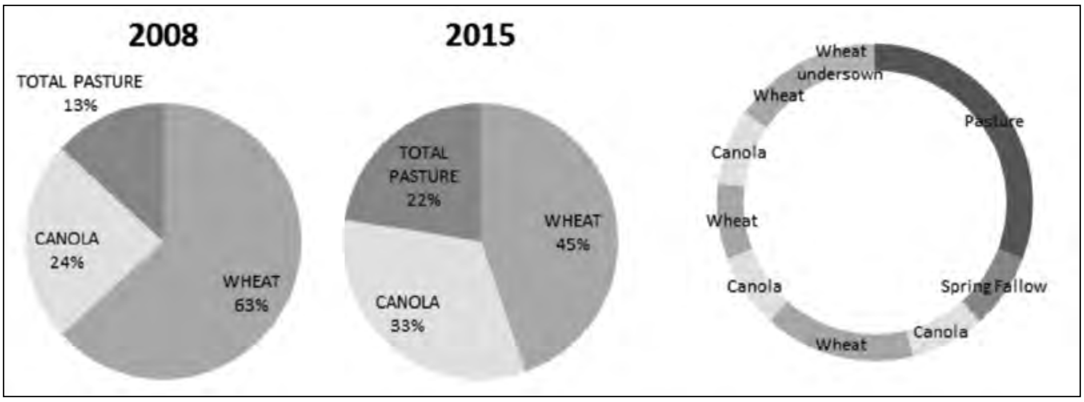

Figure 3. The change in rotation on the case study farm. Current is five years' pasture, canola, wheat, wheat, canola, wheat, canola, wheat, wheat undersown with lucerne and clover pasture.

Summary

A pasture phase can deliver substantial and lasting nutritional benefits well into the subsequent cropping phase, as well as providing the opportunity to drive weed seed banks to very low levels. To achieve these outcomes, the pasture must be dense, productive and persistent. The pasture phase is the ideal opportunity to address soil constraints that are limiting production and rebuild soil N and organic C levels. A rigorous process of soil testing, identifying all the issues then addressing them with the appropriate addition of required nutrients and/or ameliorants is just as important as the selection of the most appropriate pasture species, variety, seeding rate and establishment technique.

Well-managed productive pastures provide significant synergies to a mixed farm — firstly in terms of a major fodder resource for the livestock enterprises and secondly, by providing a range of tangible benefits that enhance the sustainability and profitability of the subsequent cropping phase.

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Notes

Pulse rhizobia performance on acid soils

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ΦExtra technical comment by Protech Consulting Pty Ltd

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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⁽ᵈ⁾ 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).

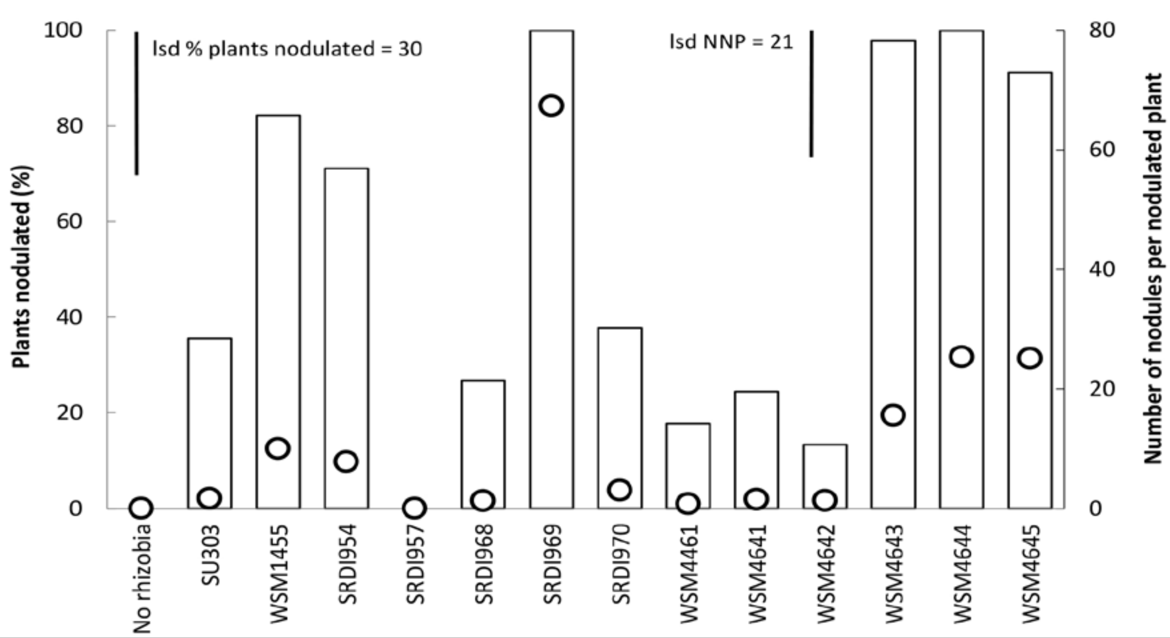

Figure 1. Effect of inoculation treatment on the percentage of Kaspa⁽ᵈ⁾ field pea seedlings forming nodules (left axis, columns) and the number of nodules per nodulated plant (NNP) (right axis, circles) at 20 days after inoculation.

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, N2-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

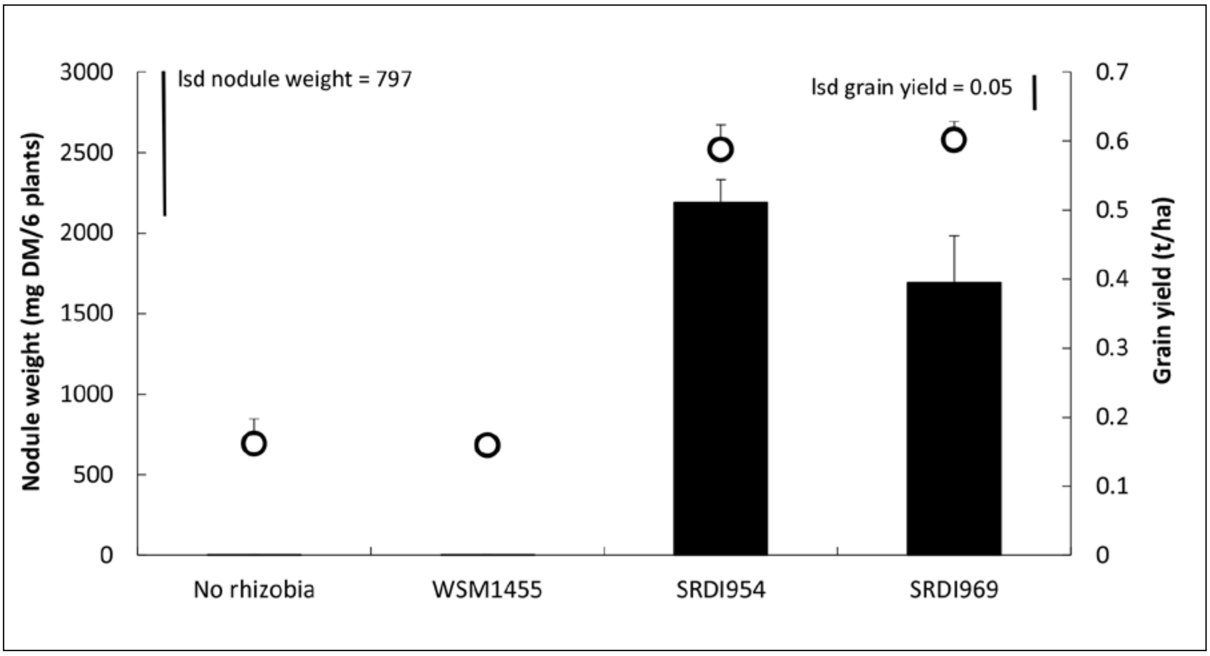

Figure 2. Effect of rhizobia strain on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⟮D⟯ faba bean at Wanilla, Eyre Peninsula, SA in 2017. Site pH$_{(Ca)}$ = 4.3, sown into dry soil 28 April. Standard rate of inoculation. Standard error of means shown as bars above 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⟮D⟯ faba bean pH$_{(Ca)}$ 4.7	Griffith, NSW PBA Ace⟮D⟯ 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*

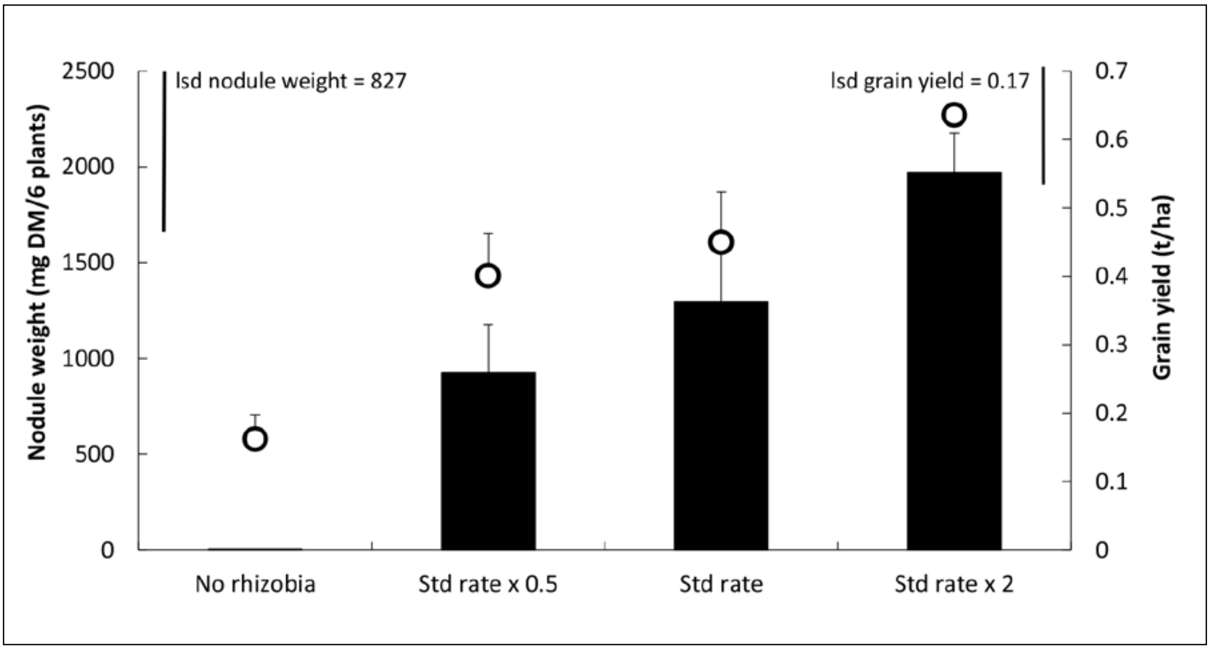

Figure 3. Effect of inoculation rate on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᵇ⁾ faba beans at Wanilla, Eyre Peninsula, SA, in 2017. Site $pH_{(Ca)}$ = 4.3, sown into dry soil 28 April. Values are the mean of three rhizobia strains (WSM-1455, SRDI-954 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® $^{\Phi}$ (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).

$^{\Phi}$Apron® 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).

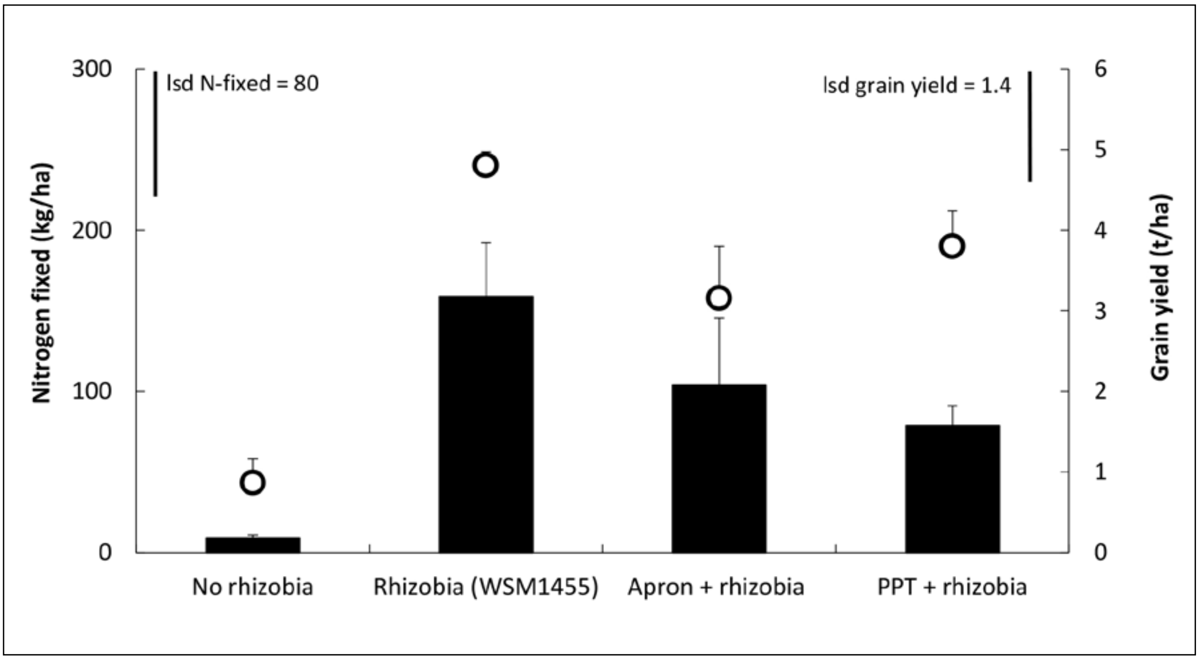

Figure 4. Effect of pesticide application to seed on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᶦ⁾ faba beans inoculated with Group F rhizobia (WSM-1455) at Ballyrogan VIC, 2016. Site pH ($_{Ca}$) = 4.6. Standard error of means shown as bars above columns and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

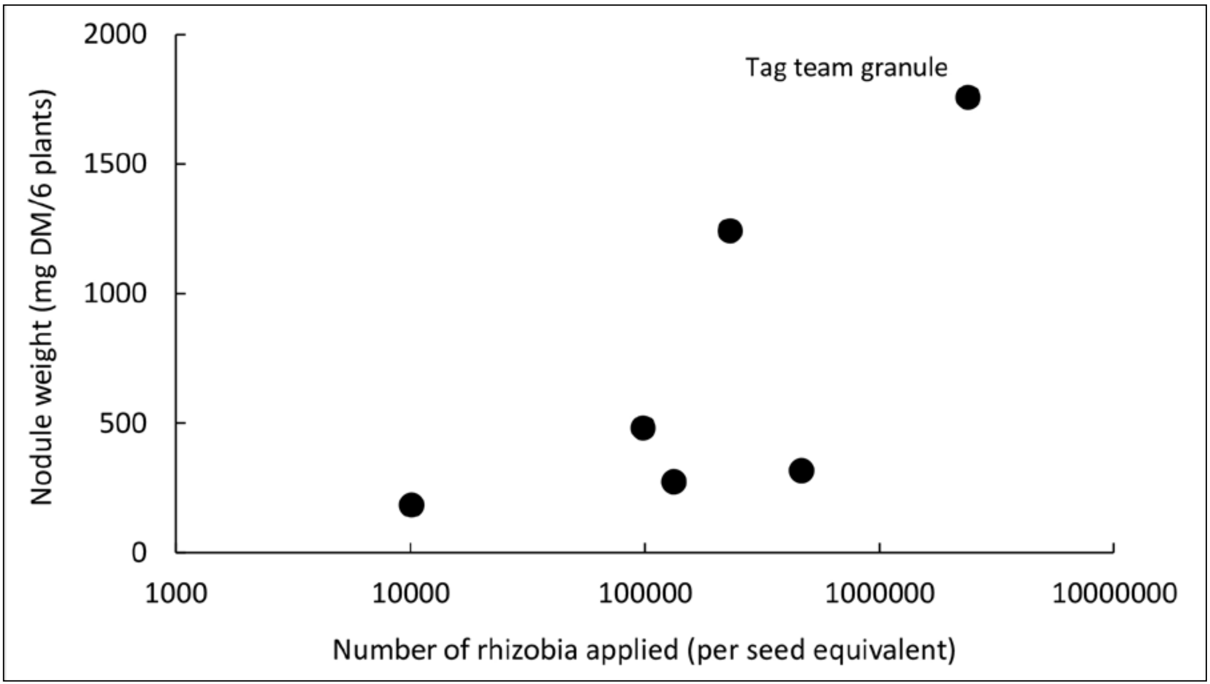

Figure 5. Relationship between number of rhizobia delivered at sowing by different inoculant formulations of rhizobia and the nodulation of PBA Samira$^{\Phi}$ faba beans sown at Wanilla, Eyre Peninsula, SA in 2017.

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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Notes

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Improving nitrogen fertiliser use efficiency in wheat using mid-row banding

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Keywords

- nitrogen (N), wheat, mid-row banding (MRB), incorporated by sowing (IBS), deep placement (DP), fertiliser timing.

Take home messages

- Mid-row banding (MRB) of urea at sowing provided a higher yield and profit response in wheat than all other N application methods other than incorporated by sowing (IBS).
- Nitrogen requirements for wheat based on targeting 13% grain protein ranged from 51 to 58kg N/t/ha for all methods of N application and were lowest for MRB (51kg N/t/ha).
- Urea incorporated by sowing (IBS) was more efficient than deep placement (DP) of urea and urea spread at early stem elongation (DC31).

Introduction

Fertiliser costs represent 20% to 25% of variable costs for growing grain crops. This proportion is likely to increase with the continued decline of soil organic matter and corresponding reduction in annual soil mineralisation of nitrogen (N) (e.g. Angus and Grace 2017). In approximate terms, the N mineralisation potential in cropping soils is declining by 50% every 25 to 30 years. Soil mineralisation of N is not enough to meet crop demand, consequently N fertiliser is typically applied to wheat at sowing, stem elongation and occasionally at booting. The in-crop efficiencies of fertiliser N retrieval vary greatly, with approximately 44% in above-ground plant parts, 34% in soil and 22% not recovered, which is presumably lost (Angus and Grace 2017). Increases in the efficiency with which wheat extracts fertiliser N from the soil can result in substantial fertiliser savings. In this study four methods of N supply to wheat were compared that included; (i) surface broadcast and incorporated by sowing (IBS), (ii) mid-row banding (MRB) at sowing (8cm deep) between every second row, (iii) deep placement (DP) at sowing under each wheat row (16cm), and (iv) broadcasting at stem elongation (BSE). Results of grain yield and protein response, estimated N use efficiency (e.g. N offtake and apparent proportion of fertiliser recovery) and returns on investment for each method and rate of N application are reported.

Background

The approach to this research was based on some previously established knowledge on N loss pathways. A brief discussion of the N loss pathways and their relation to methods of N application used in this study (MRB, DP, IBS and BSE) are provided below.

Nitrogen volatilisation

When applying urea IBS or BSE, the urea can be dissolved on and in residual stubble where it's converted to ammonia (NH_3) as the stubble has urease activity (approximately 1830mg urea/kg/ha) and a high pH (e.g. approximately pH=8 for wheat straw) which favours N volatilisation (e.g. McInnes *et al* 1985a, b). Urea washed into the soil can also be converted to ammonia and volatilised, although in southern NSW this is limited by low soil pH (note: volatilisation losses are often greatest with high pH, high temperature and drying conditions). When comparing volatilisation from IBS and BSE, the partial burial of urea with IBS application will likely reduce losses, while the warmer autumn temperatures act to increase potential losses. Any N buried below eight centimetres is considered safe from volatilisation (Rochette *et al*., 2014). As the urea moves into the soil it is converted to nitrate (e.g. urea → ammonia → ammonium → nitrite → nitrate). The ammonia form is toxic to plants and therefore it's the other forms listed that are taken up by plants, although most is taken up as nitrate some as ammonium and very little as nitrite.

The best strategies for avoiding volatilisation losses from urea include (i) burial at or below eight centimetres either as part of the sowing operation; including options such as MRB or in-crop MRB at DC31, (ii) broadcasting on a slightly acid (pH < 6.5) soil surface during winter in front of likely rainfall (BSE) and (iii) ensuring any liming applications are well mixed in the 0cm to 10cm layer as lime stratified in the 0cm to 2cm layer can substantially increase soil pH in this section of soil and increase likely volatilisation losses.

Nitrogen immobilisation

Stubble residues from the previous season are broken down by microbial activity that consume nitrogen and carbon. To grow bacteria, about 12 units of carbon (C) are consumed to one unit of N while wheat straw contains about 80 to 120 units of C for every unit of N. Consequently the bacteria utilise soil N to break down the stubble residue. As an estimate, 1000kg/ha of wheat grain produces about 1660kg/ha of stubble. This stubble is made up of approximately 40% to 45% of carbon (747kg/ha assuming 45% carbon) and has approximately 6.2kg N/ha, assuming a 120:1 C:N ratio in wheat stubble. As an estimate, 30% of the stubble is used by microbes for growth while approximately 70% is respired as carbon dioxide. Therefore the microbes would consume 224kg C/ha (30% of 747kg/ha) for growth and at a C:N ratio of 12:1 that would mean they require 18.6kg N/ha of which 6.2kg N/ha is already contained in the stubble. Therefore for every tonne of last year's grain yield, 12.4kg N/ha (18.6kg N/ha to 6.2kg N/ha) is required to break down last year's stubble residue. Where this N is not supplied, the grain yield loss from immobilisation in wheat would be 250kg/ha/t of wheat yield or 250kg/ha/1.66t of residual stubble. With high stubble loads and low C:N rations, N immobilisation can be substantial. For example a 4t/ha wheat crop that was broken down completely over the following year would immobilise an estimated 50kg N/ha or approximately 110kg/ha of urea (note wheat stubble usually takes more than one year to break down in southern NSW).

Strategies to avoid immobilisation of urea include (i) burial below the organic matter rich soil layer, (ii) late stubble burn or (iii) baling of stubble residuals. The latter two strategies result in losses of nutrients from the paddock.

Denitrification of nitrogen

Where soils are limited in oxygen (e.g. > 80% of field capacity), some soil bacteria will use the oxygen molecule in nitrite (NO_2-) and nitrate (NO_3-), causing the conversion of these forms of N to NO (nitric oxide), N_2O (Nitrous oxide) and N_2 (Nitrogen gas). Denitrification losses can be avoided by (i) holding N in the ammonium form and/or (ii) putting in place measures that limit waterlogging such as the use of controlled traffic or in more extreme cases raised beds.

Nitrogen leaching

Nitrogen leaching losses can occur where N moves either below the crop rooting depth, or to a depth where the N is not taken up at the same efficiency as N held higher in the soil profile. This may be due to factors such as root length density which decreases with increasing soil depth, particularly in sodic soils. Leaching of N occurs more readily when it is in the nitrate form as it is negatively charged and consequently does not bond to clay particles. Strategies to avoid N leaching include (i) holding N in the ammonium form which is positively charged and is less likely to leach or (ii) applying N at early stem elongation (e.g. DC31).

This study does not measure N losses directly however, differences in N losses combined with different efficiencies of soil N utilisation by wheat are likely to be reflected in grain yield, protein and straw as well as residual soil N levels. At the time of writing this paper only grain yield and protein results were available.

Methods

This experiment was sown at Wagga Wagga Agricultural Institute, NSW on 14 May and included one wheat variety (cv. Beckom(b)), eight N rates and four N application methods with N applied as mono-ammonium phosphate (MAP) and/or urea (Table 1)

Table 1. Variety, nitrogen rates and nitrogen application methods.

Variety x	N rate (kg/ha) x	Application method
Beckom⟨PBR⟩	0	Mid-row banding at sowing (May 14) [MRB]
	10	Spread and incorporated by sowing (May 14) [IBS]
	35	Deep placement under each row at sowing[DP]
	60	Broadcast at DC31 (July 28) [BSE]
	85	
	110	
	135	
	160	
	185	

in a fully randomised complete block design with four replicates. Rainfall for the growing season was 187mm (May to mid-November), stored soil water was 52mm and provides an estimated potential yield of 3.2t/ha (187 + 52 [water in] – 110 [soil evaporation] x 25 [kg gain per mm of water]). Peak grain yield was 3.8t/ha which may have been due to either less soil evaporation than estimated (110mm) or a high conversion efficiency of water to grain or a combination of both factors.

The soil at the experimental site was a Red Kandosol with a starting mineral N content of 42kg/ha to a depth of 1.5m (May 4). The previous crop was barley which was burnt late, prior to sowing. Soil pH ($CaCl_2$) was 5.8 (0cm to 10cm), 4.7 (10cm to 20cm) and 5.5 (20cm to 30cm) and Colwell P was 57mg phosphorus (P)/kg soil (0cm to 10cm). The experiment was direct sown using deep blade system (DBS) tynes spaced at 240mm. At sowing 100kg MAP (22kg P/ha and 10kg N/ha) was added to all treatments except the nil N treatment which received triple superphosphate at 22kg P/ha to balance all treatments for P. In plots receiving MAP, various amounts of urea were added to provide the N rates of 35kg N/ha through to 185kg N/ha. Mean plant density at DC14 was 127 plants/m^2 and was similar between treatments. In-crop weed control was undertaken by applying the pre-emergents Sakura® (pyroxasulfone 850g/kg) at 118g/ha and Logran® (triasulfuron 750g/kg) at 35g/ha on May 14 and was incorporated at sowing. Precautionary disease control was implemented, seed was treated with Hombre ® Ultra [Imidacloprid (360g/L) and Tebuconazole (12.5g/L)] at 200mL/100kg and Prosaro® (Prothioconazole 210g/L and Tebuconazole 210g/L) was applied at 300mL/ha at DC 31.

The experiment was harvested on 30 November (hand harvest prior to 100mm of rain) and again on 16 December (header harvest after 100mm of rain) to determine grain yield response to N rate and application method as well as the impact of rainfall on test weight, grain protein and falling numbers. Grain protein and seed quality were estimated using near infrared (NIR) (Foss Infratec 1241 Grain Analyzer) and Seed Imaging (SeedCount SC5000R), respectively. Nitrogen offtake was estimated by protein (%)/5.7 (conversion constant) x grain yield (t/ha). The proportion of apparent fertiliser N recovery in grain was calculated by (GrainN+N – GrainN-N)/N rate where GrainN+N is the grain yield with fertiliser N, GrainN-N is grain yield with no fertiliser N and N rate is the amount of fertiliser N applied. Economic returns after N costs were determined on 2017 prices (e.g. Junee 11 Dec) by multiplying grain yield (t/ha) by $210 for AUH2, AUH2, AGP1 grain grades, $250 for AWP1 grain grade, $265 for H2 grain grade and $280 for H1 grain grade. Pre- and post-rain grain price was only influenced by test weight, protein and falling numbers. Grain discolouration did not impact on price.

Soil mineral N was measured prior to sowing (May 4), early stem elongation (DC31, 29 July) anthesis (DC65, 30 September) and post-harvest (1 December) by coring to 150cm and measuring soil ammonium and nitrate at depths 0cm to 10cm, 10cm to 20cm, 20cm to 30cm, 30cm to 60cm, 60cm to 100cm, 100cm to 150cm and 150cm to 200cm. Only starting soil N results are available at the time of writing this paper.

Results and discussion

Grain yield

Grain yield response to method of N application and N rate were large (Table 2). Grain yields were highest for MRB and IBS when comparing maximum and 95% of maximum grain yield across the four methods of application. However when grain yield was compared at 13% protein, MRB alone provided the highest yield (Table 3). The DP method of N application provided the lowest yields using all three yield comparisons of 100 and 95% of maximum yield and yield at 13% protein while DC31 N application provided yields higher than DP but below that of MRB and IBS (Table 3).

One of the initial hypotheses was that IBS would be the least efficient methods of N application as some of the N applied can volatilise while the remaining N is exposed for longer periods in the nitrate form, leaving it more vulnerable to immobilisation, denitrification and leaching. Consequently the IBS results are somewhat surprising as this method of N application was comparable to MRB, a method of application that buries the N and holds it in the ammonium form for longer making it less vulnerable to loss pathways. It was also anticipated that DP would be amongst the most efficient methods of applying N at sowing. DP of urea (buried at16cm) into lower subsoil microbial populations was predicted to slow down the N mineralisation process and act as a slow release N supply. It was also surprising to observe DC31 application of N perform below that of MRB and IBS (DC31 had N applied on 28 July prior to 7mm of rainfall). It is speculated that the DC31 application performed poorly as June rainfall of two millimetres was not conducive to surface root development, N was applied on July 28 and subsequent rainfall in August (approximately 45mm) would have moved the N to approximately 10cm to 20cm based on N movement at half the rate of the wetting front and evapotranspiration. What followed was a dry September (6mm) and once the available soil water was used in the 0cm to 20cm layer the remaining soil N was not accessible. While this is a reasonable explanation it should be said that at this stage there is no evidence to support this explanation (e.g. soil data is still being processed). As a general comment, it is unlikely that immobilisation, denitrification or leaching loss pathways were substantial, as the site had low winter rainfall and the stubble was burnt just prior to sowing.

Grain protein

Grain protein responses were large for both method of N application and N rate. The lowest N rates in each method of application to achieve the H1 grade (13% protein or greater) was 135kg N/ha for DP (14.1%), 135kg N/ha for MRB (13.5%), 160kg N/ha for DC31 (13.5%) and 160kg N/ha for IBS (13.6%). The H2 protein range (10.5 to 12.9% protein) was achieved by all treatments at peak grain yield (Table 1). It was anticipated that IBS would be the method of N application that would be least efficient for improving grain protein and this was supported by the results. However it was also anticipated that DC31 N application would be the most efficient method to improve grain protein, although this was not supported by results (see previous explanation). DP and MRB were the most efficient methods for improving grain protein.

Economic returns

Economic returns after considering N costs, grain protein, falling numbers, screenings, test weight and stained grain pre and post December rainfall (100mm) are shown in Table 1. Pre-December rainfall returns after N costs were highest for MRB and IBS and lower for DP and DC31 (Table 2 and 3). Post December rainfall returns were substantially lower (lower falling numbers and test weights) however, the methods of N application performed in the same order as the pre-December rainfall results. At 13% protein, MRB alone was the highest returning method of application, IBS and DC31 had similar returns and DP the lowest (Table 3).

Nitrogen offtake

Nitrogen offtake in grain was used as an estimate of N efficiency for the different N application methods tested (Table 2). These results show that at peak yield each method of N application exported approximately 80kg N/ha. However, when considering a fixed N supply of 110kg N/ha the N offtake was highest for MRB and IBS and lowest for DC31 and DP. These efficiency differences were evident across a range of rates (Table 3).

Proportion of apparent fertiliser recovery

The proportion of apparent fertiliser N recovery in grain at 95% of maximum yield (Figure 1) was highest for MRB (0.54) and IBS (0.56) and significantly lower for DP (0.49) and DC31 (0.48).

Falling numbers

Weather damage as assessed by falling numbers was impacted by the method of N application and N rate (Figure 2). Grain that was not weather damaged had falling numbers above 300sec and these readings increased with increasing N rate. Weather damaged grain had falling numbers below 300sec however the method of N application and N rate determined the extent of the decline in falling number count (Figure 2).

Test weight

There was no effect of method of N application or N rate on test weight, however there was an impact of December rainfall on test weight with test weight prior to rainfall averaging 81.6kg/hl and after rainfall the average was 74.1kg/hl.

Table 2. Grain yield (t/ha), grain protein (%), N offtakes (kg/ha), falling numbers (sec) and net return ($/ha) after N costs for the wheat variety Beckom(PBR symbol) pre and post rainfall (100mm, 2 to 8 Dec). Bold indicates the highest value within each N application method.

Treatment	Grain yield (t/ha)	Grain protein (%)	N offtake (kg/ha)	Falling numbers pre-rainfall (sec)	Falling numbers post-rainfall (sec)	Net ($/ha) after N costs pre-rainfall	Net ($/ha) after N costs post-rainfall	Loss ($) due to rain
nil_0	1.96	7.3	25.0	354	286	461.41	405.66	55.74
MRB_10	2.41	7.7	27.8	344	**282**	555.96	464.94	91.02
MRB_35	2.99	8.1	45.2	381	252	732.30	601.49	130.82
MRB_60	3.43	9.2	59.7	411	236	859.99	694.70	165.30
MRB_85	3.71	10.6	71.3	433	229	939.02	744.57	194.46
MRB_110	**3.84**	12.1	80.0	448	228	**969.40**	**751.10**	218.30
MRB_135	3.81	13.5	85.8	**456**	232	951.12	714.29	236.83
MRB_160	3.63	14.5	**88.7**	**456**	236	884.18	634.14	250.04
MRB_185	3.29	**14.8**	**88.7**	449	239	768.59	510.65	**257.94**
IBS_10	2.34	7.5	27.3	354	258	548.74	451.43	97.31
IBS_35	2.94	8.4	45.4	372	**268**	718.80	585.45	133.34
IBS_60	3.38	9.6	59.7	388	266	840.25	676.75	163.50
IBS_85	3.65	10.8	70.4	405	255	913.10	725.33	187.78
IBS_110	**3.75**	12.0	77.4	421	241	**937.35**	**731.17**	206.18
IBS_135	3.68	12.9	**80.6**	437	229	912.99	694.28	218.71
IBS_160	3.45	13.6	80.1	**453**	224	840.03	614.66	225.37
IBS_185	3.04	**13.8**	75.9	469	231	718.47	492.32	**226.15**
DP_10	2.41	7.1	26.5	393	**276**	609.06	523.24	85.82
DP_35	2.82	8.0	41.9	415	251	689.24	568.83	120.42
DP_60	3.13	9.4	55.2	434	233	754.38	602.48	151.90
DP_85	3.34	11.0	66.3	451	221	804.47	624.20	180.27
DP_110	3.46	12.7	75.2	465	214	839.52	**633.98**	205.54
DP_135	**3.48**	14.1	81.9	477	213	859.52	631.83	227.69
DP_160	3.40	15.0	86.4	485	216	**864.48**	617.74	246.74
DP_185	3.22	**15.1**	**88.7**	**491**	224	854.39	591.71	**262.68**
DC31_10	2.34	7.5	28.9	344	272	545.95	451.39	94.56
DC31_35	2.83	8.6	43.8	375	288	671.50	551.64	119.86
DC31_60	3.21	9.7	56.4	401	**294**	768.09	623.53	144.56
DC31_85	3.48	10.8	66.8	421	293	835.72	667.04	168.68
DC31_110	3.63	11.8	74.9	436	286	874.40	**682.19**	192.21
DC31_135	**3.68**	12.7	80.6	446	277	**884.11**	668.96	215.15
DC31_160	3.61	13.5	84.2	**450**	266	864.86	627.37	237.50
DC31_185	3.43	**14.0**	**85.4**	448	256	816.66	557.41	**259.25**
LSD P=0.05	0.10	0.45	3.72	33.8	15.7	49.48	33.58	-

Treatment codes: MRB = mid-row banding (between every second row, 8 cm deep), IBS = surface spread then incorporated by sowing, DP = deep placement below every sown row (16 cm), DC31 = surface spread at early stem elongation. Numbers following the underscore ("_") signify the amount of nitrogen applied (kg N/ha).

Table 3. Grain yield (t/ha), N rate to achieve grain yield (kg N/ha) and returns after N costs ($/ha) for maximum grain yield, 95% of maximum grain yield and grain yield at 13% protein for each of the methods of N application.

N application method	100% of maximum yield (t/ha)	N rate to achieve 100% of maximum yield (kg N/ha)	Net return ($/ha) after N costs at 100% of maximum yield	95% of maximum yield (t/ha)	N rate to achieve 95% of maximum yield (kg N/ha)	Net return ($/ha) after N costs at 95% of maximum yield	Yield (t/ha) at 13% protein	N rate to achieve 13% protein	Net return ($/ha) after N costs at 13% protein
MRB	3.84	118	969	3.65	78	921	3.83	126	963
IBS	3.75	113	937	3.56	75	890	3.67	137	909
DC31	3.68	132	884	3.50	88	843	3.66	144	880
DP	3.48	127	865	3.31	80	796	3.47	115	844

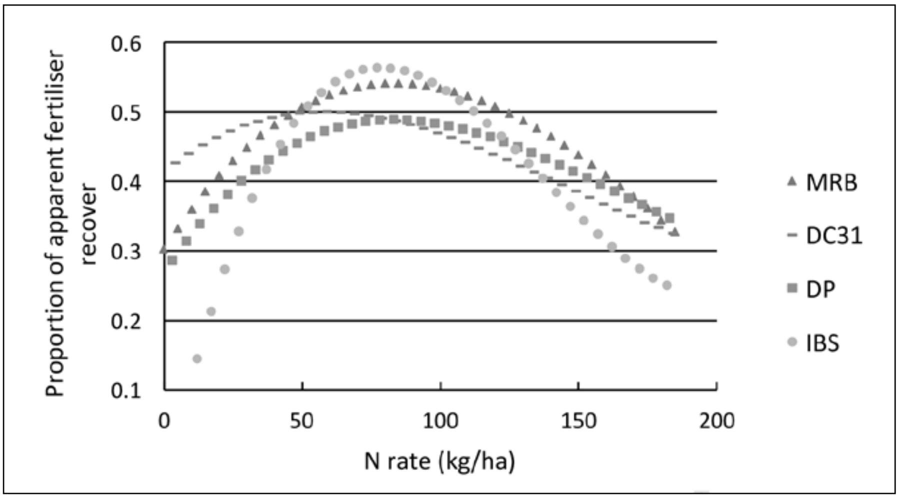

Figure 1. Apparent fertiliser-N recovery in grain for Beckom⁽ᵖ⁾ in relation to three methods of nitrogen application and nine rates of nitrogen.

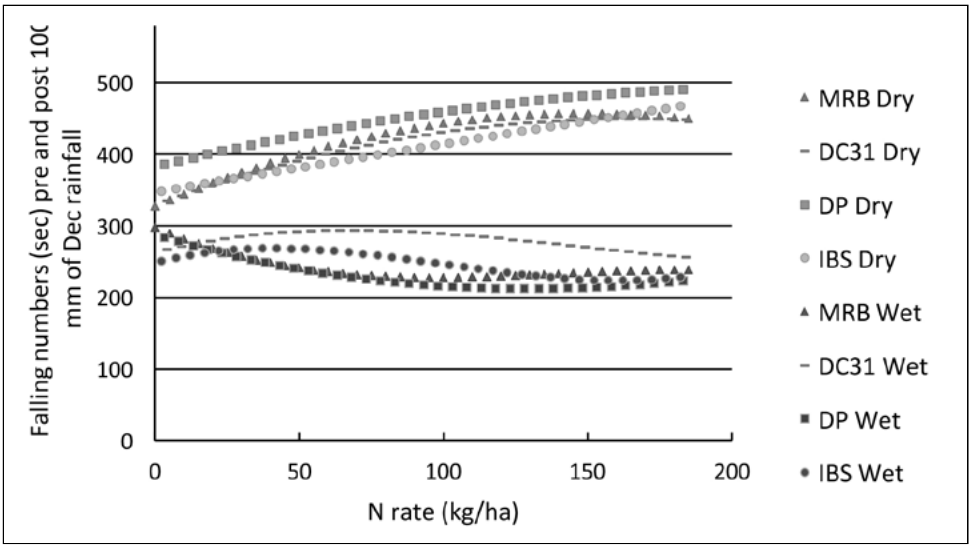

Figure 2. Falling numbers pre and post 100 mm of rainfall over December 2 to 8. Weather damaged readings were all below 300sec.

Table 4. The estimated nitrogen required (kg N/t/ha) to produce 1t/ha of wheat for 100 and 95% of maximum yield as well as N required for a 1t/ha yield at 13% protein. Assumptions included; the in-crop mineralisation was 28kg N/ha which was estimated by growing season rainfall x organic carbon x 0.15. The pre-sowing soil N content was 42kg N/ha.

N application method	100% of maximum yield (t/ha)	95% of maximum yield (t/ha)	Yield (t/ha) at 13% protein
MRB	49	41	51
IBS	49	41	56
DC31	55	45	58
DP	57	45	53

Estimated nitrogen budget

The estimated N required to produce 1t/ha of wheat ranged from 41kg/t/ha to 58kg/t/ha (Table 4). These estimates are within the range provided by Angus (2016) where [grain yield (1t/ha) X protein (11%) X 2.33]/0.5 = Soil N required of 51kg N/ha]. MRB was consistently the most efficient method of N application (Table 4).

Mid-row banding in-season

With the advent of precision guidance systems it is also possible to consider MRB of N into established crops as an alternative to topdressing or liquid applications. In situations where variable seasons or other factors dictate a greater proportion of N being applied in season, MRB may help to reduce the risk of loss to volatilisation. This could present the opportunity for growers to apply N at a time that better suits their logistics rather than aiming to apply in front of rainfall which can be hard to predict. GRDC investment in research conducted by Agriculture Victoria during 2016 and 2017 has shown that in-season MRB has the potential to improve nitrogen use efficiency; in particular increasing the proportion of fertiliser recovered by the crop (DAV00143; Wallace *et al* 2016). The effects on yield and protein have been more variable; in some cases increasing yield and or protein compared to top dressed, granular or liquid applications, but in others not. In considering a move to MRB in season, it is important to assess the ability to accurately apply N inter-row at a given row spacing, stubble load and soil moisture level, speed of operation, cost of capital and ongoing operating costs plus unforeseen impacts such as the potential for increased weed germination following inter-row soil disturbance. A link to a summary of results from the 2016 Agriculture Victoria study is provided in the 'Useful Resources' section.

Conclusion

Mid-row banding of N resulted in the highest grain yield, while the highest N removal rate and profit were achieved by MRB and IBS. Mid-row banding of N provides growers with an alternative strategy to improve nitrogen use efficiency in wheat by providing improved recovery of N in grain, higher yields and higher grain protein compared with most other N application methods.

Useful resources

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/a-test-of-nitrogen-fertiliser-use-efficiency-in-wheat-using-mid-row-banding

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/08/improving-nitrogen-use-efficiency-of-cropping-systems-of-southern-australia-by-mid-row-banding-nitrogen-fertiliser-in-season

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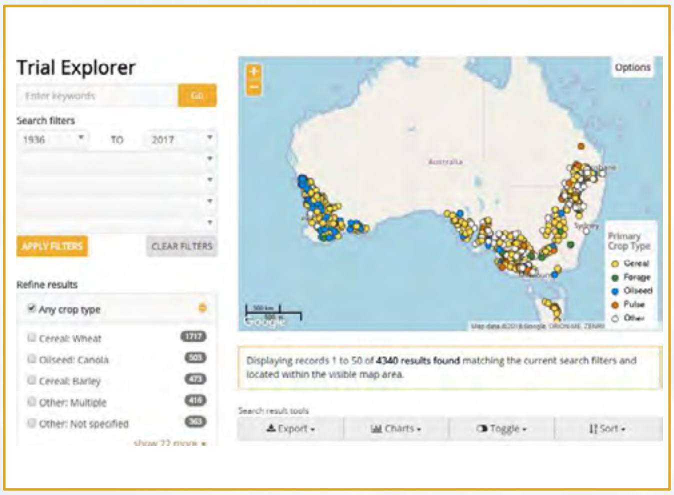

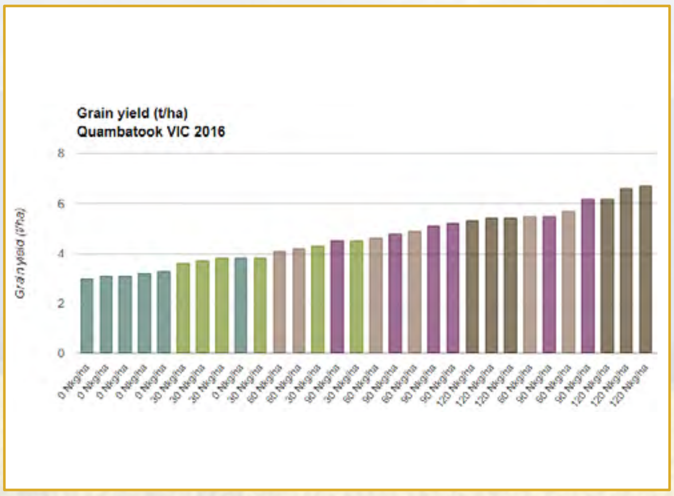

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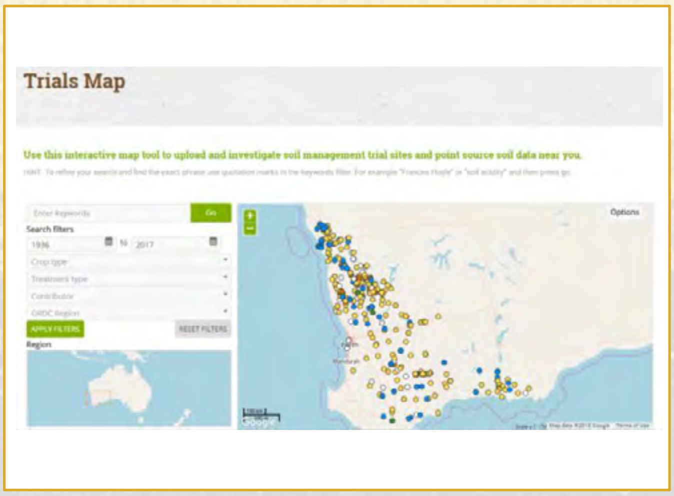

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Canola - well executed agronomy still makes a difference in a tough 2017

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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.

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.

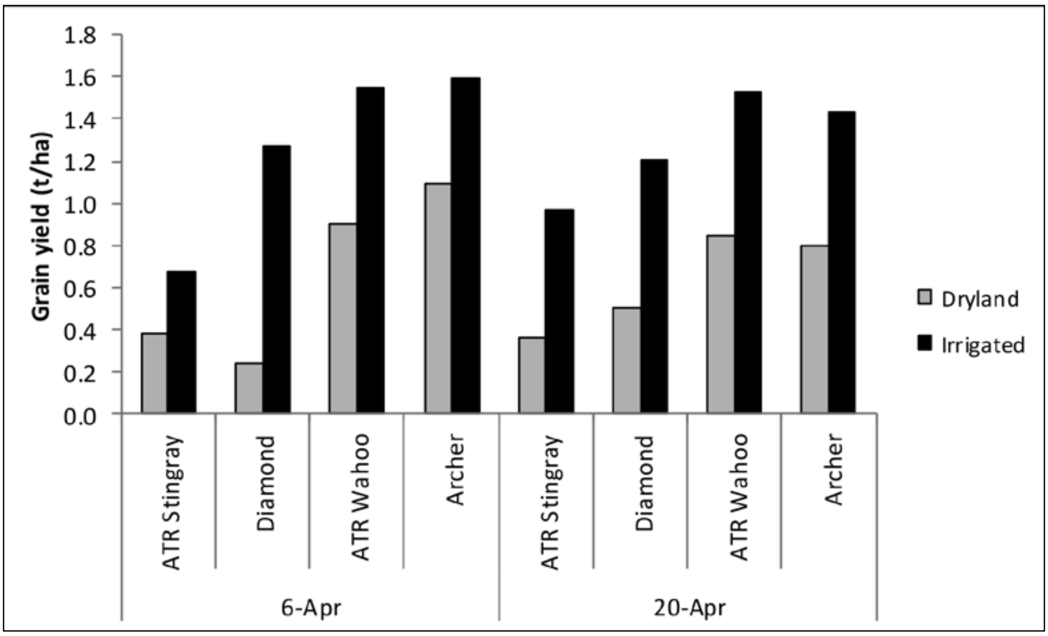

Figure 1. Grain yield of four canola varieties sown at two sowing dates, with (irrigated) or without (dryland) irrigation, at Condobolin in 2017 (l.s.d. $P<0.05$ = 0.26t/ha).

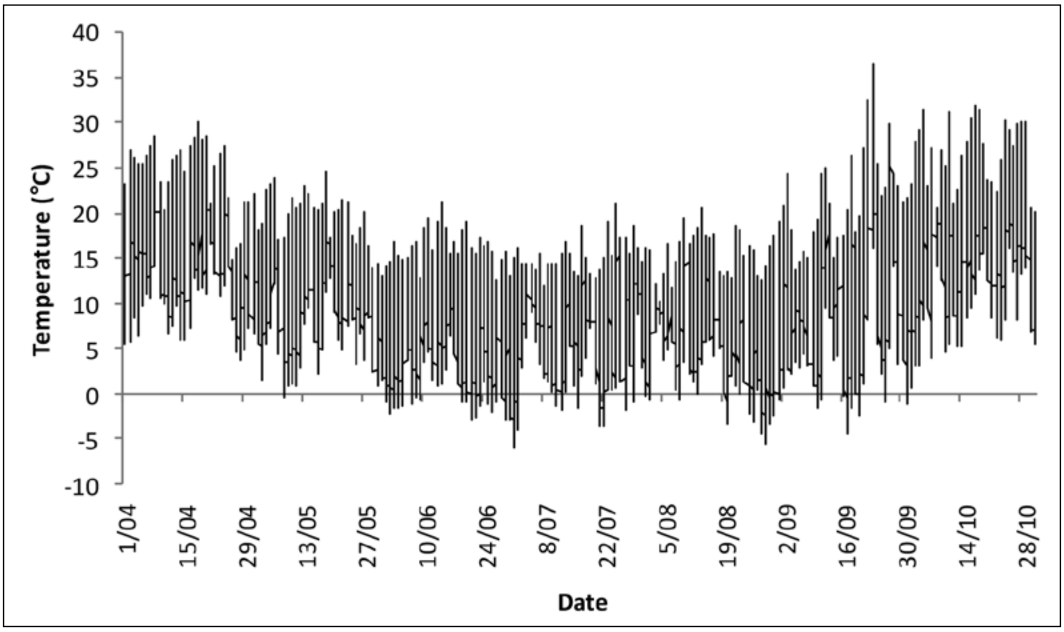

Figure 2. Temperature (°C) from 1 April to 31 October at the Ganmain experimental site, 10km north of Ganmain, NSW.

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

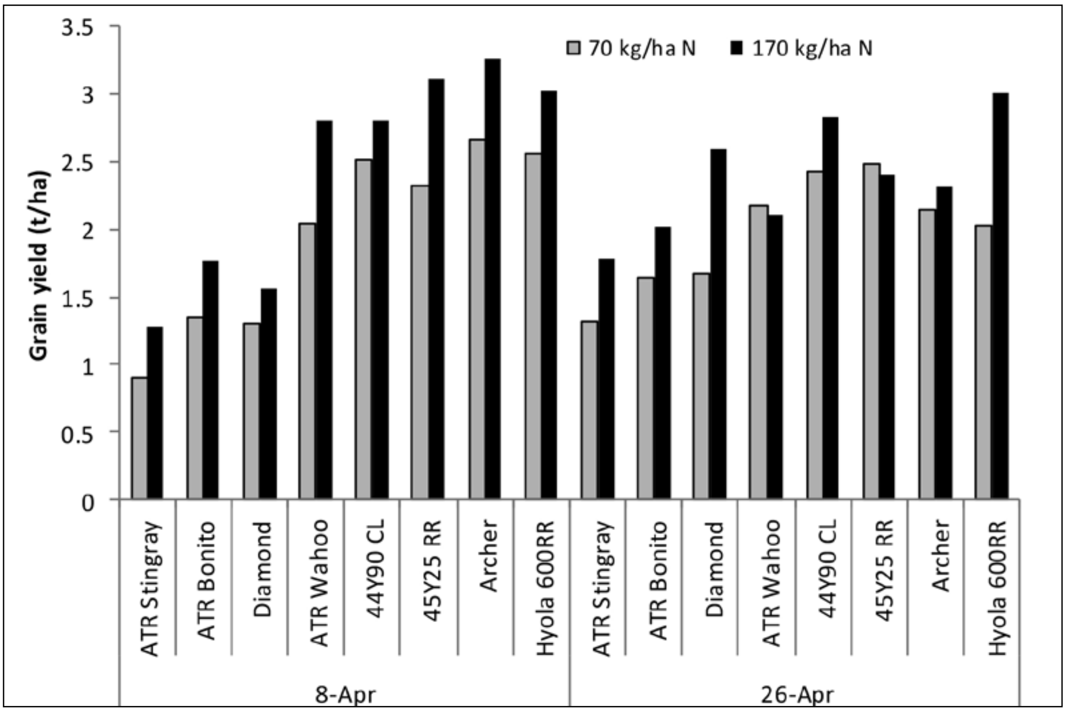

Figure 3. Grain yield of eight canola varieties sown at two sowing dates and fertilised at two nitrogen rates at Ganmain, 2017 (l.s.d. P<0.05 = 0.38t/ha).

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⁽ᵇ⁾ (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⁽ᵇ⁾ flowered in early July and both averaged less than six seeds per pod. From the same sowing date, Archer and ATR Wahoo⁽ᵇ⁾ 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⁽ᵇ⁾ 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/

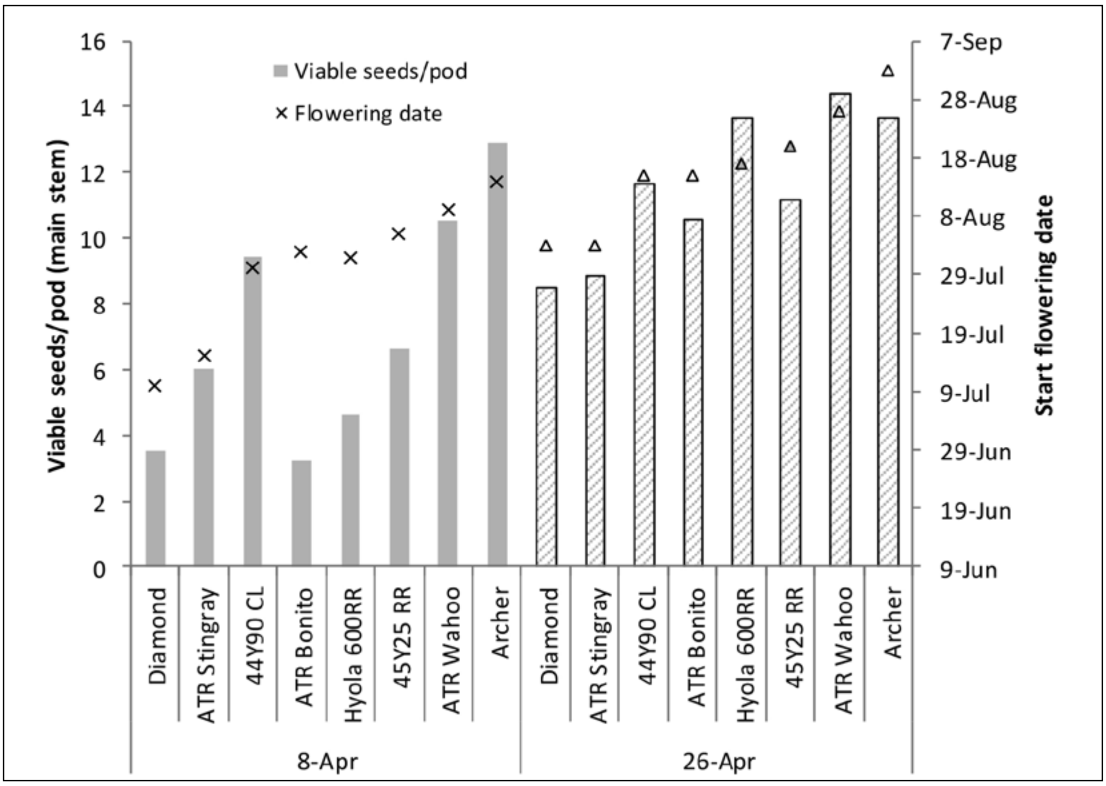

Figure 4. Viable seeds per pod (columns) and flowering date (× and Δ) of eight canola varieties sown at two sowing dates (averaged across N rates) at Ganmain, 2017 (Viable seeds/pod l.s.d. P<0.05 = 2.1)

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.

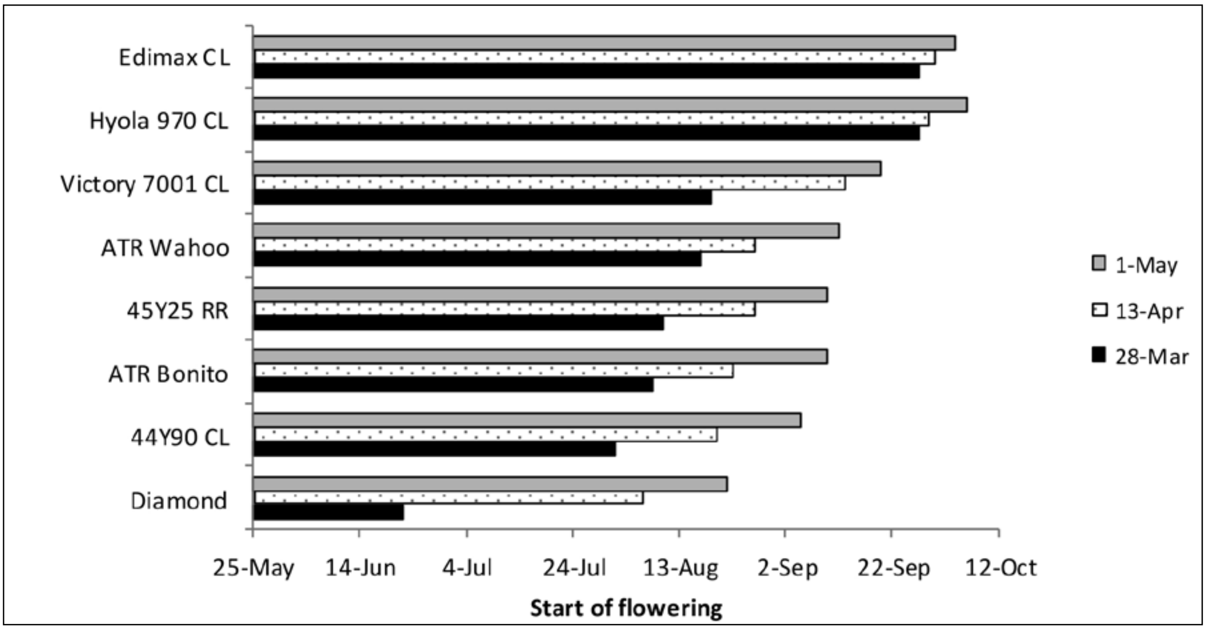

Figure 5. Start of flowering date (50% of plants with one open flower) of eight canola varieties sown at three sowing dates, Wallendbeen 2017.

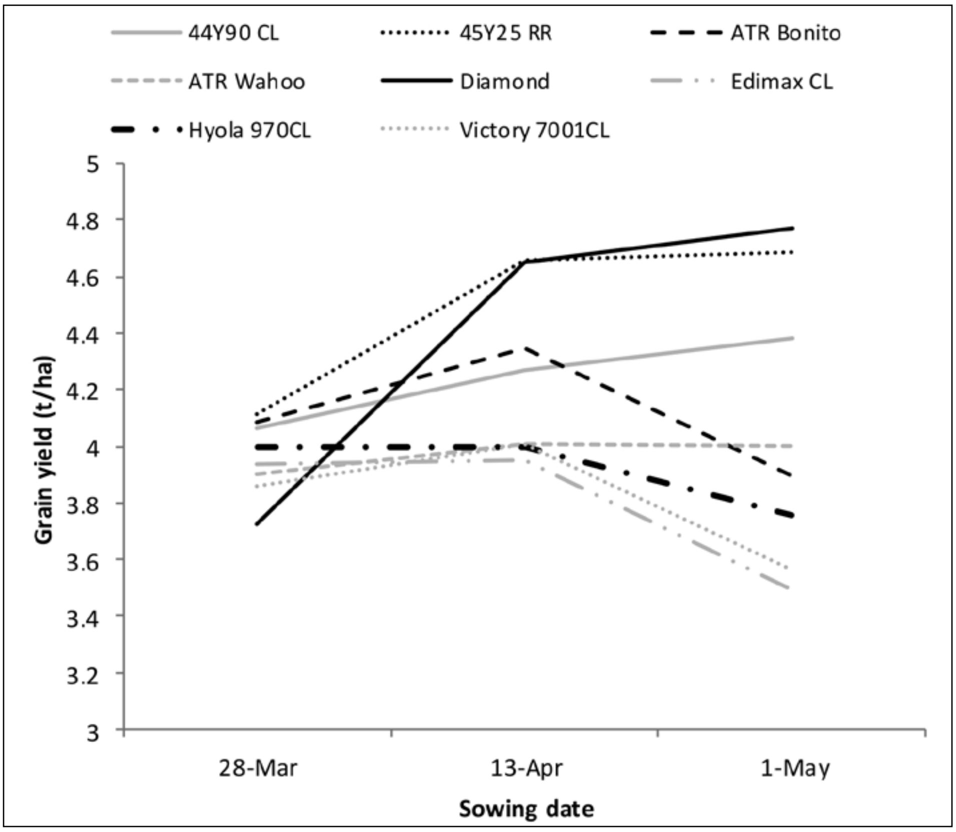

Figure 6. Grain yield of eight canola varieties sown at three sowing dates at Wallendbeen, 2017 (l.s.d. P<0.05 = 0.39t/ha).

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$^{\Phi}$ 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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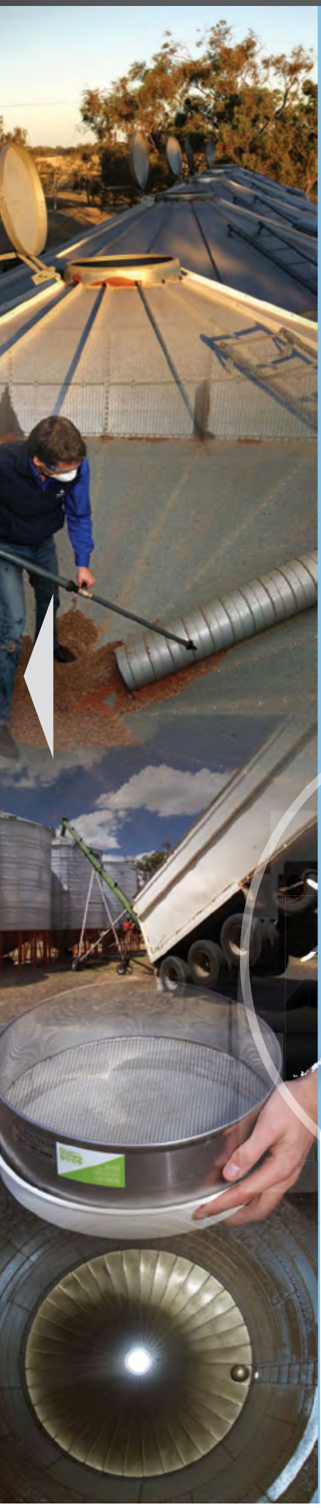

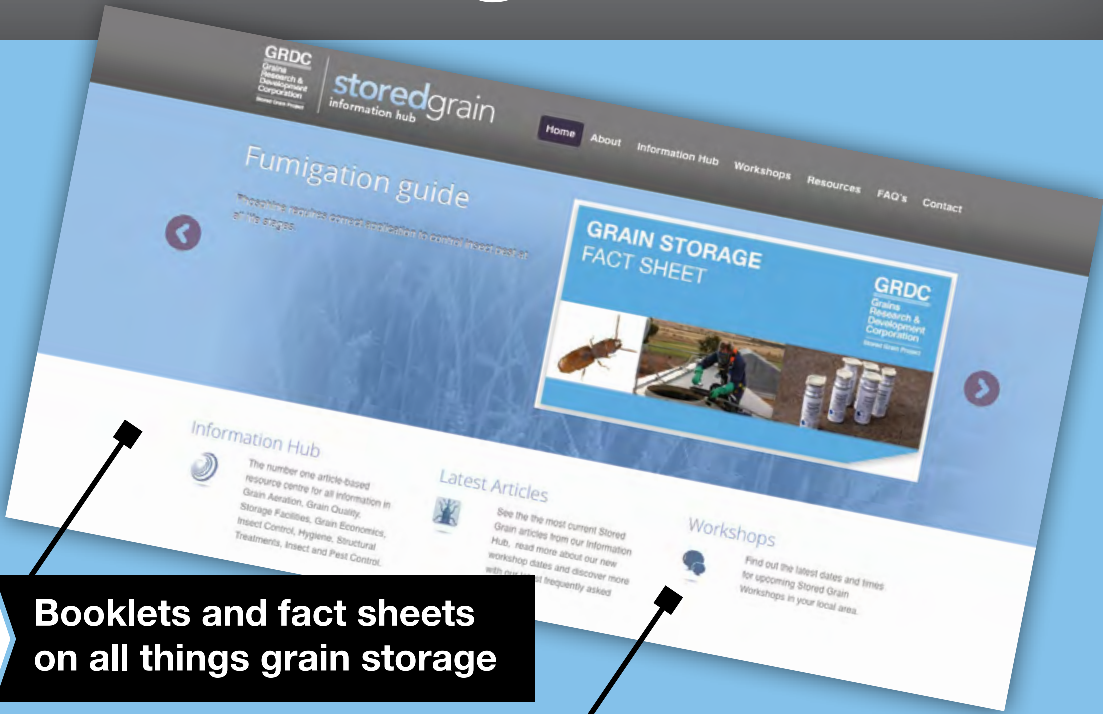

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THE 2017-2019 GRDC NORTHERN REGIONAL PANEL

FEBRUARY 2018

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CHAIR - JOHN MINOGUE

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

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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Tony is a grower from Forbes, NSW and managing director of an integrated cropping and livestock business. He is a director of the Rural Industries Research and Development Corporation. He has worked as an agricultural consultant in WA and southern NSW. With a Bachelor of Agricultural Science and a PhD in agronomy, Tony advocates agricultural RD&E and evidence based agriculture.

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Peter operates a private agronomy consulting business based in Quirindi NSW. Prior to this he was facilitator/agronomist for AgVance Farming group, a communications conduit between industry and growers. He is a passionate supporter of research and has been active in extending weed management research information to industry, particularly in central west NSW, is a former director of Conservation Farmers Inc., a former member of the North East Regional Advisory Committee and a participant in Northern Growers Alliance local research group on the Liverpool Plains.

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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 WATSON

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

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

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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.

GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK CONTACT DETAILS:

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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.

GRAIN ORANA ALLIANCE (GOA)

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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

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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.

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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.

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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:

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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.

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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

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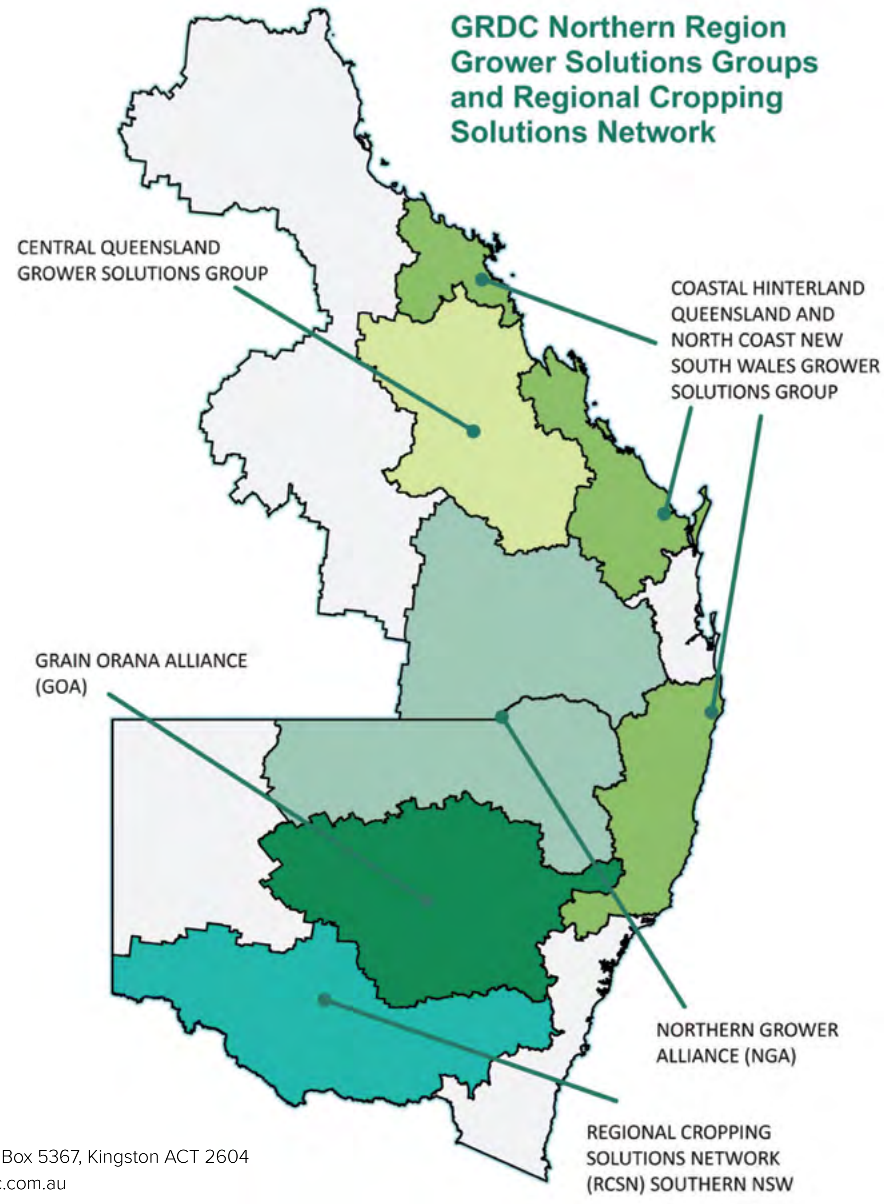
The Southern New South Wales Regional Cropping Solutions Network (RCSN) was established in 2017 to capture production ideas and opportunities identified by growers and advisers in the southern and western regions of New South Wales and ensure they translate into direct GRDC investments in local R, D & 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 planning committee that includes both government and private consultants and GRDC representatives.

- Partnering organisation: FarmLink Research

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2018 The Rock 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
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- ❑ 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. The effects of stubble on nitrogen tie-up and supply: *John Kirkegaard*

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

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

[ ]

4. Better pastures, better crops – management of pastures to optimise transfer of benefits to following crops: *Tim Condon*

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

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

[ ]

5. Inoculant survival in acid soils – latest knowledge: *Ross Ballard*

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

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

[ ]

6. Improving nitrogen fertiliser use efficiency in wheat using mid-row banding: *Graeme Sandral*

Content relevance ☐ /10 Presentation quality ☐ /10

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

7. Critical agronomy management points for optimal canola growth: *Rohan Brill*

Content relevance ☐ /10 Presentation quality ☐ /10

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

Your next steps

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

9. 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

10. 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

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

12. 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

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

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

Comments

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

Thank you for your feedback.

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Farming the Business
Sowing for your future

The GRDC's **Farming the Business** manual is for farmers and advisers to improve their farm business management skills.

It is segmented into three modules to address the following critical questions:

Module 1: What do I need to know about business to manage my farm business successfully?

Module 2: Where is my business now and where do I want it to be?

Module 3: How do I take my business to the next level?

The **Farming the Business** manual is available as:

- **Hard copy** – Freephone **1800 11 00 44** and quote Order Code: GRDC873
  There is a postage and handling charge of $10.00. Limited copies available.
- **PDF** – Downloadable from the GRDC website – **www.grdc.com.au/FarmingTheBusiness**
  or
- **eBook** – Go to **www.grdc.com.au/FarmingTheBusinesseBook** for the Apple iTunes bookstore, and download the three modules and sync the eBooks to your iPad.

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